AP42 Section:	12.2
Reference:	6
Title:	*Final Technological Report On A Systems Analysis Study Of The Integrated Iron And Steel Industry*, J. Varga and H. W. Lownie, Jr., Contract No. PH-22-68-65, U. S. Environmental Protection Agency, May, 1969. 5th edition

FINAL TECHNOLOGICAL REPORT

on

A SYSTEM ANALYSIS STUDY OF THE INTEGRATED IRON AND STEEL INDUSTRY

(Contract No. PH 22-68-65)

to

DIVISION OF PROCESS CONTROL ENGINEERING
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

May 15, 1969

by

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Gentlemen:

Final Technological Report on
A Systems Analysis Study of
The Integrated Iron and Steel Industry
(Contract No. PH 22-68-65)

Two copies of the subject report are being sent to both Mr. Edmisten and Dr. Kenline, and 96 copies to Mr. Plaks.

For the companion Final Economic Report on Cost Analyses, two copies are being sent to both Mr. Edmisten and Mr. Plaks, and 96 copies to Dr. Kenline.

Very truly yours,

HWLownie Jr.

H. W. Lownie, Jr.
Project Director

HWL:jls

TABLE OF CONTENTS

Page

SECTION I

SECTION II

TABLE OF CONTENTS
(Continued)

Page

SECTION III

SECTION IV

TABLE OF CONTENTS
(Continued)

Page

SECTION V

TABLE OF CONTENTS
(Continued)

SECTION VI

TABLE OF CONTENTS
(Continued)

SECTION VII

APPENDIX A

APPENDIX B

TABLE OF CONTENTS
(Continued)

Page

APPENDIX C

APPENDIX D

Emissions

Coke quenching	6 lb/load of coke (w/o baffles) 1½ lb/load (wit baff
Sintering	20 pounds of dust/ton of sinter
Blast Furnace	ore, coke, and limestone dust
Open Hearth	20 to 22 pounds/ton with oxygen lanc
	~8 pounds of dust/ton without
Basic Oxygen Furnace	14.5 - 27.4 pounds/ton of steel
	1 to 2% weight of the metallic charg
Electric furnace	11% of carbon steel and 36% of alloy stee
Scarfing	2-3 gr/scf at 75,000 to 135,000 cfm

Some data on fluoride emissions

Controls

Scrubbers	3.2-6.4 gr/scf to .026 - .051
Bag Houses	.004 to .006
ESP	.256 - .512

BOF + associated APC equipment

Bag house on open hearth 99.95%

Table on calculated relative efficiency of collecting equipment for various process dusts & collectors.

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(Continued)

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(Continued)

LIST OF TABLES
(Continued)

SECTION I

INTRODUCTION AND SCOPE

The National Air Pollution Control Administration (NAPCA) in fulfilling part of its responsibilities under the Air Quality Act of 1967 is sponsoring systems-analysis studies of selected industries. These studies will describe (1) the present status of control technology, (2) the economic burden of controlling air-pollutant emissions, and (3) the research and development needs requiring solution to provide for both better and more economical means for controlling air pollution. It is recognized that if solutions to air-pollution control problems are to be responsive to the needs and objectives of both industry and government, they require joint participation and involvement. Therefore, industry has been requested to participate in these studies by providing technical and cost information which will keep these studies responsive to industry's needs.

The Division of Economic Effects Research and the Division of Process Control Engineering of the National Air Pollution Control Administration jointly have funded this study of the integrated iron and steel industry. The Division of Economic Effects Research is responsible for determining the economic impact of air-quality standards on the Nation's industries, communities, and other contributing sources of pollution. The Division of Process Control Engineering is responsible for federally sponsored research and development of air-pollution control devices and processes for stationary emission sources.

The integrated iron and steel industry is among those chosen by NAPCA for study because the processes used to manufacture coke, pig iron, and steel make a contribution to air pollution. The pollution potential and the degree of control practiced vary widely depending upon the particular processes involved and the geographical location of the steel works. In addition to the technical problems associated with controlling these emissions, the industry trend toward use of newer and higher production manufacturing processes puts an increased decision-making burden upon steel-industry management when deciding to what extent emissions from existing equipment shall be controlled.

This report is concerned mainly with the technological aspects of ironmaking and steelmaking and an analysis of air-pollution technology as it applies to the integrated iron and steel industry. A companion report is concerned primarily with costs of air-pollution control. However, for orientation and fuller understanding of the technological problems, some cost information is included in this present report. For more complete information on costs, reference should be made to the companion report.

PURPOSES OF THIS STUDY

This iron and steel study has the purposes of (1) analyzing emission-control technology as it applies to the various manufacturing processes in the integrated iron and steel industry, (2) analyzing emission-control alternatives, (3) identifying the practical problems associated with controlling emissions from the iron and steel industry, and

(4) defining the problem areas and needs, thereby providing one basis for establishing priorities for federally sponsored research and development projects to be undertaken independently or on a joint-sponsorship basis with industry. In furtherance of a purpose of the Air Quality Act of 1967, the research programs are to be directed toward new, improved, and lower cost control techniques having industry-wide application.

SCOPE OF THIS STUDY

To accomplish the overall goals of this study, the following tasks were undertaken:

(1) A general description of the various processes used in each manufacturing segment, including process block-flow diagrams and schematic drawings for each process segment and for principal variations within each process segment

(2) Identification of the particulate and gaseous emissions from each manufacturing process at the point of emission

(3) A material balance to identify particulate and gaseous emissions, especially sulfur oxides, and to trace the flow of sulfur through representative models of the process segments

(4) A comprehensive and quantitative review of fuel and energy utilization to identify the total industry consumption, to identify the types of fuels used, the quantities of each, identification of the determinants of fuels choice, and interpretation of the influence on pollutant emissions from the standpoints of fuel chemistry and fuel usage

(5) A projection of industry growth and process technology changes for the periods 1970-1975 and 1975-1980, emphasizing processes that will come into future use and their associated pollution potential, as well as processes which will be phased out

(6) Description of the principal types of control equipment for the various processes, and information on the performance characteristics of the various designs in use

(7) An in-depth narrative analysis of the relative merits and limitations of applied control equipment

(8) Identification of pollution-control alternatives for the various process segments in the industry, and comparison of the relative cost and effectiveness of each

(9) Identification of gaps in air-quality control technology, and recommendations for research to fill such gaps.

The scope of the study included the following process segments of the integrated iron and steel industry with respect to the generation of data on particulate and gaseous emissions:

(1) Ore preparation (sintering and pelletizing plants)

(2) Coke-manufacturing plants and by-product facilities

(3) Blast furnaces

(4) Open-hearth furnaces (with and without oxygen lancing)

(5) Basic oxygen furnaces (upright and rotary)

(6) Electric furnaces (arc and induction, including the preheating of scrap)

(7) Vacuum degassing

(8) Casting operations (ingot practice, continuous casting, and pressure casting)

(9) Roughing-mill operations (soaking-pit practice and rolling to slabs, blooms, and billets)

(10) Hot rolling (slab, bloom, and billet conditioning; reheating and rolling to plate, sheet, strip, structural and merchant products)

(11) Cold rolling of strip and bar products

(12) Surface cleaning and coating (galvanizing, tin plating, and plastic coating)

(13) In-plant power generation.

SECTION II

SUMMARY AND RECOMMENDATIONS

The overall objectives of this study of the steel industry are to determine

(1) The present status of air-pollution-control technology

(2) The cost of applying present technology to the lessening of air-pollution by steelworks

(3) The subjects on which research and development are needed to improve the technology and economics of air-pollution control.

The study was conducted in 1968 and early 1969 by Battelle Memorial Institute, Columbus Laboratories, with subcontracted assistance from Swindell-Dressler Company of Pittsburgh and voluntary assistance from a number of steel companies that contributed information and guidance throughout the project.

This Final Technological Report is complementary to a companion report titled "A Cost Analysis of Air Pollution Controls in the Integrated Iron and Steel Industry", dated May 15, 1969.

The partition of the final Battelle reports reflects the design of this study to serve both the Division of Economic Effects Research and the Division of Process Control Engineering of the National Air Pollution Control Administration.

This Final Technological Report is the result of investigative, data-gathering operations and data analyses with respect to ironmaking and steelmaking technology and air-pollution-control technology in the integrated iron and steel industry. The status of the respective technologies is discussed in relation to present and future air-quality requirements. Technology gaps are identified so that research and development may serve to minimize the generation of emissions in the various processes, and efforts may be directed toward the development of improved pollution-control procedures.

THE NATURE OF THE INTEGRATED IRON AND STEEL INDUSTRY

The integrated iron and steel industry, as considered in this study, consists of those companies with resources of iron ore and with facilities for ore preparation, ironmaking, and steelmaking. Included as part of steelmaking are the production of semifinished products such as ingots, billets, blooms, and slabs; and the production of finished products such as sheet that is galvanized, tinplated, painted, or plastic coated. Many smaller companies utilizing scrap as their source of raw materials and electric furnaces as their melting facility have come into operation in recent years. Such small secondary (nonintegrated) plants are established to satisfy local markets or markets for a limited range of specific steel products.

Industry Efforts for the Immediate Future

The integrated iron and steel industry is faced with a dual situation, as are many industries in the United States today. First, they are in a highly competitive market which requires that they maintain an advancing metallurgical technology to meet the increased demands of an increasing population and maintain a position in the world market. Second, the industry must, as a part of the overall scheme to improve man's environment, reduce the amount of its process emissions reaching the atmosphere.

The last 10 years have seen significant advances in the technology of making iron and steel. The use of ores has changed from run-of-the-mine varieties to closely sized, select ores, and to sinter and pellets made from less-suitable ores. Use of the improved burden materials has increased ironmaking production and has resulted in a lessening of emissions from the blast furnace. However, this improvement in blast-furnace technology has resulted in an aggravated emission problem at the sinter plant, particularly when self-fluxing sinters are made.

Coal preparation and coke-making technology have been advanced to make a better, lower sulfur fuel for the blast furnace, but the coke-making process itself has not been changed basically and the coke-plant emissions are a source of continuing concern to the industry. Auxiliary fuels such as oil, natural gas, and coal have been combined with air-blast temperatures as high as 2000 F and with other technological advances to lower the amount of coke required to make a net ton of iron from 1600 pounds in 1958 to 1250 pounds in 1968. The total overall tonnage of coke, however, continues to increase because of requirements for more hot metal to make more steel. The improvements in ironmaking technology have permitted an increase in physical size of the blast furnace and a reduction in the total number of blast furnaces to satisfy ironmaking requirements.

Steelmaking technology has changed from one dominated by open-hearth technology at the start of the present decade to one shared 50 percent by open hearths, 37 percent by basic oxygen furnaces, and 13 percent by electric furnaces in 1968. Basic oxygen furnaces with capabilities of producing from 150 to 300 net tons of steel per hour have played a major role in changing steelmaking technology. The use of gaseous oxygen in the refining of steel has been the prime mover for achieving these higher production rates but, at the same time, this use of gaseous oxygen has become a major problem in control of air pollution because of the severe generation of red iron oxide fumes during its use. This pollution problem is rapidly being brought under control by the steel industry.

Conversion of steel from its molten state to a solid, more-usable state is presently undergoing technological change. The older technology which had been used in the industry practically from its inception consisted of pouring the molten steel into ingot molds, permitting the steel to solidify, removing the hot ingot from the mold, transferring the ingot to a soaking pit, and then rolling the heated ingot into billets, blooms, or slabs. The newer technologies of continuous casting and pressure casting bypass much of the intermediate processing. In continuous casting, the molten steel is poured into a special mold and the solidified steel is extracted continuously from the bottom of the mold in the form of billets, blooms, or slabs. The continuously cast semifinished products are cut to length, and then are ready for further processing into finished products. Pressure casting uses air pressure on the surface of molten steel contained in a ladle which is positioned in a special tank to force the molten steel into a graphite mold via a ceramic tube. After solidification, the slabs are ready for rolling into finished products. Although the particulates and gases generated in the casting of ingots, and rolling into semifinished products have not been a large source of air pollution, these operations are still of concern from air-quality aspects in the iron and steel industry. The new technologies of continuous and pressure casting have lowered emissions from this stage of steel processing.

The processes used in the manufacture of finished products have not been sources of large amounts of emissions to the atmosphere, but steps have been and are being implemented to lessen the small amounts of emissions generated during the rolling operations. Iron oxide fume is generated in the high-speed, high-powered, hot-strip mills, in the last few stands. This problem does not exist in the older, lower speed mills. The processes for making coated products have of necessity been designed to be made in equipment that is almost completely enclosed, either because of the safety aspects (such as the high speeds with which these processing lines operate) or because of quality requirements which dictate the use of closely controlled atmospheres in the processing lines. Overall, the processes used in the making of finished steel products are minor contributors to air pollution.

Particulate emissions have been a point of major concern in the iron and steel industry and have been the focus for concentrated efforts in the control of air pollution. However, gaseous emissions, some of which are noxious in character, should also be considered. Among these are (1) sulfur dioxide, (2) carbon monoxide, (3) fluorides, and (4) oxides of nitrogen.

Sulfur dioxide is released to the atmosphere as a result of the combustion of sulfur originating in raw materials and fuels. Although the steel industry attempts to minimize its intake of sulfur-bearing raw materials for metallurgical reasons, it is estimated that about 955,000 net tons of sulfur enter the various process segments annually in the making of iron and steel in the United States. Of this amount, about 651,000 net tons (68 percent) originates in the coal used to make coke. In accounting for the sulfur in products, by-products, and gases, about 464,000 net tons (49 percent) of sulfur is contained in blast furnace and steelmaking slags, and 39,000 net tons (4 percent) in raw steel and scrap. The burning of fuels (coke-oven gas, fuel oil, coke breeze, tar and pitch) involves an estimated 374,000 net tons of sulfur annually emitted to the atmosphere as sulfur dioxide (or removed in cleaning systems). In addition, there are about 78,000 net tons of sulfur unaccounted for.

Carbon monoxide emission to the atmosphere has not yet been treated as a problem of concern in the making of iron and steel, even though significant amounts of carbon monoxide are generated in various process segments. For example, about 550 cubic feet (43 pounds) of carbon monoxide are generated in carbonizing 1 ton of coal to make coke; and depending on specific blast furnace practice, about 16,000 to 25,000 cubic feet (about 1300 to 2000 pounds) of carbon monoxide are generated in the production of 1 net ton of pig iron. However, the large amounts of carbon monoxide generated in these processes do not reach the atmosphere because the carbon monoxide is used as a fuel in the heating of coke ovens, blast stoves, soaking pits, and other in-plant applications. This in-plant use of carbon monoxide as a fuel is one of the major economies realized by the iron and steel industry in the manufacture of steel products. Carbon monoxide is also generated in considerable amounts during the refining of steel in the basic oxygen furnace (BOF). The BOF off gases may contain as much as 90 percent carbon monoxide. However, here again, little carbon monoxide reaches the atmosphere. The carbon monoxide is burned to prevent possible explosions in pollution-control systems, or (as in the case of some wet-collection systems which pass carbon monoxide through the system) the carbon monoxide is burned and the products are flared to the atmosphere. The total amount of carbon monoxide reaching the atmosphere may be as little (in BOF steelmaking) as 33 cubic feet (2.6 pounds) per net ton of steel.

Fluoride emissions have long been suspected as contributors to air pollution because of the fluoride contained in some local iron ores, and the use of fluorspar (a calcium fluoride mineral) in the making of steel. Information concerning the amounts of fluoride emissions reaching the atmosphere have not been reported in the open literature. A recent report from Germany indicates that present air-pollution control equipment may be capable of controlling the emission of fluorides to the atmosphere.

Nitrogen oxide emissions by the iron and steel industry are an unknown quantity. The use of natural gas by the iron and steel industry has increased from about 5.7 million tons annually in 1958 to about 12.5 million tons in 1967. Combustion of natural gas is known to be a contributor to nitrogen oxide emissions. The lack of information on the amount of nitrogen oxide emissions combined with the increased use of natural gas indicates a need for investigative work in this area of air-pollution control.

FUTURE PLANS OF THE INDUSTRY

Changing market demands have resulted in the integrated iron and steel industry making plans for increasing and establishing new production facilities in the Midwest, Southwest, and Far West. Some of this has already been implemented with Bethlehem Steel Company's new plant at Burns Harbor, Indiana, and Jones & Laughlin's new plant at Hennepin, Illinois. United States Steel Corporation is placing a new electric-furnace steelmaking facility into operation in the Houston, Texas, area. National Steel has purchased property in the Corpus Christi, Texas, area, as well as in the San Francisco Bay area.

Technologically, the steelmaker has long had dreams of developing a process that would convert iron ore directly into semifinished products without the necessity of the blast furnace, steelmaking furnace, and casting operation. However, this still appears to be in the distant future. Work is being carried out at laboratory and pilot-plant levels but, as yet, none of the processes are in a position to produce the desired products at a cost competitive with present methods.

Direct-reduction processes that eliminate the need for blast furnaces to reduce iron ore are only beginning to make their entry into U. S. commercial steelmaking practice. Two plants are scheduled to start operations in 1969: one in Mobile, Alabama, and the other in Portland, Oregon. The steel industry as a whole will undoubtedly be watching the companies involved to determine how their two processes may influence decisions in the integrated iron and steel industry with respect to future expansion plans.

AIR-POLLUTION-CONTROL RESEARCH AND DEVELOPMENT

Research and development efforts are required to produce better emission-control equipment and systems, as well as to improve processes themselves in the iron and steel industry. Major needs include the development of sampling and analytical equipment that will operate on a continuous basis as a means of providing better design data to equipment manufacturers, better control data for steel plants and improved methods to monitor and measure emissions.

Temperature-sensing instrumentation is too slow in basic oxygen steelmaking practice, with the result that particulate emissions occur at the start and end of the oxygen-blowing periods. Instrumentation with faster response is necessary to correct this deficiency.

Additional basic information is needed on the electrical properties of particulate emissions and how they are affected by chemical composition; and studies are needed on more effective methods of conditioning metallurgical dusts for collection by electrostatic precipitators. For wet scrubbers, information is needed and work needs to be done to develop the necessary criteria to apply the wet system to the removal of obnoxious gases from the various processes in which wet scrubbers are used.

In the integrated iron and steel industry, research and development efforts are needed on a first-priority basis for the reduction of particulates and gaseous emissions at coke ovens and sinter plants. Another high-priority problem is the evolution of hydrogen sulfide from blast-furnace slags. An economical method for removing hydrogen sulfide from coke-oven gas is still another subject needing development. Also in the high-priority category is a need for research to lessen air-polluting emissions of particulates generated in the loading, transfer, and storage of the vast amounts of bulk raw materials. Longer range studies are required that will be directed toward the possible development of continuous-coking processes as a means for eliminating present coke-plant emission problems. Other subjects in need of research are the control of emissions from casting and flushing operations at the blast furnace, preparation of ingot molds, and methods of collecting emissions generated during the casting of ingots.

General Recommendations for Phase II Research on Technical Aspects of Control of Air-Pollution Emissions From the Integrated Iron and Steel Industry

The present report deals with Phase I, which since its inception has been expected to be followed by a Phase II research effort to fill gaps in the information developed during Phase I. Analysis and judgment by the Battelle staff of all the information accumulated during Phase I leads to the recommendation that Phase II research be conducted in the following three subject areas, each of which will be discussed in more detail:

(1) Improved control of emissions from the manufacture of metallurgical coke

(2) Instrumentation for in-plant emissions measurement and control

(3) Improved characterization of emissions from certain process segments.

These subjects have been selected because of (a) their importance to future control of air pollution, and (b) their apparent amenability to research action.

Following this general presentation, including discussion of reasons why some other subjects have been assigned lower priority for research attention, specific information is given on seven new projects that could be undertaken to implement these recommendations.

Improved Control of Emissions From the Manufacture of Metallurgical Coke

In Section VII of this report, two of the seven process segments identified as having first-priority research needs involve coke plants – oven charging, and pushing of coke. The conventional by-product coke-oven battery as it exists today as the traditional method for making metallurgical coke is viewed by Battelle and by many other observers of the situation as inherently unsuitable for close control of air-polluting emissions. In addition to charging and pushing, problems of air pollution of quantitatively undetermined magnitude are represented by gaseous emissions from lids and door seals, emissions of particulates during quenching of the coke, handling of the coke, and the coke-oven-gas system; all with the usually complex by-product system superimposed as an air-quality problem. A number of approaches mentioned throughout this report attempt to deal with pollution from one or more of these sources in the coke plant. However, until it can be demonstrated that these coking processes would have an impact on reducing air pollution from cokemaking, Battelle views many of these approaches as expedients aimed at making the coke plant tolerable until really satisfactory solutions can be found. The air-pollution problem associated with coke plants is of sufficient magnitude and the controls so inadequate that it is rare that anyone knowledgeable on the subject will deny that the coke plant is a major polluter of air. The severity of emissions is easy to see qualitatively because a number of coke-oven plants physically are sufficiently remote from other operations in a steelworks that there is little question as to which process segment in the plant is producing contamination.

Two approaches seem to warrant attention in Phase II; the first deals with improved methods of controlling emissions from present-type coke ovens, and the second involves entirely new methods of making metallurgical coke. Although a third remedy is conceivable and is receiving some attention, there appears to be little that could be done in the way of air-pollution research to promote this third alternative. The third alternative is direct reduction of iron ore – the reduction of iron ore by methods that bypass the blast furnace, and thus do not require metallurgical coke.

It is recommended that Phase II attention be given to (1) improved systems for controlling emissions from conventional slot-type coke ovens, and (2) new and improved methods for making metallurgical coke by methods other than conventional slot-type ovens, over which better control emissions could be exercised. More specific reasons for such a study, background, and the recommended scope are given in more detail under under the heading "Project 1: Processes for Making Metallurgical Coke".

Throughout consideration of new methods for making metallurgical coke, one encounters the problem that the best way to verify the suitability of a coke is actually to use it on a commercial scale in a blast furnace. This is an expensive procedure for two reasons: (1) some thousands of tons of coke are needed for a full-scale test, and few pilot plants for coke have the capability to produce such quantities, and (2) the blast-furnace tests are expensive to perform, difficult to evaluate, and involve the risk of damaging the multimillion dollar blast furnace. A reasonable step between small-scale research and full commercial operation involves the use of small "experimental" blast furnaces. There are two such furnaces in the United States. One is owned by U.S. Steel Corporation, and the other by the United States Bureau of Mines. Both are in the Pittsburgh area. U.S. Steel operates theirs when they have an appropriate problem. It is conceivable that it could be used under contract for investigations for other parties. The Bureau of Mines furnace has not been operated for several years and is being considered for disposal.

Assuming that no small experimental blast furnace is available for evaluating new types of coke, there are some possible alternatives. The chemical composition of the coke gives some indication of its suitability for blast-furnace use. Beyond this, there is a need for information on its combustibility and reactivity. Laboratory tests can be used and devised to give good information on this aspect, and some useful information can be developed from small-scale shaft-furnace tests that involve perhaps several hundred pounds of coke per test. Finally there is the question of the mechanical strength of the new coke at the temperatures involved in the blast furnace. A procedure was developed for determining such strength, and was applied to research for three steel companies.* The method is still applicable. These alternatives taken together can form a sound basis for planning commercial-scale runs on a new coke with high confidence.

Instrumentation for In-Plant Emissions Measurement and Control

Instrumentation is considered from the viewpoint that the general air-pollution problem involves needs for two types of instrumentation. The first is equipment that generally is most useful externally to the plant to determine levels of pollution existing in a general area, and to gather general information on air quality. That category is considered to be outside the scope of the present study. The second type, which is within the present scope, is anticipatory equipment which is useful within the steelworks in connection with process control and prompt measurement and detection of undesirable emissions, either particulate or gaseous. Preferably such instrumentation should be highly reliable for operation continuously in ducts under what often are trying conditions of temperature and corrosion. Continuous operation should be such as to give fast read-outs of the level and nature of emissions, and offer predictive aspects. The sensors might be interlocked with the process so as to accomplish some type of corrective action rapidly before the air is polluted. The instrumentation should contribute to the avoidance of air pollution; not only, such as is sometimes now installed, to "protect the equipment". Although the emission-control equipment usually requires some type of

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* John Varga, Jr. and H. W. Lownie, Jr., "Influence of Temperature on Mechanical Strength of Coke" Transactions of American Foundrymen's Society, 1956.

M. W. Lightner (Assistant Vice President, United States Steel Corp.), "Burdening the Blast Furnace"; Steel, February 7, 14, 21, 28, 1955.

John Varga, Jr., "High-Temperature Evaluation of Blast Furnace Coke", Proceedings of AIME Blast Furnace, Coke Oven, and Raw Materials Conference, 1960.

protection, this frequently takes the form of a bypassing system that can cause "puffing" at a frequency high enough to interfere with air quality. Instrumentation of the type needed, therefore, would perform three functions:

(1) Measure the nature and amount of emissions between the process segment and the collection system; do this in such a way as to provide signals that some undesirable change has occurred in the process; and give this readout fast enough (or act through interlocks) so that corrective action can be taken in connection with operation of the process.

(2) Provide measurements of conditions that if ignored would destroy or lower the efficiency of the emission-control equipment, and provide signals (or act through interlocks) in such a way as to protect the equipment without simple bypassing of the effluent into the atmosphere.

(3) Measure the nature and amounts of emissions from the emission-control equipment. If the emission-control system is properly designed and adequately maintained, and if the other instrumentation does its job properly, then the sensors at this stage merely confirm the proper operation of the overall system. If any upstream portion of the total system is inadequate or fails, then this location will signal the need for immediate attention to upstream process, instrumentation, and collection equipment.

During the course of this study, the investigators have been impressed by the apparent lack of availability of such instrumentation that meets the standards of the steel companies. The nature of equipment that is available and that is under development both in the United States and in Europe should be investigated in more detail in Phase II. Also the experiences of steel companies (and other heavy industry) both in the United States and overseas with the present designs of instrumentation should be investigated and analyzed to determine both the good features and the deficiencies of present equipment, and to prepare more specific recommendations for research to develop new acceptable instrumentation. "Project 4: Evaluation of Instrumentation for In-Plant Emissions Measurement and Control" deals with this subject.

Improved Characterization of Emissions from Process Segments

One of the objectives of this study was to obtain and interpret data and information on the amount, size, composition, electrical properties, and corrosive properties of particulates; composition and amounts of gaseous effluents; and to develop material balances that would permit a definition of the nature and amounts of emissions generated by ironmaking and steelmaking process segments in various parts of the United States. Attainment of the objective was handicapped by the sparsity of reliable information that could be obtained. In particular, data were generally inadequate for the preparation of complete material balances directed at the identification of emissions problems. Although the literature is fairly extensive, much of it is not adequately definitive of the conditions under which samples were taken, and some of the literature is frankly skeptical about the accuracy of the data. The European literature generally is more complete and more extensive than American literature on this subject, but there is a hesitancy to apply foreign results to the American iron and steel industry because of differences in operating practice. The shortage of reliable information on American practice stems from two factors: (1) it is Battelle's opinion that reliable data actually are rarer than many persons care to admit, and (2) some potential sources of information consider the data proprietary and confidential.

Battelle recommends that research be conducted to fill the gaps in the information on the amount, size, composition, and other properties of particulate and gaseous emissions from steelworks process segments. Such an activity will for the most part require active cooperating participation by at least one steel company. Given access to the processing equipment itself, investigators would be able to obtain the necessary samples and make the necessary analyses.

The process segment that appears to Battelle to warrant first attention in this regard is the sintering plant. Although there is some information presented in this report on particulate emissions from sintering plants, their gaseous emissions appear to warrant particular attention. "Project 3: Characterization of Emissions from Sintering Plants" is an example of a high-priority project of this type.

Characterization of the mechanism and nature of emissions of sulfur-bearing gases from blast-furnace slag during tapping from the blast furnace, during handling in the cast house, and during weathering in outside dumps has been recognized as a problem by the steel industry. Since 1966, the American Iron and Steel Institute has been sponsoring research on this subject. The research has the two objectives of identifying the mechanism of formation of the undesirable gases, and developing means for their suppression. Progress has been made, and results have been published.* More research is needed. With additional funding, the research could be conducted at an accelerated rate. Then, possibly, the results could be placed into practice some years earlier than would otherwise be the case. The problem is particularly worthy of attention because the evolutions occur over wide areas in diffuse amounts. When the slag is disposed of in dumps, the area can involve many acres; a condition that makes collection of the emissions by conventional means extremely difficult, perhaps impossible. "Project 2: Sulfur-Bearing Emissions from Blast-Furnace Slag" deals with this problem.

Other Subjects of Research Interest

In addition to the three foregoing subject areas that deserve (in Battelle's judgment) primary consideration, three additional subjects that warrant attention are (1) wide-area emissions, (2) sulfur content of fuels and of products of combustion, and (3) incineration of wastes. The reasons for assigning these subjects to a lower priority when viewed in the context of the integrated iron and steel industry are given below.

Wide-Area Emissions. These are emissions that occur generally over a wide area, often intermittently. Examples include the smoke and fume generated during the pouring of ingots and the kishing of hot metal as it is tapped from the blast furnace

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*F. H. Woehlbier and G. W. P. Rengstorff; "Preliminary Study of Gas Formation During Blast-Furnace Slag Granulation with Water"; Annual Meeting of Air Pollution Control Association; June, 1968.

and as it is transferred from vessel to vessel in the plant. These emissions occur over a wide area, often under physical conditions that make it difficult to install adequate hooding and ventilation. Often, overhead structures, and especially access to the area by overhead cranes, interfere with hooding. The technology of the process segments is such that it is unrealistic to expect that major improvement in emission control can be accomplished by a change in the process itself. Therefore, hooding or general evacuation of the building using large amounts of air exhausted through a suitable emissions-collection device appears to be the only possible solution. Although such a system would intrude upon the usual layout in a steel plant, the fact of the matter is that suitable equipment can be engineered for this purpose. Therefore, Battelle takes the view that this subject is a technical problem that can be solved by the application of existing engineering know-how. For this reason, Battelle does not consider this subject a prime candidate for research. The problem more properly belongs within the scope of engineering design and construction of steel plants.

In this general subject area, however, there are two facets deserving of research attention. These are:

(1) Experimental investigations of improved means for holding in place against weather and wind the fines stored in outside piles, especially coal piles. "Project 6: Control of Wide-Area Emissions from Storage Piles" deals with this subject.

(2) Pre-engineering and cost estimates for systems to collect and control wide-area emissions. "Project 7: Design and Costing of Systems for Collection and Control of Wide-Area Emissions Inside a Steelworks" deals with this subject.

Sulfur Content of Fuels and of Products of Combustion. Sulfur is an undesirable element in iron and steel. Therefore, steel companies have strong technological reasons to maintain the sulfur content of their raw materials at the lowest possible level consistent with considerations of cost. However, the problem of air pollution from the combustion of sulfur-bearing fuels exists in the steel industry as it exists in many other industries that burn such fuels.

Steel plants generate products of combustion at numerous locations scattered often over hundreds of acres of a steelworks. NAPCA is well aware of the problems of dealing with the combustion of sulfur-bearing fuels, the premium that must be charged for low-sulfur fuels, and the preliminary stage of development of methods developed to date to control sulfur-bearing gaseous emissions from the combustion of sulfur-bearing fuels. The treatment of coals, coke-oven gas, and petroleum products to lower their sulfur content has been studied on many fronts for many years, so that technically feasible methods have been worked out. Insofar as is known to the present investigators, no desulfurization process exists that meets today's criteria for economic feasibility. However, the present criteria may have to be changed if the nation is to have cleaner air. The general subject of desulfurization of steelworks fuels and the collection and control of sulfur-bearing gaseous emissions from combustion is not included in the list of recommendations for Phase II research because the general problem goes far beyond the steel industry. Because of the nationwide severity of this problem involving many industries, efforts should be continued to attack this problem vigorously. If an economically practical solution can be developed for the general case, its application to integrated steelworks would substantially lower the overall contribution of steelworks to air pollution by gaseous effluents.

Incineration of Wastes. Steelworks generate much combustible waste that often is burned on the premises. Because suitable incinerators and practices for their operation are considered to be available to solve this problem, this subject is not included in the present recommendations for research. However, as in the case of sulfur-bearing fuels and their products of combustion, the general problem of incineration should continue to be investigated on a base broader than that of the steel industry alone.

Specific Recommendations for Phase II Research on Technical Aspects of Control of Air-Pollution Emissions From the Integrated Iron and Steel Industry

Seven specific subjects that in Battelle's opinion warrant further research are now described. The subjects are not necessarily in any formal order of priority, but there has been an attempt to place the subjects in approximate order of urgency as viewed by the present investigators. Other investigators will have other judgments on ranking. Particular attention will be given to Project 1 – "Processes for Making Metallurgical Coke" – because it is in Battelle's judgment most urgent.

Project 1: Processes for Making Metallurgical Coke

Metallurgical coke is high-strength coke used in blast furnaces to smelt iron ores to produce molten iron that is the main ingredient for steelmaking. In the United States in 1967, about 56 million tons of metallurgical coke were used in about 170 blast furnaces to produce about 87 million tons of pig iron. Virtually all of this coke was made by the American iron and steel industry in coking plants in or associated with integrated steelworks. The production of this amount of coke required about 83 million tons of coal as the raw material. This was about 93 percent of all the coal used by the American integrated iron and steel industry in 1967 (which was a typical year). These statistics show that the American steel industry annually converts very large amounts of coal to metallurgical coke.

The manufacture of coke by the American integrated steel industry is widespread geographically. Of the total production in 1967; about 38 percent was made in Massachusetts, New York, plus Pennsylvania; about 13 percent in Indiana; about 12 percent in Maryland plus West Virginia; about 12 percent in Ohio; about 10 percent in Tennessee, Alabama, Texas, plus Oklahoma; about 6 percent in Michigan plus Minnesota; about 5 percent in Colorado, Utah, plus California; and about 4 percent in Illinois. Therefore, problems involving air pollution during the manufacture of metallurgical coke are of national interest.

The blast-furnace process is used in the United States as the method to produce over 95 percent of the pig iron on which the steel industry is based. Advancements in blast-furnace technology (such as use of higher grade ores and agglomerates, high blast temperatures, and injection of hydrocarbons) are lowering, year by year, the amount of coke needed to make 1 ton of pig iron, but the rate of production of pig iron is increasing annually so that the total tonnage of metallurgical coke required per year has been remaining about constant. The present state of the technology of the blast-furnace process does not include any factor that is expected to eliminate the high degree of dependence of the blast furnace on metallurgical coke. The main technological factor affecting the future need for metal from the blast furnace is the growth of the basic oxygen furnace (BOF) as the predominant method for making steel. Of the three major steelmaking processes, the BOF process conventionally requires about 70 percent of its charge in the form of hot metal from blast furnaces; the open-hearth process conventionally uses about 40 to 60 percent blast-furnace hot metal; and the electric-furnace process usually uses no hot metal. The BOF process (which uses high amounts of blast-furnace hot metal) has been growing rapidly in the United States, and elsewhere throughout the world. Invented in Europe in 1952, the BOF process accounted in 1968 for about 37 percent of the production of raw steel in the United States, and is expected to reach about 60 percent by 1980. This growth of the basic-oxygen process will put continuing pressure on demands for increasing amounts of hot metal from blast furnaces, which in turn will have to be supplied with increasing amounts of metallurgical coke.

The chances are low for development in the next decade or two of a commercially important method for reducing iron ore by a process other than the blast furnace in the quantities needed by the steel industry. Processes that eliminate the blast furnace are generically and loosely called "direct reduction" processes. They make use of rotary kilns, traveling grates, batch retorts, and electric smelting furnaces. Instead of metallurgical coke, they make use of coal, reformed natural gas, and/or electricity. A few percent of the world's production of iron from ore is made by such processes, and increasing attention is being given to them as possibilities for the future. Several new small plants utilizing such processes are now under construction near Mobile, Alabama; Portland, Oregon; Auckland, New Zealand; and in Korea. These plants deserve careful evaluation for their future potential in affecting the importance of the blast furnace, but it is unlikely that such processes will replace as much as 20 percent of blast-furnace pig iron in the United States within the next 15 years. Therefore, although such processes have potential commercial significance during the next decade for special situations, the blast-furnace process will remain for many years as the backbone of the American iron and steel industry.

The manufacture of metallurgical coke is conducted in batteries of slot-type by product ovens. The nature of these ovens is such that they give rise to air pollution. The research done since June, 1968, on Contract PH 22-68-65 has identified coke plants as probably the largest source of uncontrolled emissions to the air by the American steel industry. Because of the shortage of accurate and reliable data and measurements on emissions from coke plants, it is not possible at this time to prove the foregoing statement quantitatively, but knowledgeable persons in the steel industry and affiliated with it almost completely agree that coke plants represent the largest source of uncontrolled emissions by the steel industry. When the Industry Liaison Committee associated with Contract PH 22-68-65 was asked to identify air-pollution problems deserving of further study by NAPCA, every respondent mentioned some aspect of coke-plant operation. The most frequently mentioned problem was that of controlling the gaseous and particulate matter when the blend of fine coals (about 1/8 inch and down) is charged through the top into the incandescent coke oven.

In Section VII of this technological report on Contract PH 22-68-65, an evaluation is made of the process segments in the steel industry on which research and development may best be undertaken to achieve improved control of emissions to the air from the integrated iron and steel industry. Process segments are evaluated from the standpoints of (1) severity of emissions, (2) degree of present control of emissions, and (3) availability of methods for control. Of 109 sources of emissions evaluated, 7 are rated to deserve first-priority attention, 7 are given second priority, and 8 are given third priority. Of these 22 high-priority sources, 6 are associated with coke plants (2 in each of the three priority classifications). One of the first-priority subjects is control of gaseous and particulate emissions during charging of coal to the coke ovens.

It is suggested that further research attention be given to improved systems for charging coke ovens of the present design. An adequate system should be capable of injecting coal into the incandescent ovens under conditions that avoid the emission of particulates or gases during charging. Some research and development being conducted by others along these lines are, for purposes of discussion, considered to fall into three subdivisions.

The first subdivision is systems under development in Europe for this purpose. Although apparently tried to some degree in France and Canada, Germany seems to be the source of these systems. The European systems have been examined by American steelmakers, who so far have not seen fit to adopt them generally. American steelmen have stated several objections to the application of these systems in the United States. One of the objections is low reliability. One member of the steel industry said that he saw seven installations in Europe, of which one was operational and six were shut down undergoing repairs or modification. No further information was available from this source. Other American steelmen have observed that the height of some of the equipment (called a larry car and running on tracks on top of the ovens) is too great to fit under existing super-structure on American ovens. Other observers have questioned whether present American ovens can support the additional weight of the European systems. There also is an unconfirmed report that two installations of European systems on Canadian ovens resulted in damaging explosions. On Contract PH 22-68-65, it has not been possible because of contract limitations on time and money to investigate these European systems in sufficient depth to arrive at independent evaluation of their potential for the American situation. Suitability of any system that is installed on American ovens is important because installation of inadequate systems would not only be costly but could delay by several years the installation of really effective systems.

The second subdivision of systems that might be used to charge existing designs of coke ovens is identified here, for want of a better name, as "the AISI system". The American Iron and Steel Institute has had the subject under study by at least one of its committees. As a result of that study, a member of the Industry Liaison Committee has told NAPCA representatives that the AISI intends to approach NAPCA soon with a proposal for financial support for development of the "AISI system". Based on the information presently available to Battelle, the AISI system probably is a modification of one or more European systems. However, this is speculation. If the AISI (or any other organization) does ask NAPCA for support for a new system, the cost of a demonstration unit would be large. Because of this, any new system proposed for development should be compared with other alternatives that are possible. There would appear to be some merit, however, in supporting development of a system proposed by the American steel companies, because this would make the steel companies a direct part to finding a satisfactory solution to this challenging problem.

The third subdivision of this category suggested for research attention is an oven-charging system under development by the Allied Chemical Company, Wilputte Division.

This system attempts to accomplish the same thing as the foreign systems (cleaner charging of the coke oven), but also includes preheating of the coal – a technique that should decrease the coking time and increase the productivity of any oven on which it is installed. Allied has not released detailed information on this system (except that it involves preheating and pipeline charging), but is installing the system on a battery of ovens of its Semet-Solvay Division at Ironton, Ohio. It is suggested that NAPCA obtain more information on this system, and evaluate it in connection with improved information on the other two subdivisions in this category (the European equipment and the AISI system).

Turning now from the foregoing innovations aimed at better control of emissions from conventional coke ovens, it is further suggested that research attention be devoted to what Battelle considers the real long-term solution – the development of cokemaking methods that inherently lend themselves to a high degree of control over emissions. Battelle views such a system as being probably continuous so as to avoid the batch-charging and batch-ejection operations that contribute so much to air pollution from conventional ovens. Also, a new process should be designed from the ground up as a closed chemical system with specific attention to the avoidance of air pollution. At least one coal company in the United States has a process that should be investigated in more detail. This is the Chemcoke process of the Peabody Coal Company. Further investigation may show that other coal companies have something similar, or that the process is unsuitable for the manufacture of metallurgical coke. A demonstration plant for the Chemcoke process was built in 1961 at Columbia, Tennessee, and continues to operate for process development and to produce coke for chemical plants in the vicinity. The plant is rated at 100 tons of coke per day, which is quite large for a pilot plant. The process is thought to involve preliminary treatment of coal on a traveling grate in a dutch oven, followed by finishing in a shaft furnace. Most of the product has not been coke of metallurgical quality, but sources within Peabody Coal have said that they have produced coke that appears to meet the requirements of the blast furnace, but that this coke has never been tested in blast-furnace use. From these remarks, it is concluded that the process deserves more investigation and analysis. An official of Peabody has agreed orally to cooperate in further study of this subject. Based on the results in the demonstration plant, Monsanto Chemical Company in 1966 built a similar plant (rated at 500 tons of coke per day) at Decatur, Alabama, which reportedly is producing 550 tons of coke per day as reducing agent for phosphorus furnaces, an application considerably less demanding as regards mechanical strength than blast-furnace coke. The Chemcoke process at both plants is alleged to be continuous, requiring a throughput time of between 1 and 2 hours, and "completely clean" as to emissions. These allegations need confirmation, as do the prospects for the ability of this process to make metallurgical coke.

At the same time that the Peabody process is studied, an up-to-date evaluation should be made of the present status of the FMC process that produces a briquetted coke called FMC coke. This process has been under development by the FMC Corporation for more than a decade, and resulted in the construction of a demonstration plant at Kemmerer, Wyoming, to produce coke mainly for electric-furnace use. A few years ago, FMC and United States Steel cooperated in a venture to produce blast-furnace coke and evaluate this process. Such coke was made and evaluated in a small blast furnace, but the results were not sufficiently good that U.S. Steel was influenced to commit further large investment in research on this process. About 2 years ago, a larger scale evaluation was conducted in an Armco blast furnace at Hamilton, Ohio. Dusting of the FMC Coke during transportaion and handling was a problem, but FMC officials believe that the trouble was in the use of marginal briquetting equipment, and would not recur if briquetting rolls of proper size were used. The Kemmerer plant is now operating at a rate of 150 to 200 tons of coke per day for electric phosphorus furnaces of FMC Corporation at Pocatello, Idaho. In principle, the FMC process treats the coal in a fluidized bed and then agglomerates the product into briquettes. The method is one that seems to lend itself to close control of emissions.

It is recommended that new research be undertaken to make a nonexperimental technological evaluation in more depth of (1) improved systems for charging coal, pushing coke, and quenching coke made in conventional ovens so as to achieve improved control of gaseous and particulate emissions, and (2) new processes that have potential as means for manufacturing metallurgical coke under conditions that lend themsleves better than conventional coke ovens to the overall control of gaseous and particulate emissions. Based on the new information and data that would be accumulated during such research, it would then be possible to make an independent authoritative and meaningful evaluation of the future potential for such systems, and to prepare recommendations for additional hardware research that might be needed, leading perhaps to recommendations for hardware demonstration units or pilot plants that may be appropriate.

Drawing upon the foregoing background, it is suggested that the scope of new studies in Project 1 be as follows:

I. Improved Systems for Charging Coal, Pushing Coke, and Quenching Coke Made in Conventional Coke Ovens

  A. Acquire new information by direct visits to offices, laboratories, and/or installations of U.S. builders of coke ovens.

    (1) Allied Chemical Company

    (2) Koppers Company

    (3) AnDid Corporation

  B. Acquire new information by direct visits to offices, laboratories, and/or installations of European and Canadian companies.

    (1) Builders of coke ovens and coke-oven equipment

    (2) Steel companies with pertinent experience

  C. Evaluate the suitability of the technology for application to the present domestic oven design and coal blends.

II. New Processes With Potential for Manufacturing Metallurgical Coke

A. Acquire new information by direct visits to offices, laboratories, and/or installations of American companies and organizations with pertinent experience. New processes probably will be continuous, but potential processes will not be excluded solely because they are of a batch type.

  (1) Peabody Coal Company

  (2) Monsanto Chemical Company

  (3) FMC Corporation

  (4) United States Bureau of Mines

  (5) Others as may be determined during the study

B. During visits in Europe under I, search out status of European technology on such processes

C. Evaluate the suitability of the technology for application to the smelting of iron ore in blast furnaces in the United States.

III. Overall Evaluation and Recommendations

A. Evaluation

B. Recommendations

  (1) New nonexperimental studies

  (2) New research on hardware

  (3) For demonstration units or pilot plants

The foregoing scope has been prepared with the knowledge that Japanese steelmakers also face severe problems of air pollution from cokemaking operations. During the last year, Japanese visitors to the United States have made a point to observe U.S. practice along these lines, but have divulged little about the nature of solutions that they are considering or developing. During the course of the study outlined above, further information might be forthcoming about the situation in Japan. If that occurs, there may be improved reason for a later effort to acquire more information by direct visits to Japan, but such visits are not included in the present scope.

The conduct of Project 1 can be expected to require 5 or 6 months of elapsed time, and to require about 10 man-months of professional time (including supervision), plus costs for travel and support services.

Project 2: Sulfur-Bearing Emissions from Blast-Furnace Slag

The American integrated iron and steel industry annually receives in its raw materials about 1 million tons of contained sulfur. About 85 percent of this incoming sulfur content is contained in coal; mostly in the coal that is converted to coke. All of the contained sulfur that enters the steelworks leaves the works in some form. Only relatively minor amounts of sulfur are contained in the iron, steel, and steelmaking slags. The major identifiable fraction is the amount of sulfur contained in the blast-furnace slags. About 30 million tons of solid blast-furnace slag containing an average of about 1.5 percent sulfur is generated annually. This is almost half of the total amount of contained sulfur entering the American integrated steelworks.

Although a statistical analysis of the sulfur content of American blast-furnace slags is lacking, the range of sulfur contents appears to be from substantially less than 1 percent to more than 2 percent, with an average of about 1.5 percent.

What happens to the sulfur in molten slag that is tapped from a blast furnace? Some burns to SO_2 as the slag flows down the runners into granulators or slag thimbles; some converts to SO_2 and H_2S during granulation in water or in other processes where the molten slag contacts water; some is dissolved in the water and may or may not precipitate out; and some remains in the solid slag. It is known that during subsequent contact with water (as during weathering on a slag dump), additional sulfur is evolved into the air. The amount that is evolved is believed to be small, but factual data are not yet available. The fact that the evolutions do occur at these points has been established, but the relative amounts have not.

The amount of sulfur lost at various stages in the handling of blast-furnace slags is influenced by the nature of the handling process, the composition of the slag, the temperature of the slag, and presumably by other factors. It is known that some granulation processes yield a solid product with about half the sulfur content of the molten slag exiting from the blast furnace. On the other hand, some of the "hard slag" processes might yield a product with a sulfur content reduced only from about 1.5 percent in the molten condition to about 1.3 percent in the solid state, and most of this loss might report to the water used to cool the slag.

Recognizing the dearth of information on the mechanism of evolution of sulfur from blast-furnace slags, the American Iron and Steel Institute has been conducting experimental research on this subject since 1966, and the research is continuing. The experimental work is proceeding, but does not include identification of amounts of sulfur being evolved. The emphasis is on the fundamentals of the mechanism of the evolution. Although there remains much to be learned, it appears likely that the research will be extended to include some measurements on a full-size blast-furnace operation.

Battelle estimates that commercially useful results from studies on the mechanism of sulfur evolution from blast-furnace slags could be several years in the future at the present rate of effort on this subject. An expanded rate of effort would be expected to lead to earlier solution of the problem. The program also could be usefully expanded to determination of the amounts of sulfur emitted under various conditions and at the several points of handling or treatment of the slag.

The conduct of Project 2 can be expected to require at least 1 more year of experimental work at an annual rate of about 20 man months of professional time (including supervision), plus costs for support services (including considerable chemical analyses).

Project 3: Characterization of Emissions from Sintering Plants

About 50 million tons of sinter is made annually in the United States for charging to blast furnaces. Most of this sinter is made within the perimeter of integrated steelworks. The emissions include particulates and gases. The particulates are generally amenable to control by scrubbers, precipitators, and baghouses (but at substantial cost for equipment and operation). One of the major gaseous evolutions is SO_2. Sulfur enters the system in the ore, in the coke used in the sinter mix, and in fuel oil (when fuel oil is used). On the average, the amount of sulfur entering the system amounts to about 2 pounds per net ton of sinter produced. This is about 50,000 tons of contained sulfur per year. About 50 to 60 percent of this sulfur reports to the sinter, and about 30 to 40 percent probably appears in the off gases. The off gases may also contain fluorides under some conditions, but the amounts and conditions under which significant amounts of fluorides are evolved have not been identified adequately.

The present research has identified some of the characteristics and amounts of pollutants evolved from sintering plants, but the fund of reliable information requires reinforcement if the nature of sintering machines as polluters of air is to be understood thoroughly. Therefore, more research of an experimental nature is recommended.

Measurements should be made in at least two sintering plants, preferably more. The plants should be representative, but could involve at least two installations of generally similar conditions (so as to serve as a check on each other), and/or two or more different practices (to define a range). The different practices might well involve unfluxed and fluxed sinters of different basicities.

For each plant included in the project, the following is the minimum that should be determined:

(1) Prior to experimentation, define the plant and the system under study, including the nature and performance of air-pollution control equipment that is installed. Prepare flow sheets and material balances, including air. Identify unknowns in the system.

(2) Measure unknowns. Sample and characterize the amounts and compositions (including size distribution) of particulates and gases at various locations ahead of and behind any air-pollution control equipment.

(3) Develop improved and more definitive flow sheets and material balances than was possible in (1). Prepare an improved statement of the nature of the problem of control of emissions from sintering machines.

(4) Prepare recommendations for further research, if needed; and/or for construction of hardware or demonstration installations.

Project 3 requires that the investigators have virtually free access to the sintering plants being studied. Problems of sampling are expected to be considerable, and costs for particle-size and chemical analyses probably will be high. If two plants are involved in the study, Battelle estimates that about 9 months of elapsed time will be required, and that the investigation will require about 24 man-months of professional time (including supervision), plus costs for support services (including laboratory technicians and chemical and mechanical analyses of particulates and gases).

Project 4: Evaluation of Instrumentation for In-Plant Emissions Measurement and Control

Investigation to date shows that in-plant control of emissions from steelworks is hampered by a lack of suitable sensors, instrumentation, and control, and by lack of correlation of such equipment with that used external to the plant by abatement personnel. The nature of the problem is discussed earlier in Section II. New research on this problem is recommended.

New research in Project 4 should encompass the following scope:

(1) Develop from existing information a set of written hypotheses covering the present state of the art, including capabilities and limitations of present equipment.

(2) Modify or confirm each hypothesis by visits within the United States. The hypotheses will serve as a definite focal point to guide information seeking. The visits will develop new information on what is being used, what is available, and what the needs are. Visits should include steel plants, instrument companies, and abatement agencies, plus other sources of information as they develop during the investigation.

(3) Prepare a draft report on the state of the art in the United States and review this report with interested and affected parties in industry.

(4) Visits as in (2) above to Europe and to Japan.

(5) Prepare final report, including analysis of the present situation, recommendations for new research, and recommendations for hardware development or demonstration units as may be appropriate.

Project 4 is expected to require about 1 year of elapsed time. This includes provision for overseas travel and for interaction with industry on preparation of reports. The study is expected to require about 28 man-months of professional time (including supervision), plus costs for travel and support services.

Project 5: Development of Improved Flow Sheets and Material Balances for American Integrated Steelworks

In the conduct of Contract PH 22-68-65, flow sheets and material balances on process segments in the steel industry were developed from the open literature, from information accumulated during visits, and from Battelle's knowledge of the steel industry. Flow sheets and material balances prepared in this manner, generally descriptive of the situation that exists on the average for the steel industry viewed as a single entity on a national scale, have deficiencies and will introduce inaccuracies if applied to smaller segments of the industry, as for example the steelworks in a particular geographic area.

In April, 1969, the Board of Directors of the American Iron and Steel Institute offered to provide certain AISI quarterly operating reports for a one-time nonrecurring use for input to NAPCA studies of the iron and steel industry. Specified pages or sections of the reports would be provided with all individual company references deleted by mechanisms still to be worked out. None of the operating data would be deleted.

The AISI quarterly reports are prepared by the AISI from operating data submitted by process segment and by individual furnaces by companies that comprise almost the entire American iron and steel industry. A few companies do not report such information even to the AISI. These quarterly operating reports are closely held within the AISI. Approval in this case was secured by the efforts of the Industry Liaison Committee associated with Contract PH 22-68-65. Unfortunately, insufficient time was available after their release to make use of these reports on Contract PH 22-68-65.

Battelle recommends that Project 5 involve activity as follows:

(1) NAPCA would provide the investigators with definition of a number of geographic areas. These areas should not be such that analyses during the investigation will disclose the identity of particular steel plants unless the steel companies involved agree to such disclosure. As an example, geographic definitions could coincide with AISI steelmaking districts, or with state boundaries.

(2) For each area, and for the United States as a whole, flow sheets and/or material balances would be prepared so as to integrate all steelworks in the area. Breakdowns would be by major processes (e.g., blast furnaces, sintering machines, coke plants, BOF furnaces, etc.) in each area, not by company or plant within the area. It also would be possible not only to derive by direct statistical analysis the average condition within each area, but also to derive the frequency distribution of conditions deviating from the average.

(3) In the statistical analysis, emphasis could be focused on pollutants of special interest, e.g., sulfur in gases.

Project 5 would be essentially an exercise in statistical analysis of technological operating data. The AISI quarterly reports do not include information on capital or operating costs. The time required for analysis and reporting would be expected to be about 3 to 6 months, depending on the degree of detail desired, and the study is expected to require about 5 to 10 man-months of professional staff time (including supervision), plus supporting services (including the use of a digital computer).

Project 6: Control of Wide-Area Emissions from Storage Piles

Many steelworks raw materials are stored outside in bulk and in large quantities under conditions that allow fines to be airborne. The problem of air pollution is particularly severe when the material is being placed into or removed from storage. Coal is thought to be the worst offender, but fine iron ore also can be seen by simple observation to be a substantial contributor to air pollution.

It is recommended that new research be conducted to prepare a definitive and analytical report on the state of the art. In addition to the open literature (which contains little information on this subject), visits should be made and conferences held with steel companies, coal companies, ore companies, and other organizations that are potential sources of information. The report should define the nature of the problem and the state of the art in sufficient detail to support recommendations for experimental work and/or demonstration units. Among future experimental activities that should be evaluated in the report are the following:

(1) In-plant experiments on actual storage piles, including dust-fall measurements before and after changes are made.

(2) Model studies on a reduced-size scale, and including factors of pile arrangement, wind breaks, and other factors that might minimize air pollution by particulates.

Project 6 (the preparation of a definitive report to serve as the basis for decisions on experimental work) is expected to require about 5 calendar months and to involve about 10 man-months of professional time (including supervision), plus supporting services and travel costs.

Project 7: Design and Costing of Systems for Collection and Control of Wide-Area Emissions Inside a Steelworks

This final technological report on Contract PH 22-68-65 identifies wide-area emissions as those that occur over an expanse or space such that concerted attention has not yet been devoted to their collection and control. Usually this condition exists when the process segment is such that contained streams of air or other gases are not involved as part of the process. Examples (given a ranking of first-order priority in Section VII of the report) include the casting of blast-furnace hot metal, the flushing of blast-furnace slag, the disposal of blast-furnace slag, and the pigging of molten iron. Other examples include the preparation of ingot molds and the teeming of ingots (especially when exothermic hot tops are used).

In many existing steelworks, emissions of this general type are largely uncontrolled for two reasons:

(1) Collection hoods or other devices would be expected to interfere with other structures, especially with the operation of overhead cranes that service the areas.

(2) Amounts of air that might have to be handled to collect the emissions can be expected to be large, and from this capital and operating costs can be expected to be substantial.

It is recommended that activity on Project 7 involve the design and preparation of engineering drawings for suitable representative hooding systems, and the estimation of costs for the installation and operation of the systems. The report to accompany such designs and drawings should be suitable for serving as the basis for decisions regarding the construction of in-plant demonstration units. It is recommended that two types of designs be included in the project:

(1) Equipment for a typical difficult situation in an existing steelworks

(2) Equipment suitable for use in a new steelworks where the equipment can be installed as part of new construction.

Project 7 is estimated to require about 6 months of elapsed time at a cost equivalent to that of about 10 man-months of professional staff.

SECTION III

THE INTEGRATED IRON AND STEEL INDUSTRY

This Section describes some of the characteristics of the integrated iron and steel industry in the United States, and describes briefly some of the types of processing that are involved. An integrated steel plant is one that performs all of the functions necessary to convert iron ore to finished steel. Thus, an integrated steel plant usually will be large and include coke ovens, at least one blast furnace, one or more steelmaking furnaces, casting facilities, and rolling operations that yield finished steel characteristically in the form of plates, shapes, sheets, and/or strip. If a steel plant does not start with the reduction of iron ore, but for example purchases iron or steel scrap that is then remelted for processing into steel, then such a plant is not considered to be "integrated". Likewise, a steel plant that does no rolling or other processing beyond semifinished products such as billets or slabs is usually considered "nonintegrated". In the broadest sense, the integrated iron and steel industry, therefore, includes the operations of raw-material receipt and stocking, coking, reduction of iron ore, manufacture of molten steel, casting of the steel, and rolling of the steel into useful shapes. In the context in which the term is usually used, the integrated steel industry does not include small-scale operations (such as mini steel plants) that perform only a limited number of the full range of functions.

Most companies in the integrated steel industry are large, and most of the largest have several plants. About 25 steel companies in the United States have annual sales in excess of $100 million, and of these about 6 have annual sales in excess of $1,000 million.

Several distinctions should be kept in mind when considering the information and interpretations in this Section. For example, it sometimes is easy to overlook the distinction between capacity to make steel and production that deals with the amount actually made. Ratings of capacity are so difficult to make that the steel industry no longer publishes official capacities. Elimination of official but meaningless ratings for capacity came about a few years ago when production figures routinely ran over 100 percent of "capacity".

Statistics on steelmaking quantities are frequently given in terms of two main bases, and the distinction between them must be recognized. One basis is raw steel, which is steel in the form of ingots or continuously cast billets, blooms, or slabs. Until the advent of continuous casting, this basis was called ingot tonnage. The other basis is the tonnage of finished steel, which characteristically amounts on a national annual gross scale to about 70 percent of raw steel.

CHARACTERISTICS ON A NATIONAL SCALE

A statistical picture of the American integrated iron and steel industry is given in Tables III-1 through III-42. The tables are self explanatory, and cover aspects such as production, financial status, number of persons employed, employment and other costs, processes used, products manufactured, and raw materials consumed. Some of the data are given by states where such information is available.

In this group of tables, the industry is pictured at a point in time - the year 1967*. In addition to being the latest year on which statistics are available, the production of 127 million net tons of raw steel in 1967 was reasonably close to the long-term trend line that would indicate a "normal" production of about 118 million tons in 1967. Thus, 1967 was neither exceptionally "good" nor exceptionally "bad". Whereas this Section deals with the state of the industry in a single year, Section IV includes considerations of historical changes with time, and statistical projection of performance into the future.

Except where otherwise noted, information for Tables III-1 through III-42 was taken or adapted from the <u>1967 Annual Statistical Report</u> of the American Iron and Steel Institute.**

In addition to some statistical breakdowns by states in various tables from Table III-8 through III-40, Figure III-1 maps the location of the American iron and steel industry on the basis of value added by manufacture by states.(1)*** The areas of the circles centered over each steel-producing state are proportional to that state's contribution to value added. The concentration of the United States steel industry in the region of the Great Lakes is strikingly apparent. The three states Pennsylvania, Ohio, and Indiana account for well over half of the steel industry's value added.

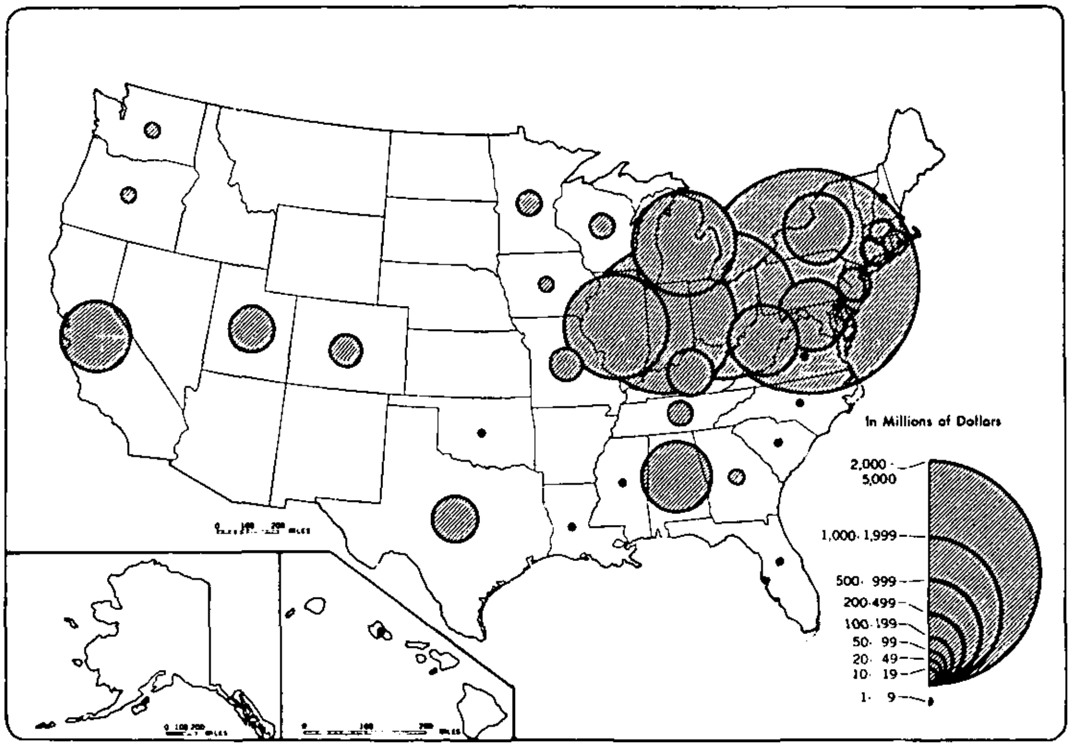

FIGURE III-1. VALUE ADDED BY MANUFACTURE BY STATE - 1963

(Blast Furnaces, Steel Works, and Rolling and Finishing Mills: SIC 331).

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*Table III-37 is an exception because shipments of iron ore are given for 1966, the latest year reported.

**The AISI Annual Statistical Report covering 1968 is expected to be released in June, 1969.

***References for Section III are given at the end of the Section.

TABLE III-1. PRODUCTION, SHIPMENTS, AND FOREIGN TRADE OF THE UNITED STATES IRON AND STEEL INDUSTRY - 1967

	Thousands of Net Tons[a]
Raw Steel Production by Type of Furnace	
Open Hearth	70,690
Basic Oxygen Process	41,434
Electric	15,089
Total	127,213
Net Shipments of Steel Products by Type of Steel	
Carbon Steel	76,042
Alloy Steel	7,018
Stainless Steel	837
Total	83,897
Foreign Trade in Mill Products	
Exports	1,685
Imports	11,455

(a) All tons are net tons of 2000 pounds.

TABLE III-2. FINANCIAL BALANCE SHEET: U.S. STEEL INDUSTRY - 1967

Assets	Millions of Dollars
Current Assets	
Cash	694.6
United States Government securities	1,119.5
Receivables, less allowances for doubtful accounts	1,742.1
Inventories	3,835.9
Total current assets	7,392.1
Miscellaneous investments and other assets	1,792.3
Fixed Assets	
Property, plant and equipment (less depletion)	26,484.4
Less - Depreciation and amortization	14,951.7
Net fixed assets	11,532.7
Intangibles	2.9
Deferred charges	173.4
Total assets	20,893.4
Liabilities and Stockholders' Equity	
Current Liabilities	
Accrued taxes, including Federal income taxes	855.7
Long-term debt maturing within one year	96.0
All other current liabilities	2,344.5
Total current liabilities	3,296.2
Long-term debt less amount maturing within one year	4,154.8
Reserves for future Federal income taxes, insurance, contingencies, deferred credits, etc.	1,013.0
Minority interest in companies not wholly owned	9.4
Stockholders' Equity	
Preferred stock	128.7
Common stock	3,243.7
Capital in excess of par or stated value of capital stock	1,149.3
Income reinvested in business	7,898.3
Total stockholders' equity	12,420.0
Total liabilities and stockholders' equity	20,893.4

TABLE III-3. INCOME, DIVIDENDS, EMPLOYMENT, AND EMPLOYMENT COSTS:
UNITED STATES STEEL INDUSTRY – 1967

Reporting Companies Represent:	
Blast furnace production, million net tons	84.0
Percent of industry	95.8
Raw steel production, million net tons	119.3
Percent of industry	93.8
Shipments of finished steel products, million net tons	80.3
Statement of Income, millions of dollars	
Revenues:	
Net billing value of products shipped and other services	$17,045.7
Interest, dividends and other income	195.6
Total revenue	17,241.3
Costs Applied to Billings and Other Services millions of dollars	
Employment costs:	
Wages and salaries[a]	5,662.6
Social security taxes	265.5
Pensions	293.3
Insurance	288.4
Savings and vacation type plans	44.5
Supplemental unemployment benefits	41.7
All other employment costs	63.5
Total employment costs	6,659.5
Materials, supplies, freight and other services, etc.	7,595.0
Depreciation, depletion and amortization	1,216.6
Interest and charges on long-term debt	188.9
State, local and miscellaneous taxes	348.9
Federal income taxes	383.8
Total costs	16,392.7
Net Income[b]	$ 848.6
Cash Dividends Declared	$ 492.1
Number of Stockholders at End of Year[c]	1,166,777
Employment Data:[d]	
Number of employees in steel industry (avg. monthly)[e]	522,008
Total number of employees receiving pay (avg. monthly)	710,005
Hours, in millions	
Man hours in the steel industry	1,015.4
Other	343.4
Total Hours	1,358.8
Payroll: (Millions of dollars)	
Wages and salaries in the steel industry	$ 4,399.3
Other	1,367.5
Total Payroll[f]	$ 5,766.8
Employment Costs, per hour:	
Wages and salaries	$ 4.244
Social security taxes	.195
Pensions	.216
Insurance	.212
Savings and vacation type plans	.033
Supplemental unemployment benefits	.031
All other employment costs	.047
Total employment costs per hour	$ 4.978

(a) Does not include portion of payroll charged to own construction or other nonoperating accounts.

(b) Some of the reporting companies, either directly or indirectly through subsidiary companies, are engaged in activities which are not a part of the steel industry and make their reports on a consolidated basis. Hence, "Net Income" as reported by such companies includes the operations of activities not concerned with steelmaking.

(c) Excludes duplication of holders of more than one class of stock of a single company but does not exclude a holder of stock of more than one company.

(d) Under "Employment Data," steel industry includes operation of coke ovens, blast furnaces, steelmaking furnaces and finishing mills, etc., and the sale of the products thereof, and "Other" includes mining and quarrying operations, transportation, warehousing, fabrication and other non-steel producing activities.

(e) Adjusted to reflect turnover of employees.

(f) Includes portion of payroll charged to own construction or other nonoperating accounts.

TABLE III-4. EMPLOYMENT, STOCKHOLDERS, AND CAPITAL EXPENDITURES: UNITED STATES STEEL INDUSTRY - 1967

Labor: (All employees)	
Number of Employees:	
Average monthly number of employees receiving wages and salaries during the year:	
Wage employees	538,522
Salaried employees	171,483
Total Employees	710,005
Man Hours Actually Worked During the Year, in millions	
Wage employees	1,009.3
Salaried employees	349.5
Total Hours	1,358.8
Total Payroll, millions of dollars(a)	
Wage employees	$ 4,028.6
Salaried employees	1,738.4
Total Payroll	5,767.0
Less portion of payroll included above but charged to own construction or other nonoperating accounts	104.4
Balance	$ 5,662.6
Stockholders:	
Number at end of year:	
Preferred	22,972
Common	1,149,123
Total(b)	1,166,777
Expenditures for additions, improvements and acquisitions, in millions of dollars	$ 2,172.8
Estimated cost to complete construction in progress, in millions of dollars	$ 3,125.9

(a) Wage and salaried payroll includes payments applicable to the prior year.

(b) Excludes duplication of holders of more than one class of stock of a single company but does not exclude a holder of stock of more than one company.

TABLE III-5. TOTAL NET SHIPMENTS OF STEEL PRODUCTS BY UNITED STATES STEEL INDUSTRY - 1967

All Grades (Including Carbon, Alloy, and Stainless Steels)

Product	Net Tons
Ingots and steel castings	289,261
Blooms, slabs, billets, sheet bars	2,478,621
Tube rounds	25,524
Skelp	2,008
Wire rods	1,266,516
Total semi-finished	4,061,930
Structural shapes (heavy)	5,591,735
Steel piling	541,186
Plates	7,948,349
Total shapes and plates	14,081,270
Rails	
Standard (over 60 pounds)	684,523
All other	45,955
Joint bars	30,934
Tie plates	144,791
Track spikes	61,998
Wheels (rolled and forged)	285,502
Axles	180,669
Total rails and accessories	1,434,372
Bars	
Hot rolled (incl. light shapes)	7,961,028
Reinforcing	3,249,479
Cold finished	1,732,575
Tool steel	109,929
Total bars and tool steel	13,053,011
Pipe and tubing	
Standard	2,712,499
Oil country goods	1,339,772
Line	3,094,920
Mechanical	1,051,711
Pressure	260,291
Structural	473,360
Stainless	36,481
Total pipe and tubing	8,969,034
Wire	
Drawn	2,507,251
Nails and staples	334,106
Barbed and twisted	102,175
Woven wire fence	116,050
Bale ties and baling wire	73,757
Total wire and wire products	3,133,339

TABLE III-5. (Continued)

Product	Net Tons
Black plate	604,487
Tin and terne plate - hot dipped	38,734
Tin plate - electrolytic	5,947,638
Total tin mill products	6,590,859
Sheets	
Hot rolled	9,311,592
Cold rolled	14,709,006
Sheets and strip	
Galvanized - hot dipped	4,218,700
Electrolytic	326,726
All other metallic coated	503,334
Electrical	721,031
Strip	
Hot rolled	1,409,339
Cold rolled	1,373,797
Total sheets and strip	32,573,525
Total shipments	83,897,340

TABLE III-6. TOTAL PRODUCTION OF HOT-ROLLED PRODUCTS (BY TYPE OF PRODUCT) BY UNITED STATES STEEL INDUSTRY – 1967

Product	Thousands of Net Tons
Plates	10,120
Sheets	37,007
Strip[a]	1,417
Coils for cold reduced black plate and tin plate	8,548
Bars – Merchant	8,921
– Concrete reinforcing	4,089
– Light shapes	1,305
Structural shapes – heavy	5,681
Steel piling[b]	519
Rails	763
Joint bars and tie plate bars	201
Skelp	3,484
Blanks or pierced billets for seamless tubing	3,949
Wire rods	4,787
Rolled forging billets	1,695
Blooms, billets, etc., for export	120
Car wheels (rolled steel)	289
All other	189
Total	93,084

(a) Includes cotton ties, balling bands and hoops.

(b) Includes H-bearing piles.

TABLE III-7. TOTAL PRODUCTION OF HOT-ROLLED STEEL PRODUCTS (BY STATE) BY UNITED STATES STEEL INDUSTRY - 1967

State	Thousands of Net Tons
Massachusetts	187
Rhode Island	
Connecticut	
New York	4,049
New Jersey	
Pennsylvania	21,060
Maryland	4,786
Delaware	
Virginia	3,559
West Virginia	
North Carolina	
Georgia	
Florida	
Ohio	15,789
Illinois	7,942
Indiana	14,665
Michigan	8,068
Minnesota	
Missouri	
Alabama	3,181
Kentucky	1,285
Mississippi	2,362(a)
Oklahoma	
Texas	
Colorado	2,819
Arizona	
Utah	
Washington	
Oregon	
California	3,332
Hawaii	
Total	93,084

(a) Includes Tennessee and Arkansas.

TABLE III-8. PRODUCTION OF PLATES AND SKELP (BY STATE) BY UNITED STATES STEEL INDUSTRY – 1967

State	Thousands of Net Tons
New York	3,647
Pennsylvania	
Delaware	1,215
Maryland	
West Virginia	
Ohio	1,330
Indiana	2,294
Illinois	1,138
Michigan	
Kentucky	2,504
Alabama	
Texas	
Colorado	1,476
Utah	
Washington	
California	
Total	13,604

TABLE III-9. PRODUCTION OF FLAT HOT-ROLLED PRODUCTS (EXCEPT PLATES)(a) BY UNITED STATES STEEL INDUSTRY – 1967 (BY STATE)

State	Thousands of Net Tons
Rhode Island	9,653
New York	
New Jersey	
Pennsylvania	
Maryland	8,295
West Virginia	
Georgia	
Kentucky	
Alabama	
Texas	
Ohio	9,535
Indiana	9,254
Illinois	1,425
Michigan	6,858
Minnesota	
Colorado	1,952
Utah	
Washington	
California	
Total	46,972

(a) Includes sheets, strip, coils for cold-reduced black plate and tin plate, hoops and cotton ties.

TABLE III-10. PRODUCTION OF MERCHANT BARS AND LIGHT SHAPES (BY STATE) BY UNITED STATES STEEL INDUSTRY – 1967

State	Thousands of Net Tons
Massachusetts	989
Connecticut	
New York	
Pennsylvania	2,437
Maryland	205
Virginia	
West Virginia	
North Carolina	
Georgia	
Florida	
Ohio	1,982
Illinois	1,617
Indiana	1,595
Michigan	542
Minnesota	
Missouri	
Alabama	161
Kentucky	205(a)
Oklahoma	
Texas	
Colorado	159
Utah	
Washington	
Oregon	
California	334
Total	10,226

(a) Includes Tennessee.

TABLE III-11. PRODUCTION OF CONCRETE REINFORCING BARS (BY STATE) BY UNITED STATES STEEL INDUSTRY – 1967

State	Thousands of Net Tons
Massachusetts	72
New York	
Pennsylvania	872
Maryland	444(a)
North Carolina	
Georgia	
Florida	
Ohio	192
Illinois	506
Indiana	392
Minnesota	
Michigan	
Missouri	
Alabama	302
Mississippi	
Oklahoma	464(b)
Texas	
Colorado	293
Arizona	
Washington	
Oregon	
Hawaii	
California	552
Total	4,089

(a) Includes West Virginia and Virginia.

(b) Includes Tennessee and Arkansas.

TABLE III-12. PRODUCTION OF HEAVY STRUCTURAL SHAPES AND STEEL PILING (BY STATE) BY UNITED STATES STEEL INDUSTRY - 1967

State	Thousands of Net Tons
New York	3,402
Pennsylvania	
West Virginia	351[(a)]
Georgia	
Alabama	
Texas	
Ohio	2,023
Indiana	
Illinois	
Missouri	
Colorado	262
Utah	
Washington	
Oregon	
California	162
Total	6,200

(a) Includes Kentucky.

TABLE III-13. PRODUCTION OF WIRE RODS (BY STATE) BY UNITED STATES STEEL INDUSTRY - 1967

State	Thousands of Net Tons
Massachusetts	273
Rhode Island	
New Jersey	
New York	46
Pennsylvania	732
Maryland	355
Georgia	
Ohio	699
Illinois	1,392
Indiana	271
Michigan	370
Minnesota	
Missouri	
Alabama	177
Texas	
Colorado	472
California	
Total	4,787

TABLE III-14. PRODUCTION OF BLANKS, TUBE ROUNDS OR PIERCED BILLETS FOR SEAMLESS TUBING (BY STATE) BY U. S. STEEL INDUSTRY - 1967

State	Thousands of Net Tons
New York	23
Pennsylvania	1,671
Ohio	1,824
Indiana	431
Illinois	
Colorado	
Total	3,949

TABLE III-15. PRODUCTION OF SEMIFINISHED STEEL FOR FORGINGS AND EXPORT (BY STATE) BY U.S. STEEL INDUSTRY - 1967

State	Thousands of Net Tons
Connecticut	910
New York	
Pennsylvania	
Maryland	266(a)
Kentucky	
Alabama	
Texas	
Ohio	622
Indiana	
Illinois	
Michigan	
Minnesota	
Colorado	17
Washington	
California	
Total	1,815

(a) Includes Georgia and West Virginia.

TABLE III-16. PRODUCTION OF COLD-ROLLED SHEETS AND STRIP BY UNITED STATES STEEL INDUSTRY – 1967

Product	Thousands of Net Tons
Finished on continuous or tandem mills	19,351
Finished on single-stand mills	2,494
Total	21,845

TABLE III-17. PRODUCTION OF COATED SHEETS AND STRIP BY UNITED STATES STEEL INDUSTRY – 1967

Product	Thousands of Net Tons
Galvanized sheets and strip	4,582
Long terne sheets	258
Electrolytic tin plate	5,776
Hot-dipped tin and terne plate	31
Total	10,647

TABLE III-18. PRODUCTION OF PIPE AND TUBING (BY TYPE) BY UNITED STATES STEEL INDUSTRY – 1967

Product	Thousands of Net Tons
Seamless	3,445
Buttweld	1,886
Electricweld	4,146
Gasweld and spiral weld	13
Total	9,609

TABLE III-19. STEEL PRODUCTION (BY GRADES) BY UNITED STATES STEEL INDUSTRY – 1967

	Thousands of Net Tons
Raw Steel plus Castings	
Carbon steel	113,190
Alloy steel	12,572
Stainless steel	1,451
Total production	127,213
Steel for Castings (included in total production)	
Carbon steel	134
Alloy steel	59
Stainless steel	1
Total for castings	194

TABLE III-20. RAW STEEL PRODUCTION (BY STATE AND BY TYPE OF FURNACE) BY UNITED STATES STEEL INDUSTRY - 1967

States	Thousands of Net Tons Total	Open Hearth	Basic Oxygen Process	Electric
New York	7,298	(a)	(a)	199
Pennsylvania	29,881	20,854(b)	5,854	3,173
Rhode Island, Connecticut, New Jersey, Delaware, Maryland	8,132	5,225	(a)	(a)
Virginia, West Virginia, Georgia, Florida, North Carolina, South Carolina	4,268	(a)	(a)	958
Kentucky	2,410	(a)	(a)	575
Alabama, Tennessee, Mississippi	4,444	(a)	(a)	344
Ohio	20,378	10,763	7,452	2,163
Indiana	17,610	11,157	(a)	(a)
Illinois	10,649	5,387	2,316	2,946
Michigan	9,245	(a)	7,250	(a)
Minnesota, Missouri, Oklahoma, Texas	4,644	2,310	--	2,334
Arizona, Colorado, Utah, Washington, Oregon, Hawaii	4,154	(a)	(a)	777
California	4,100	1,984	(a)	(a)
Total	127,213	70,690	41,434	15,089

(a) Deleted because disclosure would reveal proprietary information.

(b) Includes Bessemer.

TABLE III-21. PRODUCTION OF PIG IRON AND FERROALLOYS BY UNITED STATES STEEL INDUSTRY - 1967

Product	Thousands of Net Tons
Blast furnace production	
Pig iron (including silvery pig iron)	86,984
Ferromanganese and spiegel	663
Total blast furnace production	87,647
Ferroalloys made in electric furnaces	
Ferromanganese	280
Ferrosilicon	528
Ferrochrome	263
Ferrochrome silicon	154
Ferrophosphorus	111
Silico-manganese	230
All other	259
Total ferroalloys made in electric furnaces	1,825
Total pig iron and ferroalloys	89,472

TABLE III-22. PRODUCTION OF PIG IRON AND FERROALLOYS (BY GRADES AND KINDS) BY UNITED STATES STEEL INDUSTRY – 1967

Product	Thousands of Net Tons
Pig iron	
Basic	81,344
Bessemer	1,722
Low phosphorus	166
Foundry	1,550
Malleable	1,830
All other	372
Total pig iron	86,984
Ferroalloys (made in blast furnaces and electric furnaces)	
Ferromanganese and spiegeleisen	943
Ferrosilicon	528
All other ferroalloys	1,017
Total ferroalloys	2,488
Total pig iron and ferroalloys	89,472

TABLE III-23. NUMBER OF BLAST FURNACES PRODUCING PIG IRON AND FERROALLOYS ON JANUARY 1, 1968 (BY STATE)

State	In Blast	Total
	Pig Iron	
Alabama	9	17
California	4	4
Colorado	4	4
Illinois	14	18
Indiana	22	24
Kentucky	2	3
Maryland	10	10
Michigan	9	9
Minnesota	1	2
New York	12	15
Ohio	33	47
Pennsylvania	39	58
Tennessee	0	3
Texas	2	2
Utah	3	3
West Virginia	4	4
Total	168	223
	Ferroalloys	
Blast furnaces	5	7
GRAND TOTAL	173	230(a)

(a) Of the 57 furnaces which were idle on January 1, 1968, 5 were relining.

TABLE III-24. PRODUCTION OF PIG IRON AND FERROALLOYS (BY STATE) BY UNITED STATES STEEL INDUSTRY - 1967

State	Thousands of Net Tons
Pig Iron[a]	
New York	6,172
Pennsylvania	20,542
Maryland, West Virginia, Kentucky, Tennessee, Texas	10,824
Alabama	4,290
Ohio	14,485
Indiana	12,167
Illinois	6,309
Michigan, Minnesota	7,439
Colorado, Utah, California	4,756
Total	86,984
Ferroalloys	
New York	109
Pennsylvania	468
Virginia, West Virginia, South Carolina, Tennessee	559
Ohio	734
Other States	618
Total	2,488
GRAND TOTAL	89,472

(a) Includes silvery pig iron.

TABLE III-25. MATERIALS USED BY UNITED STATES BLAST FURNACES IN MANUFACTURE OF IRON AND FERROALLOYS - 1967

Products	Thousands of Net Tons of Material Used		
	Iron (Pig and Molten)	Ferroalloys	Total
Ore			
Iron ore (including manganiferous and block)	42,390	12	42,402
Manganese ore (including ferruginous manganese)	133	1,257	1,390
Agglomerated products (sinter, pellets, etc.)	96,875	11	96,886
Total ores and agglomerated products consumed	139,398	1,280	140,678
Less flue dust and sludge produced	3,749	58	3,807
Net ores and agglomerated products consumed	135,649	1,222	136,871
Scrap			
Total scrap consumed	4,218	9	4,227
Less produced at blast furnaces and auxiliary units	809	7	816
Net Scrap consumed	3,409	2	3,411
Mill cinder, roll scale, etc.	5,476	2	5,478
Limestone, dolomite, other flux materials	14,422	341	14,763
Coke			
Total coke consumed in blast furnaces	56,197	1,088	57,285
Less coke breeze (dust) recovered	1,280	21	1,301
Net Coke consumed	54,917	1,067	55,984

TABLE III-26. MATERIALS USED BY UNITED STATES BLAST FURNACES IN THE MANUFACTURE OF PIG IRON (BY STATES) – 1967

State	Iron Ore and Agglomerates(a)	Scrap(a)	Mill Cinder, Scale, etc.	Total
	Thousands of Net Tons			
New York	9,392	218	487	10,097
Pennsylvania	33,155	820	1,574	35,549
Maryland, West Virginia, Kentucky, Texas	16,612	252	875	17,739
Alabama	7,215	121	19	7,355
Ohio	20,453	1,114	1,453	23,020
Illinois	10,108	367	297	10,772
Indiana	19,299	189	460	19,948
Michigan, Minnesota	11,545	205	126	11,876
Colorado, Utah, California	7,870	123	185	8,178
Total	135,649	3,409	5,476	144,534

(a) Total material charged less products recovered.

TABLE III-27. CONSUMPTION OF MATERIALS PER NET TON OF PIG IRON PRODUCED IN THE UNITED STATES – 1967

Material	Net Tons
Iron ore and agglomerates(a)	1.560
Scrap(a)	0.039
Mill cinder, scale, etc.	0.063
Total	1.662
Limestone and dolomite(b)	0.257
Coke(a)	0.631

(a) Based on total material charged less products recovered.

(b) Based on total limestone and dolomite charged directly into blast furnaces, plus tonnage consumed in the production of agglomerates.

TABLE III-28. SCRAP – STOCKS, PRODUCTION, RECEIPTS, AND CONSUMPTION BY GRADE – 1967

Grade	Stocks On Hand Beginning of Year	Produced	Received	Consumed	Shipped, Transferred or Otherwise Disposed	Stocks On Hand End of Year
	Thousands of Net Tons					
Steel scrap						
Carbon	5,221	36,752	23,158	56,533	3,499	5,099
Alloy (excl. stainless)	226	2,294	403	2,598	90	235
Stainless	90	477	297	752	26	86
Cast iron, incl. borings	1,022	4,331	2,041	5,539	984	871
Total	6,559	43,854(a)	25,899	65,422	4,599	6,291

(a) Production by source:

Source	Produced
Recirculating (including home, plant or recycled iron and steel scrap)	38,118
Obsolete (including molds, stools, machinery, buildings, except rerolling rails)	3,389
Other (including slag,) etc.	2,347
Total	43,854

TABLE III-29. CONSUMPTION OF SCRAP AND PIG IRON, AND PRODUCTION OF STEEL BY TYPES OF FURNACES – 1967

Type of Furnace	Consumed: Scrap	Consumed: Pig Iron(a)	Consumed: Total	Raw Steel Production(b)
	Thousands of Net Tons			
Open hearth and Bessemer	32,298	42,266	78,564	70,560
Basic oxygen process	13,955	33,607	47,562	41,434
Electric	13,351	279	13,630	13,489
Cupola	1,048	216	1,264	--
Air	46	15	61	--
Blast	4,280	--	4,280	--
Other	444	2,467	2,911	--
Total	65,422	82,850	148,272	125,483

(a) Including molten metal.

(b) Total raw steel production: 127,213.

TABLE III-30. CONSUMPTION OF FUELS BY UNITED STATES STEEL INDUSTRY – 1967

Blast Furnace Area		Steel Melting Furnaces	Heating and Annealing Furnaces	Heating Ovens for Wire Rods	Other	Total
Blast Furnaces	Other Uses					
Fuel Oil, thousands of gallons						
67,225	14,011	567,663	403,426	(a)	201,663	1,253,988
Tar and Pitch, thousands of gallons						
20,936	(a)	248,222	(a)	(a)	33,741	302,899
Liquid Petroleum Gas, thousands of gallons						
--	(a)	(a)	11,112	--	3,853	13,965
Natural Gas, millions of cubic feet – based on 1,000 Btu per cubic foot						
44,255	5,766(b)	85,932	277,322	5,682	115,504	534,461
Coke Oven Gas, millions of cubic feet – based on 500 Btu per cubic foot						
13,433	276,923(c)	32,762	352,236	9,681	201,193	886,228
Blast Furnace Gas, millions of cubic feet – based on 95 Btu per cubic foot						
1,400,147	1,291,217(d)	(a)	162,898	--	1,276,741	4,131,003

(a) Included with "Other".

(b) Includes coke-oven underfiring.

(c) Includes 237,541 coke-oven underfiring.

(d) Includes 334,068 coke-oven underfiring.

TABLE III-31. CONSUMPTION OF ELECTRIC POWER BY UNITED STATES STEEL INDUSTRY – 1967

Power Source	Millions of kwhr
Generated	11,954
Purchased	30,557
Total	42,511

TABLE III-32. CONSUMPTION OF FLUXES BY UNITED STATES STEEL INDUSTRY - 1967

	Net Tons				
Use	Fluorspar	Limestone	Lime	Other Fluxes	Total
In agglomerated products	--	7,929,735	--	--	7,929,735
In blast furnaces	--	14,763,656	--	--	14,763,656
In steelmaking furnaces					
Open hearth	124,689	2,921,853	652,316	458,837	4,157,695
Basic oxygen process	254,630	363,211	2,997,223	238,689	3,853,753
Electric	108,843	118,880	405,336	70,738	703,797
Total	488,162	26,097,335	4,054,875	768,264	31,408,636

TABLE III-33. CONSUMPTION OF OXYGEN BY UNITED STATES STEEL INDUSTRY - 1967

	Millions of cubic feet in gaseous form(d)		
	High Purity(c)	Low Purity	Total
Purchased(a)	155,120	5,415	160,535
Produced(b)	15,456	(e)	15,456
Total	170,576	5,415	175,991
Consumption by Uses:			
Conditioning			18,355
Scrap preparation			1,998
Other burning and welding			2,617
Blast furnaces			8,662
Steelmaking:			
Open hearth			58,407
Basic oxygen process			78,707
Electric and Bessemer			3,352
Total Steelmaking			140,466
Maintenance and construction			779
All other			3,114
Total			175,991

(a) Purchased from vendors with facilities in or adjacent to plant or facilities located away from plant.

(b) Produced on companies own facilities or leased facilities.

(c) The term high purity oxygen means a gaseous mixture containing 99.5% by volume, plus or minus 0.1% of pure oxygen.

(d) Oxygen consumed in liquid form was reduced to its gaseous equivalent in these statistics.

(e) Included in high purity.

TABLE III-34. PRODUCTION AND USE OF AGGLOMERATED PRODUCTS BY UNITED STATES STEEL INDUSTRY[a] - 1967

	Net Tons			
Agglomerates	Sinter	Pellets	Briquettes, nodules and other	Total
Produced[b]	51,068,111	38,050,646	1,695,004	90,813,761
Imported	(c)	9,293,103	(c)	9,516,559
Consumed in blast furnaces	51,638,941	43,453,448	1,793,657	96,886,046
Consumed in steelmaking furnaces	(c)	603,974	(c)	988,474

(a) Includes ore agglomerates whether produced at consuming plants, at or near the mine site or several nonconsuming plants in the United States. The latter two includes plants owned and operated by Bethlehem Steel Corp., Buffalo Sintering Corp., Cleveland-Cliffs Iron Co., Erie Mining Co., Jones and Laughlin Steel Corp., Republic Steel Corp., Reserve Mining Co., and United States Steel Corp.

(b) Agglomerates produced from 96,124,000 net tons of metallic-bearing materials, 3,228,000 net tons of coal and coke, 8,259,000 net tons of fluxing materials, and 1,976,000 net tons of miscellaneous materials.

(c) Deleted because disclosure would reveal proprietary information.

TABLE III-35. CONSUMPTION OF NONFERROUS METALS FOR COATING PURPOSES BY UNITED STATES STEEL INDUSTRY - 1967

Metal	Gross Weight, net tons
Aluminum	7,186
Copper	8,751
Lead	4,506
Nickel	454
Tin	34,250
Zinc	334,776

TABLE III-36. UNITED STATES STEEL INDUSTRY IRON ORE INVENTORIES, RECEIPTS, AND CONSUMPTION - 1967

Thousands of Net Tons

	Original Source of Iron Ore							
	United States				Canada		All Other Foreign Countries	Total Iron Ore
	Great Lakes(a)	Northeastern(b)	Southern(c)	Western(d)	Great Lakes(e)	Eastern(f)		
Inventory - Beginning of year	34,753	239	1,637	1,193	1,919	10,490	10,996	61,227
Receipts	67,932	4,007	4,826	7,863	5,110	20,851	23,177	133,766
Total Available	102,685	4,246	6,463	9,056	7,029	31,341	34,173	194,993
Consumption in:								
Blast furnaces	53,176	3,508	4,558	5,172	4,504	8,140	9,424	88,482
Steel producing furnaces	319	137	43	498	197	603	2,468	4,265
Agglomerating plants	14,306	347	250	2,407	362	12,132	10,604	40,408
Total Consumption	67,801	3,992	4,851	8,077	5,063	20,875	22,496	133,155
Sold to nonreporting companies only	2	--	1	1	--	19	80	103
Total Credits	67,803	3,992	4,852	8,078	5,063	20,894	22,576	133,258
Inventory - End of year	34,882	254	1,611	978	1,966	10,447	11,597	61,735

(a) Michigan, Minnesota, Wisconsin.
(b) New England states, Delaware, New Jersey, New York, Pennsylvania.
(c) Florida, Alabama, Georgia, Missouri, New Mexico, Tennessee, Texas, Virginia.
(d) California, Nevada, Utah, Wyoming, Colorado, Montana, Washington.
(e) Ontario.
(f) Quebec, Newfoundland, Nova Scotia, Labrador, New Brunswick, Prince Edward Island.

TABLE III-37. SHIPMENTS OF IRON ORE (BY STATE) - 1966

Thousands of Gross Tons and Thousands of Dollars
(Source: United States Bureau of Mines)

	Quantity	Value
Alabama	1,508	$ 8,702
Michigan	14,377	157,377
Minnesota	55,133	499,388
New Jersey, New York, Pennsylvania, Virginia	4,511	63,241
Utah	1,956	13,478
Wyoming	1,978	19,700
Other	10,578	92,248
Total	90,041	$854,134

TABLE III-38. PRODUCTION, RECEIPTS, CONSUMPTION AND SHIPMENTS OF COKE BY UNITED STATES IRON AND STEEL INDUSTRY – 1967

Coke Movement	Net Tons
Production	
Metallurgical	57,064,984
Other coke	400,113
Total Production	57,465,097
Receipts from	
Other steel companies	604,354
Merchant producers	3,376,116
Other plants of parent company	11,238,015
Total Receipts	15,218,485
Total Production and Receipts	72,683,582
Consumption	
Blast furnaces	56,204,659
Foundries	14,345
Other uses	216,408
Total Consumption	56,435,412
Shipments to other	
Steel companies	694,077
Outside companies	1,134,800
Plants of parent company	11,864,037
Total Shipments	13,692,914
Total Consumption and Shipments	70,128,326

TABLE III-39. COKE PRODUCTION BY UNITED STATES IRON AND STEEL INDUSTRY (BY STATE) - 1967

State	Net Tons
Massachusetts, New York Pennsylvania	21,603,852
Maryland, West Virginia	6,898,895
Tennessee, Alabama, Texas, Oklahoma	5,425,566
Ohio	7,180,977
Indiana	7,730,385
Illinois	2,202,976
Michigan, Minnesota	3,318,378
Colorado, Utah, California	3,104,068
Total	59,465,097
Total (Bureau of Mines)(a)	64,570,000

(a) Includes the merchant producers in addition to coke plants associated with iron and steel plants.

TABLE III-40. COKE CONSUMPTION BY UNITED STATES IRON AND STEEL INDUSTRY (BY STATE) - 1967

State	Net Tons
Rhode Island, Massachusetts	n.a.
New York	3,765,987
Pennsylvania	13,730,906
Ohio	9,651,766
Indiana	7,295,580
Illinois	4,283,999
Michigan	4,122,323
Minnesota, Missouri	n.a.
Delaware, Maryland, Virginia, West Virginia, Georgia, Florida, North Carolina	5,111,664
Alabama	3,556,575
Tennessee, Kentucky	975,720
Oklahoma, Texas, Colorado, Utah	2,446,281
Washington, California	1,152,375
Total	56,435,412

na - not available.

TABLE III-41. COKE CONSUMPTION BY USES IN THE UNITED STATES IRON AND STEEL INDUSTRY – 1967

Use	Net Tons
Blast furnaces	56,204,659
Foundries	14,345
Other Uses	216,408
Total	56,435,412

TABLE III-42. COAL CONSUMPTION BY USES IN THE UNITED STATES IRON AND STEEL INDUSTRY – 1967

Use	Net Tons
Production of coke	82,698,190
Production of steam(a)	6,097,949
Other purposes	780,505
Total	89,576,644

(a) Includes coal consumed in generating electric power.

GEOGRAPHIC DISTRIBUTION OF THE INDUSTRY

The integrated iron and steel industry in the United States is often divided into areas or districts to facilitate statistical comparison and grouping of industrial areas. The division into eleven districts, as used by the American Iron and Steel Institute, is illustrated geographically in Figure III-2, and the tonnage of production of raw steel in each of these districts annually since 1958 is given in Figure III-3. The Chicago and Pittsburgh districts produce the most steel – each about 24 to 27 million net tons per year. These rivals are followed in descending order by the Northeast Coast District, the Youngstown District, and the Detroit District. The district with the lowest production rate (St. Louis) produces about 3 million tons of raw steel per year. The fastest growing district in terms of percentage growth is Detroit, where production has about doubled in the last decade.

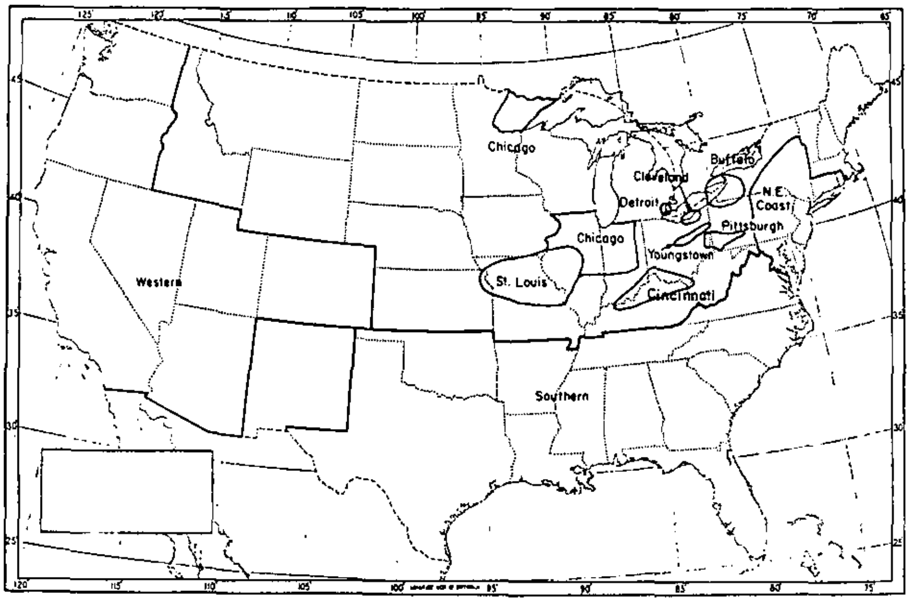

FIGURE III-2. STEELMAKING DISTRICTS IN THE UNITED STATES

Present Facilities

Maps of each district, with the names of major steelmaking facilities in each district, are given in Figures III-4 through III-12.

Current Modernization and Expansion

Estimates of the total steelmaking capacity (as differentiated from production) of the U. S. integrated iron and steel industry for 1968 varies from 165 million to as high as 192 million net tons of raw steel per year.(2) These estimates undoubtedly include many of the idle facilities, particularly open-hearth furnaces that have been on a standby basis. A more practical estimate places the current steelmaking capacity at 155 million

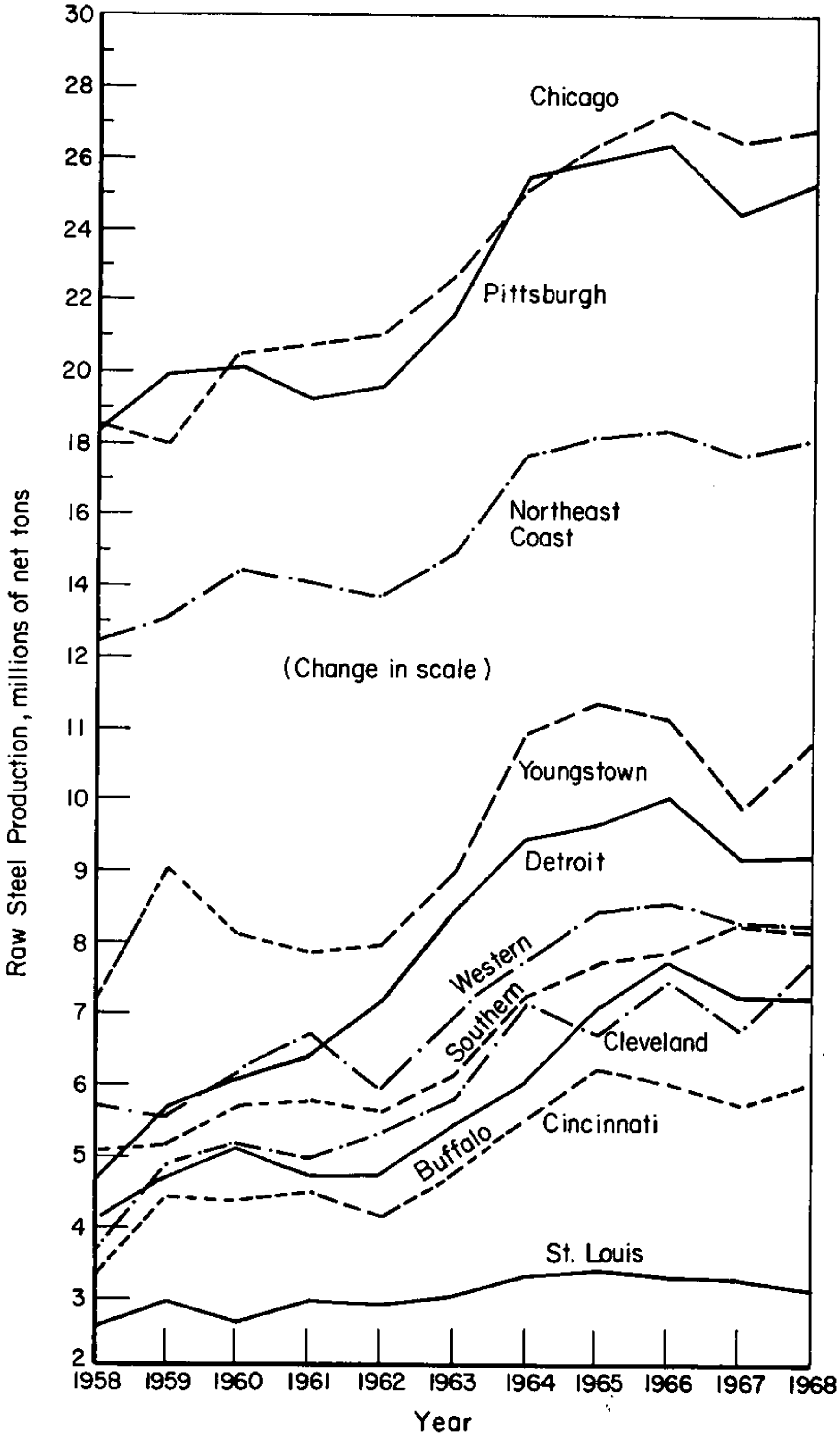

FIGURE III-3. RAW-STEEL PRODUCTION IN THE VARIOUS GEOGRAPHICAL STEELMAKING DISTRICTS

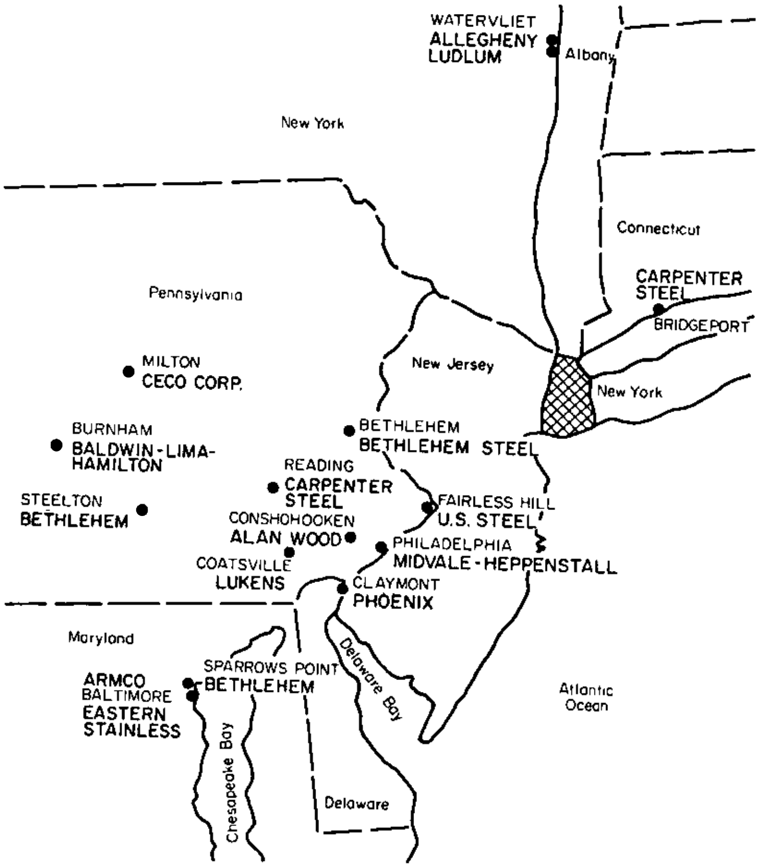

FIGURE III-4. NORTHEAST COAST DISTRICT

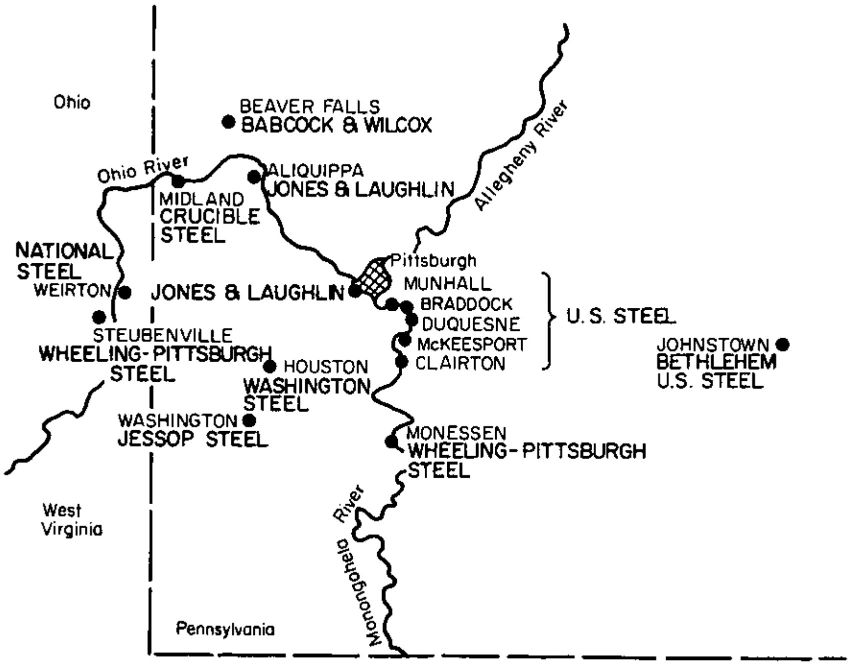

FIGURE III-5. PITTSBURGH DISTRICT

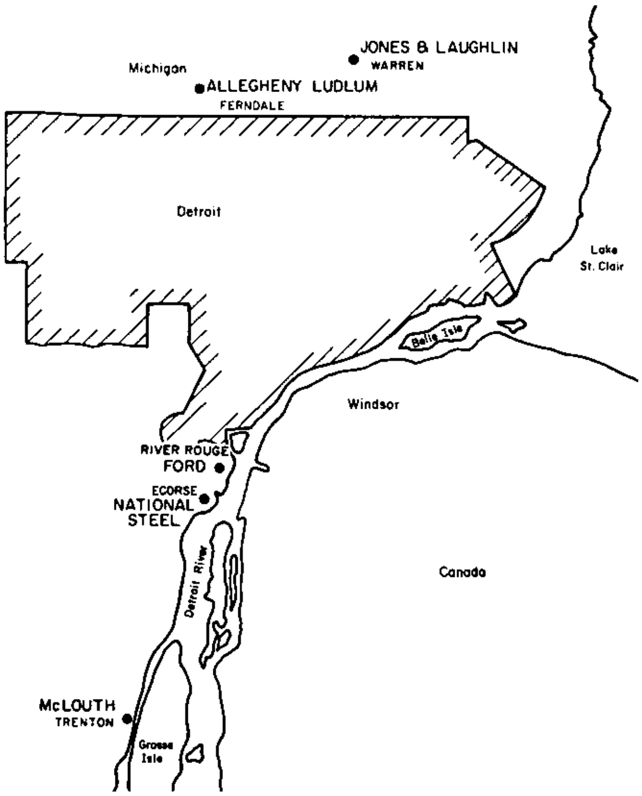

FIGURE III-6. DETROIT DISTRICT

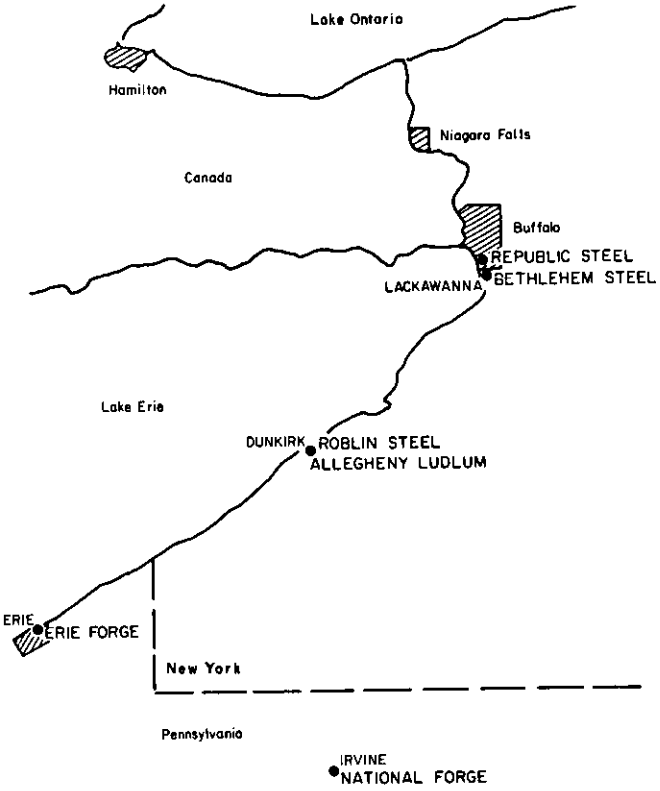

FIGURE III-7. BUFFALO DISTRICT

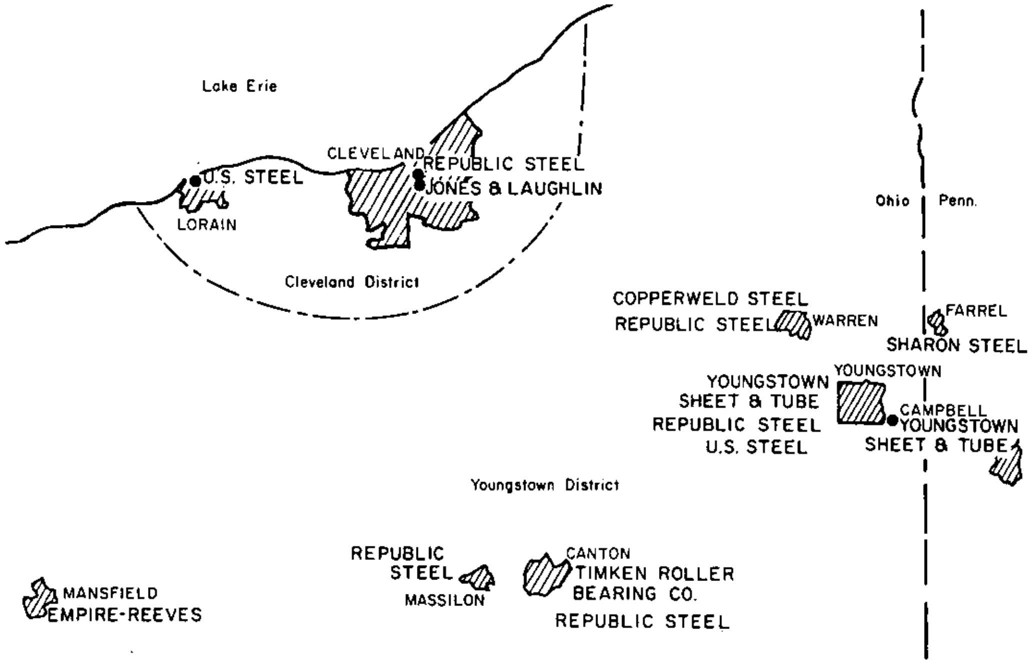

FIGURE III-8. CLEVELAND AND YOUNGSTOWN DISTRICTS

FIGURE III-9. CINCINNATI DISTRICT

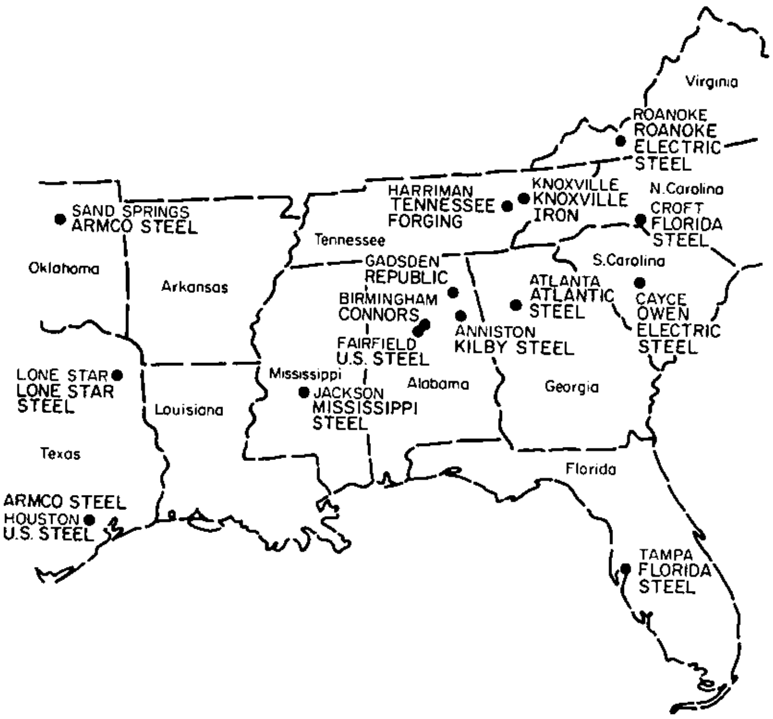

FIGURE III-10. SOUTHERN DISTRICT

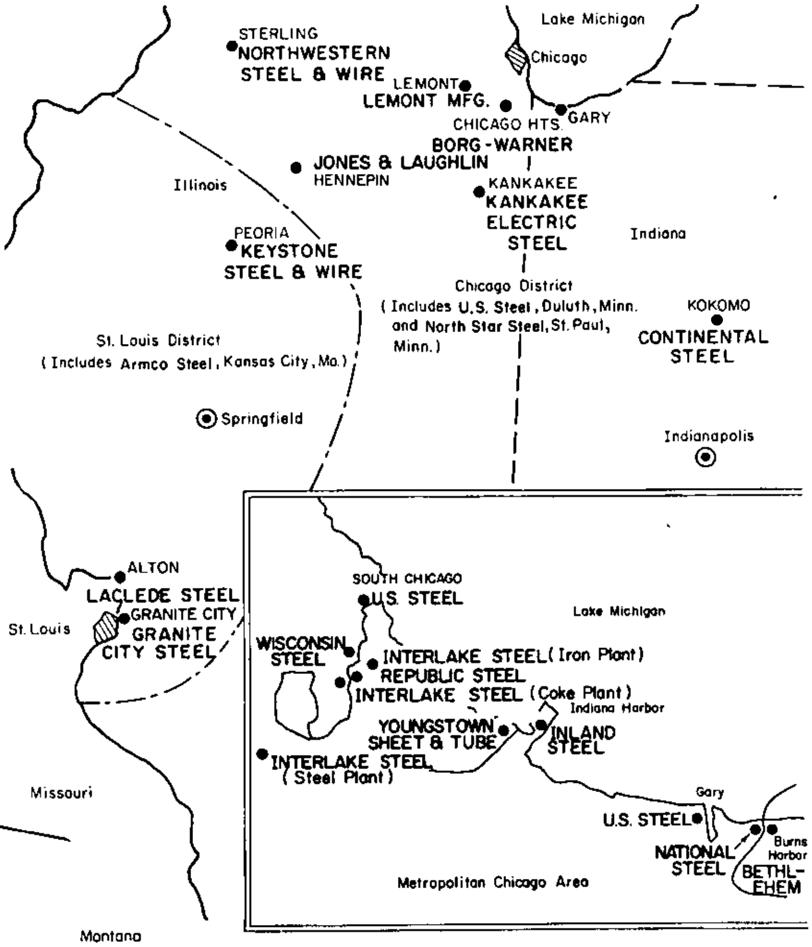

FIGURE III-11. CHICAGO AND ST. LOUIS DISTRICTS

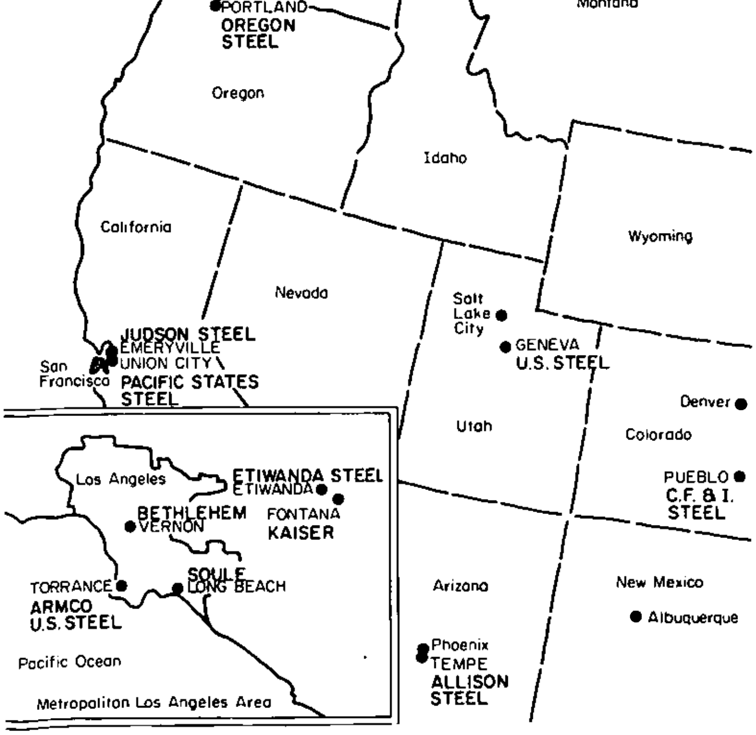

FIGURE III-12. WESTERN DISTRICTS

tons per year(2), taking into consideration only those facilities that can be placed into operation on short notice. The changes in production capacity are illustrated in Figures III-13, III-14 and III-15.

Figure III-13 shows the size distribution of open-hearth furnaces in 1968, and the furnaces of the respective sizes that are expected at this time to be removed from operation by 1973. The open hearths removed from operation are primarily those removed to make room for additional BOF capacity.

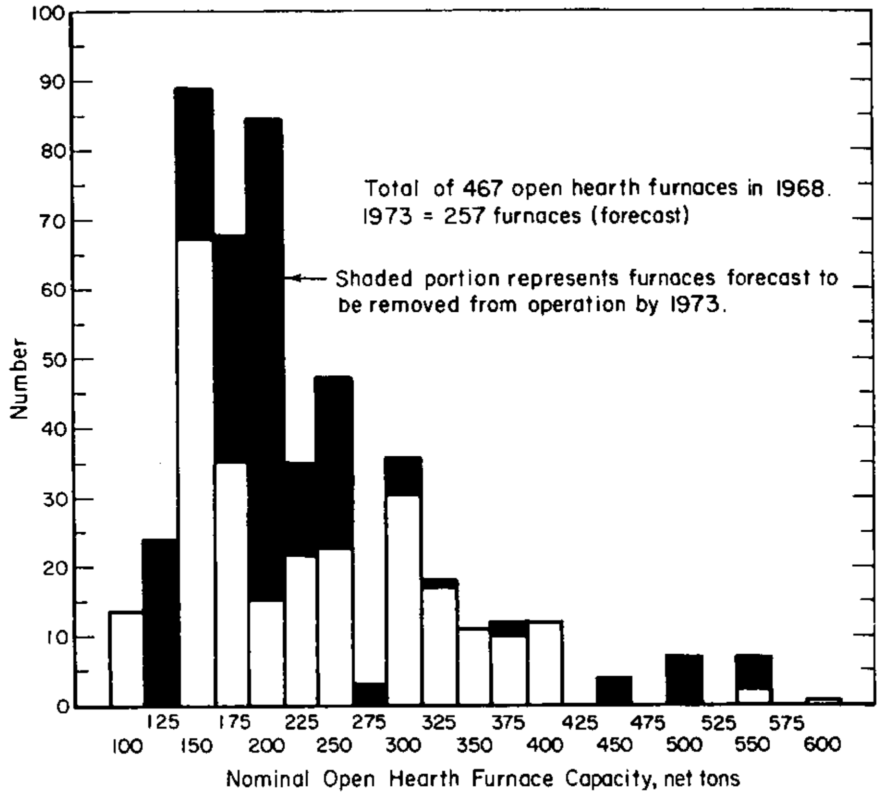

FIGURE III-13. SIZE DISTRIBUTION OF OPEN HEARTH FURNACES IN THE UNITED STATES

The trend in installation of BOF capacity is illustrated in Figure III-14. Installations planned for operational status in 1969 include BOF's by Armco Steel at Middletown, Ohio; Bethlehem Steel at Bethlehem, Pennsylvania; U.S. Steel at South Chicago, Illinois; and Youngstown Sheet and Tube at Indiana Harbor, Indiana; for a total capacity increase of 9.9 million net tons in 1969. During 1970, an additional 7 million net tons of BOF capacity is expected to be placed into operation by Bethlehem at Burns Harbor, Indiana; National Steel-Great Lakes at Ecourse, Michigan; Republic Steel at Buffalo, New York; and U.S. Steel at Lorain, Ohio. During 1972, U.S. Steel is expected to place an additional 2.25 million capacity plant in operation at the Edgar Thomson Works, followed in 1973 by Inland Steel's 2-million-net-ton plant in East Chicago, Indiana. On the basis of these expectations, by 1973 there will be a total BOF steelmaking capacity of about 76 million net tons per year.

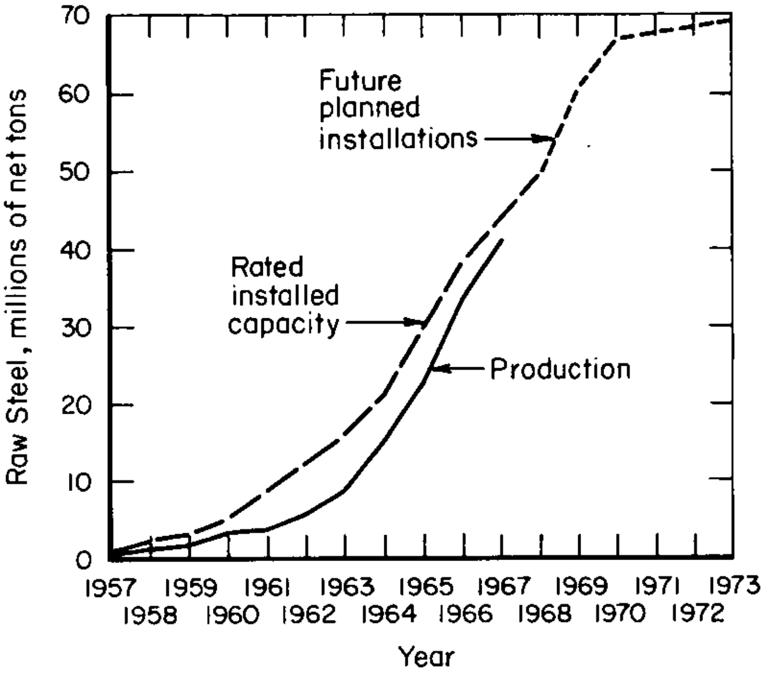

FIGURE III-14. TRENDS IN INSTALLED CAPACITY AND RAW STEEL PRODUCTION IN BOF FURNACES

Electric-furnace steelmaking capacity is also on the increase. The size distribution of electric-arc furnaces is shown in Figure III-15. The trend toward the installation of the larger furnaces is evident by the furnaces planned for installation by 1971. The most recent announcement involves Republic Steel's plans for 250-ton furnaces at their Chicago plant. In 1967, electric steelmaking furnaces accounted for 15 million tons of steel (11.9 percent of the total). This was increased in 1968 to 16 million net tons (12.3 percent of the total).[3]

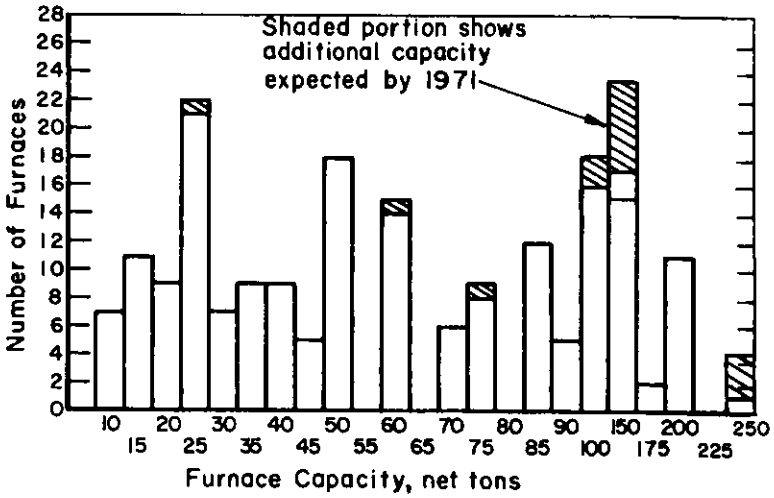

FIGURE III-15. SIZE DISTRIBUTION OF ELECTRIC STEELMAKING FURNACES

The shift in the market for steel products into the Midwest has been the motivation in heavy expansion of steelmaking facilities in the Chicago area, in addition to completely new plants at Burns Harbor, Indiana, and at Hennepin, Illinois. Considerable expansion in facilities has taken place in the Houston, Texas, area at Armco Steel's existing electric furnace shop and at U.S. Steel's electric furnace plant which is expected to be completed late in 1969.(4)

Future Plans

Plans for expansion of steel companies are usually preceded by purchases of real estate for the plants. For example, National Steel recently purchased a large tract of property at Corpus Christi, Texas.(5,6) The site has deep-water channel access to the Gulf of Mexico, with resulting ocean transport possible for high-quality ores from South America. National Steel Corporation also appears to have long-range plans for the possible construction of steelmaking facilities in California, as indicated by its contracting to purchase approximately 3300 acres on the north shore of the Sacramento River.(7,8) This site also has deep-water access to San Francisco Bay and the Pacific Ocean, so as to improve the feasibility of using high-grade foreign ores in the production of iron and steel at the new site.

Another future development (this time in technology) is heralded by the construction of a plant in Venezuela by the U.S. Steel Corporation to make one million net tons per year of prereduced agglomerate in the form of "high iron-ore briquettes".(9) The operation will make use of natural gas to perform the reduction operation, after which the briquettes will have been upgraded to an iron content of 86 percent.(10) The "high iron-ore briquettes" are expected to lower transportation cost, reduce coke consumption in the blast furnace, and result in increased production of hot metal from blast furnaces. This technology has not yet gained general acceptance in the United States. Its advent in Venezula is prompted by proximity to high-grade ore, and availability of natural gas at a price about one-quarter of that in the United States.

MAKING OF IRON AND STEEL

The major process segments concerned with the making of iron and steel are described briefly in this Section. More-detailed descriptions of the various steps in the making of iron and steel will be found in Appendix A, "Processes in the Integrated Iron and Steel Industry".

In 1967 the integrated iron and steel industry in the United States consumed 135,649,000 net tons of iron ore, 8,885,000 net tons of scrap and mill scale, 14,422,000 net tons of flux, and 54,917,000 net tons of coke to make 82,850,000 net tons of pig iron. The pig iron combined with 65,213,000 net tons of scrap was used in making 127,213,000 net tons of raw steel which in turn was converted into 83,897,000 net tons of finished steel products. The magnitude of these quantities shows that the integrated iron and steel industry is involved in a massive, continuous, material-handling problem. Much of this handling which is of an intermittent nature, is a major contributor to the problem of air pollution by the industry.

Raw Materials

The major raw materials required to make pig iron (or "hot metal" as it is called in its molten state) are iron ore, coke, limestone, and air. In recent years, auxiliary fuels (such as oil, natural gas, coal, and tar) have been used to lower the coke requirement for making iron. Raw materials are received at a steel plant by boat, barge, or railroad. Some lump iron ore is used for making hot metal, but about 70 percent of the metallics charged to American blast furnaces are agglomerated products such as pellets and sinter.

Pellets are made at the mine site by grinding the ore to a very small size (usually less than 325 mesh), adding a binder, and then forming the ore into small balls or pellets, which are subsequently hardened. Prior to pelletizing, if the ore is low-grade (i.e., low in iron content), it can be beneficiated or up-graded by various methods that remove unwanted gangue materials and result in a higher iron content in the feed to the pellet plant. After hardening, the pellets are shipped to the steel plants for use directly in the blast furnace.

Sinter plants, on the other hand, are located at the steel plant for two reasons: (1) sinter is friable and does not withstand shipping without degradation, and (2) sintering was initially developed and installed to recover and convert to a useful form the ore fines, blast-furnace flue dust, mill scale, and other iron-bearing materials that could not be used directly as charge to a blast furnace. Advancing technology showed that a properly prepared sinter would result in still further improvements in productivity if even good ore was crushed and made into sinter. This was the motivation for the construction of many sinter plants.

Although coke is the major fuel and reducing agent used to make hot metal in blast furnaces, coke is made from still another raw material (coal). Coal received from the mines (again by boat, barge, or railroad) is usually less than 1/2-inch in maximum size. It is crushed and ground further, blended with other coals, and then charged into coke ovens for conversion to coke. Conversion takes place by subjecting the coal to indirect heating in long, thin ovens, for periods of 16 to 20 hours. During the coking operation, coke-oven gas, tar, and other by-products are collected. The coke-oven gas is used for heating the coke ovens, and for other in-plant use. The tar and other materials are recovered and processed in the by-product plant. On completion of the coking cycle, the coke is pushed from the ovens into a special car, which carries it to a quenching tower where the incadescent coke is quenched by a deluge of water. The coke is then crushed and screened prior to its use in the blast furnace.

Limestone is crushed and screened to size at the quarry site, and is received at the steel plant in the proper size for use in the blast furnace. Similarly, lime required in steelmaking is prepared in lime kilns at the quarry site and shipped to the steel plant ready for use. However, there is a growing tendency to calcine limestone to lime at the steel plant.

The large amounts of raw materials needed to make hot metal require extensive storage facilities at the steel plant to ensure a continuity of operation.

Making Iron

The prepared materials (coke, iron ore, pellets, sinter, and flux) are placed in a transient storage in the blast-furnace stockhouse, from which they are withdrawn in weighed fractions and charged into the top of the blast furnace via a skip hoist. Collectively these solids are called the "burden". The newest blast furnaces constructed in the United States consume such a vast quanity of materials that continuous conveyor belts are used for charging rather than the intermittent-operating skip hoist, but this is not yet a common practice.

The heat energy necessary to affect the required chemical reactions between the iron ore, pellets, sinter, and flux is supplied by blowing air (preheated to temperatures of 1600 to 2000 F) into the bottom of the blast furnace via blowpipes known as "tuyeres". The heat energy also serves to maintain the pig iron in a molten state and at a temperature such that the iron can be removed from the furnace by "casting". The coke in the combustion zone at the tuyeres does not burn to carbon dioxide. Because of the high temperature (about 3500 F to 3600 F) and the presence of the large amount of carbon in the form of coke, carbon monoxide is formed and passes on up through the solid burden where it takes part in some of the chemical reactions necessary to produce metallic iron. The excess of carbon monoxide (diluted with carbon dioxide, nitrogen, and moisture) passes off the top of the blast furnace, and is collected for use as a fuel to heat the air blown into the blast furnace and for other in-plant heating purposes.

The hot metal produced in the blast furnace and the liquid slag (which is a fused mixture of the flux and impurities removed from the ore, pellets, sinter, and coke) are removed periodically from the blast furnace. The hot metal is "cast", while the slag is said to be "flushed". Hot metal is cast into special containers called submarine or torpede ladles (because of their elongated shape) for transfer to the steelmaking plant. Slag is disposed of at a dump, or it may be granulated to produce an aggregate that is sold.

Although almost all pig iron in the United States is made in blast furnaces, another type of processing of iron ore to metal is just starting to make its commercial appearance. This is "direct reduction", a name applied loosely to any method that bypasses the blast furnace. Direct-reduction processes characteristically are solid-state processes. Reduction of the iron ore to metal is conducted entirely in the solid state, although the metallic iron might subsequently be melted. Direct-reduction processes appear in many variations, but all use some form of carbon and/or some form of hydrogen as fuel and reducing agent. Carbon can be supplied as coal, coke, or other hydrocarbons. Carbon monoxide is one of the useful forms of carbon for this purpose. Hydrogen is supplied sometimes from reformed natural gas (when it often appears in a mixture with carbon monoxide) or from coke-oven gas. Regardless of the process, the product usually is a spongy or powdered form of metallic iron (still mixed with gangue from the iron ore) which then is intended for charging directly into steelmaking furnaces, much as steel scrap is used for steelmaking.

Making Steel

Steelmaking in the United States is done in three types of furnaces: (1) the open-hearth furnace, (2) the basic oxygen furnace, and (3) the electric-arc furnace. The open hearth is a rectangular furnace with a comparatively shallow hearth for containing and processing the steel. Scrap, flux, and hot metal are charged into the furnace via several doors located in the front of the furnace. Heating of the charge materials is done with various fuels such as oil, tar, natural gas, and combinations of these. Steel is produced by lowering the carbon, manganese, and silicon contents by oxidation to levels desired for the type of steel required. Impurities such as sulfur and phosphorus are also lowered by using slags of appropriate compositions. Lowering of the carbon, silicon, and manganese contents is accomplished by the addition of oxygen to the charge to oxidize these elements so that the carbon passes off as carbon monoxide, and the silica and manganese oxides dissolve in the slag. The older steelmaking technology used iron ore and air to supply the necessary oxygen, while the newer technology makes use of gaseous oxygen introduced into the molten bath through a water-cooled lance. Open-hearth steelmaking requires comparatively lengthy time periods, varying from 8 to 10 hours for practices not using oxygen lancing to time periods of 4 to 5 hours for practices using oxygen lancing.

The basic oxygen steelmaking (BOF) process makes use of a pear-shaped vessel to contain the charge materials required to make steel. As in the open-hearth process, the major materials are hot metal and scrap. In the basic oxygen process, no external heat is supplied to achieve the required lowering of carbon, silicon, and manganese contents. Gaseous oxygen is blown onto the surface of the molten charge at a very high rate, and the heat generated by the oxidation of the elements is sufficient to carry the process to completion and produce steel. Flux (in the form of lime) is charged into the vessel to form a slag by combining with the oxides of iron, silicon, and manganese, and to lower the contents of sulfur and phosphorus in the steel to acceptable limits.

The heat necessary to produce steel in an electric-arc furnace is supplied as electrical energy to the charge materials which in the majority of cases is solid steel scrap. Only two steelmaking plants in the United States are known to use hot metal as part of the charge in large electric furnaces. The scrap used in conventional practice is of a high quality, with compositions approximating those required in the finished steel. Oxygen (in the form of ore or gaseous oxygen) is used to achieve the desired chemical reaction necessary to produce the steel. The use of gaseous oxygen is by far the more prevalent method. While most of the stainless and alloy steels are made in electric furnaces, in recent years the increase in size of the furnaces, combined with higher powered transformers, and a greater availability of scrap, has made electric-furnace steelmaking of the plain-carbon, high-tonnage steels competitive in cost with the open hearth and with BOF steelmaking.

In all steelmaking practices, the refined steel is tapped from the furnace into ladles, after which it is transported to an adjacent area of the steel plant where it is cast into ingots, cast directly into continuous casting machines, or cast into pressure-casting molds for conversion to semifinished products.

Manufacture of Semifinished Products

Molten steel must be converted to some type of semifinished product before it can be processed to the finished products which are either sold as such or are sold to other intermediate processors for manufacture into finished products. Three methods of converting the molten steel into semifinished products are (1) casting of ingots and rolling, (2) continuous casting, and (3) pressure casting.

The practice used to process most steel into semifinished products involves teeming of the molten steel into cast iron ingot molds, permitting the steel to solidify, removing the ingots from the mold, and transporting the ingots to soaking pits for heating and temperature equalization before primary rolling. This technology is time consuming and requires large amounts of plant space and numerous personnel. After the ingots have been properly heated in the soaking pits, the hot ingots are transported to the roughing mill where they are rolled into billets, blooms, or slabs for subsequent processing into finished products.

Continuous casting of steel is a relatively new process that can eliminate much of the processing required by ingot casting and rolling. The molten steel is transported in a ladle to the continuous-casting machine, where it is poured into a water-cooled mold in which solidification starts. Solidified steel (often with a molten core) is extracted from the bottom of the mold continuously in one or several strands. The solidified steel is cut into desired lengths for further processing into finished products. Continuous-casting machines are designed to produce billets, blooms, or slabs, depending on the products to be manufactured in later stages in the plant. The trend in the United States has been toward combining electric steelmaking furnaces with billet and bloom continuous-casting operations; and the basic oxygen furnace with large slab-casting machines. One operation has succeeded in continuous-continuous casting of 1500 tons of steel in a slab-casting machine. (This was achieved by casting five, 300 ton heats consecutively, without any stoppage of the continuous casting machine.) Such technology is conducive to greater economics in the making of steel products.

Pressure casting is another new process that bypasses the ingot stage in the manufacture of steel products. Molten steel is forced into a large slab-shaped cavity via a ceramic tube inserted in the steel. The force is developed by exerting air pressure on the surface of the molten steel. The steel solidifies in the reusable graphite mold, after which the mold is opened and the slab removed. The process has been used to date mostly for casting stainless steels. However, a plant scheduled to come on-stream in 1969 will produce plain-carbon-steel slabs by the pressure-casting process.

Manufacture of Finished Products

Billets, blooms, and slabs (the semifinished products) are processed into rods, bars, wire (wire in this sense may be as large as 1-inch in diameter), angles, channels, structurals, plate, sheet, and strip depending on the particular capabilities of a given plant. Rolling is the method used to convert the semifinished products into finished products. Prior to the rolling operation, the billets, blooms, and slabs are inspected so that defects potentially detrimental to the finished products may be removed by chipping, grinding, or scarfing. After this "conditioning" operation, the billets, blooms, or slabs are heated in special reheating furnaces. On reaching the required temperature and after an appropriate soaking time, the semi-finished products are removed from the furnaces and rolled in highly specialized mills.

Further processing of the products may take place in the steel plant before shipment is made. This may include annealing, cold-rolling, galvanizing, tin electroplating, painting, or plastic coating. The coatings are applied primarily to the sheet and strip products.

REFERENCES FOR SECTION III

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(9) "U.S. Steel to Make Iron Ore Briquettes in Venezuela", The Iron Age, 201 (21), p. 26 (May 23, 1968).

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SECTION IV

PROJECTIONS REGARDING STEEL-INDUSTRY GROWTH AND CHANGES IN PROCESS TECHNOLOGY

The purpose of this section is to analyze and project the nature and extent of changes expected to take place in the integrated iron and steel industry between now and about the year 1980. Emphasis is focused on changes expected to be greatest in their effects upon air-polluting emissions. The background for these projections includes a wide variety of information sources, including the published literature, plans of various industrial companies, statistical reports, and forecasts and analyses prepared by Battelle during many other projects recently conducted or currently in process. Although some of the projections rest upon a background of hard statistics and solid technological information, the projections in most cases are set by judgmental evaluations after thorough analysis of all the available and pertinent inputs.

Anticipated Growth in Production and Consumption of Raw Steel

The steelmaking capacity of the United States is about 155 to 160 million net tons* of raw steel per year. There is no "official" statement of capacity, because capacity of any particular installation depends heavily on how it is operated. The capacity constantly changes; new facilities are always under construction, obsolete facilities are being dismantled, while existing equipment is being modified.

Steelmaking capacity is so hard to define that the AISI has abandoned its old practice of annually issuing a new rating. Part of the difficulty is that the steelmaking equipment can be operated for considerable periods at above its "nominal capacity". A few months during the first half of 1968 exemplified such a situation – production was high in anticipation of a possible strike. Many furnace installations operated considerably above their nominal capacity. How long this condition could have continued without serious equipment or labor troubles is speculative, but it is likely that the rate that was probably in excess of "nominal capacity" could not have been continued indefinitely. Thus, the "annual capacities" presented here are in a sense integrated over a period of a year, using judgment and some speculation as to how long and how great temporary displacements may be in future years.

In 1967, capital expenditures for expansion and modernization of the domestic steel industry were about $2.3 billion. A large part of the outlay went for basic-oxygen steelmaking furnaces, electric steelmaking furnaces, and continuous-casting facilities. The new steelmaking furnaces will replace existing open-hearth furnaces to a large degree.

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*Throughout this section, "tons" are net tons of 2000 pounds.

In recent years, there have been important shifts in the geographical concentration of steelmaking in the United States. Most significant is the buildup of new capacity in the Midwest, especially near the Chicago market area.

The growing West Coast market has often been investigated by interested steel companies, but competition from Japanese steel producers has been a big factor tending to discourage U. S. companies from establishing additional West Coast steel-producing facilities. Despite this competition from overseas producers, it is likely that new integrated steelmaking installations will be built by U. S. companies on the West Coast in the course of the next decade.

The annual production of raw steel in the United States since World War II has fluctuated from a low of just over 66 million tons in 1946 to a high of 134 million tons in 1966. In 1967, the production was 127 million tons. "Raw steel" is in the form of ingots or continuously cast billets or slabs and is converted to a lower tonnage of finished steel.

The production of raw steel for 1960 and 1967 and projections to 1980 are given in Table IV-1. Annual production of raw steel in the United States is projected to reach about 157 million tons in 1975 and about 180 million tons in 1980. These forecasts of total production are based primarily on judgments concerning 1975 and 1980 technology and on U. S. input-output tables prepared by Battelle's Socio-Economic Research Group as part of its _Aids to Corporate Thinking_ program.

TABLE IV-1. PRODUCTION (1000 NET TONS) OF RAW STEEL IN THE UNITED STATES, BY TYPE OF FURNACE, AND PROJECTIONS OF PRODUCTION TO 1980

Source: Annual Statistical Report, American Iron and Steel Institute, 1967. Forecasts by Battelle.

Year	Open Hearth	Bessemer	Basic-Oxygen Furnace	Electric Furnace	Total
1960	86,368	1189	3,346	8,379	99,282
1967	70,690	(a)	41,434	15,089	127,213
1975	44,000	-	80,000	33,000	157,000
1980	36,000	-	99,000	45,000	180,000

(a) Included with open-hearth production; 278, 000 tons of Bessemer steel were reported in 1966.

Production forecasts of raw steel in the United States by several other organizations or individuals are summarized in Table IV-2, which shows that the estimated annual production of raw steel for 1975 varies from 145 to 180 million net tons. For 1980, the estimates vary from 176 to 184 million net tons per year.

TABLE IV-2. U.S. PRODUCTION OF RAW STEEL, AS FORECAST BY VARIOUS SOURCES

Source	Million Net Tons	
	1975	1980
UN/ECE Steel Committee (current study)(a)	163	184
H. S. Harrison, Cleveland-Cliffs Iron Co. (October, 1965)	148	-
F. K. Maxcy, Jr., Pittsburgh Steel Co. (October, 1966)	~145	-
F. Jaicks, Inland Steel Co. (September, 1966)	165	-
Chemical Week (September 24, 1966) (September 24, 1966)	171	-
Iron Age (January 6, 1966)	180	-
Dr. Pierre Rinfret, Lionel D. Edie & Co. (September, 1962)	170	-
Resources for the Future (Medium Forecast) (September, 1962)	-	176
Arthur D. Little, Inc. (December, 1962)	~160	~180

(a) Forecast in a draft report made public at a meeting in Geneva, October 16-20, 1967. Report was to be published before June, 1968.

Production of steel in the United States by geographical area for 1960 and 1967 and forecasts to 1980 are given in Table IV-3. The forecasts by area are based on the most recent 5-year average production indexes published by the AISI, as adjusted to meet tonnage forecasts for 1975 and 1980. The Chicago area is expected to continue to be the largest producer of steel in the United States, and Pittsburgh is expected to remain in second place. On a percentage basis, the Detroit area is expected to show the fastest future growth. Production of raw steel in the Pittsburgh, Youngstown, and St. Louis areas is expected to grow at a slower rate than for other areas in the United States.

The apparent per-capita consumption of raw steel in 1960 and 1967 and forecasts to 1980 are given in Table IV-4. Apparent per-capita consumption is calculated by adding the raw-steel equivalent of imported steel to U. S. production and subtracting the raw-steel equivalent of exports, then dividing by the population. The projected per-capita consumption for 1975 and 1980 was based on the assumption that imports of steel would

TABLE IV-3. PRODUCTION OF RAW STEEL, BY AREA, IN 1960 AND 1967 AND FORECASTS TO 1980

Area	Millions of Net Tons			
	1960[a]	1967[b]	1975	1980
Chicago	20.80	26.45	33.10	37.80
Pittsburgh	20.10	24.45	27.30	31.10
Northeast Coast	14.35	17.65	20.80	24.50
Youngstown	8.35	9.90	10.90	12.50
Detroit	6.50	9.15	14.80	16.90
Western	6.15	8.25	10.20	11.70
Southern	5.65	8.25	10.30	11.70
Cleveland	5.55	6.80	9.00	10.30
Buffalo	5.20	7.25	9.00	10.30
Cincinnati	4.00	5.75	7.80	8.90
St. Louis	2.65	3.30	3.80	4.30
Total	99.30	127.20	157.00	180.00

(a) Estimated from steel-production indexes published by AISI.

(b) Preliminary breakdown by area gave production at 126.9 million net tons. This was adjusted up to 127.2 million net tons to be consistent with AISI Statistical Yearbook.

amount to 10 percent of the U. S. production of raw steel and that exports would amount to 2 percent. The apparent per-capita annual consumption of steel is expected to rise from 1408 pounds in 1967 to 1598 pounds by 1980.

TABLE IV-4. APPARENT PER-CAPITA CONSUMPTION OF RAW STEEL IN THE UNITED STATES FOR 1960 AND 1967 AND PROJECTIONS TO 1980

Year	Population[a], millions	Apparent Consumption of Equivalent Raw Steel,[b] million net tons	Per-Capita Raw Steel Consumption, pounds
1960	180.7	99.5	1101
1967	199.2	140.2	1408
1975	223.8	169.6	1516
1980	243.3	194.4	1598

(a) 1980 population estimate from Series B projection by U. S. Bureau of Census.

(b) Raw-steel production, plus imports, minus exports of mill products; both of the latter converted to raw steel equivalent based on 75 percent yield.

The foregoing estimates of consumption are based on a net importation of steel products in an amount equivalent to 8 percent of the annual U. S. production. The experience of 1967 and 1968 suggests that this net difference could reach or even exceed 20 percent by 1975 or 1980. It is possible to speculate on the future net difference, but it is impossible to prove any assumption that might be made. The net difference will be affected not only by relative costs of producing steel in various countries but also by Governmental policies and by voluntary quota arrangements. In the case of the United States, the uncertainty about the net difference between imports and exports is caused mainly by the uncertainty about the amount of imports; the amount of exports is expected to fluctuate relatively little from year to year. The net difference of 8 percent used in the present estimates is reasonably defensible on a judgmental basis. To the extent that history proves it to be in error, an increase in net imports will detract from projected U. S. production of steel rather than increase projected per-capita consumption.

Anticipated Growth in Production and Consumption of Pig Iron

The production and apparent consumption of pig iron for 1960 and 1967 and forecasts to 1980 are given in Table IV-5. During the 18-year period from 1950 to 1967, the ratio of apparent total pig-iron consumption to raw-steel production has ranged between a low of 0.651 and a high of 0.691. The trend up to 1966 was for a gradual increase in the ratio of pig iron to raw steel. This was the result of an increase in tonnage of BOF steelmaking at the expense of the open-hearth process. In 1967, the ratio dropped slightly as the production of electric-furnace steel increased percentagewise. In the future, the ratio of pig iron to raw steel is expected to remain at 0.68 as BOF and electric-furnace steelmaking continue to increase at the expense of the open-hearth process.

TABLE IV-5. PIG-IRON REQUIREMENTS FOR THE UNITED STATES IN 1960 AND 1967 AND PROJECTIONS TO 1980

Year	Raw Steel Produced, millions of net tons	Apparent Consumption of Pig Iron, millions of net tons	Ratio of Pig Iron/ Raw Steel
1960	99.3	66.5	0.670
1967	127.2	87.0	0.684
1975	157.0	106.8	0.680
1980	180.0	122.4	0.680

Anticipated Growth in Consumption of Iron Ore

The depletion of domestic direct-shipping iron-ore deposits during the past 20 years has caused the United States to rely increasingly on outside sources. In an effort to forestall continuation of the trend, domestic producers and consumers of iron ore turned to the upgrading of relatively low-iron domestic ores, such as taconites. The success of the taconite beneficiation program has in turn affected the physical and chemical specifications of imported ores.

The consumption of iron ore (and its derivatives) by the iron and steel industry in the United States in 1960 and 1967 and projections to 1980 are given in Table IV-6. The consumption in 1967 was about 132 million net tons. Consumption in 1975 is projected to be about 158 million net tons, with about 179 million net tons expected in 1980. The ratio of the consumption of iron ore (and derivatives) to production of pig iron was 1.47 in 1967 and is expected to decrease to 1.44 by 1980, because the average iron content of the ore has gone up with the increased use of pellets in the blast furnace. This trend is expected to continue.

TABLE IV-6. CONSUMPTION OF IRON ORE AND DERIVATIVES IN THE IRON AND STEEL INDUSTRY IN THE UNITED STATES AND PROJECTIONS TO 1980

Year	Iron Ore and Agglomerates Used,[a] 1000 net tons: In Blast Furnaces	Iron Ore and Agglomerates Used,[a] 1000 net tons: In Steel Furnaces	Total Consumed, 1000 net tons	Tons of Ore Per Ton of Iron
1960	106,260	8,250	114,510	1.60
1967	128,045	4,266	132,311	1.47
1975	155,000	3,500	158,500	1.45
1980	176,200	2,800	179,000	1.44

(a) Includes lump ore and ore fines used for sinter, pellets, briquettes, and nodules.

Changes in percentages of the different forms of ore consumed in the United States and forecasts for future consumption are given in Table IV-7. Burden preparation and upgrading has increased rapidly during the past 12 years, and the trend is expected to continue. Sinter and pellets represented about 65 percent of the burden in 1967; by 1980, sinter and pellets are expected to be over 80 percent of the blast-furnace burden. This will tend to reduce the amount of dust produced per ton of pig iron in the blast furnace.

TABLE IV-7. PHYSICAL FORM OF IRON ORE CONSUMED IN THE UNITED STATES AND ESTIMATES TO 1980

Year	Lump Ore		Sinter Fines[a]		Pellets		Total	
	Millions of Tons	Percent	Millions of Tons	Percent	Millions of Tons	Percent	Millions of Tons	Percent
1960	62.0	54.1	41.5	36.3	11.0	9.6	114.5	100.0
1967	46.7	35.3	42.2	31.9	43.4	32.8	132.3	100.0
1975	31.7	20.0	46.0	29.0	80.8	51.0	158.5	100.0
1980	34.9	19.5	48.3	27.0	95.8	53.5	179.0	100.0

(a) Includes only iron-ore fines used for making sinter. For example, sinter production in 1967 was 51.6 million net tons but required only 42.2 million tons of iron-ore fines. The remainder was supplied as mill scale, dust, fluxes, and the like.

As steel companies pay increasing attention to air quality, they direct their attention in two directions — (1) production of lower amounts of pollutants by the processes and (2) collection of pollutants to avoid their emission into the atmosphere. The second of these courses results in the accumulation of large amounts of fine particles, many of which are contaminated in some way that makes them unsuitable for recycling into the processes as those processes are now being run. Many of these "dusts" introduce a cost for disposal, and this cost is in addition to the cost of collection. Few of these dusts have actual by-product value. Research is needed to develop better means for the disposal of such materials. The most logical concept would involve recycling within the steel plant, but attainment of this will require further development of recycling schemes and modification of the steelmaking processes to accept such recycled materials without intolerable technological or economic penalty.

Anticipated Changes in Iron and Steel Process Technology

The continued growth of the iron and steel industry in the United States has resulted in gradual changes and improvements in processing technology. Most of these have been evolutionary rather than drastic or rapid. Many changes have taken place within the past 10 years, and gradual evolutional changes are expected to continue. Modernization and expansion programs have been conducted by most of the steel companies during the 1960s aimed at improving the competitive position of the American producer. Marginal and poorly productive facilities are gradually being shut down or phased out, but the industry probably will continue for decades to contain a substantial amount of marginal equipment.

With respect to the manufacture of iron from ore, the blast furnace will remain by far the major production unit. More pig iron will be produced each year in fewer blast furnaces that will, on the average, become larger and have higher productivity per furnace. Electric smelting and direct reduction of iron ore are expected to be relatively minor in overall importance as ironmaking processes in the United States at least until 1975, but these practices are expected to find increasing application outside the United States.

With respect to steelmaking in the United States, the BOF process and the electric-furnace process will continue to grow at the expense of the open-hearth process. Vacuum degassing of steel and continuous casting will assume increasing importance over the next two decades. Large steel plants will tend to become larger and the number of small steel plants ("mini steel plants") will increase, but the latter will account for relatively little tonnage of steel. From an overall air-quality viewpoint, the large integrated plants will continue to pose the major problems.

Processing of Iron Ore at or Near the Source of the Ore

Processing of iron ore includes all steps in beneficiation and agglomeration as well as reduction (smelting) of the ore to metal:

(1) There will be a continuing strong trend toward closer sizing of lump ore. There is no uniformity from company to company as yet on specifications for size of lump ore, but the trend is for the upper dimensional limit to become smaller. The trend in size is toward something like plus 1/4 inch by minus 1 inch. The allowable percent of minus 1/4-inch material will also trend downward. Fines generated from the crushing and grinding of lump ore during sizing operations will be used as sinter fines or will be ground further for pelletizing.

(2) There is expected to be a continuation of a present strong trend toward further upgrading of the chemical quality of ore as mined (increased iron content and decreased gangue content). This will be accomplished through the following:

(a) Probable increase in the use of autogenous grinding when the characteristics of the ore permit

(b) Use of grinding equipment of larger size

(c) Wider application of more sophisticated beneficiation practices

(d) Possible application of reduction roasting, followed by magnetic beneficiation of hematitic taconites and other ores amenable to such a process

(e) Construction of additional new large oxide pellet plants at or near iron-ore mines to permit broader use of fines

(f) Probable establishment during the 1970s of direct-reduction plants at or near ore mines to produce prereduced materials. The use of this material will be discussed later in this section.

Coke Ovens and Coke Production

Coke production reached its peak in 1953 with an annual output of 78 million tons and bottomed out in 1962 at 51 million tons. In 1966 (a record-tonnage steel year), coke production was 67 million tons.

Improvements in blast-furnace technology during the past 15 years have lowered by 30 percent the amount of coke necessary to produce 1 ton of hot metal. Little capital has been put into new coke ovens because of the great number of coke ovens installed from 1950 to 1960 (5,617 ovens accounting for 52 percent of the total number of ovens operating in 1969), and commitments to other major projects from 1960 to date. Of the total number of coke ovens in operation in 1969 at iron and steel plants, 32 percent are over 20 years old, 52 percent are between 11 and 20 years old, and 16 percent are less than 10 years old. From this information, it is likely that within the next 10 years, much of the 32 percent increment will be replaced with new ovens, and after that there may be a heavy period of coke-oven construction to replace much of the 52 percent increment. If research and development is to be done to replace the slot-oven method of making blast-furnace coke, the work should be completed by 1980 before the period for replacement of the 52 percent increment of coke ovens arrives.

During the past 8 years, conventional by-product slot-type ovens have produced 98 percent of the coke consumed in North America. Beehive coke ovens produced the remaining 2 percent.

Beehive ovens are generally located in remote areas, partially because of their air-polluting characteristics, and partially because they tend to be located near the coal mines. Beehive ovens produce a low-grade metallurgical coke that can be used only for a limited number of applications in the steel plant. Although the cost of producing beehive coke may be from $3 to $4 per ton cheaper than producing conventional coke, there is little interest in beehive coke. The conventional beehive ovens now in existence are mostly in western Pennsylvania. They may continue to remain in existence as a hedge to provide reserve cokemaking capacity in case of an emergency, but, from technological, economic, and air-quality aspects strong arguments could be mustered to encourage their abandonment. At some future date, nonrecovery type coke ovens may have greater application due to the deteriorating coal chemical market.

With respect to conventional slot-type ovens, there has not been much activity or success in the steel industry in improving coking practice, but people directly engaged in coking and coke-oven research and development probably will deny this generality, because there has been a gradual evolutionary change in the direction of better coke for blast-furnace use. Nevertheless, present cokemaking equipment and practices persist not because they are really good and appropriate but because there is no proven better method at this time. Starting and stopping of a conventional by-product coke-oven battery is one of the most complex procedures in the steel-plant operation. Replacement of existing coking facilities is not expected to occur until the requirements of blast furnaces for coke exceed the capacities of existing ovens, which have high operating costs because of their antiquity (but low allocable fixed charges for the same reason).

Of the problems remaining to be resolved in the control of air pollution in the iron and steel industry, coke-plant operations are among the worst offenders as far as air pollution is concerned. Coke-oven operations cause air pollution mainly through three aspects of the process: (1) coal preparation, (2) coal charging, and (3) coke pushing and quenching.

In spite of the low amount of new coking-facility construction in recent years and the advanced age of existing coke plants, several developments in processing are taking place which lead to the following expectations about the future:

(1) An improvement in coke-oven refractories by changes in shape (design), composition, density, and the processes by which the refractories are produced.

(2) A shortening of coking time by using higher flue temperatures and by developing methods for reversal of flue-heating gases. The improved refractories are essential for this practice.

(3) More research in coal petrography to develop a wider range of blends of coal for coking. The Bureau of Mines has determined the coking properties of more than 1200 individual coals in the United States.

(4) The use of larger coke ovens capable of producing 80 percent more coke per oven than the largest ovens now in use in the United States. New ovens are 20 feet high, 50 feet long, and 18 inches wide; older ovens are 10 to 14 feet high, 30 to 45 feet long, and 17 to 18 inches wide.

(5) The development of new coking processes. Several new methods for carbonization of coal are under study and development. Some of these are continuous. To date, no continuous coking process has been judged suitable by the U. S. steel industry.

(6) Development of equipment to control, especially, particulates emitted into the air. New methods currently in use in Europe may fall short of really effective control, if applied to operations on U. S. coke ovens.

(7) Nominal continued improvement in the strength and composition of the coke (but no drastic improvement is foreseen).

All of the foregoing relates to coke made from coal. Petroleum-based coke seems to warrant more attention than it has received in the past. It has the advantage of higher carbon content and less ash, but these advantages have been more than offset to date by the higher sulfur content of petroleum coke. Currently known processes for producing petroleum coke low in sulfur have been too expensive for high-tonnage use, and no breakthrough on this problem appears to be in sight.

The Ironmaking Blast Furnace

The blast furnace will continue to be the major producer of pig iron in the United States, as it is throughout the world. Blast-furnace technology has improved a great deal in the past few years and has led to increased productivity of existing and new furnaces. New furnaces are larger than those they replace, thus causing the statistical average size of furnaces to increase from year to year.

The most important single factor that will influence the future of the blast furnace is the continuing growth in capacity of BOF steelmaking capacity in the United States. The BOF process uses a high percentage of hot metal in its charge (say 70 percent), and the blast furnace is the main source of this hot metal.

Size and Number of Blast Furnaces. A trend in the United States and elsewhere has been to enlarge the inner volume of existing blast furnaces during relining and rebuilding. Because of the large number of small blast furnaces that have been maintained in operation, the average size of the blast furnaces has not increased much during recent years. The mean diameter has increased from about 23 feet in 1960 to about 24 feet in 1967. The largest blast furnace in the United States has a hearth diameter of 32 feet.

The total number of blast furnaces in the United States has decreased from 250 in 1960 to 225 in 1967. The total number of furnaces on blast (excluding those on standby and undergoing relining) in 1960 was 218 and on January 1, 1967, the number on blast was 158. Production of pig iron in 1960 was 66.5 million tons and in 1967 the production was 87 million tons.

The average production of pig iron per blast furnace per day in 1960 and 1967 and projections to 1980 are given in Table IV-8. The average rose from about 1200 net tons per furnace day in 1960 to almost 1600 in 1967. By 1980, average production of pig iron per blast furnace per day is expected to be about 2200 net tons.

TABLE IV-8. AVERAGE PRODUCTION OF PIG IRON PER U. S. BLAST FURNACE PER DAY FOR 1960 AND 1967 AND PROJECTIONS TO 1980

Year	Total Days in Blast	Average Per Blast Furnace, net tons/day
1960	52,266	1181
1967	55,414	1570
1975[(a)]	55,625	1920
1980[(a)]	55,636	2200

(a) Projections by Battelle.

The average production per furnace day will continue to increase because of the retirement of some of the older and smaller furnaces, increases in the sizes of some existing furnaces during relining, and the very large size of new furnaces that will be built. Improvements in controls and in processing techniques will also augment the productivity per furnace, especially for newer and larger furnaces. Probably little money (on a relative basis) will be devoted to improvement of older and smaller furnaces. Because of these factors, the total number of blast furnaces in operation in the United States is expected to decrease, thus decreasing the number of potential sources of air pollution.

Changes in Blast-Furnace Technology. The productivity of blast furnaces as a class has increased because they have tended to become larger on the average, the raw materials have been upgraded, and improved operating techniques have been developed. The major factors that have affected the recent past and that are expected to affect the future of blast furnaces are as follows:

(1) The increased use of pellets and sinter in the burden, which provides a richer ore and less gangue and permits a lower coke rate.

(2) Emphasis on burden preparation to upgrade the chemical composition and the physical form of the burden. Sizing of the ore, sinter, coke, and limestone provides a more uniform material in the stack of the furnace.

(3) There has been some improvement in the quality of coke used in the blast furnace. Coke has tended to become somewhat harder and denser and to contain a lower ash content, so less coke is needed per ton of iron produced.

(4) The use of higher wind rates to increase the driving rate of blast furnaces generally and, in turn, to raise productivity.

(5) Increased top pressure to aid in controlling the furnace operation when higher wind rates are used. However, progress along these lines has been slow and is not expected to be really substantial in the next decade.

(6) The use of increased blast temperature to lower coke consumption per ton of iron and thus to increase productivity per furnace. The upper blast temperature, however, is limited by problems with regard to refractories, valving, and ducting.

(7) The injection of cheaper hydrocarbons to replace some of the coke and permit use of higher blast temperatures.

(8) Increased use of instrumentation to aid in controlling the more modern high-production units.

The productivity of U. S. blast furnaces is expected to continue to increase in the future. The changes in technology just tabulated are expected to increase in degree; for example, even higher wind rates and blast temperatures will be used in the future as well as higher percentages of pellets and sinter in the burden.

The development of new equipment is expected to extend the practical limits of the processing techniques now being employed.

In addition to the established methods of increasing the productivity of the blast furnace, the use of metallized or prereduced material may also become an accepted practice in achieving additional improvements in blast-furnace productivity. Limited investigations of use of such material indicate an increase in productivity of the furnace and a decrease in coke consumption.

The improved prevailing technology and expected future changes in technology of U. S. blast-furnace operations will decrease air-pollution problems for the following reasons:

(1) The number of operating units is expected to decrease because of the larger average size and increased productivity per unit.

(2) A decrease is expected in the amount of dust produced per ton of hot metal, because of constantly improving burdens and lower coke rates.

(3) Improved control, including improved collection and control of emissions, and reduction in the number of "slips" that emit dust into the atmosphere is expected.

Electric-Furnace Pig Iron

Electric smelting furnaces are used in several parts of the world to produce pig iron. Their pig-iron capacity is about 4.4 million tons per year. The electric pig-iron furnace is well suited to locations having ready access to cheap electric power and/or low-strength raw materials that are not suitable for conventional blast furnaces. A clear distinction must be recognized by the reader between electric smelting furnaces (now under discussion) and electric melting or steelmaking furnaces. At the present time, electric smelting furnaces are not used for the production of pig iron in the United States nor are they expected to be a major factor in the production of pig iron in the United States in the future.

An electric smelting furnace is being installed near Mobile, Alabama, at the present time as part of an operation known as the D-LM process. Pellets containing iron ore and coal are partially reduced on a traveling grate and then hot charged into a smelting furnace to complete the reduction of the ore to produce molten pig iron. The initial production capacity is announced at 200,000 net tons per year. Some of the claims of the D-LM process with respect to air quality and water quality control are as follows:

(1) Minimum combustion products are generated because coking, agglomerating, and prereduction are all carried out coincidentially.

(2) Entrainment of solids during pelletizing is minimized because the agglomerates are maintained in a quiescent bed (nonagitating) and the draft is exhausted through a filter bed of wet green pellets.

(3) Direct charge of preheated burden avoids air contamination from water and draft quenching of hot intermediate products.

(4) Electric smelting provides endothermal energy without direct combustion products.

(5) Wet systems for grinding, gas cleaning, and returns transport avoid secondary dust entrainment.

(6) Full water recycle for mill and cooling systems involves extensive evaporation which does not require continual discharge of liquid effluent.

The next two decades may see several more small electric-furnace pig-iron plants installed in the United States, but there are several reasons (in addition to rarity) to expect that, in the aggregate, they will not be important contributors to air pollution. The components of the facility can be compactly arranged, and the economy of the method generally may be expected to depend upon full use of all by-products which must be collected before utilization.

Direct-Reduction Processes

Several direct-reduction processes have been developed to produce sponge iron or molten pig iron without the use of the blast furnace.

The D-LM installation mentioned in the discussion on electric smelting is the first commercial venture of this nature in the United States. A direct-reduction plant for producing sponge iron is under construction near Portland, Oregon. Its rated sponge-iron capacity is 450,000 net tons a year. The sponge iron will be converted to steel in electric steelmaking furnaces nearby. Other small plants of this type are likely to be constructed in the United States in the future if the first two are successful, but proliferation of such plants in the United States during the next 20 years is unlikely.

During the past 10 years there has been considerable discussion about the economic potential for large sponge-iron plants in the United States. "Large" in this sense means an annual capacity of 1 million tons or more of metallized product. U. S. Steel Corporation is building such a plant in Venezuela. Standard Oil of New Jersey has a process of this nature for which the imminent construction of a plant in the United States frequently has been rumored. For the most part, however, there are no confirmed plans for such construction in the United States; and this means that it is extremely unlikely that there will be any large U. S. plants of this type operational before 1975. Conditions for economical operation of such plants currently favor locations outside the United States because of proximity to suitable ore deposits, lower labor rates, lower costs for natural gas and electricity, and other factors including political aspects. In the event that such plants are built in the United States, they probably would be located near the sources of ore, which means generally remote from present steelmaking centers and urban areas. Furthermore, the sophisticated technology involved in such plants, plus the fact that they involve new concepts, tends to maximize opportunities to build in truly modern and effective air-quality control.

Basic-Oxygen-Furnace (BOF) Steelmaking

The annual production of steel in the United States by the BOF process has increased from about 300,000 tons in 1955 to 41.4 million tons in 1967. It is estimated that, by 1980, the BOF process will produce 99 million tons of steel annually in the United States. Similar growth in this process also is taking place in most other countries that are major producers of steel.

Of significance in the phenomenal growth of BOF steelmaking is that it is displacing some relatively modern open-hearth shops. One example of the new trend is Granite City Steel Company's new BOF shop that has replaced production from seven large open hearths constructed during and after World War II. To date, about twelve open-hearth shops in the United States have been placed on standby or have been demolished to make way for new BOF capacity.

Some steel companies are now entering their second phase of BOF construction and are replacing small BOF vessels with larger vessels. For example, Jones and Laughlin Steel Corporation at Aliquippa, Pennsylvania, has constructed a new three-vessel (160/190 tons each) shop and retired a two-vessel (80 tons each) plant built in 1957; and McLouth Steel Corporation is replacing three 60-ton vessels with two 110-ton units, with corresponding enlargement of the supporting meltshop facilities. Crucible Steel Company at Midland, Pennsylvania, demolished three open-hearth furnaces to provide space for a new BOF shop. Youngstown Sheet and Tube Company at Indiana Harbor has under construction two 265-ton BOF vessels in a shop scheduled for completion in 1970 to replace their No. 1 open-hearth shop consisting of nine furnaces, which will be dismantled. The No. 2 open-hearth shop (already equipped with air-pollution control equipment) will remain in use to make open-hearth grades of steel and to give the company continued flexibility to melt scrap in quantities larger than can be handled conventionally in the BOF vessels.

The first installation in the United States of a new Japanese gas-collection process (OG Process) will be located in Armco's new BOF plant at Middletown, Ohio. This process, which incorporates a noncombustion technique for collecting CO gas and fumes from BOF furnaces and cleans the gas by high-energy scrubbing, is now operating overseas on twelve BOF furnaces, with several more installations under construction. Bethlehem Steel is equipping two 250-ton BOF vessels currently under construction with tubular-membrane hoods for steam production.

Future trends for BOF steelmaking in the United States are expected to include the following:

(1) Increased total capacity, estimated at 99 million tons annually by 1980

(2) Replacement of small BOF vessels rated at 30 to 80 tons per heat by larger vessels with capacities of 100 to 300 tons per heat

(3) Increased use of waste heat from fume-collection systems as a source of in-plant energy.

These trends will reduce the number of open-hearth furnaces in the United States by about 50 percent by 1980. This change-over will tend to alleviate the air-pollution problem, because the open hearth has been a major source of air pollution in the past, especially when oxygen lancing has been applied.

Electric-Furnace Steelmaking

The annual production of steel in the electric-arc furnace has increased from about 8 million tons in 1955 to over 15 million tons in 1967. The electric furnace's future is so promising that one forecaster has stated that, within 25 years, U. S. steelmaking capacity will be divided between electric furnaces (45 percent) and BOF furnaces (55 percent) – no surviving open-hearth furnaces are foreseen by that forecaster.

There are presently about 200 electric-arc steelmaking furnaces (over 12-foot shell diameter) operational in the United States, with about 14 in Canada and another 17 million tons of capacity under construction.

As examples of the trend, Armco Steel Corporation is installing three 22-foot furnaces rated at about 150 tons per heat at its Butler Works. Bethlehem Steel Corporation has announced the construction of an electric-furnace meltshop to replace ten open hearths at Steelton, Pennsylvania. This Bethlehem complex of three 150-ton furnaces will be equipped with "the most modern facilities for dust collection and fume abatement". Completion of the Steelton shop is scheduled for late 1969. Republic Steel Corporation's plant at Canton, Ohio, has constructed and placed into operation a new meltshop housing four 200-ton electric steelmaking furnaces, each about 26 feet in diameter. Several other steel companies have announced plans to install electric-arc furnaces. Each of these undertakings is by a major steel company that is adding new capacity to its plants or replacing existing open-hearth capacity by electric-arc capacity.

From the standpoint of the large integrated steel companies, BOF furnaces and electric steelmaking furnaces are natural complements to each other. The fading open-hearth process had considerable flexibility to accept various ratios of hot metal and solid-steel scrap. Considered independently of each other, the BOF and the electric furnace each have less flexibility along these lines than the open hearth. But the BOF process is essentially a hot-metal process, and the electric furnace is essentially a scrap-based process. Therefore, combinations of BOF furnaces and electric furnaces cannot only restore the flexibility of the former open-hearth situation but even can extend that flexibility. This is a strong reason for the general expectation that the continued growth of the BOF process will be a strong factor encouraging parallel growth of electric-furnace steelmaking in large integrated plants that produce millions of tons of steel per year.

A notable trend in electric steelmaking involves the use of "high-powered" and "ultra-high-powered" furnaces. New steelmaking furnaces now are being designed and built to operate from transformers of much greater power input than was common only a few years ago. For example, 80,000 kva on a 22-foot furnace (say, 150 tons per heat) is a high-powered installation, and there is some discussion that such a furnace may be capable of handling power input at a level of even 150,000 kva. Such installations permit much faster meltdown of the scrap charged to the furnace, shorten heat times, increase the productivity of the furnace, and, hopefully, will lower steelmaking costs (but such units do involve increased capital investments and some experimentation that truly is "large scale").

To the extent that steel is made in electric furnaces instead of in BOF or open hearths, the potential for air pollution is lowered. The BOF and the open-hearth processes both have large volumes of effluent gases, because both involve large-scale combustion and oxidation. However, even though electric furnace steelmaking produces lower gas and particulate emissions the problem of pollution control is a difficult one. Top-charge furnace emissions combined with those from electrode parts, slagging spouts, and tapping spouts, make the entrapment and containment of emissions difficult.

Mini Steel Plants

Although there were a few such plants prior to the 1940s, about 20 new small steel plants have been built in the United States since World War II. These are described in the industry's vernacular as "mini steel plants". They are nonintegrated plants in that they do not smelt ore, but generally melt iron and steel scrap in electric furnaces to produce their steel. Steelmaking capacity per plant is low when compared with large integrated plants and averages about 100,000 tons per year. Although a few of the mini steel plants are in areas that also contain large integrated plants, most are in areas remote from high-tonnage steelmaking and have been located primarily so as to be close to specific local markets. Because they depend on steel scrap melted in electric furnaces, the availability and price of scrap and of electric energy become important determinants in the location of such plants. While their products are sold on the open market in competition with integrated steel plants, their product line is limited and usually consists of reinforcing bars, merchant rounds, and light shapes.

The total annual production of mini steel plants at the present time is variously estimated at about 2 or 3 million tons. By 1980, it is expected that the annual production of steel by mini steel plants will rise to about 4 to 5 million tons. The number of such plants is expected to increase to about 35 by 1980.

This particular type of steelmaking may present a problem with air pollution. The plants are usually located in remote areas and to date generally have not paid much attention to pollution of the air. However, the compact nature of the plants and the nature of the processing that they use lend themselves technologically to virtually complete control of emissions. The main deterrent is that these plants exist and profit mainly because of low capital investments per ton of steelmaking capacity, and substantial investments for air-control equipment could change the entire picture of their economic viability. The situation is not unlike that faced by the ferrous foundry industry in controlling emissions from cupolas. Although requirements for air quality are expected to be a factor tending to slow the future growth of mini steel plants, it is expected that this deterrent will be offset by other factors and that such plants will increase substantially in number during the next two decades.

Sponge Iron for Steelmaking

"Sponge iron" is a product of the solid-state reduction of iron ore. The reductant is usually carbon, carbon monoxide, hydrogen, or some combination of these. Because melting is not involved, the product contains the gangue (such as silica) that was originally present in the ore. The terminology regarding this type of product is inconsistent. For the present purposes, the term "sponge iron" is taken to include "prereduced ore", "prereduced pellets", "metallized pellets", and the like.

The use of sponge iron for producing carbon steel in electric furnaces has been practiced in Mexico for more than 10 years. Swedish steelmakers have used sponge iron in electric furnaces and in open hearths for producing alloy steel since 1941. The Steel Company of Canada has conducted many commercial-scale experiments for producing carbon steel from sponge iron in the electric steelmaking furnace, with successful results.

When sponge iron or similar materials are used in steelmaking, they generally will be used in much the same way that steel scrap presently is used. An exception is that some forms of sponge iron (particularly metallized pellets) lend themselves to continuous charging to the melting furnace, in contrast to the conventional batch-charging methods now used for scrap. From the standpoint of air pollution, replacement of some or all of the scrap in a steelmaking operation with sponge iron is unlikely to increase problems of control of emissions and offers an opportunity (for example, through continuous charging) for lowering the amount of such emissions.

The Oregon Steel Division of the Gilmore Steel Corporation is building an electric-furnace shop near Portland, Oregon, that will use sponge iron for producing carbon steel. The associated sponge-iron facility will have a rated annual capacity of about 450,000 net tons and therefore is a larger operation than the so-called mini steel plants. The success of the Oregon Steel Company operation and other similar facilities now under construction around the world will determine the amount of sponge iron used in the future for electric-furnace steelmaking. Some large integrated steel companies (such as Armco) also are considering the use of sponge iron in their electric-furnace meltshops. It is reasonable to expect that about 2 million tons of sponge iron may be consumed in steelmaking by 1975 in North America.

Open-Hearth Steelmaking

Steelmaking by the open-hearth process has declined rapidly in the United States from its peak of 103 million tons in 1956 to 70.7 million tons in 1967. This trend is expected to continue, as has been discussed previously in this section.

Continuous Casting of Steel

In the traditional method of manufacture, molten steel is teemed (poured) into large cast-iron ingot molds, in which it is allowed to solidify. The solidified ingot of steel then is stripped out of the ingot mold and, after suitable conditioning (surface preparation and reheating to the desired uniform temperature), rolled down to smaller sizes. Because the ingots often are very large, the rolling mill is large, massive, and, hence, expensive. This traditional procedure has given rise to the practice of rating steel production and capacity in terms of "ingot tons".

Most steel still is cast by the conventional method just described, but during the past decade a different method called "continuous casting" has emerged commercially. This eliminates the ingot mold and the ingot. Molten steel is poured into water-cooled copper molds, from which the resulting quickly cooled shape is withdrawn continuously and cut to desired lengths. The advent of this new method has brought a change to the tonnage rating system from "ingot tons" to "raw steel", in which the latter term includes ingots cast in the conventional manner plus billets and slabs cast continuously.

Most of the continuous casting units in production before 1968 in the United States have been in plants with less than 200,000 tons of annual capacity. The total installed U. S. annual capacity for continuous casting, as reported in May, 1968, was about 1.3 million tons. Continuous casting has been limited to date in the United States primarily to the production of billets (about 4 by 4 inches) for subsequent rolling into rebar and wire rod. By the end of 1968, the installed U. S. continuous-casting annual capacity was about 3.5 million tons, and by the end of 1969 it probably will be about 13 million tons. The rapid increase is a result of large installations for the continuous casting of slabs and blooms in large integrated steel plants. An additional 30 million tons of annual capacity is expected to be installed by the end of 1972.

Even the most optimistic proponents of continuous casting believe that only about 50 percent of U. S. steel production can eventually be cast continuously. However, any process that may be a factor in the production of up to half of all U. S. steel introduces a drastic change in process technology.

From the standpoint of air pollution, continuous casting offers considerable potential for mitigation of air-quality problems. The casting operation is conducted at a fixed location rather than being spread out over the larger area required by conventional ingot molds. Thus, collection systems for fumes can be more localized and, hopefully, can be made more effective. Furthermore, the coatings used to protect molds during continuous casting appear to offer fewer opportunities for undesirable emissions than do the coatings used on the conventional ingot molds.

Pressure Pouring

This process (originally developed to produce cast-steel railway car wheels in graphite molds) is now being applied to slabs, billets, and pressure-cast hollow tubes. The process is expected to be used only for special alloys and for special products and not to be a major process for tonnage steel production. Air pollution is not likely to be a problem with pressure pouring.

Vacuum Degassing

Originally developed for application to high-cost alloy and special forging steels, vacuum degassing is rapidly being extended to tonnage grades of carbon steel. Vacuum processing of steel lowers the incidence of refractory nonmetallic inclusions in the steel and produces high-quality, clean steel with high consistency. Vacuum degassing may provide an economical method for producing continuously cast rimming-type steel, but because of other applications it will probably be used at an increasing rate that will be more rapid than the growth of continuous casting of steel. Vacuum degassing is not expected to have any major effect on air-quality problems, pro or con. Most of the particulate matter that is generated in the process is trapped by the steam ejectors used to produce the vacuum. The ejectors act similarly to high-energy scrubbers in this respect. The gas from a vacuum-degassing unit will contain carbon monoxide, but if this gas was not emitted at this fixed location, it would be emitted somewhere else where collection would be more difficult. Depending on the system, the carbon monoxide may be burned or emitted from stacks. The total amount of carbon monoxide emitted during degassing can be as high as 90 cubic feet per ton (7 pounds), or 675 cubic feet per minute, for an average degassing time of 20 minutes.

Rolling

Hot Strip Mills. Installation of new hot strip mills in the United States presently is at low ebb, because a considerable number of new units of this type have been erected during the past 10 years. In that period, new wide, powerful, sophisticated units were installed, and many of these are now in production, startup, or final stages of construction. As one example, the Granite City Steel Company rolled the first coil on its new 80-inch hot strip mill in August, 1967. This facility is powered by a total of 105,000 hp and is computer controlled.

The installation and modernization of hot strip mills invariably includes provision for control of emissions. As with all steel-rolling mills, water pollution is the main pollution problem. Emissions to the air consist largely of steam, and are confined to the immediate vicinity of the mill.

Future trends in hot strip processing are expected to include the following:

(1) Increased consumption of electrical energy and faster processing of hot strip

(2) Closer control of processing with the aid of computers

(3) Provisions for better control of water pollution.

Plate Mills. The tonnages of plate shipped by the steel industry have been on the increase during recent years, and this trend is expected to continue for the next decade or two. As with hot strip installations, new plate mills will be more powerful, will provide for control of the mill by computer, and will include increased attention to water-pollution problems. The requirements for wider, stronger, and better shaped plate have been met by several recent installations of new facilities. For example, Republic Steel at Gadsden, Alabama, installed a new mill in 1967 that will produce plate up to 120 inches wide with good shape control. U. S. Steel Corporation has begun construction of a 160-inch plate mill at its Texas Works, and Armco will improve its plate mill at Houston. When present plans are completed, plate capacity in the United States will be more than 13 million tons annually.

Plate mills involve practically no problem in the control of air quality.

Pipe and Tube Mills. The recent trends involving longer lengths, higher speeds, and faster roll changes are expected to continue. For example, the increasing market for longer lengths of heat-exchanger and condenser tubing has influenced Crucible Steel Company to build a new tube mill at its Trent Tube Mill at Midland, Pennsylvania. Initially, conventional-length tubing will be produced, but as anticipated requirements for specialized tubing in power plants and desalinization plants become a reality, the mill will be in a position to supply a wider range of market demands. Tube diameter will range from 1/2 to 3 inches in various materials including stainless steel, titanium, and other metals. Roll changes necessary to alter the diameter of the tubing, which formerly required 4 to 8 hours, are expected to require less than 1 hour on the new unit. Designed speed for production on this mill is up to 300 fpm.

Pipe and tubing mills present no problem as far as air-quality control is concerned.

Merchant, Rod, and Bar Mills. Bar-mill facilities are now undergoing a cycle of modernization and expansion. Much of this will take place over the next 2 or 3 years. Atlantic Steel Company's new rod mill is using a novel approach. From reheating to finishing, the mill is designed for continuous operation. Billets proceed from a reheat furnace directly to a swing-forging stand for reduction before rolling. The advantage of the swing-forging machine is that it permits a 7 by 7-inch by 30-foot bloom to be processed into one 5000-pound coil of finished rod up to 1/2 inch in diameter. The swing-forging machine reduces the bloom in a single pass. Four dies work the bloom, two vertically and two horizontally. Other features include a high-speed roll-changing unit, a designed finishing speed of 10,000 fpm, and a high utilization rate.

U. S. Steel, Republic Steel, Inland Steel, Allegheny Ludlum Steel, Latrobe Steel, and others are among those planning modernization of merchant, rod, and bar mills.

Future trends involving this type of mill are expected to include the following:

(1) Higher speeds of operation

(2) Faster roll changes, with spare mill stands completely assembled and ready for installation as needed

(3) Improvements in surface quality and in dimensional tolerances in the heavier rod sizes

(4) Improved control by means of computers.

Mills of this type are not important contributors to air pollution.

Cold-Rolling Mills. Higher speed, computer control, higher power, and thinner gages are the future trends expected in cold mills.

As an example of current developments, Armco broke ground in 1968 at Middletown, Ohio, for a new cold-rolling facility. The 86-inch (wide) mill will be one of the widest in the world. It will produce strip and sheet stock 24 to 80 inches wide and 0.070 to 0.200 inch thick. The five-stand mill will be powered by 41,536 hp and will deliver strip at a speed of 5200 fpm. To facilitate production of 200,000 tons per month, the mill will be equipped with automatic coil-handling equipment, gage-control equipment, and it will use computers to log operating data. Completion is expected in 1970. As another example, Inland Steel Company at Indiana Harbor will add a five-stand tandem cold mill and a single-stand temper mill to increase capacity by 1 million tons per year. The unit will be capable of producing 100,000-pound coils in widths up to 76 inches. Completion is expected in late 1970. The new mill will be operated by a process-control computer and equipped with automatic gage control.

Modern, well-ventilated cold-rolling mills are relatively minor contributors to air pollution.

Finishing

Coating Processes. Various forms of surface protection, such as galvanizing, tin plating, cladding, or painting, have been applied to steel sheet for many years, but more time and attention recently have been focused on improving old methods and developing new ones. Precoated steel strip is a good example. A number of steel producers have facilities for applying alkyds, acrylics, vinyls, vinylalkyds, silicones, and organsols. Coil coating (painting or laminating) has been growing at a rate of about 25 percent annually over the past 5 years, and fast growth is expected to continue at least for another decade.

Electrocoating (electrophoretic deposition) is a method whereby an electric charge is applied to a solution of paint in a water medium, causing the resins to migrate to any conductive surface immersed in the solution. Paint particles adhere so tightly that the water is squeezed out. Parts are then washed and the paint is baked on the surface. The process has in less than 2 years changed from pilot-plant investigation to full production status and appears to have technical and economic aspects that make greater use of the method quite likely during the next decade. As of January, 1968, there were about 36 electrocoating lines in operation in the United States, and the total is expected to double by 1970. One forecast estimates that 50 percent of all paint applied to metal eventually will involve the electropainting process.

Coating with lead phosphate (a new type of conversion coating) has advantages over conventional zinc phosphate coating. The major advantage is that it does not impair the weldability of the steel. The lead phosphate coating can be applied to the steel at the mill, serve as a protective coating during storage and shipment, and facilitate subsequent forming, drawing, and coating operations.

The use of galvanized steel has increased because of its ability to resist corrosion and abrasion. Increased use of galvanized materials by the automobile industry stimulated production of galvanized strip steel. In early 1967, there were 53 continuous hot-dip galvanizing lines and nine continuous electrogalvanizing lines in the United States (all handling steel strip over 24 inches wide).

One major producer of cans has stated that, within a few years, tin-free steel will account for more than 50 percent of its can production. The problem of closing the side seam (soldering) has limited the acceptance of tin-free steel in the can industry, but two recent developments (bonding and welding) make it practical to use this metal extensively. Improved versions of tin-free steel (such as chromium-plated sheet) hold much promise for the container industry because of their better corrosion resistance and higher luster finish.

A chromium-coating process developed in England looks promising. Steel strip is coated with chromium chemicals and then annealed in a hydrogen atmosphere for 5 hours. The process produces a layer of chromium steel 0.002 inch thick with 38 percent chromium on the outer side. The process is reported (perhaps too optimistically) to produce a strip with the corrosion resistance of stainless steel at the cost of mild-carbon steel.

All signs point to greatly increased production of coated steels of many types by the integrated steel companies. Because most of the methods of coating involve the use of chemicals and solvents, there appears to be a substantial opportunity for air pollution, unless each installation is engineered to control emissions. The emissions of concern are most likely to be mists and organics. Solid particulates probably will not be evolved in sufficient amount to constitute a problem. However, general statements of this type may not apply to every type of coating process. The variety of processes is wide, some are very new, and each installation should be considered as a separate problem until there emerges more of a pattern of performance than exists today.

Pickling. The use of hydrochloric acid for pickling of steel has increased rapidly in the past few years. It is estimated that about 18 million tons of steel per year now are pickled with hydrochloric acid, which is rapidly replacing sulfuric acid as the pickling agent. A recent prediction is that half the lines in the U. S. will be of the hydrochloric-acid type by 1970. However, not all steel men are thoroughly convinced that this is the correct approach. The relative advantages and disadvantages of hydrochloric acid and sulfuric acid are still being evaluated. The uncertainties involve matters of original cost, maintenance problems, economics of operation, customer preferences, water pollution, production capability, and equipment arrangement. As an example of current thinking, the U. S. Steel Corporation's expansion at its Irvin Works includes an 84-inch continuous pickling line that is designed to operate on either sulfuric or hydrochloric acid.

Heating Furnaces and Controls

The trend among U. S. steelmakers to better control of quality has increased the industry's demands for more complex heating and reheating equipment. Automation of furnace operations, specially designed material-handling systems, and scale-free heating is now being applied more frequently and more extensively. The use of electric heating has apparently broken through an earlier economic barrier and applications are increasing. For example, McLouth Steel will use very large electric induction coils for heating large slabs to rolling temperature. The facility will heat 20 slabs per hour at a rate up to 680 tons per hour. Copperweld Steel has installed an electric induction heater to equalize billet temperature just prior to entering the first roughing stand of an 18-inch continuous bar mill. Ford Motor Company is installing 24 recuperative-type soaking pits at its mill in Dearborn, Michigan. The new pits will incorporate a high-velocity combustion system and a newly developed air seal for scale-free operation. Jones and Laughlin Steel Corporation this year completed installation of a heat-treating facility at the rod and wire mill at Aliquippa, Pennsylvania. The new furnaces are instrumented to insure positive control of temperature and furnace atmosphere in each zone through which the coil travels during heat treatment, thereby providing ultimate decarburization control and uniformity of microstructure. A continuous annealing facility for cold-finished carburized bar was installed at Republic's Union Drawn Division at Gary, Indiana. The new furnace is a continuous type that can carburize up to 300 tons or anneal 1500 tons of carbon or alloy bars per month.

The future trends in heating furnaces in the integrated steel industry are expected to include the following:

(1) An increase in the number of electric heating units

(2) More emphasis on scale-free reheating furnaces to increase yield and to improve surface quality

(3) Improved instrumentation to control the temperature and the atmosphere in the furnaces

(4) Faster heating cycles.

Because of their nature (tight enclosure and use of clean fuels), heating and reheating furnaces do not constitute a major threat to clean air. Many furnaces of this type already are only minor contributors to air pollution (if at all), and the trend in the design and use of the new furnaces is toward further cleanliness. In particular, automatic combustion controls are being applied more generally and perform well in promoting cleanliness of the waste gases from combustion systems. Especially when combined with the use of natural gas as the fuel, combustion-control systems have the potential for almost eliminating even fuel-fired furnaces as a source of major pollutants from reheating furnaces in the steel industry.

Explosive Bonding

Explosive bonding offers a relatively inexpensive method of forming high-strength metallurgical bonds between dissimilar and incompatible metals. Several of the available conventional explosives are not sensitive to shock or heat and can be handled without usual precaution. Suitable chambers can be erected to control the noise and blast and to help overcome the reluctance of some potential users to work with explosives. This new process is expected to receive widespread application in the specialty field, such as in cladding of carbon-steel plates with stainless steel, tantalum, or titanium. The process is not a contributor to air pollution and its use may displace some of the conventional bonding processes that do tend to pollute the air.

Electrical-Energy Consumption and Generation

The consumption of electrical energy has been increasing in the steel industry as the processing becomes more sophisticated. The consumption of electrical energy in the steel industry has increased from an average of 305 kwhr per ton of raw steel in 1965 to an average of 334 kwhr in 1967. In 1967, the steel industry consumed about 42.5 billion kilowatt hours of electrical energy. About 28 percent of this was generated within steel plants. This was down from 33 percent generated in-plant in 1964, and the trend is continuing.

The future trend in the steel industry will be toward an increase in the consumption of electrical energy (both total and per ton of steel) and a decrease in the percentage of energy generated at the plant site. The increased consumption of electrical energy will be caused by the following:

(1) An increase in production of steel in electric-arc furnaces

(2) Increased use of oxygen in ironmaking and steelmaking and the use of large blocks of electricity to produce this oxygen

(3) An increase in the total horsepower of mill equipment

(4) An increase in automation and labor-saving devices that are consumers of electrical energy.

In general, the expected increased use of purchased electrical energy in the steel industry will help significantly to reduce this industry's contribution to air pollution.

SECTION V

SOURCES OF AIR POLLUTION IN THE INTEGRATED IRON AND STEEL INDUSTRY

The American iron and steel industry must handle a vast tonnage of solid materials (many of which are of very fine size) and must carry out much of its processing at high temperatures (in some instances exceeding 3500 F), often with the use of high volumes of gas. This section presents an overview of some of the processing methods and the air-pollution problems that result.

This section is divided into three parts. The first describes processes and emissions in the steel industry. The second part concentrates on the use of fuels and energy in the steel industry. The third is concerned with noxious emissions – sulfur dioxide, carbon monoxide, fluorides, and nitrogen oxides.

Process Segments as Sources of Air Pollution

The following discussion is oriented on the basis of major processing segments used in the manufacture of iron and steel. More detailed information concerning the types of steelmaking equipment, identification of emissions, amounts of emissions, and methods used for their control are given in Appendixes A, B, and C of this report.

Receipt, Storage, and Handling of Raw Materials

Raw materials arrive at steel plants by boat, barge, or railroad, with some minor amounts of materials arriving via truck. The raw materials are unloaded to open stockpiles, with the exception of a few materials such as lime which is shipped in closed hoppers or container cars and then transferred to enclosed hoppers without exposure to the atmosphere. Most of the materials received are in a presized condition; most of the crushing and sizing having been done at the mine, quarry, or pelletizing plant.

Transfer of the materials into and out of storage and to the processing centers creates a somewhat persistent dust problem because of the fine material always associated with bulk handling of ore, coal, and limestone. Dusts from iron ores are oxides of iron, silicon, calcium, and magnesium. Dusts from limestone and dolomite are carbonates of calcium and magnesium, magnesium oxide, and silica. Dust from fluorspar (which is used as a fluxing material) consists of calcium fluoride, calcium carbonate, and oxides of iron, aluminum, and silicon.

One of the more persistent sources of dusting is coal, which, because of its small size (one-half inch or less as received from the mine), offers ample opportunity for dusting during handling and storage. Open stockpiles of coal may reach a height of 100 feet and cover up to 10 acres.

Because stockpiles of raw materials are exposed to the weather, and can be affected seriously by dry conditions, various techniques have been tried to suppress dusting. These methods have included simple wetting with water and spraying with special plastic materials, but none have been truly successful. The large scale and available methods of stockpiling and reclaiming make it economically impractical to house or shroud the stockpiles.

Transfers from stockpiles usually are by means of overhead clam-bucket gantries to bottom-dump cars, or by endless conveyor belts for upward movement, and gravity chutes for downward movement. Dust is created at each transfer point. Outdoor belts conventionally are covered but not enclosed, and dusting can occur during windy weather. Emission of particulates to the atmosphere from materials once received in a particular building usually can be controlled. Emission control at indoor transfer points often is controlled by cyclone dust collectors. At transfer points inside a coal crushing and grinding plant, the dusting can be controlled by the use of wetting agents combined with water sprays.

Although dusting from raw-material stockpiles is a problem of concern, there is a shortage of reliable data on the amounts of dusts that become airborne.

Coking Process

Coke is the major source of fuel in the blast furnace. Over 98 percent of the total production of metallurgical coke is made by the by-product oven process. Unlike the older beehive process, the valuable ingredients in the volatile matter from heating coal in the absence of air are recovered in the by-product oven rather than exhausted to contaminate the atmosphere. After the extraction process, the gas is used for underfiring the coke ovens, as well as for heating in other processes in the steel plant. This gas is free of particulates, but usually contains some hydrogen sulfide.

A modern by-product oven may receive a charge of up to 40 tons of coal through four or five ports aligned at the top. Each oven may be up to 60 feet long, 18 feet high, and 20 inches wide. As many as 100 ovens may be set together in a battery. Flues between adjoining ovens are heated by hot combustion gases. Regenerative checkerwork located under the battery preheats the combustion air. Charging vehicles called larry cars have separate hoppers for bottom discharging into each port of the oven. Charging is done with the oven walls at an incandescent temperature. The coal has a top size of about 1/8 inch. After a coking period of 16 to 20 hours in the sealed ovens, doors at both ends of the oven are opened and a ram pushes the entire load of coke onto special railway cars. At a quenching station the load is deluged with water to cool it, after which the coke is crushed and screened to size.

Coke-Oven Charging

Steam, flame, smoke, and fine particles of coal rush out of the oven ports during the charging cycle. During the coking period, leakage of vapors may occur at the lids sealing the charging ports and at door seals. Characteristics of the emissions from these specific sources are not available. The origin of particulates for all operations in a coke plant appear to be about 40 percent from coke, 30 percent from coal, and 30 percent from other mineral dusts normally found in a steel plant.

Leakage of toxic, obnoxious vapors at door and port seals during the early coking stages (when the oven is under some positive pressure) can be minimized by adequate attention to maintenance of the seals. A satisfactory solution to the problem of emissions during charging has not been found. Some improvement results from the use of steam jets in the raw-gas ascension pipes to decrease the pressure in the open oven during charging. A method receiving attention in Europe involves the use of a larry car that drops the coal through a sleeve that is lowered into the oven, and which collects the emissions in a disintegrator after exercising controlled combustion. Without controlled combustion ahead of the collector, an explosion could occur. Unfortunately, space and structural limitations of present American ovens may not permit direct adoption of this system. A pneumatic charging method is being worked on in the United States, but details on its development have not yet been released.

The emission during charging and during the early stages of coking (when the ovens are under positive pressure) is considered by Battelle and by steel companies to be a serious problem that may require a long time to reach a satisfactory solution.

Coke-Oven Pushing

When the incandescent coke is pushed out of the oven onto an open hopper car, a strong draft is induced in the immediate surroundings. Fine particulates and smoke are blown high into the atmosphere. Some of the particulates come from coal dust that had settled in the area because of prior coal handling. Most of the particulates come from abrasion of the coke during pushing and from incompletely coked coal. If the amount of uncoked coal is great, then smoke may also be emitted for a short time during combustion of the green coke. Good coking practice results in reduced emission of particulates and smoke, but details on the sizes and concentrations of the emissions are not available.

In Europe, a hood at one plant was used over the hopper car holding the coke. This experiment has been abandoned. In a high wind, most of the smoke does not reach the hood. The near-future prospects for development of a pushing system having good control of emissions is considered to be unencouraging. The need for control is great.

Coke Quenching

The open hopper car contains the incandescent coke on a sloping bottom with side gates made of grating. The car is moved to the quench tower which is a large brick chimney that will accept the car at its lower end. Water sprays in the chimney deluge and cool the hot coke. The cloud of steam rising in the chimney lifts particulates of coke into the atmosphere, but the particulates tend to fall out in the vicinity of the tower. About 87 percent of the particulate emission occurs in the first minute of a 2-minute quenching time.

Baffles installed in a trial quench tower reduced the emission of particulates into the atmosphere from 6 pounds to about 1-1/2 pounds per load of coke. This can amount to a capture of 900 pounds of particulates per day for one tower. A still more efficient control system is desirable. However, the localized fall-out of particulates results in coke quenching being rated as a relatively low contributor to air pollution.

Coke Handling

The quenched coke is dumped onto a sloping brick wharf from which conveyors transport it to sizing and screening operations. Steel and rubber shrouding at the transfer points, at the crusher, and at the screens minimize dust loss. Indoor transfer points may use a cyclone to collect the dust. Fines are removed before the sized coke is transferred to stock or to the blast furnace. The fines are usually dumped via chutes into open hopper cars for transport to the sinter plant.

Although data are not available on the amounts of emission, dusting during coke handling is considered not to be a serious problem, except in windy weather.

By-Product Processing

The gases and volatile products that come off the coal during coking are drawn by downstream exhaust fans into ascension pipes at both ends of each oven and into collector mains. The gases are carbon monoxide, hydrogen, methane, hydrogen sulfide, ammonia, and nitrogen. The volatile products are anthracene and other tarry compounds, benzene, toluene, xylene, naphthalene, phenols, and pitch. Recovery of these by-products by well-established chemical techniques starts as the cooled raw gases leave the mains.

Usually only minor emissions can occur at the primary end of the system, because it is under negative pressure. Some odor of free vapor is present at the tar collectors and decanters and at locations where the liquor runs in lines that are not fully closed. Ammonia and organic fumes are particularly strong at sumps where decanted liquor and other flush liquor is recycled to the sprays for cooling the collector mains. Emission of ammonia is minor because leakage is detected promptly and the leaks are repaired. In older plants, the addition of strong sulfuric acid to the ammonium sulfate precipitator tank can cause considerable fuming of the acid. In large plants, phenol and pyridine bases dissolved in the ammonium sulfate precipitator are recovered in systems that are closed except for tank vents which do not create an emission problem. In small plants, the weak liquor containing ammonia and phenols is added to the water that is used to quench coke.

Tars are heavily loaded with polycyclic aromatic hydrocarbons that are considered to be hazardous. Emissions from vents on processing and storage tanks are led through scrubbers to absorb or destroy the fumes. However, the tars tend to condense and foul the scrubbers, whereupon the scrubbers discharge the raw vapors.

Vapors of the light oils are toxic and flammable. Condensers and some of the process tanks are vented. The sweet odor of the aromatic vapors often pervade a large area. Some leakage and vapor loss is inevitable in the by-product system. Forced ventilation in the pumphouse is a necessity. Major leakage or fires are rare because the high hazard level prompts strong preventative measures.

The stripped gas from the by-product plant enters the plant fuel system. It has a heat content of 500 to 550 Btu per cubic foot. Tar also finds some use as a fuel for open-hearth furnaces. The tar used for fuel is not cleaned. It contains about 0.6 percent sulfur, which becomes sulfur oxide upon combustion.

High-volume petrochemical processing has drastically lowered the market prices of many organic chemicals. By-product recovery from coke-oven gas is no longer as economically attractive as in the past. However, most coke plants have by-product systems, and these systems do provide credits to the coking process.

By-product processing of coke-oven gas results in the escape of a relatively small amount of obnoxious vapors, chiefly from vents, sumps, and seals. Data on the concentration of these vapors are not available. Because the vapors are obnoxious, they are considered to be a serious contributor to air pollution and are, therefore, collected for disposal or flared to the atmosphere.

Preprocessing of Raw Materials

Sintering

Sintering plants convert iron-ore fines and metallurgical dust, including mill scale, into an agglomerated product that is strong enough and large enough for charging into the blast furnace. The iron-bearing materials are mixed with coke dust to form a bed on a slow-moving grate in the form of an endless belt. The bed is raised to its kindling temperature in a gas-fired or oil-fired ignition furnace; then a down draft of air keeps the bed burning. A screen catches the sintered material when it is dumped from the traveling grate. Undersized material is recycled. Cooling air is blown over the sinter as it passes through an enclosed cooler on a moving apron or grate. The cooled sinter is dumped directly into cars or conveyors for transport to the blast furnace. Plant capacities range from 2000 to 6000 tons of sinter per day.

Sintering machines process a wide variety of feed materials and produce a considerable amount of emissions. The quantity and nature of the emissions are variable from plant to plant.

Minor amounts of dust are created in the handling and grinding of raw materials. Emissions include dust sucked through the grate bars into the windbox, combustion gases from ignition and firing, and dust generated in the screening and cooling operations. Complete combustion exists during sintering and makes it unlikely that the exhaust gas contains unburned hydrocarbons. However, the coke-oven gas used for ignition and the sulfur in the sinter-mix coke contribute to the presence of sulfur dioxide in the combustion products. Sinter dust may contain particles of iron oxides, calcite, iron-calcium silicates, and quartz. Dusts going into the atmosphere from the dust collector are probably similar in composition but finer in size.

The concentration of particulates in the windbox under the grate during ignition appears to be about 0.5 to 3 grains/scf*. According to one report, about 20 pounds of dust per ton of sinter is produced in 225,000 scf of gas per ton of sinter; this gives a concentration of 0.62 grains/scf from the windbox and traveling grate. The size distribution was 3.7 percent over 420 microns, 22.6 percent at 178 to 420 microns, 36.8 percent at 76 to 178 microns, and 36.9 percent under 76 microns. At the discharge from the grate, the size distribution was about 50 percent over 100 microns and

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*scf = standard cubic foot.

10 percent under 10 microns. At the discharge from the enclosed cooler (at an exhaust volume of 2000 scfm* per ton of sinter), the particulate concentration is 5.8 to 6.6 grains/scf.

Multicyclones, electrostatic precipitators, venturi scrubbers, mechanical collectors, and baghouses have been used in various combinations at the various points of emission. Wet scrubbers have high maintenance cost from lime buildup and add to water-treatment problems. Baghouses suffer from the abrasiveness of the dust. The abrasive dust can also create a major problem in maintaining operation of the fans in the sintering machines. With sinter that contains flux, the efficiency of electrostatic precipitators decreases with increase in the basicity of the sinter. In subsequent handling of sinter and sinter fines, spraying with water containing wetting agents has been used effectively in some cases to reduce dusting at transfer points.

The state of the art for effective, efficient control of emissions is considered to be at a low level. Operation and maintenance costs are high. Control of particulate emissions to a level under 0.05 grain/scf is possible, but can be so expensive that pellets might become a more economical burden material than sinter.

Pelletizing

Pellets are made by rolling fine concentrates of iron ores mixed with a clay binder (usually bentonite) to form damp balls about 1/2 inch in diameter. The balls are dried and fired (usually in a shaft furnace) to harden them. Pellets are made at plants located at the mine sites. In crushing the ores, fines that are unsuitable for pelletizing, because of mineral characteristics, are shipped to steel plants for processing into sinter. Although pellets are strong and attrition is low during loading for shipment to and receiving at the steel plant, the large volume of material handled in a shipment can result in some airborne dust.

Concentrates received at the pelletizing plant are usually in a moist condition, so that dust generation during receiving frequently is not a problem. Bentonite is received in covered hopper cars and is unloaded into special bins that meter the bentonite into the pelletizing operation. Particulate emissions are magnetite, hematite, and bentonite. The minor amounts of dust generated in the plant are handled usually by simple cyclones or baghouses. The induration operation (heat hardening) is conducted at relatively low air-flow rates so that formation of particulate emissions usually is not substantial.

The concentration of airborne dust generated by pellets at shipment-transfer points is not available, but the accumulative amount is considered to be so great that the fall-out is a serious problem.

Ironmaking

The blast furnace is a refractory-lined structure about 100 feet high and up to 30 feet or more in diameter at the hearth. Raw materials are charged at the top through a series of seals called bells. Air, preheated in regenerative stoves, is forced through ports called tuyeres arranged around and just above the hearth. The air

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*scfm = standard cubic feet per minute.

(usually augmented with oil, gas, oxygen, or steam) rises through the charge and reacts with the hot coke to generate hot reducing gases which, in turn, react with the oxygen in the ore to start the formation of metallic iron. As the burden (the charge) moves downward into the fusion zone, the iron becomes molten and collects in the hearth. The limestone in the burden reacts with impurities in the ore and coke and forms a molten layer of slag on the pool of iron. Periodically, the hot metal (molten iron) is cast (drawn off) into special enclosed railway tank cars that deliver it to the steelmaking furnace. Slag is cast into steel pots and transported to a dump area, or is granulated with water. The gas ascending in the blast furnace is removed at the top, stripped of dust, and then used to fire the regenerative air-blast stoves of the blast furnace. The blast-furnace gas also is used as fuel in the powerhouse and as fuel for other operations in the plant.

Charging

The charging practice for a blast furnace can vary widely. Modern burdens consist of screened ore, sinter, pellets, or a mixture of these. Some blast furnaces operate on 100 percent pellet burdens or 100 percent sinter burdens.

Raw materials are moved from the stockpiles to surge hoppers (called pockets) at the blast furnace. Coke is usually transferred to the pockets by conveyor belt; ore and flux by bottom-dump cars. Materials drawn from the pockets are weighed and transferred to the top of the blast furnace by a skip hoist, or, in some newer installations, by a conveyor belt. Usually a scale-mounted car is used for the transfer of ore and flux from the pockets, and a conveyor belt for the transfer of coke.

The raw materials are dumped into a receiving hopper at the top of the furnace. In step-wise fashion, the materials are dropped through a series of two or more sealed hoppers. This system minimizes the escape of furnace gas as charges are added and pass successively from one sealed hopper to the next sealed hopper.

The transfer at the top of the furnace is highly exposed, but partial shrouding is possible. Leakage of gases, which also contain particulates, can develop in the bell system as a result of abrasion wear, creep, and distortion. In high-pressure blast furnaces, three-bell hoppers are used, and a steam system maintains back-pressure between two closed bells during each transfer. Leakage from instrumentation, such as from ports for rods used to determine the height of the burden in the furnace, is considered to be minor.

The particulate emissions attributable to blast-furnace charging operations consist of ore dust (Fe_2O_3 and Fe_3O_4), coke dust (chiefly carbon), and limestone dust ($CaCO_3$ and $MgCO_3$). Shrouding at transfer points aids in keeping air pollution to a moderate level.

Smelting

The cleaned blast-furnace gas is used for firing the regenerative stoves that preheat the air blast. If the gas is too lean, it is enriched with coke-oven gas or natural gas. Because the gas is burned with excess air, the chimney effluent is relatively free of objectionable particulate or gaseous components, except for the presence of sulfur oxides if sulfur-bearing coke-oven gas is used to raise the caloric value.

Auxiliary fuels added to the air blast normally do not alter the types of emissions. At start-up, however, injection of large amounts of auxiliary fuels may cause incomplete combustion and create soot. The soot usually will blow through the furnace and foul the dust-collecting system. Operating experience is expected to resolve such occurrences.

Slips are sudden movements of the burden in the furnace. Slips generate high pressures that are relieved by bleeders (safety valves) in the uptakes (gas-collection mains) at the top of the furnace. Relief of the pressure is accompanied by the emission of dust and gas into the atmosphere. Improved raw materials lower the dust loading in the furnace and minimize abnormal operating conditions that cause slips. Control of blast furnaces has advanced to the stage where bleeders on some furnaces rarely open, or open infrequently and only for short time intervals. Some blast furnace operators deliberately use slips (i.e., controlled slips) to facilitate operating practice. However, these controlled slips rarely cause the release of emissions to the atmosphere.

The blast-furnace gas consists chiefly of steam, nitrogen, carbon monoxide, and carbon dioxide. The carbon monoxide content is about 25 to 30 percent. The hydrogen content is higher with higher moisture content in the blast, and ranges from 1 to 4 percent. It is likely that at least some of the gas discharges continuously through leaks at the bells and in areas where the furnace shell is pierced for instruments and coolers.

Dust entrained in the blast-furnace gas results from abrasion of the burden during charging and during the early stages of its passage down the blast furnace. Improvement in the burden by increasing the amounts of sinter and pellets decreases the amount of dust generated. For example, the addition of 3000 pounds of sinter plus pellets per net ton of hot metal can decrease the dust from 300 to 30 pounds per net ton of hot metal.

The amount of dust in the blast-furnace gas generally varies from 30 to 90 pounds per net ton of hot metal. The dust typically contains 15 percent metallic iron, 40 percent red iron oxide (hematite) that is usually finer than 2 microns, 40 percent magnetic iron oxide (magnetite) that is partially or completely covered by red iron oxide, and 5 percent limestone that is also usually covered with red iron oxide.

The gas is cleaned to a dust concentration of less than 0.01 grain/scf to assure that clogging and slagging reactions do not occur when the gas is used as a fuel to fire the regenerative blast stoves. About 30 percent of the gas is used to heat the stoves; the rest is used as fuel for other in-plant heating purposes.

Systems for emission control depend upon the operating practice and the available space around the blast furnace. Commonly a system will include a dust catcher and a primary washer. Additional equipment is used as dictated by the in-plant use of the gas. A system consisting of a dust catcher, two automatically adjustable venturi scrubbers, and a gas-cooling tower has been claimed to clean the gas to a dust concentration of 0.005 grain/scf. It is concluded that control of emissions during smelting in the blast furnace is quite good.

Casting and Flushing

The molten iron in the blast furnace is saturated with carbon. As soon as the hot metal emerges from the furnace, graphite flakes (called kish) are rejected and rise to the surface where currents of heated air sweep the kish into the atmosphere. Manganese vapor is also given off and oxidizes to form a fine dust, but the amount is quite small. The kish is a nuisance because it is readily carried long distances by a light breeze, and its oily tenacity makes it difficult to remove after it has settled. The emissions of kish consist of about 90 percent graphite, 5 percent Fe_3O_4, 5 percent Fe_2O_3, and traces of quartz and calcite.

Kish control consists of running the iron short distances to minimize the amount that can form before the iron flows into closed, preheated "submarine" ladles. Kish rising to the opening of the submarine ladle can be raked out and disposed of before it becomes airborne. Older plants that use long runners to open-top ladles release considerable amounts of kish to the air. A need exists for control of kish emissions during casting. Transfer of hot metal to a mixer ladle or from the submarine ladle to pouring ladles that are used to charge steelmaking furnaces releases a moderate amount of kish. Some steel plants are starting to give attention to control of kish emissions at this latter transfer point.

The slag volume from the blast furnace, somewhat less than the volume of hot metal, is flushed out of the furnace usually twice for each cast of hot metal unless fast operations require frequent casts. The sulfur load on the slag is 6.5 to 9.5 pounds per ton of hot metal. The content of sulfur in the slag ranges from 1.0 to 1.8 percent.

During flushing, the sulfur in the slag reacts with oxygen in the air to form sulfur dioxide near the slag runners. In damp weather, hydrogen sulfide may also be formed. Long runners at older furnaces give greater surface exposure and increased fouling of the air. Most slags are transported in open ladles to dump areas where hydrogen sulfide is evolved as the slag cools and weathers. In newer practices, the slag runs a short distance and is granulated with high-pressure water. However, the formation of hydrogen sulfide may continue in the granulation pit at low temperature.

Data on the amounts of hydrogen sulfide formed upon granulation of the slag or at the slag dump are not available, but even low concentrations have an unpleasant odor. This emission is considered to be a serious problem and research to control it is being conducted under the sponsorship of the American Iron and Steel Institute.

Pigging of Iron

Only a small portion of the molten iron from the blast furnace is solidified into "pigs" for distribution in the solid state. The kish problem discussed earlier occurs during pigging. Hooding has resulted in modest effectiveness in the control of kish emissions during transfer from the open ladles to the pigging machines. The problem in this area probably will be solved when an effective control is developed to control kish emissions in the transfer of hot metal to steelmaking furnaces.

Other Ironmaking Processes

Two plants are under construction in the United States for production of iron by different direct-reduction processes that bypass the blast furnace. It is estimated that their combined output will be about 0.3 percent of the total metallic iron produced in the United States. In the Dwight-Lloyd McWane (D-LM) process pellets of powdered ore and powdered coal are partially reduced in a sintering machine. Final reduction and melting are then completed in an electric smelting furnace to produce pig iron.

The raw materials are ground wet. Particulates in the products of combustion during reduction are small. Data on the amount and characteristics of particulate and gaseous emissions are not available. The overall process probably contributes little to air pollution.

The other method is known as the Midland-Ross "Midrex" process. It uses reformed natural gas as the main source of heat and reductant in shaft furnaces to produce metallized pellets that are processed in a manner similar to scrap in steelmaking furnaces.

Because direct reduction of iron ore on a high-tonnage basis is still to be made operational in the United States, the problems of emissions from such plants are still to be determined. The future likely will see a modest growth of such plants in the United States, but for the next decade their number and output likely will be so small as to involve attention only on the local level. Because such plants are being born in a time that involves much attention to control of the quality of air and water, one hopes that the innovators at these new plants will incorporate the latest in control systems. Battelle's expectations are that plants of this type will be considerably cleaner than conventional plants based on blast furnaces.

Steelmaking

Open Hearth

With the increase in new BOF (basic oxygen furnace) steelmaking capacity, the percentage of American steel made in open-hearth furnaces has decreased, and was at 55 percent in 1967. Some forecasters have predicted the virtual extinction of the open hearth furnace by 1990. This is fortunate from the standpoint of air quality, because the physical nature of the open-hearth shop and the large volumes of gas involved in the process render control of air quality difficult and expensive. Although the advent of the BOF process has exerted strong pressure favoring retirement of even existing open hearth furnaces, the cost of controlling emissions adequately probably has applied the coup de grace as far as open hearth furnaces are concerned.

Open-hearth furnaces differ greatly in capacity, with the median being between 100 and 200 tons. Time to produce a heat ranges from 8 to 12 hours, which can be shortened by lancing the bath with oxygen.

Special charging machines dump the solid raw materials through side-placed doors onto the hearth of the furnace. The original charge usually includes solid pig iron, iron ore, limestone, scrap iron, and scrap steel. The flame from combustion of oil, tar, coke-oven gas, natural gas, or producer gas travels the length of the furnace and heats and melts the charge. The hot gases are led through regenerative chambers called checkers. Upon reversal of the flow of the flame (once every 15 to 20 minutes), the heated set of checkers preheats the combustion air. When the solid material has melted, either (1) two batches of additional solid pig iron and/or steel scrap are added in a cold-metal furnace, or (2) molten hot metal from a blast furnace is added in a hot-metal furnace. The hot metal is poured from a large ladle into a spout set temporarily in the furnace door. After these additions, release of carbon monoxide by oxidation of carbon in the molten bath creates a gentle boiling action called the ore boil. This is followed by a more violent turbulence, when carbon dioxide is released by calcination of the limestone, called the lime boil. After the heat is refined to the desired composition with the slag conditioned for partitioning of impurities into it, the molten steel is ready for deoxidation and tapping. The tap hole is at the base of the back wall and is located above a pit that contains a ladle. Ingot molds are filled from this ladle.

To shorten the time of a heat, oxygen is injected into the bath by water-cooled lances extending through the roof of the furnace. High-carbon heats are usually not lanced. When lancing is used, it may occur during the refining period, or it may start at the time of hot-metal addition. In the latter case, oxygen consumption may range from 600 to 1000 cubic feet per ton (900 to 1667 scfm during injection), and production rates of over 90 tons per hour are possible in a 300-ton furnace.

Minor emissions of particulates occur during the charging of the furnace and during tapping of the heat. The dust consists of two kinds of particles. One is magnetic iron oxide having jagged edges and generally, coated with red iron oxide. The other is red iron oxide and is rounded and usually smaller than 2 microns. They occur as free particles or as simple agglomerates.

Three components make up most of the dust during the period of hot-metal addition to lime-up: (1) loose agglomerates of transparent grains of hydrated iron oxide, usually smaller than 1 micron, (2) rounded, transparent grains of red iron oxide, usually less than 1 micron, and (3) rounded, opaque spheres of magnetic iron oxide which may be coated with hydrated iron oxide or red iron oxide. Lime dust and sulfur in the form of sulfates are also present in small quantities.

Dust from the period of tap to charge (during which repairs are made to the hearth) is similar to the dust during charging of the furnace.

Particulates in the combustion product usually consist of about 85 percent rounded, transparent red iron oxide smaller than 1 micron, and 15 percent opaque spheres of magnetic iron oxide ranging in size from 3 to 5 microns. The smaller grains appear to be orange in top light and tend to form loose agglomerates.

Composition of the products of combustion was not available for open hearths in the United States. It is known that the gas usually contains sulfur compounds from the use of fuels such as oil, tar, and coke-oven gas. Firing with oil is reported to create a lower average dust loading than firing with tar.

The amount of dust generated varies at different stages of the steelmaking process and with the particular practice. One source gives a dust loading of 0.78 grain/scf at 60,000 scfm gas flow at meltdown, 1.9 grain/scf at 64,000 scfm gas flow at hot-metal addition, 2.70 grain/scf at 66,000 scfm gas flow at the lime boil, up to 5 grain/scf during lancing, and 0.21 grain/scf at 64,000 scfm gas flow during refining. Typical dust loadings for oxygen-lanced furnaces are estimated to be 20 to 22 pounds per net ton of raw steel. Without oxygen lancing, a value of about 8 pounds of dust per net ton of steel was reported.

The only data available on the size distribution of particulate emissions compares a composite sample with a sample taken during the lime boil. About 46 percent of the particles in the composite sample were smaller than 5 microns, while 77 percent from the lime boil were below this size.

The slag pockets, checker chambers, and flues to waste-heat boilers provide opportunities for settling out of dust from the waste gases, and, thus, served as fairly efficient dust collectors before the advent of oxygen lancing. The use of oxygen lancing increases the dust loading and generates large volumes of fume. Effective control of the emissions is obtained with electrostatic precipitators. Venturi scrubbers and bag houses are also being used.

Control technology is adequate for handling the particulate emissions which otherwise constitute a serious air-pollution problem.

In the teeming area, ingot molds on a string of cars are filled from the ladle containing the entire batch of steel from the furnace. In 1967, about 94 percent of the raw steel produced in the United States was poured into ingot molds. The use of tar and bitumens as mold coatings has been curtailed in the past decade to give a decrease in the amount of visible emission during teeming. However, with some present teeming practices, visibility can become highly restricted at the teeming station. No information is available on the characteristics of the emissions at the teeming station or on methods of controlling the emissions. Generally, the degree of pollution contributed by emissions during teeming may be classified as moderate, but deserving of more attention than it receives.

Basic Oxygen Furnace

About half of the steel in the United States will be made by the basic oxygen furnace (BOF) process by the end of 1969. The furnace is a pear-shaped steel shell lined with refractory brick, charged through the top and tilted for tapping. The charge usually consists of hot metal and scrap in the ratio of about 70 to 30, plus burnt lime. A water-cooled lance impinges oxygen at high velocity on the surface of the charge to cause violent agitation and intimate mixing of the oxygen with the molten iron. Rapid oxidation of carbon, silicon, manganese, and some of the iron occurs. These exothermic reactions supply heat to reach the tapping temperature. Impurities in the charge enter the slag. A typical 150-ton furnace can produce a batch of steel in about 35 minutes.

Kish is released when the hot metal is charged and cooled by contact with the cold-scrap charge. Only part of the kish is contained in the furnace. Dark brown smoke evolves at the start of the blow from oxidation of the iron. It persists until the silicon, manganese, and phosphorus begin to oxidize; these oxides enter the slag. Some silica, lime fume, and small amounts of manganese enter the off gas. Then carbon is oxidized and evolved, chiefly as carbon monoxide. An excess of air is usually mixed with the off gases to burn the carbon monoxide as the off gases are collected. This eliminates the possibility of an explosion from ignition within the exhaust system. Many furnaces are equipped with waste-heat boilers for thermal recovery from burning of the carbon monoxide. Some newer practices, not yet in use in the United States, deliberately minimize the amount of air aspirated into the off gases to reduce the problems from overheating of the hood and duct work.and to reduce the volume of gas that must be cleaned. The cleaned gas is then flared safely into the atmosphere, or is collected and stored for subsequent use as fuel.

The kish formed during the charging of hot metal consists of angular flakes of graphite having smooth surfaces. The emission of kish may include coarse fragments of opaque magnetic iron oxide particles, rounded particles of red iron oxide, and traces of quartz and calcite.

The silica fume that occurs in the early part of the blow is collected as a gray to off-white material. It often contains small amounts of iron, manganese, and carbon.

During the BOF blow with oxygen the predominant particulate emission is brown iron oxide. The particulates are rounded, transparent, smaller than 1 micron, and tend to agglomerate. Some fine, black spheres of magnetite are present and are covered with red iron oxide. If galvanized scrap is part of the charge, zinc oxide in the collected dust makes the dust unsuitable for sintering for feed to the blast furnace.

The fineness of the BOF particulates makes them difficult to measure. As a result, size analyses have varied widely. Reports show (1) 95 percent are smaller than 1 micron, with a median of 0.45 micron, and (2) 99 percent smaller than 0.2 micron, with a median of 0.065 micron. A more recent report gives a median diameter of 0.012 micron. Another report states that 20 percent is smaller than 0.5 micron, 65 percent is between 0.5 and 1.0 micron, and 15 percent is between 1.0 and 1.5 microns.

Dust concentration (as reported by one source) varied from 2.02 to 4.96 grains/scf. Another source states it is up to 20 grains/scf. The volume of exhaust gas (at temperature of combustion) is about 25 times greater than the volume of oxygen blown. The amount of dust per net ton of raw steel was reported in 1959 to range from 14.5 to 27.4 pounds. In 1968, an average of 40 pounds per ton was reported by one plant. Others state it is 1 to 2 percent of the weight of the metallic charge.

In the Stora-Kaldo Oxygen Process, a cylindrical vessel is rotated in almost a horizontal position. Operating principles are similar to those for the upright BOF vessels. More scrap can be charged than in the BOF, but the heat time is longer. The Sharon Steel Corporation has the only two Kaldo furnaces in the United States, rated at 150 tons per heat. The size of particulate emissions is reported to be larger than particulate emissions from the BOF; only 6 percent is smaller than 1 micron, probably as a result of agglomeration. About 10 pounds of dust are said to be generated per net ton of raw steel.

Teeming of BOF steel is conducted in the same manner as was described for open-hearth steel.

Electric Furnace

In 1967, electric furnaces produced about 11 percent of the total raw carbon steel made in the United States and 36 percent of the alloy and stainless steels. About 59 percent of the electric-furnace heats were carbon steels. These furnaces are refractory-lined cylindrical basins having a capacity of up to 250 tons. In 1968, 40 percent were under 50 tons, 36 percent were between 50 and 90 tons, and 24 percent were over 90 tons in capacity.

High-current electrical energy is passed through large graphite electrodes extending down through the roof of the furnace. The charge consists of select steel scrap, cast-iron scrap, pig iron, alloying elements to achieve the desired composition, and flux. Melting is accomplished by the heat of the arc between the electrodes and the charge.

Preheating of the steel scrap is not a common practice for shortening the heat time. If preheating is practiced, it is done most commonly with air-fuel burners. Oxygen-fuel burners are used to a limited extent. The scrap is rarely heated to above 1800 F. Thus, preheating creates no significant emission problems, unless combustible materials such as oil or rubber are in the scrap.

Electric induction furnaces melt special alloys on a small scale. If the charge is free of tramp combustibles, emission from these furnaces is minor and is readily collected in simple equipment.

Emissions in the electric-arc furnace can originate from light scrap that oxidizes readily, from dirty scrap (a major source), and from oxygen lancing. The emissions are fume from scrap preheating, dust from the melting operations, and furnace off gas. Information is not available on the nature of the dust from preheating scrap. The composition of the dust will be influenced by the freedom of the scrap from volatile or combustible matter. The dust from operation of the furnace consists of opaque, rounded grains that are peach to reddish in top light. Its composition is dependent upon the composition of the steel being melted and stages of making a heat.

The amount of dust per net ton of steel is dependent upon the condition of the scrap and whether or not oxygen lancing is used. Particularly dirty scrap can raise the dust emissions to as high as 30 pounds per net ton of steel. It has been estimated that oxygen lancing produces 20 percent of the total emissions in making a heat.

The composition of the off gas from the electric furnace varies with the slag practice, the stage of the heat, and whether or not oxygen lancing is used. The chief constituents are carbon monoxide, carbon dioxide, nitrogen, and oxygen. Changes in the composition of the off gas during the course of a heat can vary considerably. Typically the carbon monoxide content rises sharply during the boil and again during oxygen lancing, while the carbon dioxide content usually stays below 15 percent at all times.

Emissions leave the furnace through the electrode ports in the furnace roof, out of the tapping spout and slagging door, and (in the case of top-charged furnaces) through the open furnace top during charging. Three main types of systems are used to collect the emissions: (1) hoods over and around the furnace at points of emission, (2) direct extraction from the interior of the furnace, and (3) shop-roof systems.

In the first system, hoods are fitted at the points of emission, and ducts pass the emissions to the dust collector. Hoods must be movable when used with top-charging furnaces. They also add to operational hazards because they tend to obscure the visibility from the crane-operator's cab. Warpage of the hoods is a problem. They seldom last 1 year.

Direct extraction by means of a duct entering the furnace roof causes air to flow into the furnace, and thus minimizes the discharge of emissions through the doors and electrode ports. This system increases roof life by 16 percent and decreases electrode consumption by 8 percent. It causes lower recovery of some alloying elements in the steel bath, and creates some difficulties with carbide slags that are used in refining of special steels. Heat exchangers must be used, or a minimum duct length (600 feet is required in some cases), to cool the gases by radiation to a safe temperature before they enter a bag house.

In the shop-roof extraction system, the shop building serves as the collector hood. Ducts in the roof of the building exhaust the emissions to the dust-collecting system.

Teeming practice is the same as for open-hearth and BOF steels. Some electric-furnace shops use roof-extraction exhaust systems in the teeming building to collect the fumes and exhaust them to the main bag house.

Heats of leaded and resulfurized grades of steel can be made in the open hearth, BOF, or electric furnace. For leaded steels, a hood exhaust system to a bag house collects the toxic fume during teeming. Shrouding of the stream with argon (as is practiced to prevent reoxidation during continuous casting of vacuum-degassed heats) is probably impractical for emission control when teeming into a series of ingot molds.

High-energy scrubbers installed on one oxygen-lanced electric furnace producing a dust concentration of 3.2 to 6.4 grains/scf have reduced the dust output to the range of 0.026 to 0.0512 grains/scf. Bag houses have reduced it to the range of 0.004 to 0.0064 grains/scf. Electrostatic precipitators, not performing as well, reduced the dust loadings to a range of only 0.256 to 0.512 grains/scf.

Electric furnaces do not evolve the high gas volumes generated by either open hearth or BOF furnaces. This is not to imply that the control of emissions from electric furnaces is easier. The majority of electric furnaces are top-charging furnaces, which means that during the charging operation the furnace is open to the atmosphere and considerable amounts of emissions can be released. Other design characteristics of electric furnaces contribute to the problem of effectively controlling electric-furnace emissions. These problems have resulted, in some cases, of using complete building evacuation as a means of pollution control. In spite of the fact that many new electric furnaces are now being installed and have been installed recently, most of these with emission-control systems, accurate information on the amount, size, and composition of particulate and gaseous effluents were remarkably sparse and difficult to obtain during the present study. This dearth of reliable and complete information should be remedied because the next decade will see continued growth of the electric-steelmaking process.

Vacuum Degassing of Molten Steel

For certain critical applications, the steel must be cleaner with respect to inclusions and lower in hydrogen content than is commonly achieved by conventional steelmaking practices. These objectives are attained by vacuum treatment of the molten steel. Three methods are used: (1) stream degassing, (2) circulation degassing, and (3) ladle degassing.

In stream degassing, a bottom-pour ladle is sealed to a vacuum chamber containing an ingot mold. The stream of steel from the ladle is degassed as it falls into the mold. If the stream is collected in a second ladle in the vacuum chamber, the process is called ladle-stream degassing. The second ladle is removed from the chamber for pouring the steel into ingot molds or into a continuous-casting machine.

To achieve the highest degree of degassing, either the circulation-degassing or ladle-degassing method is used. In circulation degassing, part of the molten steel in the open ladle is lifted via a snorkel into a vacuum chamber. Only one snorkel is used in the D-H process in which the steel is sucked up and returned repeatedly until the hydrogen and oxygen contents in the steel drop to the desired levels. In the Thermo-Flow process and the R-H process, two snorkels are used. Both processes inject an inert gas in one snorkel to cause the steel to flow up that snorkel, into the vacuum chamber, and down the other snorkel back to the ladle. In the Thermo-Flow process, circulation in the snorkels is enhanced by the directional stirring force from electrical induction coils surrounding the snorkels.

In ladle degassing, the filled ladle is set in a vacuum tank. Degassing time is decreased by agitating the molten metal by bubbling argon through it or by stirring it by means of an induction coil.

The source of emissions is the molten steel in the vacuum chamber. The three principal gases emitted are carbon dioxide and carbon monoxide from the reaction of carbon and oxygen in the steel and the hydrogen from solution in the steel. Violent agitation of the molten steel and vaporization of the metallics (because of the low pressure) both generate dust, much of which deposits on the walls in the vacuum chamber.

The composition of the off gases varies with the grade of steel and the extent of the vacuum treatment. In the circulation-degassing D-H process, the average composition is up to 80 percent carbon monoxide, up to 20 percent carbon dioxide, and up to 15 percent hydrogen. The composition of the off gases from vacuum-stream degassing can vary from 18 to 50 percent carbon monoxide, 20 to 70 percent hydrogen, 15 to 75 percent nitrogen, and 1 to 6 percent carbon dioxide. Nitrogen and argon are present in the off gases from air in the system or from aspirated air. Water is always present from the steam ejector.

The dust that is deposited on the walls of the vacuum chamber is finely divided – often so fine that it is pyrophoric and ignites when air is admitted into the chamber. The composition of the dust varies according to the composition of the steel being treated. Data on the amount and size of the dust carried from the vacuum system is sparse and difficult to obtain.

The steam ejectors that are used to create the vacuum also serve as scrubbers. Thus, little dust is released to the atmosphere. One source of information states that about 10 pounds of dust are collected in degassing 100-ton heats.

Depending on the amount of steel to be treated and on the level of vacuum required, a degassing installation may have from 4 to 6 steam ejectors with intercondensers. Usually the cleaned gases are emitted to the atmosphere. If the gases are passed through a water hot well (to avoid a hazard to personnel), the gases are ignited and flared to the atmosphere. The amount of gases depends on the carbon content of the steel and the amount of hydrogen that is to be removed.

Control of particulate emissions is good and is accomplished economically by entrapment in the hot wells of the steam ejector system. The cleaned off gas contains considerable amounts of carbon monoxide and hydrogen which sometimes is flared for dispersal in the atmosphere.

Although vacuum degassing of steel is increasing in commercial importance and use, its contribution both to particulate and gaseous emissions from a steel plant is minuscule, and is expected to remain so.

Continuous Casting

In continuous casting, molten steel, poured into a water-cooled copper mold, quickly cools to the shape of the mold and is withdrawn continuously. The estimated capacity in the United States in 1968 is about 7 million net tons per year, and is expected to be doubled in 1969. The ultimate capacity is expected not to exceed 50 percent of the total steel production.

Emissions during continuous casting are markedly lower than for teeming into ingot molds, because the rape seed mold coating creates only a small amount of fume. Continuous casting is conducted in one location rather than over a large area such as used for conventional teeming. This confinement permits the use of a more localized fume-collecting system to enhance the efficiency of collection. The tundish is sometimes blanketed with a reducing gas to minimize oxidation of the steel. To prevent reoxidation of vacuum-degassed heats, the stream of steel from the tundish to the mold sometimes is shrouded with argon. This also serves to inhibit escape of emissions from this area. Steam generated by the secondary cooling sprays is collected in an exhaust system.

Continuous casting contributes very little to air pollution. As in the case of increasing replacement of open-hearth furnaces by BOF and electric furnaces, it is fortunate that the newer and growing technology (continuous casting) presents much less of an air-pollution problem than the process that is tending to be replaced (conventional teeming of ingot molds).

Pressure Casting

In pressure casting, the ladle of molten steel is placed in a pressure tank. When air pressure is increased in the tank, the molten metal flows up through a ceramic tube leading from the bottom of the ladle, through the top of the tank, and into a graphite mold where solidification takes place. Total U. S. production is estimated to be only about 1/2 million net tons in 1967, with an increase to about 1 million in 1969. Although this process has been used mainly for casting stainless steel slabs and some billets and tubes, in 1969 a plant will be placed in operation to cast carbon steels.

Emissions contributing to air pollution are considered to be negligible in the pressure-casting process. Minor amounts of iron oxide fumes are generated by the exothermic mixture in the hot top and from cutting off the riser and gate from the casting with a torch.

Pressure casting represents such a small percentage of steel cast that this method deserves consideration from an air-quality standpoint only on a local basis where the process is employed.

Steel Shaping

Soaking Pits and Primary Breakdown

Soaking pits are furnaces in which ingots are brought to the desired equalized temperature for rolling. They are fired with blast-furnace gas, coke-oven gas, or a mixture. Data are not available on the emissions that occur during charging and removing of ingots, or during firing, but the amounts of particulate emissions are considered to be negligible. Gaseous emissions are mixtures of carbon dioxide and carbon monoxide. Sulfur dioxide is also present if the coke-oven gas has not been freed of hydrogen sulfide. No economical commercial method is available for removal of the sulfur dioxide in the exhaust gases.

During breakdown of the ingots by rolling into billets, blooms, or slabs, the major emission is steam which is confined in the building. Emission of dust is minor.

Conditioning, Reheating, and Hot Rolling

After ingots are rolled to billets, blooms, or slabs, they are cooled and inspected, and surface defects are removed by grinding, chipping, peeling, or scarfing with hand torches. Then the steel is reheated in a once-through furnace fired with coke-oven gas, blast-furnace gas, or natural gas. Some plants reheat slabs and billets with electrical induction coils. Reheated slabs are usually scarfed with automatic machines before they enter the hot-strip mill.

The fine particulates generated during grinding are airborne only a short distance, and probably only rarely escape the building. Sometimes they are collected at the grinding station. Chipping and peeling create insignificant emissions. Billet scarfing causes a metal loss ranging from 3 to 6 percent; but most of the loss is spatter, not fume. Usually no emission control is used in hand scarfing, except that hoods are used sometimes if the shop practice calls for extensive hand scarfing. The loss in scarfing of slabs is up to 2.5 percent, and up to 7 percent for blooms. One reference gives a concentration of 0.2 to 4.4 grains/scf for scarfing slabs. Another places it at 2 to 3 grains/scf when the gas flow rate is 75,000 to 135,000 cfm during the short period of operation of a scarfing machine. The emissions are chiefly iron oxides and are collected with electrostatic precipitators or high-energy scrubbers. Machine scarfing would result in serious air pollution if collection-control systems were not used.

Emissions during reheating of steel billets and slabs are mixtures of carbon monoxide, carbon dioxide, nitrogen, and moisture from the combustion of natural gas. Emissions at the rolling mills themselves consist mostly of steam which is confined to the area of the mills. The emission of submicron iron oxide at strip-finishing stands is considered to be significant enough that some mills collect these emissions with high-energy scrubbers.

Except for scarfing operations, no serious emission problem exists in the operations that involve conditioning, reheating, and hot rolling. This conclusion applies also to hot-forging and hot-forming operations. Control systems are available to contain the emissions from scarfing operations.

Acid Pickling

Acid treatment (called pickling) is used to clean the oxidized surface of hot-rolled steel in preparation for cold rolling. Although some pickling lines are being converted from sulfuric to hydrochloric acid, the overall economics and advantages of the use of one over the other have not yet been resolved. Acid fumes are the chief emissions during pickling. Hoods exhaust these fumes usually to a wet scrubber and packed tower. One source states the collection rate is about 100 grains of hydrochloric acid per ton of steel. For pickling low tonnages of steel, the cleaning system may be considered to be too costly and the fumes may be ejected to the atmosphere through a roof exhaust.

Pickling can contribute moderately to air pollution if systems are not used to collect and capture the acid fumes.

Cold Rolling and Cold Forming

In high-speed cold rolling, a water-oil mist is generated from the emulsion lubricant applied to the rolls. Collection of this emission is by mechanical mist eliminators or wet scrubbers. Neither cold-rolling nor cold-forming operations contribute to air pollution.

Annealing

Annealing of steel sheet or strip is done in a batch or continuous manner. In the batch process, a removable shell covers the coiled steel. Combustion gases heat the shell, and a prepared gas or protective atmosphere inside the shell prevents oxidation of the coil. In the continuous process, the coil is annealed by passing it as a single strand through a furnace having a controlled atmosphere in the heating, holding, and cooling zones of the furnace. Products other than sheet and strip are usually heated directly by combustion gases.

Air pollution from annealing operations is insignificant, except when sulfur-bearing coke-oven gas is used as the fuel for firing the furnaces.

Steel Finishing

Continuous-strip lines lend themselves to ready control of emissions during coating operations. Coatings are zinc, tin, terne (lead alloy), aluminum, chromium, nickel, copper, phosphate, and a broad spectrum of paints and other organic materials. Prior to coating, the strip is heated to carbonize grease or oil films, and the lightly oxidized surface is cleaned in an acid tank or by the action of a reducing atmosphere in a furnace. A hot alkaline solution may be used instead of heat to remove the grease film before pickling.

In dip coating (zinc, aluminum, and terne coat), the preheated strip is treated with a flux or passed through a flux layer on top of the metal bath. In electrolytic processes (zinc, chromium, nickel, and copper), the cleaned strip enters directly into the plating bath. Recent processes for coating with chromium and nickel involve coating with chemicals that are reduced in a hydrogen atmosphere to produce the coating metal. Phosphate coatings are produced by dipping steel in a dilute acid phosphate solution saturated with a metal such as zinc, cadmium, aluminum, or lead. The metal surface is converted to an insoluble crystalline phosphate coating. Paints are applied to cleaned strip by an electrophoretic process by passing cleaned, warm strip through a paint tank, or by roller coating. In the electrophoretic process, an electrical charge applied to a solution of paint in water causes the resins to move to the oppositely charged steel strip immersed in the solution. Upon contacting the steel strip, the paint particles squeeze out the water. After washing, the paint is baked on the surface. Painting operations emit solvent vapors which are collected by an exhaust system that disperses the vapors to the atmosphere outside the building. During baking, the evolved vapors are combusted in direct-fired ovens or are exhausted to the air in indirectly heated ovens.

In these finishing operations, emission of particulates is negligible. Heating of the steel results in stack gases having the normal compositions from combustion of natural gas. Acid mists from pickling and vapors from electroplating baths are readily collected by hoods and removed in wet scrubbers and packed towers. Some particulates and/or vapors are emitted from dip-coating baths, but data are meager. Information from two job-shop dip-galvanizing plants indicate that the size of the particulates is about 2 microns. No information was available on the emission-control systems.

In general, the amounts of particulate emissions from steel-finishing operations are relatively minor and appear to be susceptible to good control. Gaseous emissions appear to be a problem only (1) when fuels contain sulfur, and (2) when the process emits vapors from organic materials used in coatings. The former always is a problem; the latter is amenable to good control by application of existing washing equipment.

FUEL AND ENERGY UTILIZATION

During the past 10 years, the patterns of use of fuel and energy in iron and steel plants have been changing significantly. The most important changes include (1) the advent of oxygen steelmaking, (2) major improvements in blast-furnace technology, (3) increase in average iron content of materials in the blast-furnace charge, and (4) a 16 percent decline overall in the amount of fuel energy used per ton of iron and steel produced.

From the standpoint of the steelmaker, the sulfur content of his fuels would be an item of high concern, even if air-polluting influences of high-sulfur fuels could be ignored. Fuels are the main source of inputs of sulfur into the steelmaking process, and sulfur is an undesirable element in most iron and steel. Because most steelmaking energy is derived ultimately from coal (in part by coking it and then burning the coke, and in part by burning coal to produce electricity), steelmakers must be vitally concerned with a variety of coal-based problems – (1) particulate matter from the combustion of coal or coke, (2) sulfur that enters the iron or steel because of the use of coal and coke in the process, and (3) gaseous emissions from combustion of the coal or coke.

This discussion was prepared to analyze some of the principal trends and countertrends of fuel and energy use in steel plants. It will be useful as background for evaluating the possible effects of changes in air-quality standards upon future patterns of use of steelmaking energy. There are three parts to the analysis:

> The first part presents a statistical summary of fuels used over the 10 years from 1958 to 1967 by type of fuel. The summary includes information on purchased electricity and steelmaking oxygen. Although electricity and oxygen are not fuels, they have had a strong influence on overall energy patterns in the steel industry, and their manufacture requires heavy use of fuels and/or energy. Electricity can be used directly for melting metal, and this use is growing. Oxygen used during steelmaking causes some components in the metal to serve as fuels, and thus indirectly supplants conventional fuels.
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> In the second part, the application of energy sources to key operations of ironmaking, steelmaking, and steel processing is examined. The known determinants of fuel choice are stated, with attention to fuel economics, process technology, and other influences. From this part of the analysis, it is possible to draw some preliminary conclusions about future evolution in the absence of new constraints such as tighter emission standards.
>
> The third part draws upon the first two and illustrates how considerations of pollution control and process economics may be expected to interact. In those situations in which present trends are in the direction of cleaner fuels, the rate of change determines the effect on air quality. When the present trend of emissions is unfavorable, the magnitude of economic pressure behind the change is important. It may well be that anticipated changes in air-quality standards will tend to accelerate some of the present

trends and to reverse others. Attention is called, finally, to the long-term future situation regarding U. S. fuel supplies. It is possible that short-term decisions to use "clean" fuels, made now on the basis of pollution criteria, may not be sustainable in the long term if natural gas and oil become scarce.

10-Year Summary of Fuel Usage

The American Iron and Steel Institute publishes annual data on the use of fuels in iron and steel plants. These data are partly subdivided according to broad categories of use (e.g., steelmaking furnaces). Corresponding data for use of oxygen and electricity in steel plants are also given by the AISI. Typically, these statistics cover about 95 percent of the productive capacity of the U. S. steel industry.

Table V-1 summarizes the total use of steelmaking oxygen, purchased electricity, and each principal fuel for the 10 years from 1958 to 1967. Although the weight of coal used to make coke is reported by the AISI, coking coal has been deleted from this summary because the fuel use of coking coal occurs in the forms of coke, coke-oven gas, and tar or pitch. Table V-1 shows consumption of blast-furnace gas for 1966 and 1967, but data are missing for prior years. All blast-furnace gas is ultimately derived as a recuperation from use of other fuels in the blast furnace.

The few trends illustrated in Table V-1 are uncomplicated. There are no definite trends in total consumption industry-wide of coal, tar and pitch, or coke-oven gas, but there may be a downward trend (since 1965) in total use of fuel oil. The overall consumptions of coke, natural gas, and LP gas* have clearly risen with increased steel and iron production. Total consumption of steelmaking oxygen and purchased electricity (listed for purposes of comparison) have shown strong and sustained increases over the past decade.

The information of Table V-1 is presented in a different context in Table V-2, in which the data are adjusted to consumption per ton of crude steel plus merchant pig iron. In Table V-2, clear downtrends appear in the use of coal, coke, oil, and tar per ton of steel. No clear trends may be cited for consumptions of LP gas, natural gas, and coke-oven gas; but (just as for total consumption in Table V-1) both oxygen and purchased electricity show strong growth per ton of steel. The trends toward use of more electricity and more oxygen per ton of steel and of much less liquid and solid fuel are principal findings of this part of the study. However, it is to be noted that not all of the changes are continuing: unit consumption of coal and tar per ton of steel seems to have stabilized as of 1964, and coke consumption per ton of steel has been steady since 1963.

Table V-3 presents a suggested basis for direct energy comparisons among fuels. The stated energy contents (expressed in British thermal units) are typical for the fuels studied, but a given lot of any fuel could differ substantially from the quoted energy rating. The terms "high" or "gross" applied to energy ratings of fuels merely signify that the value includes heat from condensation of the water vapor produced during combustion. The assignment of a specific energy value to steelmaking oxygen is

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*Liquefied petroleum gas or bottled gas, usually propane.

TABLE V-1. TOTAL FUELS, STEELMAKING OXYGEN, AND PURCHASED ELECTRICITY CONSUMED BY STEEL PLANTS IN THE UNITED STATES, 1958-1967

Source: American Iron and Steel Institute, <u>Annual Statistical Report</u>, 1962 and 1967 editions.

Item	Units	Total Consumption by the Steel Industry									
		1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Fuels											
Coal[(a)]	10^3 NT	7, 158	6, 819	7, 337	7, 235	6, 994	6, 882	7, 045	7, 372	7, 392	6, 878
Coke	10^3 NT	47, 818	49, 487	52, 464	47, 241	46, 725	49, 222	57, 558	59, 519	59, 926	56, 435
Fuel oil	10^6 gal	1, 607	1, 735	1, 699	1, 543	1, 418	1, 575	1, 678	1, 611	1, 451	1, 254
Tar and pitch	10^6 gal	309	322	365	274	284	292	295	334	315	303
LP gas	10^6 gal	8.4	8.6	8.8	7.5	7.8	10.9	10.5	18.0	13.9	14.0
Natural gas	10^9 ft^3	279	317	361	399	434	464	513	547	517	534
Coke-oven gas	10^9 ft^3	675	750	900	708	690	610	716	788	915	886
Blast-furnace gas[(b)]	10^9 ft^3	- Unreported -								4, 076	4, 131
Oxygen	10^6 ft^3	13, 049	18, 307	29, 213	44, 170	54, 675	69, 761	90, 626	104, 396	128, 681	140, 466
Electricity	10^6 kwhr	15, 934	17, 050	18, 810	19, 429	21, 229	23, 652	26, 049	28, 006	29, 891	30, 557

(a) To avoid duplication, coal used in the manufacture of coke is excluded.

(b) Ultimately derived from coke and tuyere injectants, hence duplicative in the sense of energy sources.

TABLE V-2. FUELS, STEELMAKING OXYGEN, AND PURCHASED ELECTRICITY CONSUMED PER TON OF STEEL PRODUCED IN THE UNITED STATES, 1958-1967

Source: American Iron and Steel Institute, Annual Statistical Report, 1962 and 1967 editions. Data of Table V-1 were divided by the sum of crude steel production plus pig-iron shipments to outsiders. It is assumed that electric-furnace ferroalloys are reflected in steel production.

Item	Unit	Approximate Consumption per Net Ton of Steel									
		1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Fuels											
Coal[a]	Lb	160	138	142	142	138	122	108	109	107	105
Coke	Lb	1,071	1,013	1,016	927	920	876	880	879	869	866
Fuel oil	Gal	17.99	17.55	16.45	15.14	13.97	14.01	12.83	11.90	10.53	9.62
Tar and pitch	Gal	3.46	3.26	3.53	2.69	2.80	2.60	2.26	2.47	2.29	2.32
LP gas	Gal	0.09	0.09	0.08	0.07	0.08	0.10	0.08	0.13	0.10	0.11
Natural gas	Ft^3	3,123	3,207	3,495	3,916	4,274	4,127	3,923	4,041	3,751	4,096
Coke-oven gas	Ft^3	7,556	7,588	8,713	6,948	6,796	5,425	5,476	5,822	6,638	6,796
Blast-furnace gas[b]	Ft^3	- - - - - - Unreported - - - - - -								29,600	31,700
Oxygen	Ft^3	146	185	283	433	538	620	693	771	934	1,077
Electricity	kwhr	178	172	182	191	209	210	199	207	217	234

(a) To avoid duplication, coal used in the manufacture of coke is excluded.

(b) Ultimately derived from coke and tuyere injectants, hence duplicative in the sense of energy sources.

TABLE V-3. CONVERSION FACTORS FOR FUELS, STEELMAKING OXYGEN, AND ELECTRICITY AS APPLIED IN STEELMAKING

Item	Common Physical Unit	Energy Factor, approximate gross or high Btu released per unit used
Fuels		
Coal	Lb (bituminous, 7 percent ash)	14,030
Coke	Lb (by-product, 7 percent ash)	13,220
Fuel oil	Gal (residual)	148,600
Tar and pitch	Gal (crude)	145,200
LP gas	Gal (commercial propane)	91,500
Natural gas	Ft^3 (standardized)	1,000
Coke-oven gas	Ft^3 (standardized)	500
Blast-furnace gas	Ft^3 (standardized)	95(a)
Oxygen	Ft^3 (based on refining of hot metal to steel)	435(b)
Electricity	kwhr	3,413

(a) Memorandum only - duplicates heat assigned to coke, fuel oil, and gas charged to blast furnace.

(b) Conjectural; for use of 153.5 pounds of oxygen at 0.084 pound per cubic foot to refine 18 lb silicon, 84 lb carbon, and 14 lb manganese from hot metal, incidentally consuming 60 lb iron. Thermodynamic data taken from Tables 8D-1 and 8D-2 of *Elliott, Gleiser, and Ramakrishna*, *Thermochemistry for Steelmaking*, Vol. II, *Reading, Mass.*, 1963, Addison-Wesley. (This information is invalid for oxygen used in the electric furnace or for enriching combustion in endwall burners of open-hearth furnaces.)

conjectural, approximate, and invalid for some instances, but this does not bias the energy analysis significantly, because the greatest part of steelmaking oxygen reacts as illustrated in the explanatory footnote.

Table V-4 summarizes the 10 years of fuel, oxygen, and electricity data in energy equivalents per ton of iron and steel produced. This final adjustment of the industry-wide consumptions of Table V-1 shows the relative amount of energy supplied per ton of iron and steel produced and allows direct comparisons among the fuels. It is noteworthy that roughly half of all steelworks' energy is supplied as coke and that coke-oven gas and natural gas dominate the remainder. Electricity and oxygen, despite their crucial importance to modern steelmaking, are seen to be of minor significance as contributors to total energy – oxygen mainly has contributed savings in time, not in energy, to the business of converting iron to steel.

Figures V-1 and V-2 portray the 10-year energy patterns graphically. In Figure V-1, the decline in use of solid and liquid fuels per ton of steel is shown clearly, as is the irregular pattern in use of gases. Despite the steady growth pattern for the nonfuels (oxygen and electricity), energetically these sources have not even offset the decline in use of oil, tar, and pitch as fuels. Also, in Figure V-1, the sharp breaks in use of solid fuels from 1958 to 1959 and from 1960 to 1961 are shown to be irregularities in an otherwise regular downtrending pattern.

Figure V-2 divides the graphic portrayal of energy use to distinguish among nonfuels, fossil fuels used directly in their normal form, and coal-conversion fuels (coke, tar, pitch, and coke-oven gas) made from coal at the coke ovens. This shows that ordinary fossil fuels were replacing coal-conversion fuels from 1958 to 1962. Thereafter, both declined for 2 years. Since 1964, use of coal-conversion fuels per unit of iron and steel has been steady or increasing, and direct use of fossil fuels has continued to drop. The 1966-67 average consumption of coal, oil, LP gas, and natural gas was almost 6 percent below the 1964-65 average.

It is appropriate here to restate the principal trends, fuel by fuel, as a prelude to the next discussion, which analyzes fuel applications according to categories of use:

(1) The use of coal (as coal) has been steady in total amount used by the industry but has declined more than 34 percent per ton of iron and steel produced.

(2) The industry's consumption of coke has risen with steel production but has declined about 19 percent per ton of iron and steel produced.

(3) The total consumption of fuel oil was steady, except in the past 2 years when it appeared to decline. Per ton of steel produced, consumption of fuel oil has declined steadily to a level 44 percent below that of 1958.

(4) The use of tar and pitch has been stable in total amount but has dropped by 33 percent in terms of use per ton of iron and steel product.

TABLE V-4. DISTRIBUTION OF AMOUNTS OF ENERGY USED PER TON OF IRON AND STEEL PRODUCED IN UNITED STATES STEEL PLANTS, 1958-1967

Source: Derived from Tables V-1, V-2, and V-3.

Item	Energy Consumption, millions of Btu (high or gross), Per Ton of Iron and Steel									
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Fuels										
Coal(a)	2.245	1.936	1.992	1.992	1.936	1.712	1.515	1.529	1.501	1.473
Coke	14.158	13.392	13.432	12.255	12.162	11.581	11.634	11.620	11.488	11.449
Fuel oil	2.673	2.608	2.444	2.250	2.076	2.082	1.907	1.768	1.565	1.430
Tar and pitch	0.502	0.473	0.513	0.391	0.407	0.378	0.328	0.359	0.333	0.337
LP gas	0.008	0.008	0.007	0.006	0.007	0.009	0.007	0.012	0.009	0.010
Natural gas	3.123	3.207	3.495	3.916	4.274	4.127	3.923	4.041	3.751	4.096
Coke-oven gas	3.778	3.794	4.357	3.474	3.398	2.713	2.738	2.911	3.319	3.398
Summary, Fuels:										
Solid fuels	16.403	15.328	15.424	14.247	14.098	13.293	13.149	13.149	12.989	12.922
Liquids(b)	3.183	3.089	2.964	2.647	2.490	2.469	2.242	2.139	1.907	1.777
Gases	6.901	7.001	7.852	7.390	7.672	6.840	6.661	6.952	7.070	7.494
Total	26.487	25.418	26.240	24.284	24.260	22.602	22.052	22.240	21.966	22.193
Oxygen(c)	0.064	0.080	0.123	0.188	0.234	0.270	0.301	0.335	0.406	0.468
Electricity	0.608	0.587	0.621	0.652	0.713	0.717	0.679	0.706	0.741	0.799
Summary, Energy:										
Fuels	26.487	25.418	26.240	24.284	24.260	22.602	22.052	22.240	21.966	22.193
Nonfuels	0.672	0.667	0.744	0.840	0.947	0.987	0.980	1.041	1.147	1.267
Total	27.159	26.085	26.984	25.124	25.207	23.589	23.032	23.281	23.113	23.460

(a) Excludes coking coal.

(b) *Includes LP gas.*

(c) Conjectural, but overall effect on energy balance is not greatly distorted. See Note (b), Table V-3.

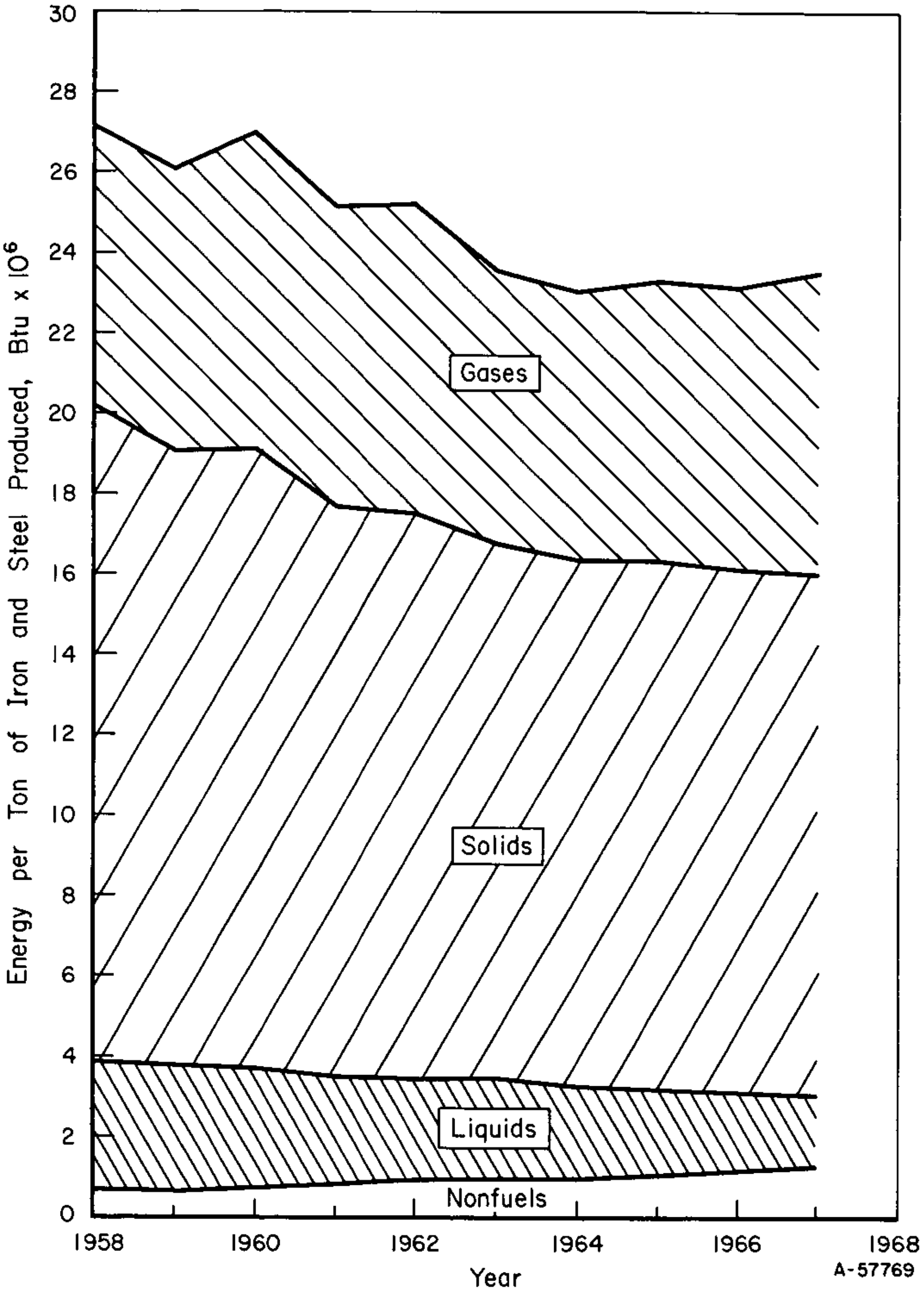

FIGURE V-1. TOTAL ENERGY CONSUMED PER TON OF IRON AND STEEL, ACCORDING TO PHYSICAL FORM OF THE FUELS USED

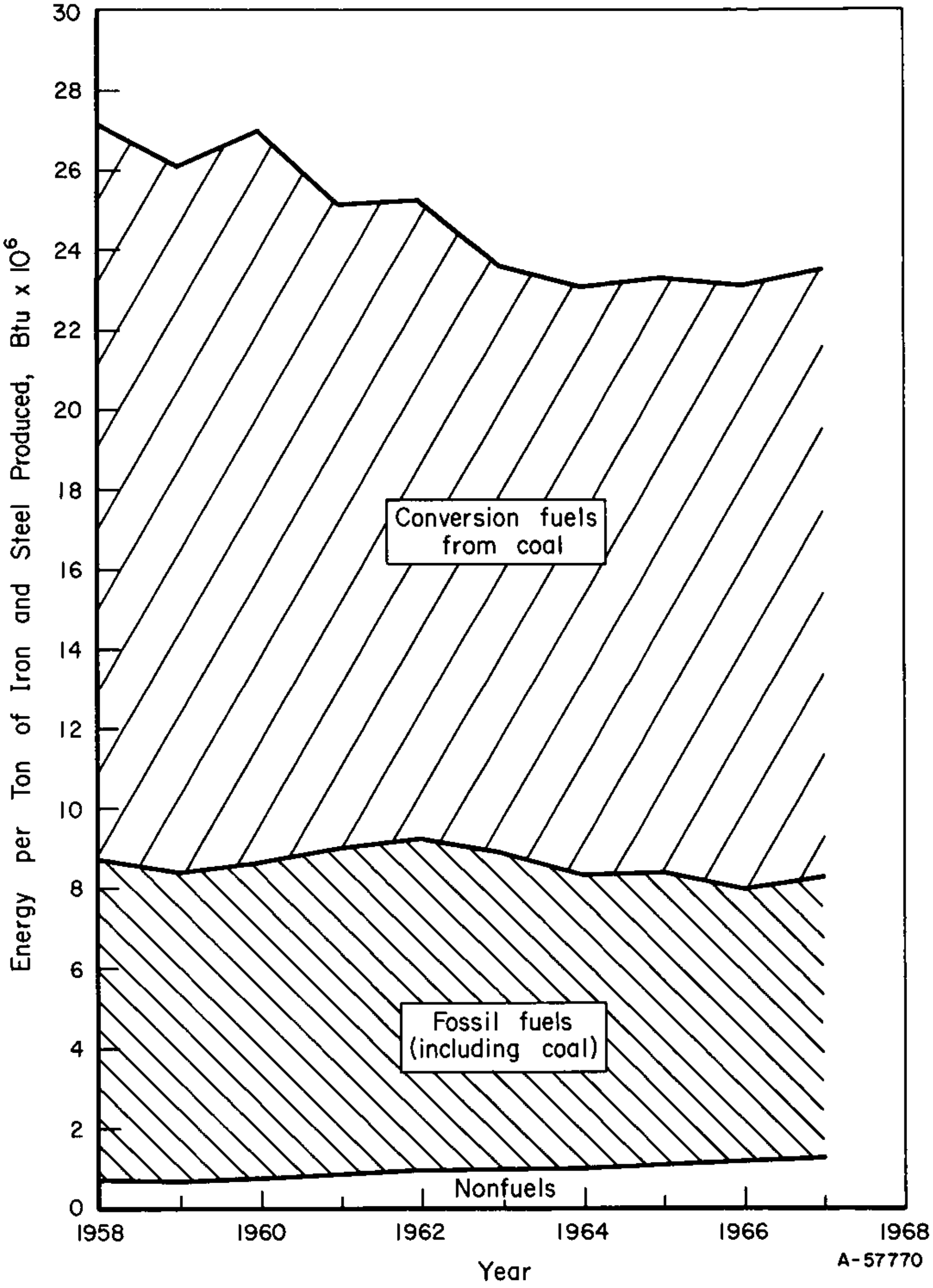

FIGURE V-2. TOTAL ENERGY CONSUMED PER TON OF IRON AND STEEL, ACCORDING TO ULTIMATE SOURCE OF THE ENERGY

(5) LP gas contributes only trivially to steelmaking-energy consumption. There has been a rise in total consumption but no clear trend in consumption per ton of steel.

(6) The total use of natural gas has risen sharply, but irregularly, by about 91 percent over 1958 levels. Per ton of iron and steel, almost all of the 31 percent rise occurred between 1958 and 1961.

(7) The total use of coke-oven gas has been irregular, with sharp peaks in 1960 and 1966. Consumption per ton of iron and steel for the years 1965-67 averaged 15 percent below unit consumption per ton in 1958-59.

(8) Incomplete data indicate that about 13 percent of the energy originally paid for as coke is ultimately used in the form of blast-furnace gas (a by-product of ironmaking).

(9) The total use of steelmaking oxygen has increased almost eleven-fold in 10 years. The use of oxygen per ton of iron and steel has increased more than seven-fold in the same period.

(10) The amount of electricity purchased from outside suppliers almost doubled in the 10 years from 1958 to 1967. Consumption per ton of iron and steel rose by about 56 kilowatt-hours, or 31 percent.

(11) Solid and liquid fuels lost ground during the past decade to gases and nonfuels.

(12) Although both direct-used fossil fuels and fuels converted from coking coal lost ground in the 10-year period, the conversion fuels have fared better since 1963.

Analysis by Applications

There are seven principal uses of fuels, steelmaking oxygen, and electrical energy within the iron and steel industry:

(1) Firing of coke ovens for conversion of coal to coke and by-products

(2) Sintering of dusts and fine ores to make blast-furnace feed

(3) Smelting of iron ores and agglomerates in the blast furnace

(4) Steelmaking, including remelting of scrap and conversion of hot metal to steel

(5) Steam raising for compressing blast and for generating electricity

(6) Reheating, annealing, and heat treating of steel during processing

(7) Driving of mills, forges, and process lines to shape, coat, and finish steel products.

Minor uses (as for comfort heating, curing of refractories, welding and cutting, and operation of peripheral equipment) are numerous.

Energy sources compete with each other technically and economically in all but the last of the listed uses. Electricity long has had a technical near-monopoly upon the driving of mill mechanical equipment used in the rolling of steels. When steam is still used, as in some forges, it is commonly raised in the same boilers that power the plant's electrical generators. Accordingly, Use (7) is not discussed as an application of energy to major processes.

Firing of Coke Ovens

The slot-like ovens that convert coal to coke are arranged in long batteries, like books on a shelf. Between each pair of ovens there are flues heated by hot combustion gases. The system of flues, ovens, and burners rests upon regenerative checkerwork preheaters for the combustion air, and firing is reversed on a preset schedule so that waste heat from the flues is recuperated.

The principal criteria for fuels used in underfiring coke ovens are cleanliness, uniformity of heat release, and proper (nonexplosive) behavior during reversal of the regenerative cycle. Risks of explosive conditions, deposits in the flue system, and uneven heating must be avoided, because a coking battery is expected to operate continuously for 30 years or more without major repairs.

Coke-oven gas and blast-furnace gas furnish most of the energy requirements for underfiring American coke ovens. Natural gas is used only to the extent that it is mixed with by-product gases to enrich them. Although coke-oven gas commonly is used to enrich blast-furnace gas in steel plants, special mixing of these gases for coke-oven underfiring is not in ordinary practice. AISI statistics indicate that some fuel oil was used for underfiring during 1966, but the data (which are not explicit) show that the amount used was very small.

Table V-5 presents the estimated breakdown of fuels used in underfiring coke ovens averaged for the years 1966 and 1967. The estimated use of natural gas is obtained differentially from the estimate that, typically, 1000 Btu are required per pound of coal coked. (It was inferred from oil-consumption figures for 1965 and 1967 that the use of oil for underfiring in 1966 involved about 8 million gallons.)

The main determinant of fuel choice for underfiring coke ovens is the plant gas balance. Use of coke-oven gas and blast-furnace gas made in the plant is preferred economically to any purchase of fuels from outside. Blast-furnace gas is applicable only to controlled-combustion systems with large ducts; thus, it is used, first, in the blast-furnace stoves, second, in steam raising for blast compression, and, third, to underfire coke ovens or to heat process furnaces (mainly soaking pits for reheating steel ingots). If there is a net shortage of energy in the gas for these uses, it may be enriched or partly diverted away from steam raising to bring about balance. If the

TABLE V-5. ESTIMATED USE OF VARIOUS FUELS FOR UNDERFIRING COKE OVENS (1966-1967 AVERAGES)

Average coke produced, net tons/year	58,180,591
Average coal consumed in coking, net tons/year	84,108,905
Average coal per ton of coke, tons	1.446
Estimated underfiring heat, per ton of coal, Btu	2,000,000
per ton of coke, Btu	2,892,000
Average annual underfiring heat, million Btu	168,000,000
Percentage of total industry energy used	5.39
Average Annual Coke-Oven Gas Used In Underfiring:	
Millions of cubic feet	231,330
Cubic feet per ton of coke	3,976
Millions of Btu	116,000,000
Percent of total underfiring energy	68.74
Average Annual Blast-Furnace Gas Used in Underfiring:	
Millions of cubic feet	346,178
Cubic feet per ton of coke	5,950
Millions of Btu	33,000,000
Percent of total underfiring energy	19.54
Estimated Average Annual Fuel Oil Used In Underfiring:(a)	
Thousands of gallons	~3,900
Gallons per ton of coke	~0.07
Millions of Btu	~600,000
Percent of total underfiring energy	~0.35
Estimated Average Annual Natural Gas Used In Underfiring:(b)	
Millions of cubic feet	~19,000
Cubic feet per ton of coke	~330
Millions of Btu	~19,000,000
Percent of total underfiring energy	~11.00

(a) Estimated by comparing 1966 rise in "other uses, blast-furnace area" over average for 1965 and 1967.

(b) By difference – contains cumulative error of all estimates.

shortage is great, blast-furnace gas is not used to underfire the coke ovens, in which case any resulting surplus may be assigned to steam raising or may even be flared.

A second determinant is physical plant layout. Blast-furnace gas is under low pressure after cleaning, and its low energy content does not justify use of booster pumps to raise the transmission pressure. Accordingly, coke plants that are any substantial distance from the blast furnaces are underfired with their own coke-oven gas. This practice consumes roughly half of the coke-oven gas produced; the balance is compressed and sent to the plant for other uses.

Merchant-iron plants that have coke ovens usually have a great surplus of both coke-oven gas and blast-furnace gas owing to the absence of heating furnaces and soaking pits. For these plants, it is often advantageous to underfire the ovens with blast-furnace gas and to sell most of the coke-oven gas produced to an electric utility, another steelworks, or to some other single user.

Sintering of Dusts and Ores

Dusts collected during the cleaning of blast-furnace gas, along with mill scale and fine ore, are commonly mixed with coke breeze and fluxes, then sintered in an 8 to 12-inch layer on a traveling grate. Coal may also be used as a part of the mix. The sintering mix is ignited as the grate passes under an intense gas flame. The sintering reactions are sustained during and after ignition by heat from the combustion of coke. This heat is forced by suction of air down through the ignited mix.

The American Iron and Steel Institute's statistics on raw materials show that an average of about 53 million tons of sinter were charged into blast furnaces annually between 1963 and 1967. This consumption was fairly stable, as shown in Figure V-3. Over the 10 years from 1958 to 1967, average sinter consumption per ton of hot metal increased from 989 to 1178 pounds, or 19 percent. All of the increase occurred prior to 1965, with total annual consumption of sinter nearly doubling from 1958 through 1964.

The average use of coke breeze (coke too small for most other uses) in manufacture of agglomerates (including sinter, pellets, and briquets) was 2.48 million tons annually from 1963 to 1967, or 4.69 percent by weight of sinter consumed. It may be safely estimated that little or no coke breeze was used in making pellets or other agglomerates.

When supplies of coke breeze are insufficient, anthracite may be used in making sinter. The 1963-67 average use of coal (for all agglomerates) was 0.89 million tons per year, or 1.68 percent of sinter consumed. As with coke breeze, it is estimated that nearly all coal used in agglomeration is mixed with sinter feed. The total of coal and coke is about 6.37 percent of sinter consumed, or 1.8 million Btu per ton of sinter. This is a maximum, allowing for no use of coke breeze or coal for other agglomeration.

At present, the determinant of solid fuel for the sintering mix is the availability of coke breeze. When sintering was first used, it served mainly as a means for recycling dust and other wastes. As the excellent smelting properties of sinter became

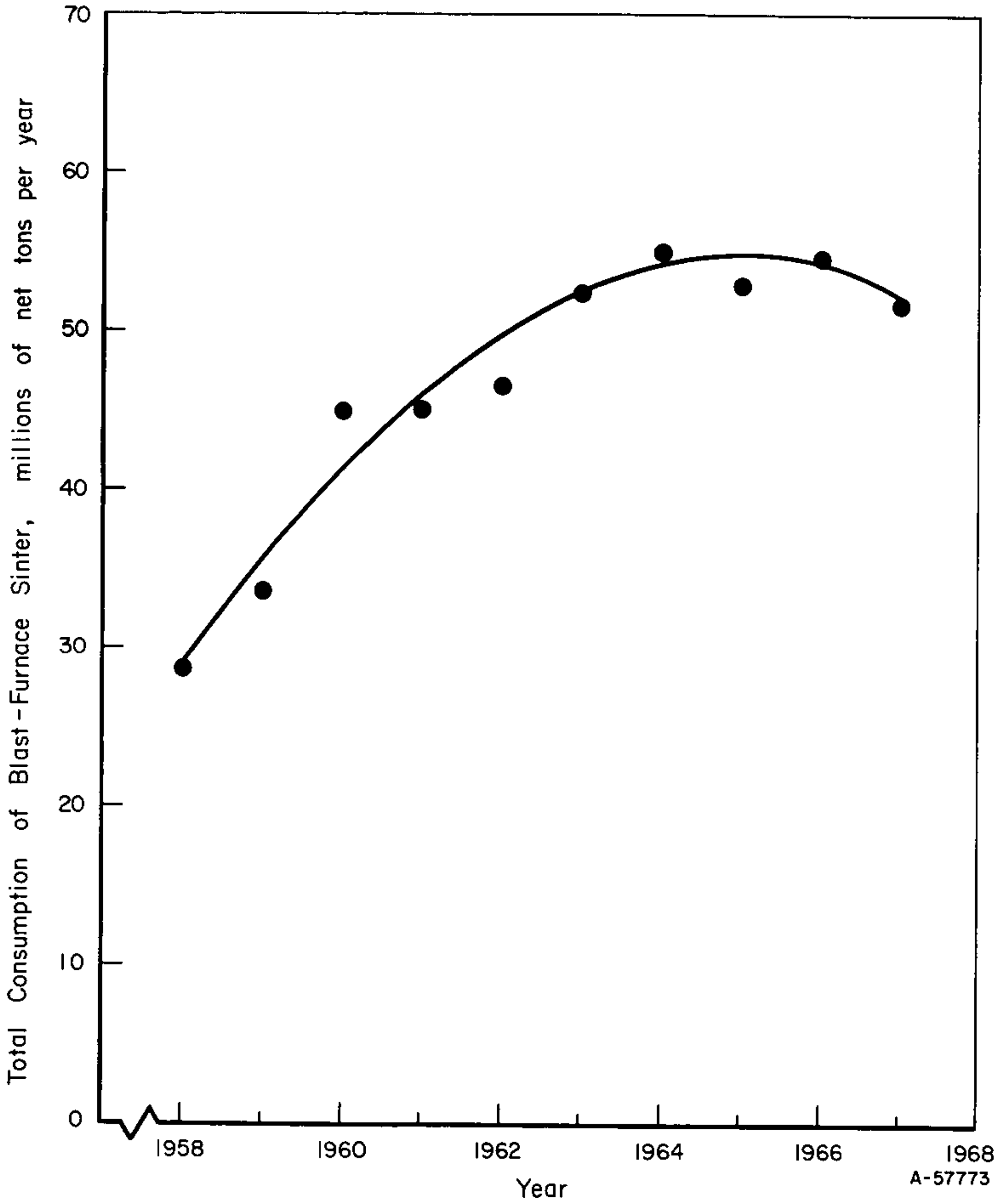

FIGURE V-3. TREND IN USE OF SINTER IN BLAST FURNACES IN THE UNITED STATES known, sinter plants became larger and more numerous. Whereas once there was plenty of coke breeze for sintering and for boiler use, more and more breeze was diverted to the sinter plants, until a breeze shortage occurred. Just as coal replaced coke breeze in the boilers, it has been used to supplement breeze in sintering. Coal is inferior to coke breeze for this purpose, but anthracite works passably.

Unfortunately, the AISI offers no statistics on the use of ignition fuels in sintering. Coke-oven gas usually is preferred, because it is cheaper than natural gas, develops a similar flame temperature, and is readily used in downward-pointing burners. Blast-furnace gas does not develop adequate temperatures, and fuel oil would tend to coke the fuel nozzles as it is burned in the radiant ignition hood.

With the growing shortage of coke breeze, some plants make extra coke to be ground into sinter fuel. An alternative is to extend the length of the ignition hood and to use extra ignition energy to offset a part of the solid-fuel requirements.

Smelting of Iron Ores and Agglomerates

Because the principal fuel used in smelting of iron ore is coke, an important concern of ironmakers is to minimize the amount of coke used. If fixed charges and overheads are included, the cost of energy from coke is over 60 cents per million Btu, well above the cost of energy from other fuels. For example, interruptible* natural gas in the Chicago area sells for less than 35 cents per million Btu in large amounts.

The decade from 1958 to 1967 was one of great progress in ironmaking, including a 21 percent decline in pounds of coke (or energy from coke) applied to smelting. Figure V-4 illustrates this change. Some coke has been eliminated by use of hotter blast, some by better sizing and beneficiation of ores and other burden materials, and some by injection of gas, oil, or tar into the blast tuyeres. In 1967, auxiliary fuels supplied about 4.1 percent of all smelting energy.

The use of coke as the primary smelting fuel is dictated by chemical and physical considerations. Chemically, coke has proper reactivity: it burns efficiently at the tuyeres, yet it reacts but slowly with carbon dioxide and other oxygen-bearing gases in the blast-furnace stack. Physically, coke retains its strength at high temperatures and so helps to maintain good overall permeability of the burden in the shaft of the blast furnace. Without coke, iron ores would tend to pack tightly and to block the flow of reducing gas. If coal were used, it would decrepitate (by giving off mixed hydrocarbons and by disintegrating physically) long before it reached the zone of combustion.

The injection of fluid fuels (or powdered coal) to replace some blast-furnace coke depends upon technical conditions. The hydrocarbons in oil, coal, and natural gas must be dissociated endothermically in the tuyere flame, and even coke-oven gas contains appreciable methane, the most endothermic of hydrocarbons. These endothermic tendencies and the lack of sensible heat in the injectants depress the flame temperature at the tuyeres. The depression in flame temperature lowers the availability of high-temperature heat, which is vitally needed to offset heat losses from the hearth, to fuse metal and slag and to perform critical chemical tasks such as the reduction of silica to silicon. The amount of injected fuel, therefore, must not be so great as to interfere

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*Gas contract provides that the gas company can interrupt service during periods of peak demand. Actual interruption is usually confined to evenings in January and February.

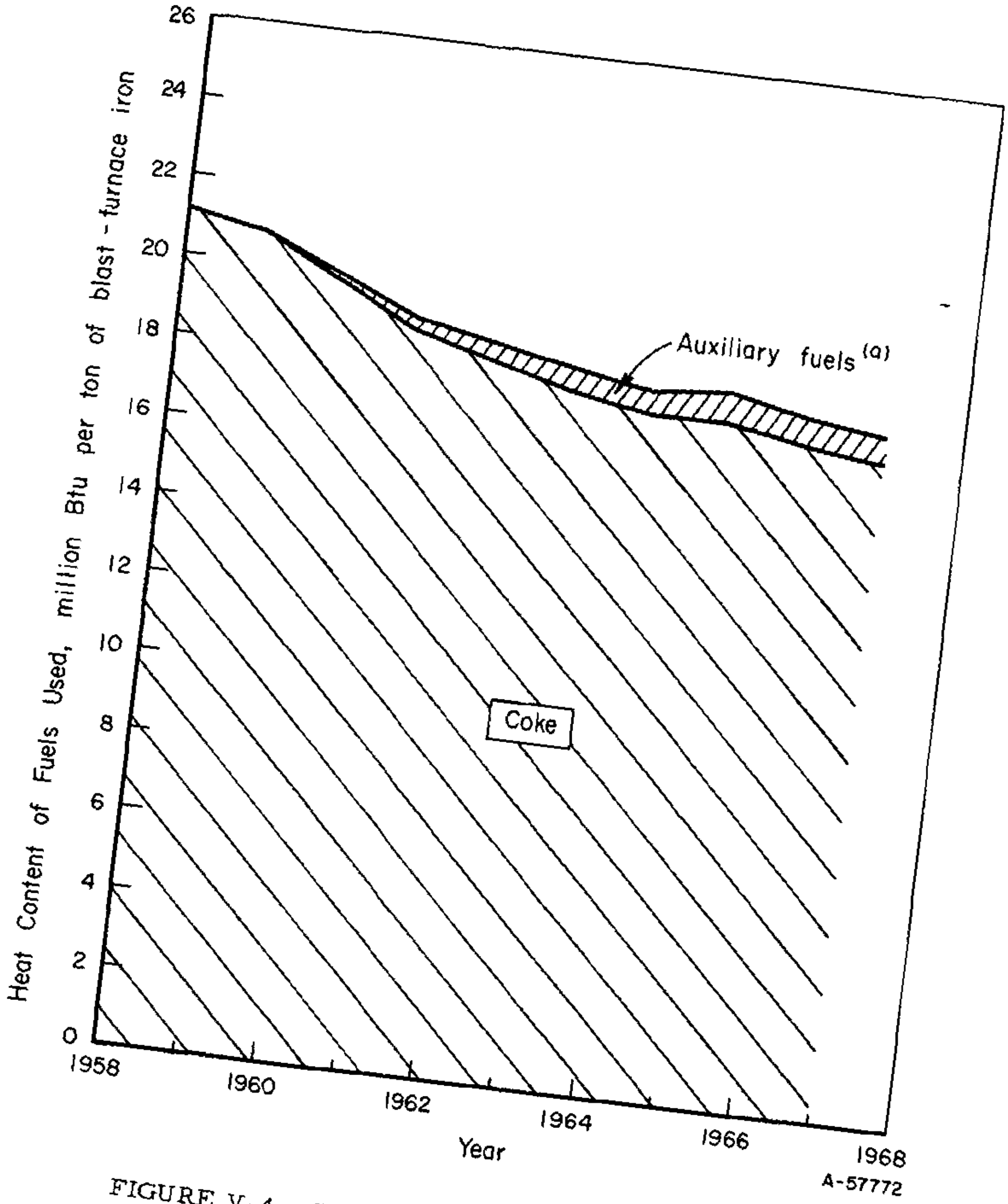

FIGURE V-4. SOURCES OF SMELTING ENERGY

(a) Includes enrichment of blast-furnace gas for stoves.

with the heat balance in the hearth. Commonly, the installation of fuel-injection apparatus is accompanied by efforts to decrease the blast moisture and/or increase the blast temperature. To date, the maximum efficient use for fuels injected at the tuyeres per ton of pig iron produced has been:

(1) About 12 gallons (100 pounds) of oil or tar, or
(2) About 2000 cubic feet of natural gas or coke-oven gas, or
(3) About 120 pounds of bituminous coal.

The definition of "efficient use" depends upon local fuel economics.

There is a significant trend toward using tar as an injected fuel. This trend is promoted by the decline of its use in open-hearth steel furnaces. Tar need not be sold as fuel; it also is useful for highway construction and maintenance. But the low price of asphalt in recent years has tended to keep coal tar in the steel plants as a fuel, and the blast-furnace is one logical outlet. Almost 7 percent of all fuel tar was injected into blast furnaces during 1967. In prior years, no separate listing was made.

Steelmaking

Steelmaking includes the remelting of scrap steels, the oxidation of carbon and other unwanted elements from blast-furnace iron, and the careful adjustment of final chemistry and temperature to specification. The energy that is supplied to a steelmaking furnace must offset heat losses, fuse the solids that are charged, and raise the temperature of all materials to their hottest level (usually above 2800 F).

Three steelmaking processes compete vigorously – basic-oxygen, open-hearth, and electric-arc furnace. They are strikingly different from each other, in that each uses a different source of energy, a different mix of charges, and a different physical configuration. Table V-6 outlines some of these major differences, indicates the bases for competition, and shows the proportion of steel made in each type in 1958 and in 1967.

AISI statistical summaries distinguish among the steelmaking processes in their use of oxygen. Although there is a separate listing of fuels applied to steelmaking furnaces taken as a group, no breakdown by process type is given. The main application of fuels in steelmaking is to the endwall burners of the presently dominant open-hearth process. In spite of the use of gases (and perhaps oil) for preheating ladles and new linings for furnaces, and in spite of various ancillary uses for fuels in any melt shop, the analysis must assume that fuels assigned to steel-melting furnaces by the AISI were used in the open hearth.

Similarly, no breakdown of applications for electrical energy is given in the statistical summaries. The requirements for energy in electric-arc melting are fairly well known, however. A good working average is 600 kwhr per ton of carbon steels and 800 kwhr per ton of alloy and stainless grades. Subject to these necessary assumptions, the energy sources for steelmaking are shown for the 6 years from 1962 to 1967 in Table V-7. Prior to 1962, applications of steelmaking oxygen were not separated by process.

TABLE V-6. THE THREE MAJOR STEELMAKING PROCESSES: NATURE, ATTRIBUTES, AND BASES FOR COMPETITION

Basic-Oxygen Steelmaking	Open-Hearth Steelmaking	Electric-Arc Steelmaking
1958: 1,323,000 net tons 1967: 41,434,000 net tons	1958: 75,880,000 net tons 1967: 70,690,000 net tons	1958: 6,656,000 net tons 1967: 15,089,000 net tons
Furnace shaped somewhat like a pear or a teacup, with upper walls slanted conically inward. Discharges gases to a hood. Fired by a vertical water-cooled oxygen lance, inserted vertically to within a foot or so of the bath.	Furnace shaped like a wide, flat rectangular bathtub to maximize slag-metal interface and heat-receiving surface. Fired by burners at each end, used alternately. Combustion air preheated by regenerative checkerwork in flue systems.	Furnace shaped like a circular bowl of variable depth. Roof may lift and swing to admit charges. Fired by 3-phase moderate-voltage power applied to equispaced carbon electrodes. Electrode heights adjust automatically to maintain arcs.
Energy obtained primarily from sensible heat in hot metal, secondarily from reactions between oxygen and unwanted elements dissolved in the hot metal (Si, Mn, P, C).	Energy obtained primarily from endwall burners, supplemented by sensible heat in hot metal and by oxidation of impurities from hot metal. Oxygen lances now in general use for refining.	Energy obtained almost entirely from electrical discharge in the arcs. No fuels used in operation. Use of blown oxygen confined to relatively minor adjustments in carbon analysis.
Charges 22 to 31 percent scrap steel, 69 to 78 percent molten hot metal from blast furnace.	Charges any combination of hot metal and scrap, most plants close to a 50/50 mixture.	Charges mainly steel scrap, but hot metal has been used to a limited degree.
Best mix of speed and versatility for new or modernized plants, at low capital cost, provided hot metal is available in large quantities. To reach 99 million tons in 1980.	Versatile but slow. Used heavily, and competitive solely on the basis of sunk capital. No new installations anywhere since 1959. Oxygen roof lances are a competitive modification.	Extremely versatile and faster than open-hearth. Suited to small plants with no hot-metal supply. Strong in stainless and alloy steels.
Oxygen per ton crude steel: 1958 1925 cu ft 1962 1917 cu ft 1967 1900 cu ft	Oxygen per ton crude steel: 1958 120 cu ft (estimated) 1962 508 cu ft 1967 826 cu ft	Oxygen per ton crude steel:(a) 1958 175 cu ft (estimated) 1962 188 cu ft 1967 222 cu ft

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(a) Includes oxygen used in the Bessemer process, which was fading fast in 1962 and all but gone in 1967.

TABLE V-7. ESTIMATION OF SOURCES OF ENERGY FOR STEELMAKING PROCESSES (OTHER THAN SENSIBLE HEAT IN CHARGES)

Note: This tabulation necessarily includes estimation as explained in the text and in footnotes. Statistics given herein should not be applied indiscriminately to uses other than for those intended here.

Process and Energy Source	Energy Unit	Consumption Per Ton of Steel					
		1962	1963	1964	1965	1966	1967
Open-hearth steelmaking[a]							
Fuel oil	Gal	10.66	10.37	10.28	9.44	8.49	8.03
Tar and pitch	Gal	3.19	3.09	2.86	3.38	3.52	3.51
Natural gas	Ft^3	1355	1073	1106	1121	1129	1216
Coke-oven gas	Ft^3	817	845	778	763	647	463
Steelmaking oxygen	Ft^3	508	578	592	625	737	826
Total, as energy[b]	10^6 Btu	4.03	3.74	3.70	3.67	3.55	3.51
Basic-oxygen steelmaking							
Steelmaking oxygen	Ft^3	1918	1909	1944	1864	1853	1900
Total, as energy[b]	10^6 Btu	0.83	0.83	0.85	0.81	0.81	0.83
Electric-arc steelmaking[c]							
Electricity (total)	kwhr	643	678	677	678	677	666
Steelmaking oxygen[d]	Ft^3	188	178	190	199	208	222
Total, as energy[b]	10^6 Btu	2.28	2.39	2.39	2.40	2.40	2.37

(a) Assumed to use all fuels ascribed to steel-melting furnaces in AISI statistical reports.

(b) Oxygen valued at 435 Btu/cubic foot energy equivalent. This is correct for roof lances of open-hearth and for the basic-oxygen process, but only approximate for use of oxygen in open-hearth endwall burners or in refining of electric-furnace heats made from melting of scrap steel.

(c) No figures on energy consumption are available. Estimate based on assumed 600 kwhr per ton of carbon steel and 800 kwhr per ton of stainless or alloy steel.

(d) Statistic includes the (fading) Bessemer process, both in oxygen used and in steel produced.

The statistics of fuel consumption for open-hearth steelmaking (as approximated in Table V-7) illustrate a decline in energy requirements per ton of open-hearth steel. A more exact assignment of fuels among the three processes would tend to increase this trend, inasmuch as use of both basic-oxygen and electric-arc steelmaking is growing. For the open-hearth, the lower consumption of energy per ton of steel reflects replacement of the more obsolete shops (by basic-oxygen furnaces), offsetting of fuel requirements by time-saving injection of oxygen, and use of oxygen in endwall burners to augment flame temperature and save additional time.

The use of fuel oil and of coke-oven gas in open-hearth furnaces has declined significantly, but the use of natural gas and tar has been steady. The reasons for these trends are not obvious and deserve more investigation. Possible causes include

(1) Growing difficulties in the sale of tar

(2) Hazards in the use of fuel oil and tar with oxygen-augmented endwall burners

(3) Problems with the high flame velocity of coke-oven gas (a long and luminous flame is desired)

(4) Natural displacement of oil- and coke-oven gas-fired open hearths by basic-oxygen steelmaking

(5) Concern over sulfur contamination from oil, tar, and coke-oven gas.

Proponents of basic-oxygen steelmaking seem certain that the open-hearth must go the way of the Bessemer converter, and proponents of electric steelmaking are equally sure that huge electric furnaces will take a constantly increasing share of total steelmaking production. These claims may be overstated, at least for the next decade. The existence of large investments in the larger, newer open hearths will slow the demise of the open-hearth process as an important producer of steel.

Steam Raising

An integrated steelworks usually has substantial boiler capacity, because steam power is very useful and because it represents convenient recovery of the energy in certain plant by-products, especially waste heat and blast-furnace gas. The uses of steam in the steel plant include

(1) Compression of air for blast furnaces (via turbine)
(2) Generation of electric energy
(3) Distillation of coking by-products
(4) Pumping of coke-oven gas
(5) Powering of forges and presses
(6) Warming of residual oil and tar lines
(7) Comfort heating and housekeeping.

Most integrated plants use steam as the common denominator of power. The boiler station often is equipped to burn almost any available fuel. When the plant is in full operation, a minimum number of turbogenerators will be operating at full electrical output, and purchased fuel (usually coal) will be brought in to complete the balance. In some instances, the generating plant is competitive in cost with outside power sources and will be operated at rated capacity most of the time. This is especially true when the power station supplements inadequate outside sources of electricity.

The management of steaming and generating capacity depends on company philosophy. If the cost of the boilers is charged mainly to the blast-furnace blowing engines, there will be a tendency to generate considerable power internally. Overall, the steel industry buys about 70 percent of the electricity it uses. If the in-plant generators are envisioned as noncompetitive, their use will be minimized. At any rate, the first priority rests with recovering the fuel value of blast-furnace gas and the second, with balancing out coke-oven gas and coke breeze on a plant basis and utilizing the heat recovered in waste-heat boilers.

The principal fuel used in the boiler plant (after blast-furnace gas) is coal. Use of other fuels (at least in the East) is incidental. In the 10-year period from 1958 to 1967, steel plants used from 6.1 to 6.7 million tons of coal per year (the average was 6.44 million tons), and there was no consistent trend from year to year. Roughly 90 percent of all noncoking coal used by steelmakers was applied to steam raising.

Heating of Steel in Process

When new molten steel first solidifies into an ingot, it has a temperature somewhat above 2800 F. From this time until it has been almost completely formed to saleable shape, the steel must be maintained at (or reheated to) red heat. Maintenance of temperature for steel in process is a major application of energy.

The kinds of furnaces used for in-process heating include soaking pits (in which newly stripped ingots are allowed to equalize in temperature for a few hours before rolling begins). Soaking pits (which may be fired with either blast-furnace gas, coke-oven gas, or a mixture) are intended to make the temperature of the steel uniform, not to add large amounts of heat to the steel.

An ingot is conventionally removed from its soaking pit and rolled to a bloom or slab, then allowed to cool for inspection. The cool steel is carefully examined, and defects are removed with an oxygen torch in a process called scarfing. The prepared steel is then reheated in a once-through furnace, with careful attention to both accuracy and uniformity of the final temperature. The reheated slab or bloom is then finish rolled to plate, strip, merchant shapes, or wire rod. Thereafter, any reheating is usually intended to produce some metallurgical change (such as an improvement in strength or ductility). Furnaces used to alter steel metallurgically (called heat-treating furnaces) often are operated with special atmospheres to promote a clean appearance on the product. Table V-8 presents a 10-year analysis of fuels used in heating and annealing furnaces. The tabulated data illustrate no particular trend in the use of fuel energy per ton of steel in heating and annealing furnaces. However, prior to 1962, both oil and tar declined in importance, as did coke-oven gas. The use of natural gas rose during the same period, indicating a general preference for lower sulfur fuels. The rise in use of LP gas may be a correspondent change for areas in which natural gas is not available or in temporary relighting of furnaces built for fluid fuels.

TABLE V-8. USE OF FUELS TO FIRE HEATING AND ANNEALING FURNACES IN THE UNITED STATES STEEL INDUSTRY, 1958-1967

Source: Derived from AISI statistics.

Fuel	Unit	Consumption Per Ton of Finished Steel Products									
		1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Fuel oil	10^3 gal	372, 652	410, 201	367, 053	333, 956	335, 283	391, 046	392, 300	448, 649	461, 939	403, 426
per ton product	gal	6.32	6.17	5.37	5.25	4.94	5.39	4.80	5.09	5.37	5.02
energy per ton	10^6 Btu	0.94	0.92	0.80	0.78	0.73	0.80	0.71	0.76	0.80	0.75
Tar and pitch	10^3 gal	5, 296	4, 519	5, 163	4, 282	4, 146	- - - - - - - - - - - Not separately listed - - - - - - - - - -				
per ton product	gal	0.09	0.07	0.08	0.07	0.06					
energy per ton	10^6 Btu	0.01	0.01	0.01	0.01	0.01	- - - - - - - - - - Assumed 0.01 million Btu - - - - - - - - -				
LP gas	10^3 gal	4, 861	5, 176	6, 278	4, 941	6, 395	9, 317	7, 828	13, 952	9, 901	11, 112
per ton product	gal	0.08	0.08	0.09	0.08	0.09	0.13	0.10	0.16	0.11	0.14
energy per ton	10^6 Btu	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Natural gas	10^6 ft^3	149, 388	177, 907	199, 352	206, 732	222, 739	236, 515	256, 256	277, 317	264, 228	283, 004
per ton product	ft^3	2, 532	2, 675	2, 914	3, 250	3, 280	3, 258	3, 133	3, 148	3, 069	3, 524
energy per ton	10^6 Btu	2.53	2.68	2.91	3.25	3.28	3.26	3.13	3.15	3.07	3.52
Coke-oven gas	10^6 ft^3	318, 835	353, 063	477, 481	324, 736	280, 789	255, 673	339, 567	354, 500	365, 327	361, 917
per ton product	ft^3	5, 404	5, 309	6, 981	5, 106	4, 135	3, 522	4, 151	4, 024	4, 243	4, 507
energy per ton	10^6 Btu	2.70	2.65	3.49	2.55	2.07	1.76	2.08	2.01	2.12	2.25
Blast-furnace gas	10^6 ft^3	- Data not given -								156, 010	162, 898
per ton product	ft^3									1, 812	2, 028
energy per ton	10^6 Btu	- Assumed 0.17 million Btu -								0.17	0.19
Total Energy	10^6 Btu	6.36	6.44	7.39	6.77	6.27	6.01	6.11	6.11	6.06	6.73

Principal Findings

The following statements summarize the existing applications of fuels to steelmaking activities and refer to determinants that are expected to dominate future choices:

> Coking – Blast-furnace gas and coke-oven gas are now the preferred fuels for underfiring coke ovens; this preference will not change. Between them, the main factors of choice include physical layout and the overall plant gas balance. All factors tending to improve the value of coke-oven gas as a plant fuel similarly tend to increase the likelihood of underfiring with blast-furnace gas. Natural gas participates in underfiring only insofar as it is used to enrich the other gases.
>
> Sintering – Two kinds of fuels are required. Among solid fuels, coke breeze is preferred, and the sinter plant preempts breeze requirements in other parts of the steelworks. Coal, especially anthracite, is usable as a poor substitute for coke breeze. Longer ignition cycles can lessen solid-fuel requirements for sintering. Most ignition is done with coke-oven gas or mixed coke-oven and blast-furnace gas. These fuels usually are preferred over natural gas for economic reasons. Fuel oil is not used, because the configuration of the ignition system is technically unfavorable.
>
> Smelting – Full development of hot-blast operation with prepared burdens and auxiliary injected fuels could cut coke rates to well under 1000 pounds per ton of hot metal (from present levels averaging over 1250 pounds per ton). However, the suggested improvements usually must wait upon a strain on ironmaking capacity – at present, America has blast furnaces to spare. The vast improvements in ironmaking fuel economy which began in 1958 have nearly stopped under present conditions of steel demand. Among the auxiliary fuels, regional economics will probably govern. Coal injection, now in development, should dominate the inland East, oil probably will be preferred near the coasts, and natural gas probably will be the preferred injectant west of Cleveland.
>
> Steelmaking – Two of the three steelmaking processes (the basic-oxygen process and electric steelmaking) do not use fuels in the usual sense, and there is no reason to suggest that they may become fuel consumers in the future. The third (open-hearth steelmaking) is much maligned for its obsolescence but will be with us for at least two decades. There is a clear trend away from both oil and coke-oven gas as open-hearth fuels; yet, tar, which is also sulfurous, continues as an important source of melting energy. The changes are probably compound and include the consideration of an oversold market for road and waterproofing tars. More investigation of open-hearth fuel determinants is advisable. The increased use of oxygen in open hearths has cut the overall energy requirement, but at a high cost in dust-control problems. Much has been written about preheating of scrap to increase its use in basic-oxygen steelmaking, but this remains only marginally economic, except as an expedient in special situations.

Steam Raising - The management of steam raising is founded on the principle that the boiler plant is to balance plant-energy sources and needs for optimal net-energy cost. Surpluses and shortages of gases are balanced at the boilers on a day-to-day basis, and variable amounts of electric power are generated. This compound economic system is a study in itself and worthy of much more attention. At least in the East and Midwest, purchased coal is the most probable fuel for adjustment of boiler-energy requirements.

Steel Heating - Various furnaces (usually at least two) are used to equalize and control steel temperature during processing. Others may be used near the end of primary manufacture to soften, harden, or resurface the product. These furnaces run mainly on coke-oven gas and natural gas, with natural gas preferred when sulfur in the furnace atmosphere could cause metallurgical trouble.

No aspect of the analysis by uses disclosed strong trends toward the "clean" fuels. The primary economic determinant of fuel choice in any steelworks is and will be to use the homemade fuels completely before buying energy in the open market. However, the sulfur content of fuels will continue to receive examination, because fuels are the major source of undesirable amounts of sulfur in iron and steel.

Some Facets of the Relationship Between Clean Air and the Fuel and Energy Aspects of the Steel Industry

This present study is concerned, of course, with the broad relationship between the integrated steel industry and national concern with problems of polluted air. One portion of that relationship can be examined by considering the nature of some of the avenues open to the steel industry to raise air quality by making adjustments in the industry's usage of fuels and energy. It will be assumed for the balance of this discussion that increasingly stringent standards for air quality are established in steel-producing areas. Another assumption is that decreased emission of sulfur-bearing gases will be a specific objective and that meeting of this objective will require treatment of combustion gases resulting from the burning of coal, tar, and coke-oven gas. At present, some steel plants remove hydrogen sulfide from coke-oven gas, but the hydrogen sulfide that is recovered is burned in power boilers.

One general response by the steel industry (already foreseen in existing technology) would be the cleaning of coke-oven gas to remove hydrogen sulfide. It is anticipated that the relative cost of natural gas will rise generally in the future and that this economic readjustment of the relative costs of coke-oven gas and natural gas might justify the cost of cleaning the coke-oven gas. However, present operating practices make the recovery of sulfur dioxide, in most steel plants, an uneconomical process.

Another general response would be a sharp decline in use of fuel oil, even as an injectant to blast furnaces. As a fuel in open-hearth furnaces and steel-heating furnaces, fuel oil would be seriously disadvantaged by sulfur-control regulations. It is to be expected that a new wave of conversions from open-hearth steelmaking to the basic-oxygen or electric-arc process would occur and that surviving open hearths would be fueled with tar or coke-oven gas. The use of tar is being forced by a deteriorating market for coal chemicals and by-products. (These conclusions assume that fuel oil cannot be economically desulfurized.)

It should be noted that an increase in the relative price of natural gas could make fuel oil relatively more competitive as a blast-furnace injectant than it is now. Fuel oil causes no problems in the blast furnace because its sulfur content goes mainly into the slag (not directly into the air). However, tar and pitch would be displaced from melting furnaces equally with oil, and then probably would preempt oil in blast-furnace injection.

Another general response would be an alteration in the economic rules for operation of in-plant boilers. Blast-furnace gas is a clean fuel, and its use would continue. But the use of coal as a balancing supplement would be much altered by the obligation to process the stack gases from solid-fuel boilers. Indeed, barring a large-scale shortage of electric energy, it is possible that strong efforts would be made to altogether eliminate steelworks' use of coal for this purpose. It would probably be more economical to trim steam raising to a minimum and to use purchased natural gas for minor energy balancing.

Overall, it is anticipated that in the event of stringent stack-emission standards, the steel industry would suffer rather less per unit of energy consumed than some other industries, such as the electric-power industry. The blast furnace, with its ability to use dirty fuels, acts as a partial shield. The technology for desulfurizing coke-oven gas exists, although there is a handicap economically. Steelmaking practices may be converted to fuel-less techniques (like the basic-oxygen process and the electric-furnace process).

It is a general conclusion of this portion of the study (concerned with fuels and energy) that requirements for cleaner air would not unreasonably interfere with the technology of steelmaking and would not require unreasonable responses by the steel industry, providing that sufficient time is allowed for the response. Nonetheless, the steel industry uses well over 23 million Btu of total energy per ton of product. If the average cost of that energy is 75 cents per million Btu, the associated cost to raw steel is at least $17 per ton. This works out to an annual cost of something over $2,000 million per year for steelworks' energy. Upward changes in the costs that are this large already will of course be reflected in higher costs of manufacturing steel and higher costs to consumers for steel.

In October, 1968, the Energy Division of the Chase Manhattan Bank (New York) published the pamphlet "Outlook for Energy in the United States". This review and forecast highlighted some elementary but important considerations in planning long-range energy sources and showed the following:

(1) The demand for high-grade energy (gasoline, distillate oil, jet fuel, and natural gas) is skyrocketing, with no end in sight. Both the number of users and the demand per capita are increasing sharply.

(2) In those geographic areas that contain most U. S. steel plants, there is already a serious net energy deficit and substantial traffic in importation of energy from the Gulf Coast and abroad.

(3) The anticipated expanded use of nuclear energy will not meet anticipated requirements for additional energy.

(4) The expanded use of coal relative to other fuels is inevitable in the far future - it is our only certain resource and the only one potentially convertible to fluid fuels replacing those now derived from gas and oil.

These conclusions serve as a reminder to be cautious about taking action that lowers our national capability to use coal. Compared with ordinary fuel-burning uses, the steel industry seems to offer an excellent opportunity to use coal under controlled conditions that minimize air pollution. The use of coal in coking and thence to the blast furnace seems to involve an excellent opportunity for concentration of the technologies that suppress emission of sulfur compounds.

SOURCES AND AMOUNTS OF NOXIOUS EMISSIONS IN THE IRON AND STEEL INDUSTRY

Raw materials and fuels consumed in the iron and steel industry contain sulfur in varied amounts. Coal, iron ore, steel scrap, fluxes, and ferroalloys are the major bulk raw materials used by the steel industry. Large quantities of liquid and gaseous fuels and electrical energy are also consumed in the many processing steps requiring heat.

The presence of sulfur in the raw materials and fuels gives the ironmakers and steelmakers a problem of controlling the amount of sulfur that ends up in the final finished product. Sulfur is a deleterious element in most irons and steels. Much of the refining of steel is conducted to lower its sulfur content. Steelmaking technology permits low sulfur levels to be attained in the metal, accompanied by correspondingly high sulfur levels in the slags.

During the combustion of fuels in iron and steel processing, some of the reactions are not complete, with the result that CO is present in some of the combustion gases. Coke-oven gas, blast-furnace gas, and BOF gas normally contain CO due to the processing techniques. Gas from coke ovens and blast furnaces is collected and used as a fuel. Processes have been developed to collect and use BOF gas, but more commonly it is burned within the collecting system and then exhausted to the atmosphere. Other combustion processes within the steel plant generally go to completion unless there is a malfunction of equipment. However, small amounts of CO (less than 0.5 percent) may be found in some exit gases.

Fluoride emissions can be a problem in the making of iron and steel if they are uncontrolled. Some iron ores in certain local areas contain fluorides of sufficient content that vegetation has been affected by emissions from steelworks. Calcium fluoride (in the form of fluorspar) is used in steelmaking to make slags more fluid, and emissions from this use can be ejected into the atmosphere if uncontrolled.

Seven oxides of nitrogen theoretically can exist in the atmosphere. However, for practical purposes, those of concern appear to be nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), and possibly nitrogen pentoxide (N_2O_5)(1)*. Little is known of these in relation to steelmaking activities.

Sulfur in Iron and Steel Plant Processes

The major sources of sulfur in the making of iron and steel exist in the fuels required to carry out the various processes. By far most of this sulfur originates in the coal used to make the coke that is a vital requirement for making the blast-furnace hot metal. During the coking operation, various by-products are recovered and in turn some of these are used as fuels. These are coke-oven gas, tar, and pitch. Fuel oil also contains sulfur which is a contributor to sulfur-oxide emissions. The total consumption of the various hydrocarbon fuels in the manufacture of iron and steel is shown for the period from 1958 to 1967 in Figure V-5. The rapid increase in consumption of natural gas is quite evident. Consumption of hydrocarbon fuels per net ton of raw steel

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*Numbers in parentheses refer to reference list at end of this section.

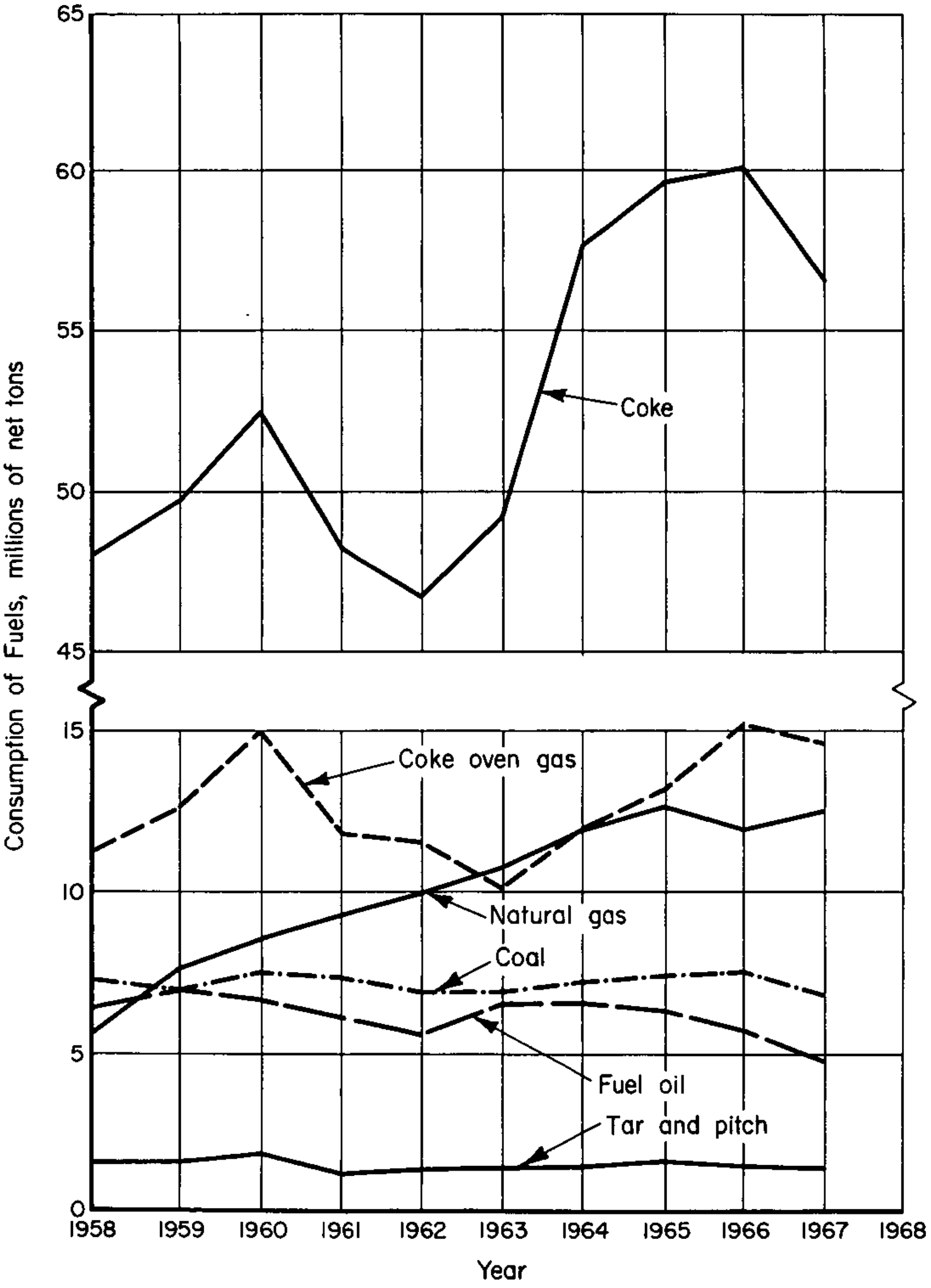

FIGURE V-5. CONSUMPTION OF HYDROCARBON FUELS IN THE MAKING OF IRON AND STEEL IN THE UNITED STATES

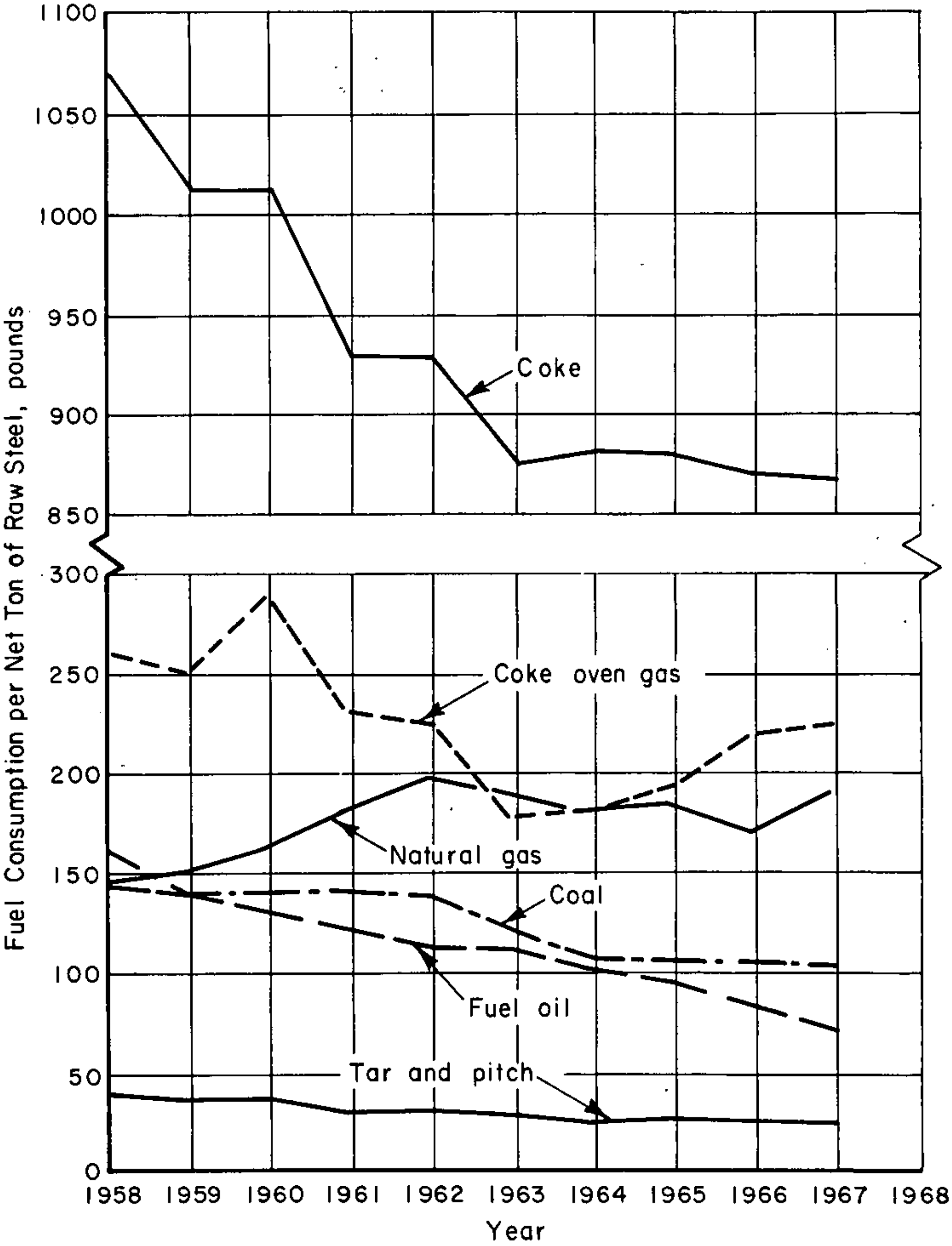

FIGURE V-6. CONSUMPTION OF HYDROCARBON FUELS PER NET TON OF RAW STEEL IN THE UNITED STATES produced is shown in Figure V-6 for the same period of time. The trends illustrated in Figure V-6 are somewhat biased in that the total consumption of each hydrocarbon has been divided by the total production of raw steel. During the period considered, electric furnace steelmaking accounted for about 3 percent of all steel in 1958, which increased to 12.5 percent in 1967. The decreasing use of fuel oil shown in both Figures V-5 and V-6 is a reflection in the decline of open-hearth production of steel, which was a large consumer of fuel oil. Increased use of natural gas occurred mainly in reheating furnaces, as well as a slight increase in firing power plant and steam boilers. The latter applications have become more common as a means for lowering the generation of sulfur emissions by replacing sulfur-containing coals with natural gas that is practically sulfur-free. The rather constant consumption of tar and pitch is also quite interesting. Early use of tar and pitch was in the firing of open hearths, but as this use declined because of the decrease in the number of open hearths, tar and pitch began to be used as auxiliary fuels in the blast furnace, where the sulfur contained in the tars and pitch was controlled by the slag action of the blast furnace, rather than entering the atmosphere as a sulfur-bearing gas, as was the case when used as an open-hearth fuel.

Making Coke

The major source of sulfur in the making of iron and steel is the sulfur content of the coal used for making coke and the coal used for the firing of power-plant boilers to generate electricity. A relationship between the percent sulfur content of the coal and the percent sulfur content of the resulting coke is shown in Figure V-7 for experimental cokes and for steel-plant blast-furnace cokes(2, 3, 4, 5). A similar relationship is shown in Figure V-8 between the percent sulfur content of the coal and pounds of sulfur contained in the coke made from 1 net ton of coal.

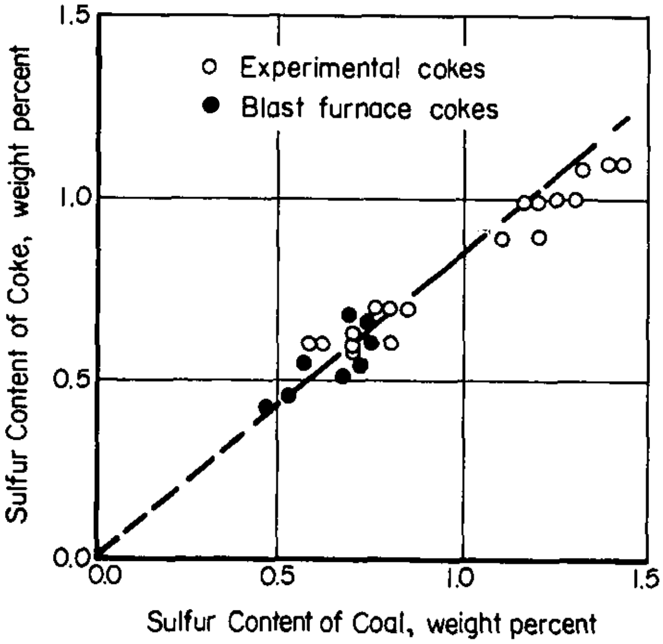

FIGURE V-7. SULFUR CONTENT OF COKE AS RELATED TO THE SULFUR CONTENT OF THE CORRESPONDING COAL

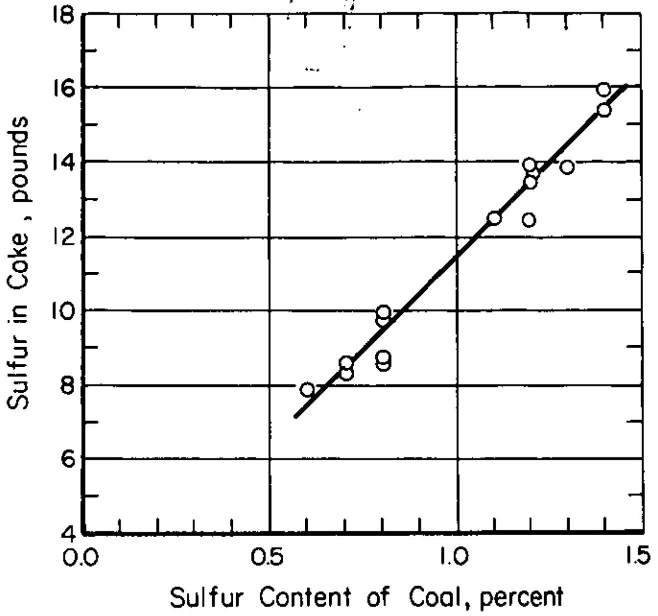

FIGURE V-8. POUNDS OF SULFUR IN COKE RESULTING FROM THE COKING OF ONE NET TON OF COAL

The sulfur content of the resulting coke-oven gas, also produced from the same coals, is shown by the relationship in Figure V-9.

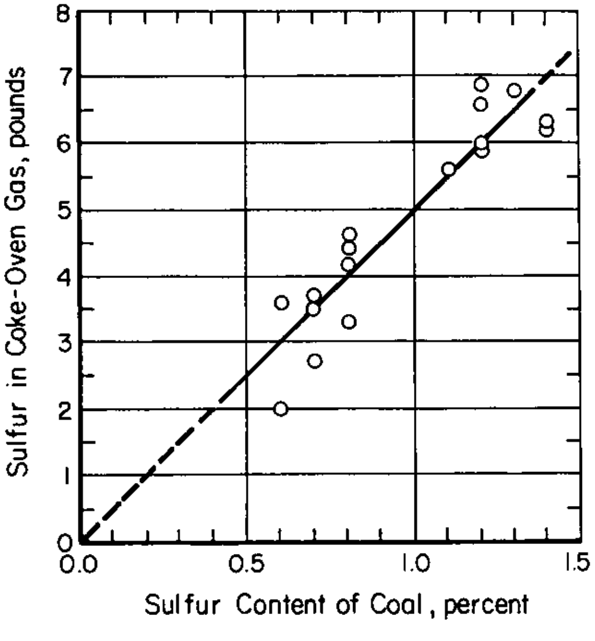

FIGURE V-9. SULFUR IN COKE-OVEN GAS RESULTING FROM THE COKING OF ONE NET TON OF COAL

The sulfur content of bituminous coals shipped to American coke plants varies between 0.5 and 2.1 percent(6). The sulfur content of blast-furnace cokes in the United

States varies between 0.5 and 1.10 percent, with the average at 0.80 percent. A sulfur balance for a coke-oven operation in the United States for a coking coal containing 0.8 percent sulfur is given in Table V-9. About 63 percent of the sulfur remains with the coke and 37 percent goes to the by-products and coke-oven gas. Table V-9 shows that the production of 1 ton of coke produces about 15,000 cubic feet of coke-oven gas with a sulfur content of 1.45 percent.

TABLE V-9. SULFUR BALANCE FOR COKE OVEN OPERATION

(Based on Production of One Net Ton of Coke)

Item	Amount, pounds	Sulfur, percent	Amount of Sulfur, pounds
	Input		
Coal	2950	0.8	23.60
	Output		
Coke and breeze	2121	0.700	14.85
By-products	290	0.344	1.00
Coke-oven gas[a]	534	1.45	7.75
		Total	23.60

(a) Coke-oven gas produced is 15,000 ft^3.

About 40 percent of the coke-oven gas is burnt in the oven to supply heat for the coking process. The combustion of 1 standard cubic foot of coke-oven gas produces 5.78 standard cubic feet of combustion gases.

The coke-oven gas not consumed in the coke oven may be used as a fuel elsewhere in the plant, or exhausted to the atmosphere. Sulfur is generally not removed from the coke-oven gas before use or before venting to the atmosphere.

Sintering Machine

Table V-10 gives a sulfur balance for a sintering-machine operation. Sources of sulfur are the iron-bearing material, coke breeze, fuel oil, and limestone. Sulfur is carried out of the system with the product sinter and as SO_2 in the combustion gases. It was estimated that about 36 percent of the sulfur entering the system leaves in the combustion gases.

TABLE V-10. SULFUR BALANCE FOR SINTERING MACHINE OPERATION

(Based on the Production of One Net Ton of Sinter)

Item	Amount, pounds	Sulfur Content, percent	Amount of Sulfur, pounds
		Input	
Iron-bearing material	2200	0.041	0.90
Coke	100	0.70	0.70
Oil	50	0.55	0.27
Limestone	200	0.049	0.10
		Total	1.97
		Output	
Sinter	2000	0.055	1.10
Sinter fines	289	0.055	0.16
Sulfur in combustion gases			0.71
		Total	1.97

Blast Furnaces

Sulfur enters the blast furnace from practically all of the raw materials used for making iron; the major source being the sulfur in the coke. Because of the reducing conditions in the blast furnace, it is not possible for any of the sulfur present in the charge materials to be oxidized and leave the blast furnace as sulfur dioxide. Sulfur balances, based on chemical analyses of the iron and slag, have shown this to be the case. However, chemical analyses of slags are subject to variations, and such balances do hold a possibility for error. Analysis of blast-furnace gases during full-scale tests of oil-injection in the Bureau of Mines experimental blast furnace verified that sulfur gases are absent from the flue gas. Quoting from the reports, "It was suggested that some of the sulfur from the oil might leave the furnace in the top gas. However, careful analyses of the top gas throughout the test program showed no traces of sulfur compounds."(7)

A sulfur balance for a blast furnace operating with sinter and screened ore (based on the material balance for a blast furnace shown in Figure C-24 in Appendix C) is given in Table V-11.

TABLE V-11. SULFUR BALANCE FOR BLAST FURNACE FROM FIGURE C-24 IN APPENDIX C

(Based on Production of One Net Ton of Pig Iron)

Item	Amount, pounds	Sulfur Content, percent		Amount of Sulfur, pounds
		Input		
Sinter	2300	0.055		1.26
Screened ore	790	0.040		0.32
Coke	1025	0.700		7.18
Limestone	125	0.049		0.06
Natural gas	45	Nil[a]		--
			Total	8.82
		Output		
Pig iron	2000	0.030		0.60
Slag	460	1.786		8.22
			Total	8.82

(a) Columbia Gas stated that the sulfur content of natural gas is less than 0.001 percent.

When sulfur-bearing slag is flushed from the blast furnace, the sulfur reacts with oxygen to form sulfur dioxide near the runner of the blast furnace. In wet weather, the sulfur in the solid slag may react with water to form hydrogen sulfide which is released to the atmosphere. The latter reaction also occurs during the granulation of hot slag with water.

Open Hearth Steelmaking

Sulfur enters the open hearth steelmaking system from the raw materials and from the fuels used for combustion. A comprehensive survey conducted on sulfur balances in open hearths showed average source values listed in Table V-12(8). Other investigators have shown that the type of scrap can influence sulfur pickup by the scrap from the fuel, with subsequent partition of the sulfur to the slag or metal. The results showed that heavy scrap resulted in a sulfur pickup of 0.015 percent, while a light scrap melted with the same fuel resulted in a sulfur pickup of 0.044 percent(9). Natural-gas firing in open hearths is also reported to remove sulfur from the charge materials up to as much as 0.020 percent(9). This means that even though a sulfur-free fuel is used, sulfur emissions to the atmosphere may occur because of pickup of sulfur from the open-hearth charge materials. It has been reported that 25 percent of the sulfur in fuel oil used to fire open hearths is retained in the metal and slag, and that this entire amount is absorbed by the scrap during the meltdown period of the heat(10). A relationship between the sulfur content of the fuel oil and the effect of increasing sulfur content on the final sulfur in the steel is shown in Figure V-10.

TABLE V-12. SOURCES OF SULFUR IN OPEN HEARTH STEELMAKING

Source	Sulfur Concentration, percent
Hot metal	38
Fuel	22
Scrap	19
Limestone	14
Ore	5
Others	2

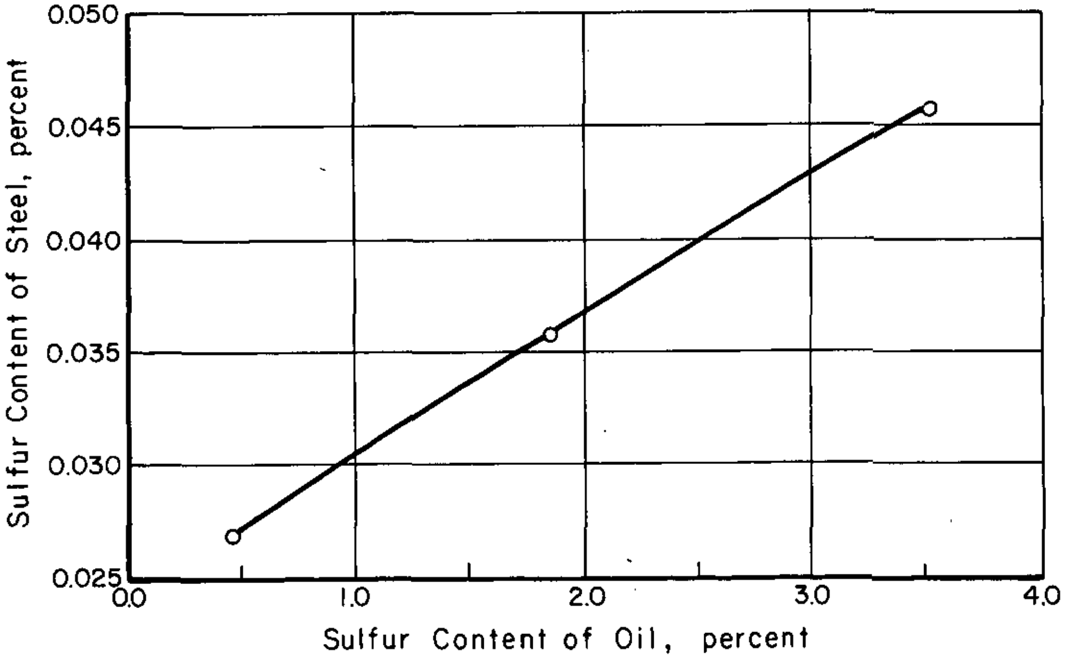

FIGURE V-10. SULFUR CONTENT IN STEEL AS AFFECTED BY INCREASED SULFUR IN FUEL OIL

About 47 percent of the sulfur entering the open-hearth system leaves in the metal and slag. The remaining sulfur exits with the products of combustion in the form of sulfur dioxide. A sulfur balance for an open-hearth furnace using 60 percent hot metal and 40 percent steel scrap (as shown in the flow sheet and material balance in Figure C-41 in Appendix C) is given in Table V-13.

TABLE V-13. SULFUR BALANCE FOR OPEN HEARTH FURNACE WITH 60 PERCENT HOT METAL AND 40 PERCENT STEEL SCRAP OXYGEN PRACTICE (FROM FIGURE C-41 IN APPENDIX C)

(Based on Production of One Net Ton of Raw Steel)

Item	Amount, pounds	Sulfur Content, percent		Amount of Sulfur, pounds
		Input		
Hot metal	1361	0.030		0.41
Steel scrap	907	0.020		0.18
Iron ore	70	0.040		0.03
Flux	150	0.049		0.07
Fuel oil	111	0.55		0.61
Ferroalloys	14	0.07		0.01
			Total	1.31
		Output		
Steel and scrap	2060	0.02		0.41
Slag	200	0.10		0.20
Combustion gases				0.70
			Total	1.31

Basic Oxygen Furnace Steelmaking

The major source of sulfur in the basic oxygen steelmaking process is the sulfur in the hot metal from the blast furnace. External fuels are not required to supply heat to bring about the desired chemical reactions for refining. High-purity gaseous oxygen impinged on the surface of the molten iron causes rapid oxidation of silicon carbon, and iron; which in turn supplies the heat necessary for completion of refining.

Slag chemistry controls the removal of sulfur from the hot metal during the refining operation, in a manner similar to that for other steelmaking processes. The major difference in the BOF process is that burnt lime (CaO) is used to provide the desired slag characteristics, rather than limestone ($CaCO_3$), as in open-hearth steelmaking. The rapidity of the refining process in BOF practice (again as compared to open hearth practice) dictates this requirement. There is not sufficient time to calcine limestone. The effects of slag basicity $\left(\text{in this case the ratio of } \frac{CaO}{SiO_2}\right)$ on the sulfur content of the refined steel is shown in Figure V-11(11). A relationship between the sulfur content in the hot metal and sulfur content in the steel as affected by slag basicity is shown in Figure V-12. The percentage of sulfur removed from the hot metal as affected by slag basicity is shown in Figure V-13(11). Sulfur content of the burnt lime has little effect on the final sulfur content of the steel, as shown in Figure V-14(11). The relationships shown in Figures V-11 through V-14 can be considered as representative of sulfur removal in basic oxygen steelmaking practice. Specific results may vary from plant to plant depending on the silicon content of the hot metal, sulfur content of the scrap, and specific slag practices.

A sulfur balance for a BOF practice using 70 percent hot metal and 30 percent steel scrap, and based on the material balance shown in Figure C-55 in Appendix C, is given in Table V-14. Almost all of the sulfur leaves the system in the metal and slag, with only about 4 percent of the sulfur leaving as sulfur dioxide in the off-gas. Detailed information on the sulfur content of BOF off-gases is not available in the published literature.

TABLE V-14. SULFUR BALANCE FOR BOF STEELMAKING BASED ON MATERIAL BALANCE GIVEN IN FIGURE C-55 WITH 70 PERCENT HOT METAL AND 30 PERCENT STEEL SCRAP

(Based on Production of One Net Ton of Raw Steel.)

Item	Amount, pounds	Sulfur Content, percent	Amount of Sulfur, pounds
		Input	
Hot metal	1581	0.030	0.47
Steel scrap	678	0.020	0.14
Burnt lime	142	0.060	0.08
Ferroalloys	14	0.070	0.01
		Total	0.70
		Output	
Steel and scrap	2077	0.020	0.41
Slag	263	0.100	0.26
Sulfur in off-gas			0.03
		Total	0.70

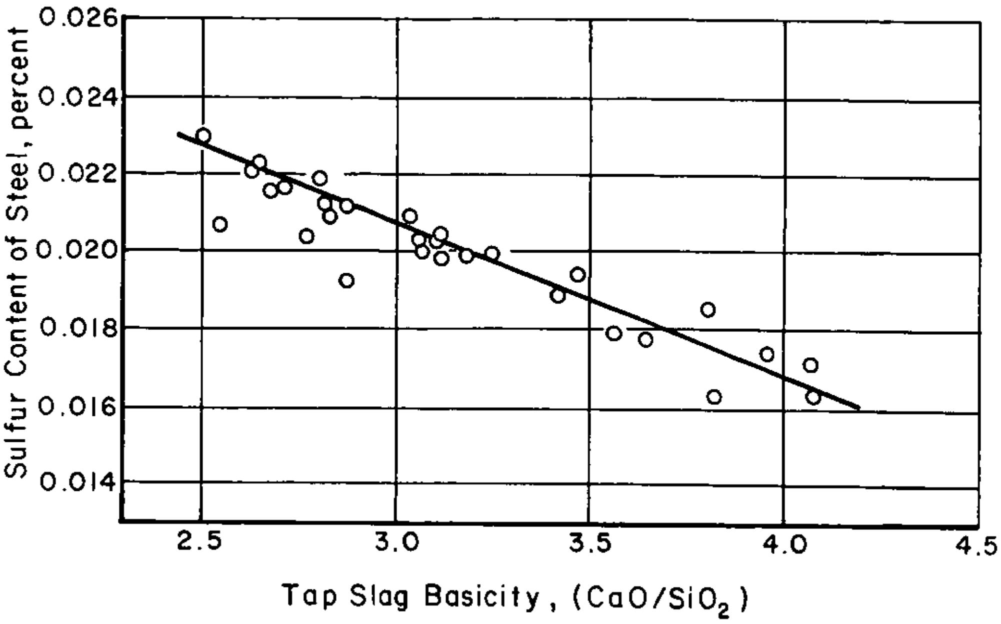

FIGURE V-11. SULFUR CONTENT OF BOF STEEL AS AFFECTED BY BASICITY OF THE TAP SLAG

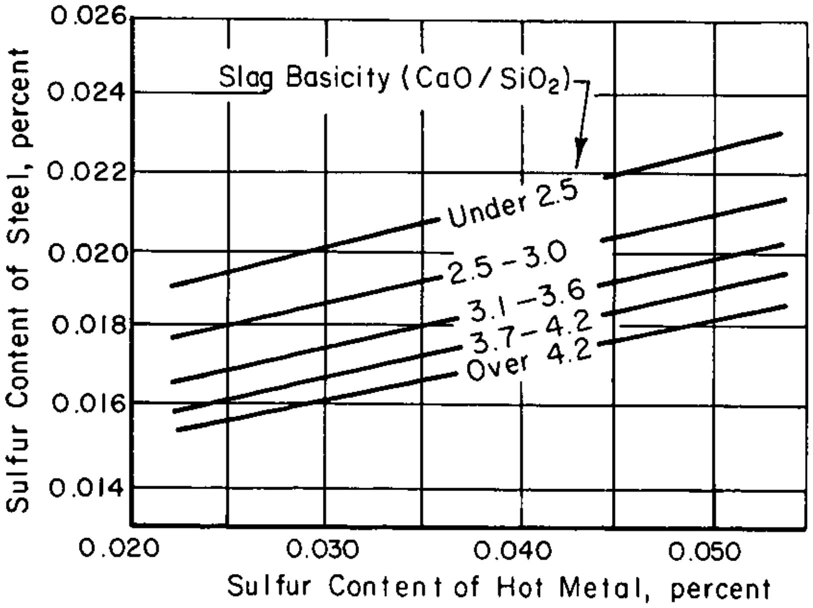

FIGURE V-12. RELATIONSHIP BETWEEN SULFUR CONTENT IN HOT METAL AND SULFUR CONTENT IN BOF STEEL AS AFFECTED BY SLAG BASICITY

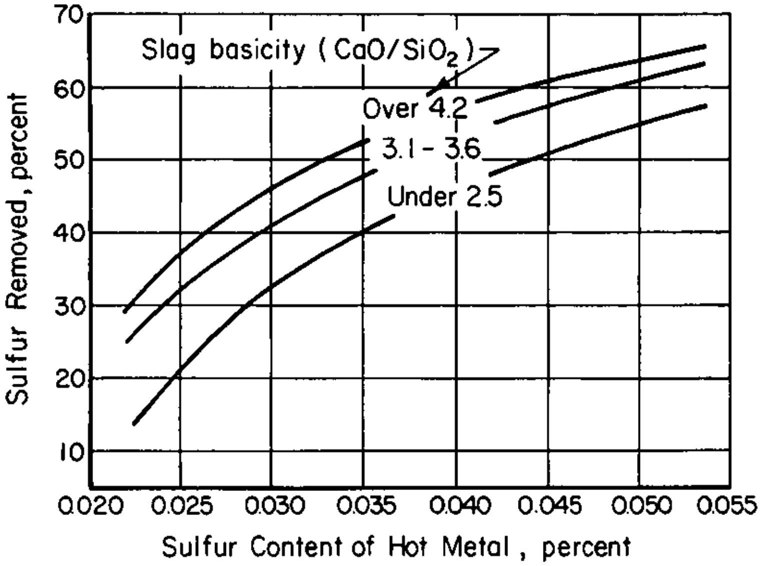

FIGURE V-13. EFFECT OF SLAG BASICITY ON THE PERCENT OF SULFUR REMOVED FROM THE HOT METAL

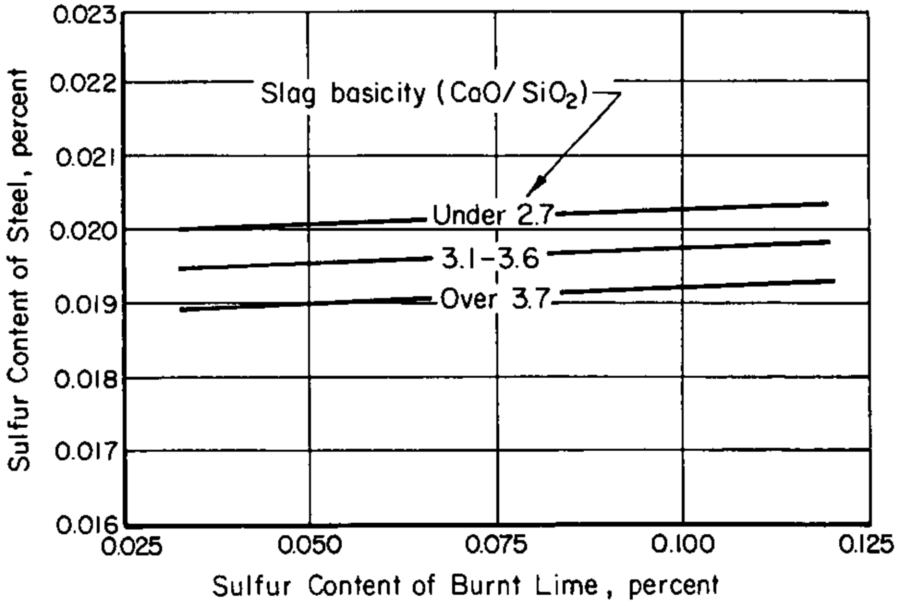

FIGURE V-14. EFFECT OF SULFUR CONTENT IN THE LIME AND SLAG BASICITY ON THE SULFUR CONTENT OF BOF STEEL

Electric Furnace Steelmaking

Like the BOF process, the electric-furnace steelmaking process does not depend on a sulfur-bearing fuel as the major source of energy. Electrical energy provides the heat for melting and refining steel scrap to produce molten metal. Sulfur enters the system with the steelmaking raw materials. Small amounts of coke breeze are added to provide carbon for the carbon boil during the refining period. As in the other steelmaking processes, slag control plays a major role in removal of sulfur from the steel. Because many high-carbon steels are made in electric furnaces (as compared to the lower-carbon steels made in open hearths and BOFs), the carbon content of the steel produced must also be taken into consideration in the desulfurization slag practice. A relationship between the carbon content of the steel and the sulfur content for several different kinds of steel made in two different plants is shown in Figure V-15(12, 13). The relationship between slag basicity and the partition of sulfur between the metal and slag is shown in Figure V-16(14). The effect of the time under a reducing slag on the sulfur content of AISI 52100 steel is illustrated in Figure V-17(12). The percent reduction in sulfur content for several high-carbon steels made in electric furnaces is shown in Figure V-18(13).

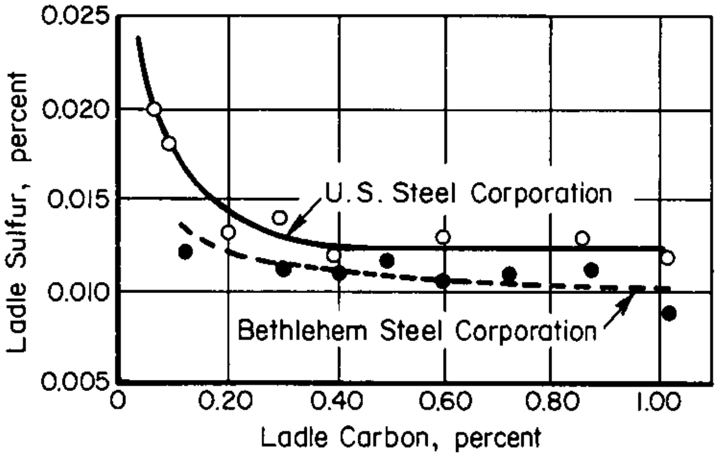

FIGURE V-15. RELATIONSHIP BETWEEN CARBON CONTENT IN THE STEEL AND SULFUR CONTENT IN THE STEEL

A sulfur balance for electric-furnace steelmaking (based on the material balance given in Figure C-65 in Appendix C) is given in Table V-15. Data on the sulfur content in electric-furnace steelmaking off-gases are not available in the published literature.

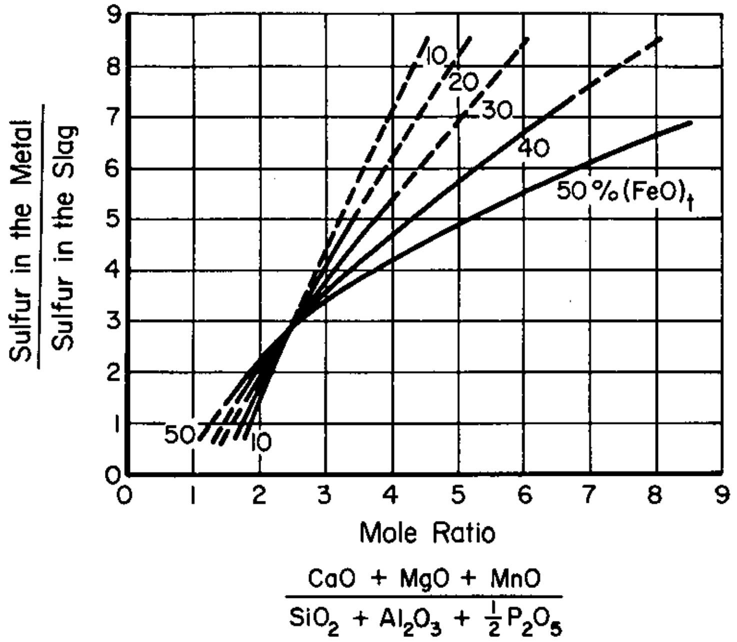

FIGURE V-16. RELATIONSHIP BETWEEN SLAG BASICITY, IRON OXIDE CONTENT OF THE SLAG, AND THE PARTITION OF SULFUR BETWEEN THE METAL AND THE SLAG

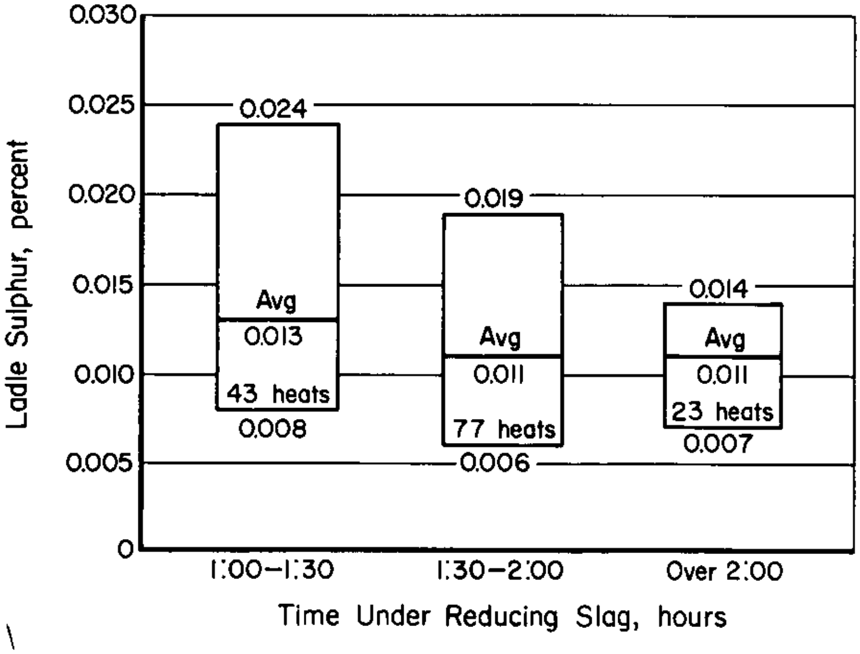

FIGURE V-17. EFFECT OF TIME UNDER A REDUCING SLAG ON THE SULFUR CONTENT OF AISI 52100 GRADE STEEL

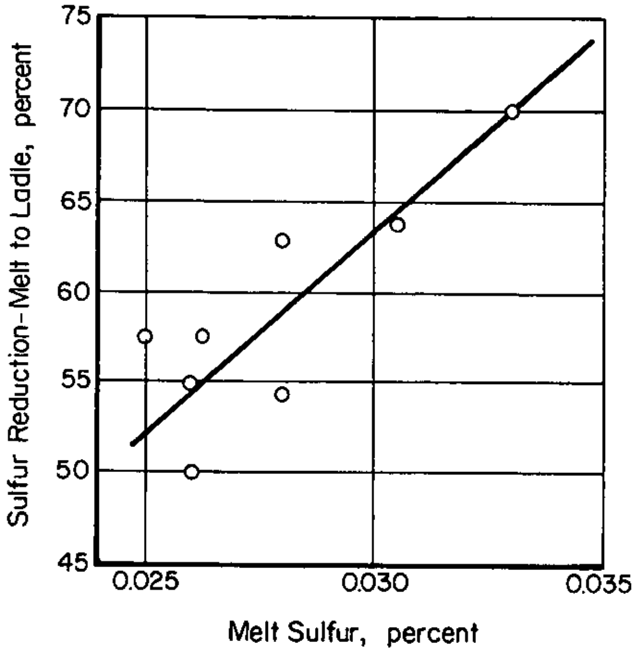

FIGURE V-18. SULFUR REDUCTION IN ELECTRIC FURNACE STEELMAKING

TABLE V-15. SULFUR BALANCE FOR ELECTRIC FURNACE STEELMAKING USING A CHARGE OF COLD STEEL SCRAP AND OXYGEN PRACTICE (FROM FIGURE C-65 IN APPENDIX C)

(Based on the Production of One Net Ton of Raw Steel)

Item	Amount, pounds	Sulfur Content, percent		Amount of Sulfur, pounds
		Input		
Steel scrap	2136	0.020		0.43
Coke breeze	6	0.700		0.04
Burnt lime	99	0.060		0.06
Ferroalloys	14	0.070		0.01
			Total	0.54
		Output		
Steel and scrap	2060	0.020		0.42
Slag	140	0.080		0.11
Off-gas				0.01
			Total	0.54

Summary Balance of Sulfur for Iron and Steel Industry

The amounts of sulfur-bearing raw materials and fuels consumed in the U. S. iron and steel industry were tabulated from The Statistical Yearbook (1967) of the AISI. The average sulfur content of the materials was estimated to compile a tentative sulfur balance for the U. S. steel industry. The resulting tentative summary balance for sulfur is given in Table V-16. The tentative and uncertain nature of this balance should be recognized. In particular, gaseous emissions were obtained by difference. This is a hazardous procedure, but the best available for estimation using the presently available data. Some additional research on this subject undoubtedly could produce balances with a higher degree of authenticity.

Nearly 76 percent of the sulfur input to the system came from the coal used to produce coke and to generate electric power. Iron ore accounted for 9.8 percent of the sulfur input. Steel scrap, fluxes and ferroalloys resulted in an input of about 4 percent of the sulfur. Fuels for the open hearth furnace operation (oil, tar, and pitch) accounted for about 3.3 percent of the sulfur input. Providing that the coke-oven gas was consumed in the coke oven, blast furnace stoves, and soaking pits; almost all of the sulfur input would be in the iron and steelmaking area.

The output of sulfur in the blast furnace slag is about 47 percent of the total sulfur entering the system. The steel and steelmaking slag contain about 6 percent of the sulfur output. According to this calculation, 39 percent of the sulfur would be in off-gas or in products of combustion, and 8 percent unaccountable.

In the heating of steel for rolling or forging, there is no change in the sulfur content of the steel. When heating with natural gas with a low sulfur content or with electric power, little or no sulfur would appear in the products of combustion.

If sulfur-bearing fuel oil or gas is used for heating or for reheating furnaces, the sulfur in the form of SO_2 will be in the exhaust gas. During processing, the scale on steel may absorb sulfur in an amount up to 1 percent when sulfur is present in the exhaust gas.

CO Balances for the Iron and Steel Industry

Three steelmaking process segments normally produce an off-gas containing substantial amounts of CO: (1) coke-oven gas contains from 4.5 to 6.9 percent CO, depending upon the coal used during the coking process; (2) the blast-furnace top gas may have a CO content from about 20 to 30 percent, depending upon operating practice; and (3) the BOF gas before combustion with aspirated air may contain from 74 to 90.5 percent CO, and after combustion with aspirated air from 0.0 to 0.3 percent.

Off-gas from other steel-plant processes will not normally contain any appreciable amounts of CO as the combustion process is meant to go to completion. However, such gas may contain from 0.3 to 0.5 percent CO.

TABLE V-16. ESTIMATED SUMMARY OF SULFUR BALANCE FOR THE U. S. IRON AND STEEL INDUSTRY (1967)

Item		Amount, million NT	Estimated Average Sulfur Content, percent	Total Sulfur Content, NT
	Input			
Coal		82.7	0.95	(786,000)
Coking				
Coke oven gas	196,000 NT			196,000
Coke	455,000 NT			455,000
Tar and pitch	21,000 NT			
Other by-products	114,000 NT			
	786,000 NT			
Other		6.9	1.00	69,000
Iron ore		133.3	0.07	93,000
Steel scrap		65.4	0.03	20,000
Ferroalloys		2.5	0.07	2,000
Fluxes		31.4	0.05-1.00	21,000
Fuel oil				
Blast furnace		0.3	1.80	5,000
Other use (fuel)		4.7	1.80	85,000
Tar and pitch				
Blast furnace		0.2	0.60	1,000
Other use		1.3	0.60	8,000
Liquid petroleum gas		0.1	Nil	--
Natural gas		12.2	Nil	--
	Total			955,000
	Output			
Blast furnace slag		30.0	1.50	450,000
Coke	431,000 NT			
Iron ore	93,000 NT			
Flux	15,000 NT			
Fuel oil	5,000 NT			
Tar and pitch	1,000 NT			
	545,000 NT			
Sulfur to hot metal	-27,000 NT			
	518,000 NT			
Raw steel and scrap		131.7	0.03	39,000
Steelmaking slag		13.6	0.10	14,000
Fuels				
Coke oven gas	196,000 NT			
Fuel oil	77,000 NT			
Tar and pitch	8,000 NT			
Coke breeze	24,000 NT			
Coal	69,000 NT			
	374,000 NT			374,000
Possible loss from slag (518,000-450,000)				68,000
Unaccounted for				10,000
	Total			955,000

Coke-Oven Gas

A conventional size of slot oven in the United States carbonizes about 24 tons of coal per day. Table V-9 shows that about 15,000 cubic feet of coke-oven gas is produced for each ton of coke. This is about 10,000 cubic feet of gas for each ton of coal that is carbonized.

A base of carbonizing 1 ton of coal per hour was selected to illustrate the flow of coke-oven gas and its CO component:

Item	Volume Gas	CO Content
Source		
Coke-oven gas	10,000 ft^3	550 ft^3
Use		
Coke-oven gas to ovens	4,000 ft^3	220 ft^3
Other plant use	6,000 ft^3	330 ft^3
End Product		
Products of combustion from coke-oven gas	44,800 ft^3	Nil

The CO component of coke-oven gas using the above basis may vary from 490 to 690 cubic feet per hour. Under normal conditions, raw coke-oven gas will not be released to the air. However, leaks in the collecting system would release both CO and sulfur-bearing gas to the atmosphere.

Blast Furnace Top Gas

Based on Figure C-24 in Appendix C, the material balance shows the production of 6450 pounds of blast-furnace top gas per net ton of hot metal. The approximate typical disposition of the top gas and its CO component is tabulated below:

Item	Amount, pounds	CO, pounds
Source		
Blast furnace top gas	6450	1612.5
Use		
Soaking pits or other plant use	4850	1212.5
Blast furnace stoves	1600	400.0
End Product		
Combustion products from stoves	2460	Nil

The amount of CO produced per net ton of pig iron may vary from 1290 to 1935 pounds. The gas is collected and cleaned before use, and under normal operating conditions is not exhausted to the atmosphere.

BOF Process

Based on Figure C-65 in Appendix C, the BOF process produces about 168 pounds of off-gas per ton of steel. The typical and approximate disposition of the top gas and the CO component is tabulated below:

Item	Amount of Gas, pounds per net ton of steel	CO, pounds per net ton of steel
Source		
Off-gas	168	124.3-152
Aspirated air added (theoretical)	717-877	
End Product		
Total off-gas	885-1045	0-2.6

The off-gas from a BOF operation based on the example above will produce about 124 to 152 pounds of CO per ton of steel. After aspirated air is added to the off-gas, the weight of gas will increase to about 885 to 1045 pounds per ton of steel and will contain from 0 to about 2.6 pounds of CO.

During the normal operation of an iron and steel plant, only small amounts of CO would reach the atmosphere from this source.

Fluoride Emissions

The detrimental effect of fluoride emissions on vegetation has been documented and will not be discussed further here. In years past, uncontrolled emissions of fluorides from some localized steel plant operations have contributed to this situation. Because fluorspar (a calcium fluoride mineral) is used extensively in the making of steel, the industry has been suspect as a contributor to fluoride emissions. This doubt has been further advanced because no data are available concerning the fluoride emissions generated in the different steelmaking processes. A recent report on work done in Germany at August Thyssen-Hutte AG, Duisburg-Hamborn, has shown that fluoride emissions generated during steelmaking in basic oxygen furnaces and electric furnaces become bonded to the other particulates generated and are removed during the cleaning operations of existing emission control equipment(15). Analyses for fluoride emissions were made continually during the course of two, 90-ton BOF heats. The fluoride content of the emissions to the atmosphere varied from 0.000045 grain per cubic foot (STP) to 0.0005 grain per cubic foot (STP) in the first heat; and from 0.000045 to 0.0009 grain per cubic foot (STP) in the second heat. Similar tests carried out with 20-ton electric-arc furnaces showed fluoride particulate contents of 0.023 to 0.250 grain per cubic foot (STP) and gaseous fluoride contents of 0.003 to 0.025 grain per cubic foot (STP) in the raw gas. These values were reduced to 0.004 to 0.04 grain per cubic foot for particulates and 0.002 to 0.02 grain per cubic foot for gaseous fluorides. Collection efficiency for the particulate fluorides was reported to be 90 percent, while collection of gaseous fluorides was reported to be only 65 percent. The low collection efficiency for the gaseous fluorides was suggested to be due to moisture in the off-gases which combined with the gaseous fluorides to form hydrofluoric acid which in turn decomposed on the gas probes to give high gaseous emissions in the off-gas. Fluoride contents of sinter-plant waste gases were determined to vary from 0.0003 to 0.002 grain per cubic foot for particulates, and 0.0009 to 0.01 grain per cubic foot for gaseous fluorides.

Nitrogen Oxide Emissions

The amount of nitrogen oxide emissions generated in the steelmaking and allied processes is not available in the published literature. Based on results obtained in other industries, nitrogen oxide emissions probably occur in the steel industry. Because natural gas is used quite extensively in the iron and steel industry, this alone would indicate a source of nitrogen oxide emissions. Gas analyses, specifically for nitrogen gases, apparently have not been considered as a matter for even sporadic attention by the steel industry.

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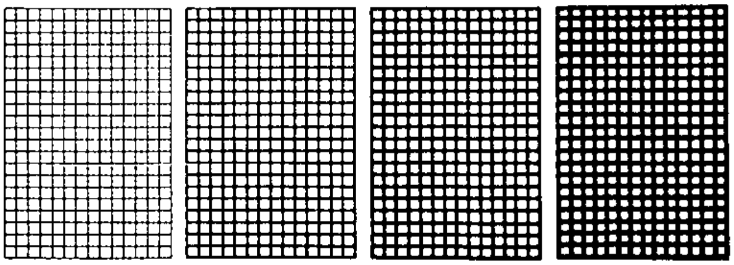
SECTION VI

ANALYSIS OF APPLIED CONTROL SYSTEMS

An explicit analysis of the various air-pollution control systems as they are applied in the integrated iron and steel industry would of necessity be based on complete, accurate, first-hand information pertaining to the various systems as they perform their function in various iron and steelmaking operations. Unfortunately, information with these qualities has not been readily available in Phase I. Therefore, analysis as it applies to this study must be based to a considerable degree on (1) what the capabilities and limitations of various systems appear to be, (2) information available in the published literature, and (3) information obtained by visitations to selected plants during the study.

An analysis of several comparable pieces of equipment, processes, process components, or materials usually is made with reference to some common standard or boundary conditions. A well-defined, generally accepted standard of reference for comparing performance of equipment for controlling metallurgical emissions to the air is not yet available. One standard that is used as a means of rating some pollution-control systems is highly dependent on personal evaluation. This is the "Ringelmann Chart" illustrated in Figure 1.(1)* Development of the Ringelmann Chart was done on an arbitrary basis by Maximilien Ringelmann (of France) and was introduced to the technical community of the United States in 1897 via a technical news publication. The Technologic Branch of the U. S. Geological Survey (predecessor to the Bureau of Mines) used the chart in studies of smokeless combustion in 1904, and by 1910 the chart was recognized officially in Boston smoke ordinances.(2) Over the years, the Ringelmann Chart has become accepted in the United States as a means of determining emission levels. It has been only recently that equipment has been developed to monitor emissions from a steelmaking process – the basic oxygen furnace.(3) Monitoring of emissions by this new method is based on grain loading per cubic foot of gas Equipment manufacturers are reported to be unwilling to supply pollution-control equipment to any Ringelmann requirement for metallurgical emissions, but do supply equipment to meet the various grain-loading requirements.(4)



Equivalent to 20 per cent black. Equivalent to 40 per cent black. Equivalent to 60 per cent black. Equivalent to 80 per cent black.

FIGURE VI-1. RINGELMANN SMOKE CHART

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* References for Section VI-1 are given at the end of the Section.

Comparison of reported operating efficiences for the various emission-control installations covered in this study is done on the basis of grain loadings per cubic foot of exhaust gas. This method of comparing operating efficiences is used because there appears to be no better method of making comparisons.

Even with the use of specific operating data, comparisons based on theoretical calculations are not considered to be sufficient for good comparisons, as shown by the following statements made in 1963(5):

> "A rational theoretical equation covering all mechanisms in filtration does not yet exist nor is there an exact overall equation for electrostatic charging and separation for all sizes considering all properties of particles in an electrostatically charged field."

> "For the more complex cases we will still depend on 'pilot plant' evaluations because of the economic risk in selecting a collector if only a limited number of parameters can be resolved by the best measuring techniques."

According to technologists knowledgeable in this area of air-pollution control technology(6), these same statements hold true in 1968.

The selection of an air-pollution control system for a particular ironmaking or steelmaking process or process segment is not a straightforward, "off the shelf" type of selection. Process variables, space availability, operating costs, inherent control-equipment advantages, and future allowable-emission regulations must all be considered in selecting emission-control equipment.(7) The factor of future allowable-emission levels is of major concern because no one knows what these standards may be, and steel companies are in a position of installing equipment without knowing what future requirements will be. Usually, equipment installed to meet one level of control cannot be upgraded inexpensively to meet a stricter level.

Many ordinances of a local nature establish requirements for allowable emissions at the level of 0.05 grain per cubic foot of gas. However, this is not to say that this will continue to be the acceptable level of allowable emissions. Color of emissions and other factors are rapidly becoming points of concern to the steel industry and regulatory agencies.

The effect of particulate emissions on weather patterns is currently under study by the National Center for Atmospheric Research. A recent report contains the following statements with respect to the generation of ice nuclei and their possible effect on increased rainfall(8):

> "A search was made for strong local sources of ice nuclei. Apart from dust blown up by strong winds, steel mills have proven to be the only source."

> "The test on 15 August was made to locate the source of the nuclei-which was traced to two orange plumes emanating from two stacks of a Gary steel mill."

From the situations presented by these statements, it is apparent that the level of allowable emissions is not stabilized, and the definition of an air pollutant has not been completely resolved.

A factor affecting the economics of air-pollution control in the iron and steel industry is the amount of allowable emissions based on the weight of materials processed. The Los Angeles County, California, Air Pollution Control District permits a maximum discharge weight of 40 pounds per hour for a process weight of 30 or more tons per hour(9). This is based on the discharge from a single stack. If two or more steelmaking furnaces, each making 30 tons per hour of steel, are operated simultaneously and the emissions collected by a manifolding system for collection, the allowable discharge to the atmosphere is still only 40 pounds per hour. This means that the collection system would have to be designed and constructed to a higher level of efficiency at an increased cost.

This analysis of the various types of emission-control equipment used in the integrated iron and steel industry deals primarily with the types of equipment as they apply to the various process segments; additional analytical consideration is given to process segments that have problems associated with the process itself, rather than with the collection equipment (such as coke making). As a point of information, a preliminary tabulation of the types of equipment used in the various processes is given in Table VI-1. This tabulation is not complete, and is based mainly on information in the published literature. The tabulation shows, however, that electrostatic precipitators have found the greatest application in the iron and steel industry; followed by scrubbers, mechanical collectors (which are primarily cyclones), and fabric filters (bag houses).

TABLE VI-1. REPRESENTATIVE EMISSION-CONTROL APPLICATIONS IN THE INTEGRATED IRON AND STEEL INDUSTRY

Iron or Steelmaking Segment	Type of Emission-Control Equipment			
	Mechanical	Scrubbers	Precipitators	Fabrics
Sinter plant	17	2	9	3
Blast furnace[(a)]	13[(b)]	51	108	0
Open-hearth furnace	0	6	93	0
Basic oxygen furnace	0	15	23	0
Electric furnace	0	5	1	29
Scarfing	4	4	3	2

(a) Final control equipment.

(b) Dust collectors followed by other equipment are not considered.

Electrostatic Precipitators

The removal of dust particles (primarily iron oxide) from exhaust gases of ironmaking and steelmaking processes is accomplished by passing the dust-laden gas between a pair of electrodes; one being a discharge electrode at a high potential and the other an electrically grounded electrode (which is the collecting electrode). The potential difference must be great enough to establish a corona discharge around the discharge electrode. Gas ions formed in the corona move rapidly toward the collecting electrode under the action of the electrical field, and transfer their charge to the dust particles by collision with them. The electrical field interacting with the charge on the particles causes the particles to drift toward the collecting electrode and to be deposited on the collecting electrode.(10)

Electrostatic precipitators are of two types, (1) wire-in-tube and (2) wire-and-plate (see Figures B-5 and B-6, in Appendix B). The wire-and-plate type is generally used for the control of emissions in the integrated iron and steel industry.

The electrical theory used to design electrostatic precipitators is well developed, and will not be discussed here. Interested readers can refer to some of the texts on the subject.(10, 11, 12) In addition to the electrical environment within the precipitator, other factors that affect the performance of electrical precipitators include (1) resistivity of the dust, (2) its moisture content, (3) the gas-flow rate, and (4) the distribution of gas flow within the precipitator.

Resistivity must be taken into account in the initial design phases of the precipitator. This information must either be obtained by experimental methods or be available from studies on similar operations. The variability of resistivity for processes producing iron oxide dusts is illustrated in Figure VI-2.(11, 13) The wide range of resistivities that can be encountered makes it preferable to determine resistivities for the specific process than to rely on speculation.

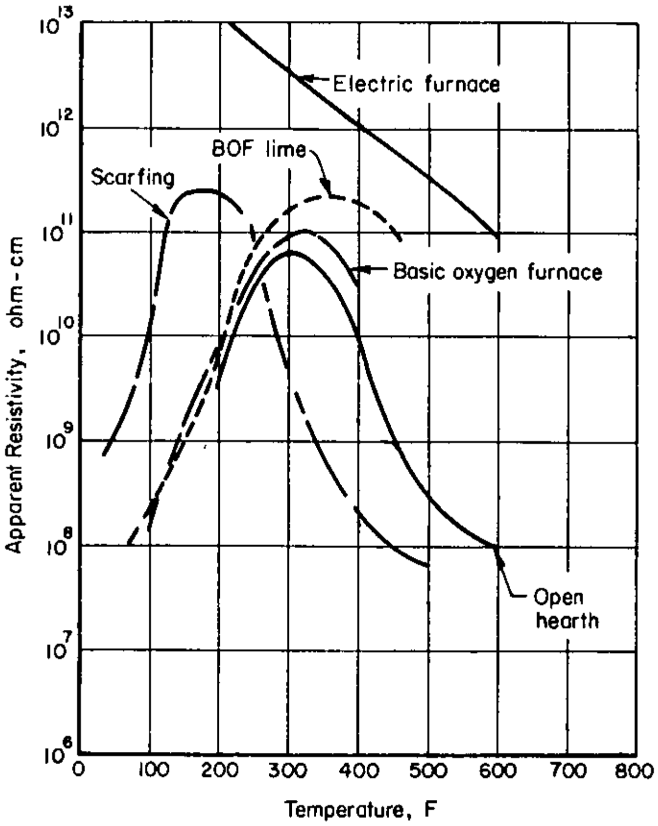
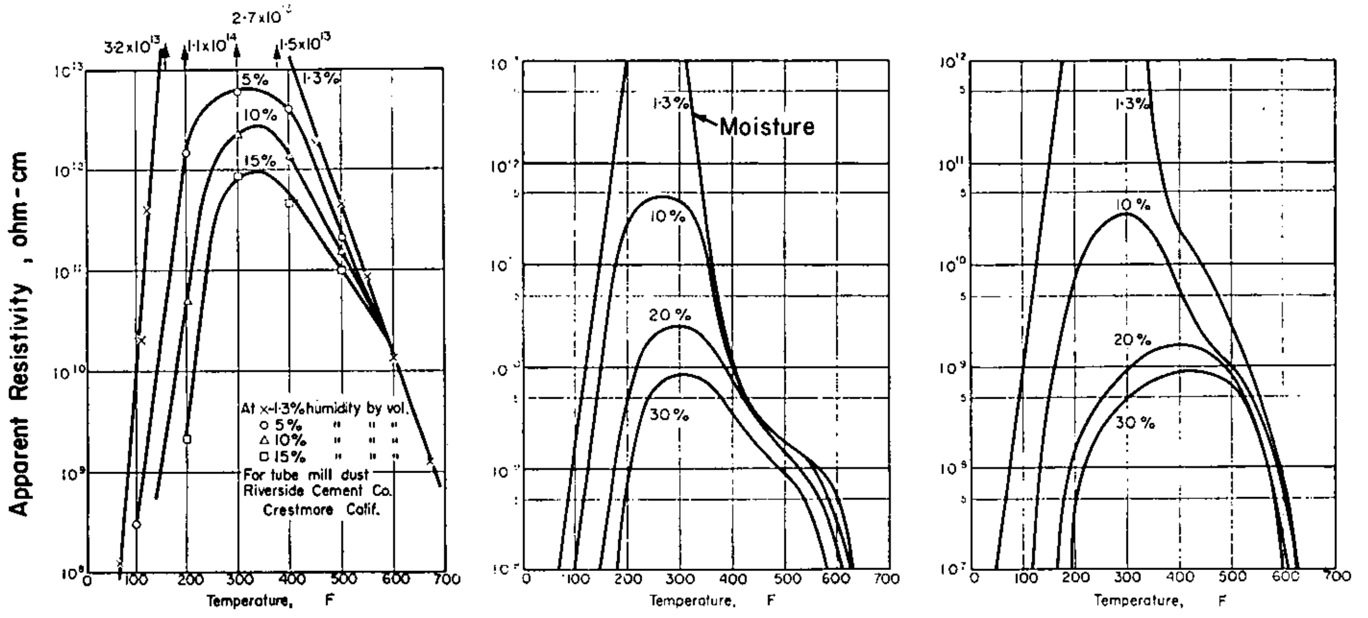


FIGURE VI-2. APPARENT RESISTIVITIES OF METALLURGICAL DUSTS

Dusts can be conditioned to lower the resistivities and to make dust collection easier in the electrostatic precipitator. The lower the resistivity of the dust, the less electrical power is required to affect collection. Conditioning of metallurgical dusts for collection is done in the iron and steel industry by the addition of water, which serves the purpose of cooling the gases in addition to conditioning them. Figure VI-3 shows the variation in resistivity as it is affected by temperature and moisture content.(14) Here again, the difference in resistivities for the fume for two different open hearths is apparent, and illustrates the necessity for knowledge about the characteristics of specific fumes. The great difference in resistivities between limestone dust and the open-hearth dust points up a factor that can cause operating problems in the operation of electrostatic precipitators for collecting open-hearth and BOF fume. Dust resulting from the use of limestone ($CaCO_3$) as a fluxing agent in open hearths can cause less than-optimum performance of the electrostatic precipitator because of this large difference in resistivities. Similar problems are associated with the use of lime (CaO) as a fluxing agent in BOF practice.



Limestone Dust

Open Hearth Dust

Open Hearth Dust

FIGURE VI-3. APPARENT RESISTIVITIES AS AFFECTED BY MOISTURE

High gas-flow rates that exceed the designed flow rate for the installation adversely affect the performance of electrostatic precipitators. Gas-flow rates have a direct influence on the operating efficiency of precipitators, and this effect can be shown by using an expression developed for precipitator efficiency(10, 15):

$$E = 1 - e^{-\left(\frac{A}{V}\right)w} ,$$

where

E = efficiency
A = collecting-surface area in square feet
V = gas-volume flow in cubic feet per second
w = drift velocity in feet per second.

Values of "w" determined by using data obtained from commercial installations do not agree with values determined on the basis of theoretical calculations.(15) Because experimentally determined values are generally one-half the theoretical values, the drift velocity for commercial installations should be determined experimentally. The relationships among the various efficiency factors is illustrated in Figure VI-4.

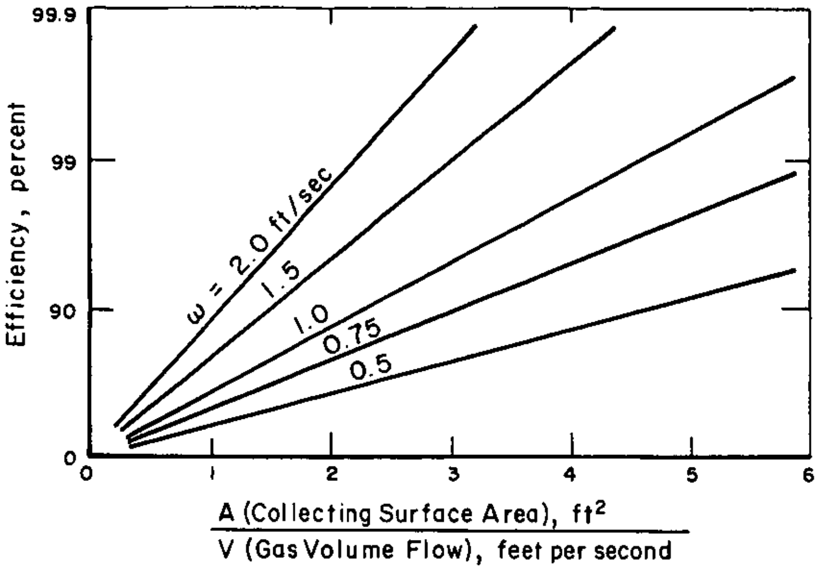


FIGURE VI-4. PRECIPITATOR EFFICIENCY AS RELATED TO COLLECTING-SURFACE AREA, GAS-FLOW RATE, AND DRIFT VELOCITY

The effect of variations in gas-volume flow on precipitator efficiency is illustrated in Figure VI-5. The decrease in efficiency as the rated volume of the precipitators is exceeded is quite evident.

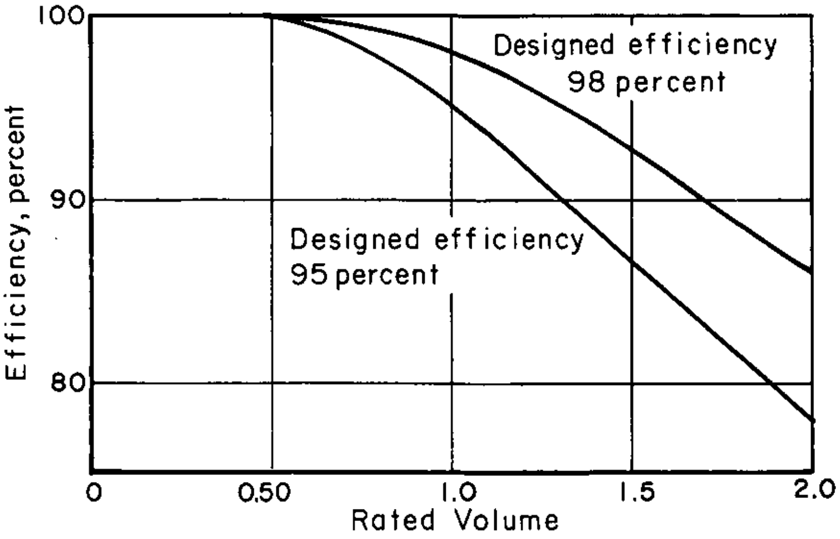


FIGURE VI-5. EFFECT OF GAS VOLUME ON PRECIPITATOR EFFICIENCY

Electrostatic precipitators are used for a variety of processes in the iron and steel industry, ranging from their use in sinter plants to their application in scarfing operations.

Sinter-Plant Applications of Electrostatic Precipitators

The very nature of a sinter plant (with its multitude of transfer points for materials, and discharge points for receiving, cooling, and screening the sinter) creates a severe emission problem. Various types of pollution-control equipment are used for a single plant; or if the operation can be sufficiently enclosed, a central pollution-control installation may suffice. Electrostatic precipitators are used as secondary air-cleaning units in sinter-plant operations for the treatment of dust-laden gases coming from sintering-strand windboxes. The only reported information located on dust loadings for electrostatic precipitators on sintering machines is that for the Inland Steel Company sintering machine in East Chicago, Indiana. This installation was reported to handle an input dust loading of 2.5 grains/scf of gas at 457,000 cfm, and yield an output dust loading of 0.038 grain/scf gas;(16) an efficiency of 98.5 percent. However, since the pollution-control system was installed, the materials charged to the sintering machine have changed from straight ore fines to ore, flue dust, and lime. The characteristics of the ore used has also changed. These changes in materials have resulted in an increase of output dust loading to 0.25 grains per cubic foot, and a decrease in collection efficiency to 90 percent.

Installation of most sintering machines in the United States was done at a time when the advantages of self-fluxing sinter as blast-furnace burden had not been well established. However, with the advancement of sinter technology, the use and production of self-fluxing sinters became the rule rather than the exception. Lime additions required in the production of self-fluxing sinters created increased dust problems for the dust-collecting systems, with the result that additional electrostatic precipitator capacity was required(17), or use was made of other types of equipment that were not as vulnerable to such changes in operating procedures.

Blast-Furnace Applications of Electrostatic Precipitators

The use of electrostatic precipitators for cleaning blast-furnace gas has come about because of the requirements for cleaner gas for the hot-blast stoves. Trends toward the use of higher blast temperatures required the use of checker bricks with smaller holes, which in turn dictated the requirement for cleaner blast-furnace gas to prevent plugging of the holes. Plugging would present major problems in efficient operation of the blast stoves. In all recorded installations, electrostatic precipitators have been added to the existing emission-control systems on blast furnaces.

Operating problems have not been a point of major concern for application of electrostatic precipitators to blast-furnace emissions. There are two possible reasons for this trouble-free operation. First, the blast furnace is an almost continuous producer of gas, except for the comparatively short intervals when the blowing rate of the blast furnace is lowered during the time slag is flushed or iron is cast. Second, a high percentage of the particulate emissions are removed by the wet-scrubbing systems that had previously been used to clean the gases. In addition to performing a significant cleaning operation, the wet scrubbers serve to condition the gases prior to their entry into the electrostatic precipitator.

Open-Hearth Applications of Electrostatic Precipitators

Use of oxygen lancing in the refining of steel in open-hearth furnaces made the use of some type of pollution-control equipment mandatory. Electrostatic precipitators were used first in the treatment of this emission problem. They were a rather logical choice because some existing open hearths made use of waste-heat boilers to recover heat and to generate steam from the exhaust gases, so no additional conditioning equipment was required.

Electrostatic precipitators can be applied to open hearths in various ways. The first installations in 1953 were essentially a precipitator for each open hearth. Kaiser Steel Corporation, Fontana, California, installed one precipitator for each of nine open hearths(18), and in the same year the U. S. Steel Corporation (at its Fairless Plant) installed twin, parallel precipitators for each of nine open hearths(19). In 1959, U. S. Steel installed four electrostatic precipitators to treat emissions from 11 open hearths(20), followed by Bethlehem Steel's (Sparrows Point) installation of six precipitators for seven furnaces(21), and Weirton's 1965 installation of one precipitator for two open hearths(22). *This sampling of installations appears to suggest indecision on* the part of the various companies as to what type of precipitator installation best suited their particular open-hearth shops. This however, was not necessarily the case. Availability of space was a major factor in many cases in determining whether to use one precipitator per furnace or not. Most of the earlier installations did have sufficient space available, and there were technological uncertainties about the suitability of the precipitators. These factors encouraged the use of one precipitator per furnace. U. S. Steel's installation of four precipitators to serve 11 furnaces was the first attempt at manifolding the gas off takes from the furnaces into a common collecting main that in turn channeled the gases into four precipitators.

Manifolding of the exhaust gases from 11 open hearths served two purposes: (1) it provided a mixing of the waste gases so that the temperature would not exceed 600 F, even though two waste-heat boilers could be by-passed with the discharge of waste gases at 1200 F into the collecting main, and (2) a diluting of the fume and dust took place with the result that the gas entering the precipitator had a more uniform dust loading.(20) Diluting and mixing of the dust was a particular advantage because the open-hearth furnaces in the shop were at different stages of processing the heats at any given time, and at any instant the generation of emissions was different from each furnace. One of the most-recent precipitator installations (1968) for open hearths uses manifolded gas collection. Inland Steel Company's seven-furnace open hearth shop at Indiana Harbor, East Chicago, Indiana, has one large precipitator.(23) The new installation at Youngstown Sheet and Tube Company's, Campbell Works will make use of essentially a one-to-one installation with six precipitators for seven furnaces.(24) The first unit was placed into operation in October, 1968.

Two major problems that have faced steel companies and equipment manufacturers in the installation of electrostatic precipitators for open hearths have been (1) the design of the ducts used to carry the gases from the open hearths to the precipitators, and (2) the design of the gas-distribution systems at the entrance to the precipitators. Even though a great deal of theoretical knowledge is available on the design of ducts, the use of transparent models is considered to be almost a necessity in the practical design of ducting. This approach was used in the design of the precipitator system at Kaiser in 1953(18), at Bethlehem – Sparrows Point in 1961(21), and at Weirton in 1965(22).

The major problem with respect to actual efficiency of electrostatic precipitators on open hearths is the open-hearth process itself. The problem stems from the variations in fuel used during the open-hearth refining of steel, which in turn affects the moisture content of the gases.(25, 26) A dry-gas condition occurs shortly after the hot-metal addition, and lasts for about 15 to 20 minutes. The low moisture content is caused by a low fuel-firing rate, low use of atomizing steam, and a low initial oxygen-lancing rate.(26) The moisture content drops as low as 2 percent, which is a basic cause of poor efficiency, because low moisture levels result in higher resistivities with accompanying higher power requirements to achieve collection of the fume. In some cases, the situation may be corrected in two ways: (1) power input to the precipitator can be increased, or (2) a steam-injection system can be installed to supply the desired moisture. Increased power may be ineffective, as in the case of lime which causes back ionization.

Basic-Oxygen-Furnace Applications of Electrostatic Precipitators

Electrostatic precipitators were not the first type of pollution-control equipment installed on basic oxygen furnaces. The first system was a wet system that was combined with a distintegrator at McLouth Steel Corporation in 1955.(25) The first electrostatic precipitators were placed into service in 1957 by Jones and Laughlin at their Aliquippa plant, followed in 1958 by the Kaiser Steel Corporation at Fontana, California.(26) A list of the basic oxygen steelmaking shops in the United States, with their respective pollution-control equipment is given in Table VI-2. The compilation is based on the latest available information pertaining to current installations, plus reported plans for new installations.

Problems associated with applications of electrostatic precipitators to basic oxygen furnaces are basically those of variability in gas flow and the moisture content and temperature of the entering gases, (which are functions of the process) and of maintenance. Gas-flow rates for the process must be determined on the basis of theoretical calculations(27), or on data obtained from similar operations. Calculation of theoretical gas volumes is quite straight-forward and can even be developed as a nomograph, as shown in Figure VI-6, that was developed as part of this study. As illustrated by the dashed line in Figure VI-6, the off-gas volume for a 220-ton BOF heat using 70 percent hot metal at 4.0 percent carbon, an excess air factor of 100 percent, and a blowing time of 20 minutes would be 53,000 cfm. However, elimination of carbon from the hot metal is not the only source of carbon monoxide, and it appears that reactions in the hot metal and slag contribute additional gases. This is illustrated in Figure VI-7, which shows gas evolution from three different plants as they compare to the theoretical maximum values.(28)

A significant design problem that is encountered in the design of electrostatic precipitators for new basic oxygen furnace installations is the potential production rate of the BOF. The existing state of technology may predict a certain rate of production, and the electrostatic pollution-control system may be designed for a nominal increase in capacity; but should the BOF technology develop (as is quite likely) so as to result in a larger increase in production, the electrostatic pollution-control equipment may soon be inadequate. Production increases as high as 20 percent can be realized, as shown by a 150-ton BOF plant in the Chicago area that is now producing 205 net tons per heat.(29) Some of the increased productivity is undoubtedly due to increased oxygen-blowing rates. What effect such increases may have on the amounts of particulates is not known, but it can be assumed that there will be at least a proportionate increase in iron-oxide fume.

TABLE VI-2. BASIC OXYGEN FURNACE INSTALLATIONS AND ASSOCIATED AIR-POLLUTION CONTROL EQUIPMENT

		Number	Net Tons Per Heat	Annual Capacity, net tons March 1969	Annual Capacity, net tons Future	Startup Date	Electrostatic Precipitator	High-Energy Wet
Alan Wood Steel Co.	Conshohocken, Pa.	2	140	1,250,000		1968	X	
Allegheny-Ludlum Steel Corp.	Natrona, Pa.	2	80	500,000		1966		X
Armco Steel Corp.	Ashland, Ky.	2	160	1,400,000		1963	X	
	Middletown, Ohio	2	200		2,000,000	1969		X
Bethlehem Steel Corp.	Bethlehem, Pa.	2	250	2,500,000		1968	X	
	Burns Harbor, Ind.	2	250		1,800,000	1970		X
	Lackawanna, N. Y.	3	290	4,700,000		1964-66		X
	Sparrows Point, Md.	2	200	2,500,000		1966		X
CF & I Steel Corp.	Pueblo, Colo.	2	120	1,100,000		1961	X	
Crucible Steel Corp.	Midland, Pa.	2	90	1,250,000		1968		X
Ford Motor Co.	Dearborn, Mich.	2	250	2,500,000		1964	X	
Granite City Steel Co.	Granite City, Ill.	2	225	2,200,000		1967	X	
Inland Steel Co.	East Chicago, Ind.	2	255	3,000,000		1966		X
		2	210		2,000,000	1973		X
Interlake Steel Corp.	Chicago, Ill.	2	75	730,000		1959	X	
Jones & Laughlin Steel Corp.	Aliquippa, Pa.	2	80	1,000,000		1957	X	
		3	200	3,000,000		1968	X	
	Cleveland, Ohio	2	225	2,250,000		1961	X	
Kaiser Steel Corp.	Fontana, Calif.	3	110	1,440,000		1958	X	
McLouth Steel Corp.	Trenton, Mich.	2	110			1958	X	
		1	110	2,800,000		1960	X	
		2	110			1969	X	
National Steel Corp.								
Great Lakes Steel Div.	Ecourse, Mich.	2	300	3,500,000		1962	X	
		2	200		2,000,000	1970	X	
Weirton Steel Div.	Weirton, W. Va.	2	325	3,400,000		1967		X
Republic Steel Corp.	Buffalo, N. Y.	2	100		1,000,000	1970	X	
	Cleveland, Ohio	2	240	2,400,000		1966	X	
	Gadsden, Alabama	2	190	1,500,000		1965	X	
	Warren, Ohio	2	180	1,600,000		1965	X	
United States Steel Corp.	Braddock, Pa.	2	220		2,250,000	1972		X
	Duquesne, Pa.	2	215	2,400,000		1963		X
	Gary, Indiana	3	200	3,700,000		1965		X
	Lorain, Ohio	2	220		2,250,000	1970		X
	South Chicago, Ill.	3	150		3,000,000	1969		X
Wheeling-Pittsburgh Steel Corp.	Monessen, Pa.	2	200	1,500,000		1964	X	
	Steubenville, Ohio	2	250	2,000,000		1965		X
Wisconsin Steel Div.								
International Harvester Co.	South Chicago, Ill.	2	140	1,200,000		1964	X	
Youngstown Sheet & Tube Co.	East Chicago, Ill.	2	265		2,400,000	1969	X	
		Total		57,320,000	18,700,000		23	15

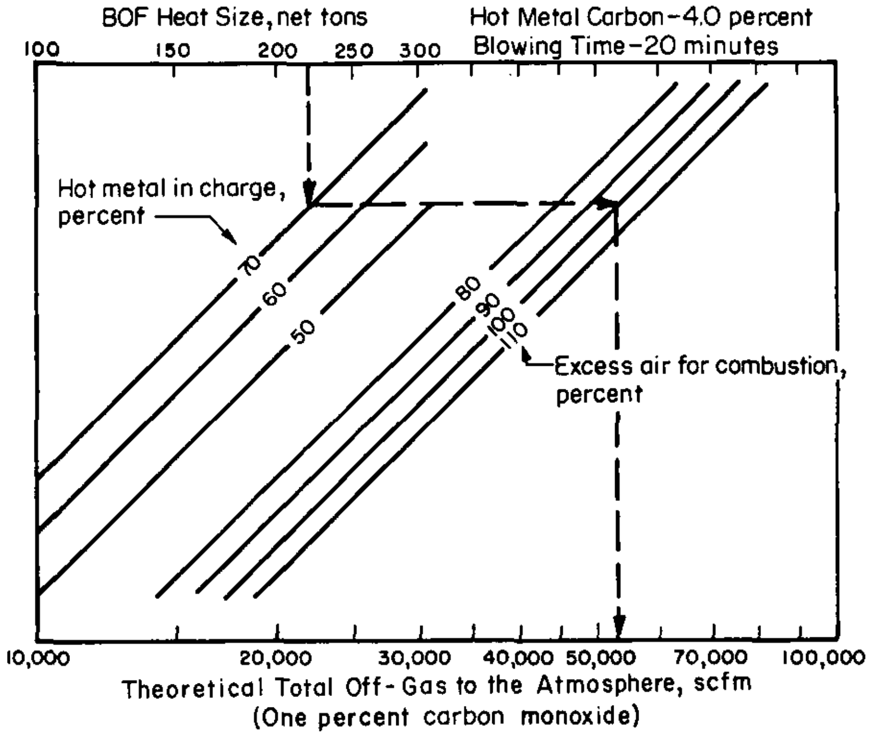


FIGURE VI-6. THEORETICAL TOTAL OFF-GAS VOLUME FROM BOF FURNACES AS INFLUENCED BY HEAT SIZE, PERCENT HOT METAL, AND EXCESS COMBUSTION AIR FOR A 4.0 PERCENT CARBON HOT METAL AND 20-MINUTE BLOWING TIME

Notes: (a) For other carbon contents in hot metal, multiply off-gas volume by the ratio: new carbon content/4.0.

(b) For other blowing times, multiply off-gas volume by the ratio: 20 minutes/new blowing time.

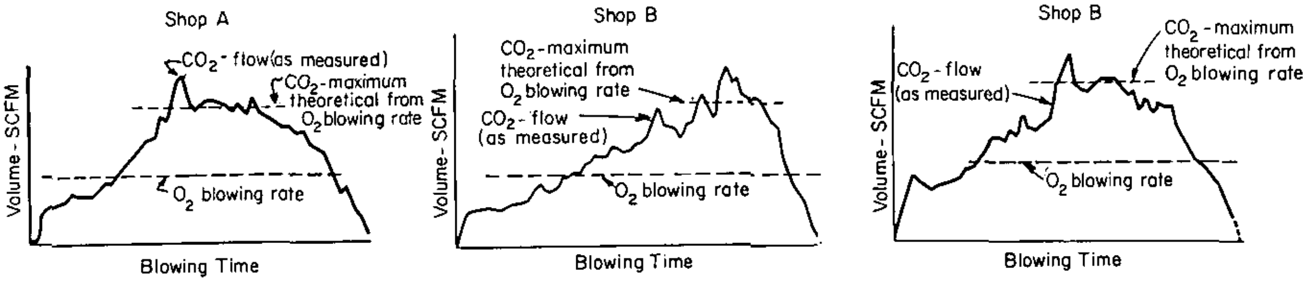


FIGURE VI-7. THEORETICAL AND ACTUAL GAS RATES DURING BLOWING

Maintenance problems with electrostatic precipitators are generally associated with the precipitator proper which includes rappers, vibrators, and insulators. The hoods over the BOF are a necessary part of the collection system, and can result in operating problems. The gap between the BOF and the hood is usually dictated by the anticipated operating conditions and the anticipated buildup of a skull on the mouth of the furnace. Excess buildup can restrict the flow of air required for combustion of the carbon monoxide, with the result that a significant amount of carbon monoxide may reach the electrostatic precipitator with possible disasterous results. The explosion hazard with an electrostatic precipitator is a reality, and not just an anticipated possibility, as attested by an explosion in 1968 at the Monessen, Pa., plant of the Wheeling-Pittsburgh Steel Corp.(30) All iron and steel production was stopped for 1 week, and only partially resumed for the second week while repairs were completed.

Electric-Furnace Applications of Electrostatic Precipitators

Only one known installation of an electrostatic percipitator with an electric-furnace plant is in operation. This installation is the electric-furnace shop of the Jones and Laughlin Steel Corporation, Cleveland, Ohio. The electrostatic precipitators are considered to be operating satisfactorily. Bethlehem Steel Corporation installed electrostatic precipitators on the electric furnace plant at Los Angeles, California in 1955. They were replaced by bag houses in 1967.

Wet Scrubbers

Wet scrubbers of various types have been used in the integrated iron and steel industry for many years. The first wet scrubbers were simple spray towers used to clean blast-furnace gas. However, as cleaner gas became a requirement for firing blast-furnace stoves to higher temperatures, other types of wet scrubbing were used. The introduction of fixed-orifice, then variable-orifice, and finally venturi scrubbers was a natural for blast-furnace operation. Advances in blast-furnace technology and improvements in burden materials started to reach a point where improvements in the flow of reducing gases up through the burden became a necessity. One method of obtaining such improvement was the use of blast-furnace top pressures that were above atmospheric pressure. In essence, the blast furnace system became a pressurized system. The installation of orifice, variable-orifice, or venturi scrubbers in the gas system was a practical way of obtaining cleaner gas. The pressure required to achieve the necessary cleaning action was already in the blast furnace, and little additional auxiliary equipment was required.

High-energy scrubbers (i.e., those capable of pressure drops of 30 inches of water or higher) are used in steel-plant applications. High-energy scrubbers are used for controlling emissions from sinter plants, open hearths, BOF's, as well as from blast furnaces. In some operations where particulates in blast-furnace gas must be lowered to 0.005 grain per cubic foot, electrostatic precipitators have been installed in series with wet scrubbers to obtain final cleaning.

One of the principal advantages of high-energy wet scrubbers is their ability to handle variations in gas volumes, while still maintaining the required operating efficiency. This characteristic of venturi scrubbers is illustrated in Figure VI-8(31),

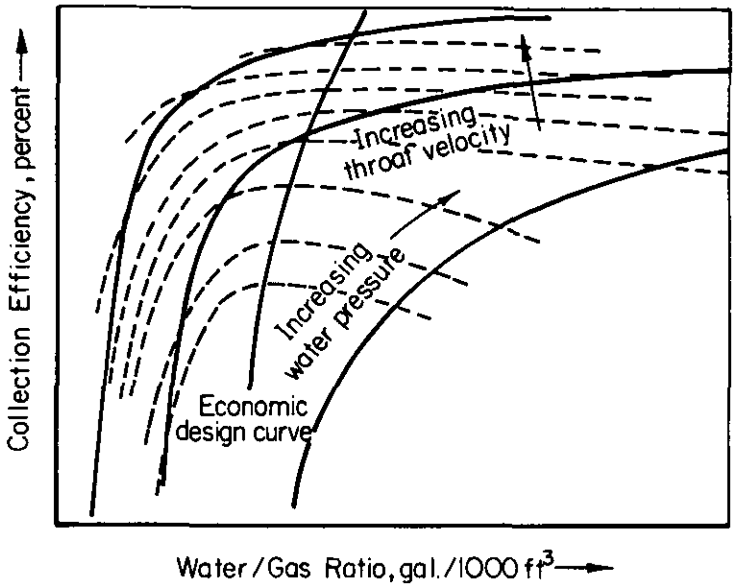


FIGURE VI-8. OPERATING CONDITIONS FOR A VENTURI SCRUBBER

The effect of water rate at a constant throat velocity on the output dust loading of a venturi scrubber handling blast-furnace gas is shown in Figure VI-9.(32)

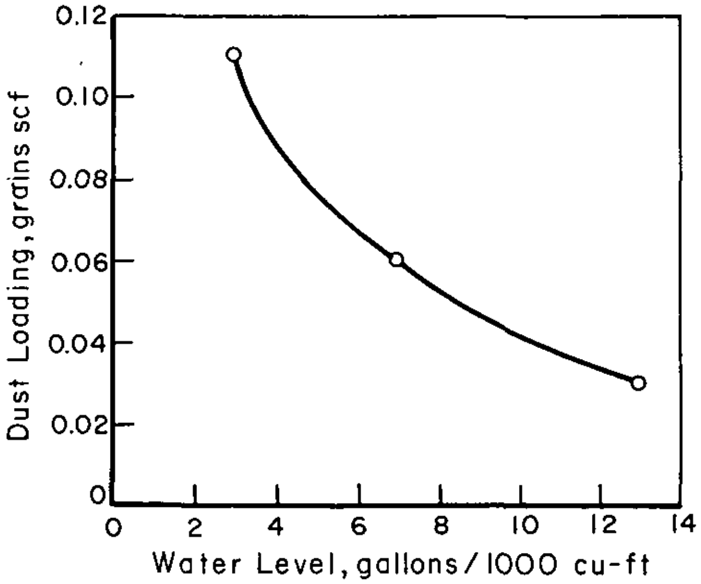


FIGURE VI-9. EFFECT OF WATER RATE ON OUTPUT DUST LOADING FOR A VENTURI SCRUBBER

Theories that can explain the various mechanisms of collection involved in the performance of wet scrubbers and can serve as a basis for comparison are not completely developed, as indicated from the following statement from a recently published manual on the subject.(33)

where it can be seen that for a given throat velocity of the gases, the efficiency is increased by increasing the water/gas ratio, or simply by pumping water at an increased rate. However, the maximum and minimum values of water and/or gas rates for high-energy scrubbers used in the iron and steel industry are unknown.

> "The theories of the various mechanisms involved in wet collection have not been completely developed; some, such as the electrostatic effect and humidification are more presumed than understood, and the air cleaning tasks to which wet collectors are applied rarely involve a simple, uniform, nonreactive particulate dispersed in a simple carrier gas. The wet collectors themselves are typically not single mechanism units but usually function on the basis of several collection mechanisms. This makes clear-cut classification of equipment impossible and imposes difficulties in selecting a collector for a given task without knowledge of their previous application."

An empirical method has been developed to correlate scrubber efficiencies. This method is called "The Contacting-Power Concept", and is defined as follows(34):

> "In the gas-liquid contacting process, power is dissipated in fluid turbulence (in gas and liquid phases) and, ultimately, as heat; it is this power, expressed as power per unit of volumetric gas flow rate, that is the criterion of scrubber efficiency, and it has been designated 'contacting power'."

It should be noted that the power referred to excludes power consumed by motors, friction, and mechanical losses. A conclusion of the initial investigators which led to the development of the contacting-power concept is as follows(35):

> "When compared at the same gas power consumption, all scrubbers give substantially the same degree of collection of a given dispersed dust, regardless of the mechanism involved and regardless of whether the pressure drop is obtained by high gas flow rates or high water flow rates. The collection efficiency increases as the pressure drop increases, the increase being especially rapid for pressure drops over 10-in. water."

Mathematically the contacting-power concept can be expressed as follows:

$$N_t = \alpha P_T^{\gamma} \quad ,$$

where

N_t = the number of transfer units

$N_t = 2.3 \log \frac{1}{1-E}$

E = collection efficiency

P_T = total contacting power.

While the calculation of N_t is quite simple, similar calculations for P_T require data on the gas-flow rate, water-flow rate, and water feed pressure. When the required data is plotted on log-log coordinates, a straight line correlation is evident as shown in Figures VI-10 and VI-11(34). The coefficient α is the value of the intercept where P_T is

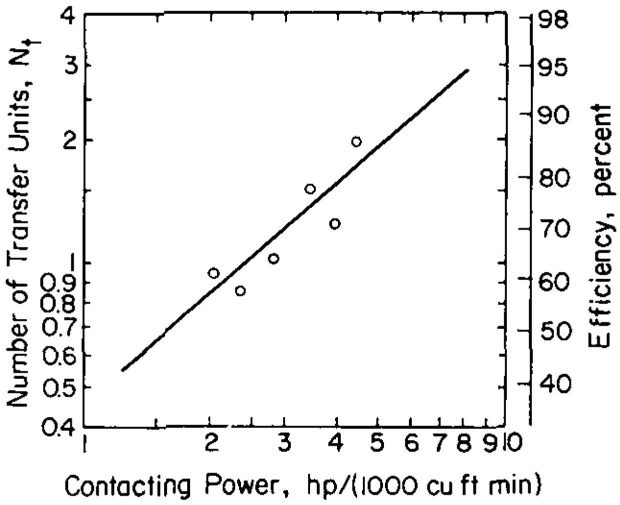


FIGURE VI-10. PERFORMANCE OF A VENTURI SCRUBBER ON A METALLURGICAL FUME

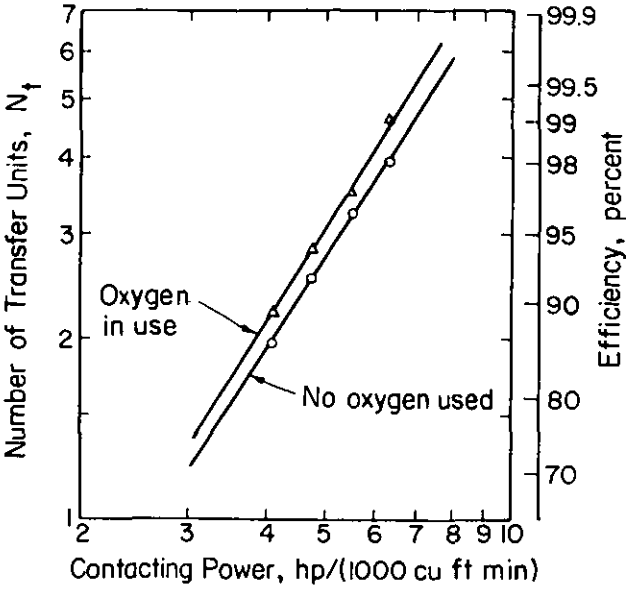


FIGURE VI-11. PERFORMANCE OF A VENTURI SCRUBBER ON OPEN-HEARTH FUME

one, and γ is the slope of the line. The coefficients are essentially functions of the dust and/or fume, and are not influenced by the way the contacting power is applied to the scrubber. Some industrial data were used in analyzing the contacting power concept; however, full-scale industrial tests in steel plants were not made.

A characteristic of wet scrubbers over other types of emission-control equipment is that gases such as carbon dioxide and sulfur dioxide will dissolve in the water.(36) This can be particularly advantageous where sulfur dioxide is in concentrations that would exceed the concentrations permitted by regulations. However, this plus in performance is offset by the severe corrosion problems resulting from the formation of the respective acids, and by the effects the acidified water has on the operation of the water-treatment facilities. If the maintenance problems involved are disregarded, the wet scrubber may be an effective means of reducing the emission of sulfur dioxide to the atmosphere. It has been stated that there is a significant removal of sulfur dioxide by wet scrubbers(37), but also that there are no data on the input and output of sulfur dioxide for wet scrubbers(38).

Application of Wet Scrubbers in Sinter Plants

Of about 40 sinter plants at various steel plants, only two are known to have wet-scrubber installations. One uses a venturi scrubber to treat emissions from the windbox of the machine(39), and the other uses flooded-disk scrubbers at the discharge end of the sintering machine(40). The output loading of the flooded-disk scrubbers is reportedly 0.01 grain per cubic foot.

Early application of wet scrubbers to sinter plants resulted in operating problems which were traced to erosion and imbalance of the fan blades on the exhaust-system blowers. These are the blowers that provide the draft through the sinter bed required to ignite the fuel. Erosion of the blades has been a problem even with dry pollution-control systems. However, the imbalance occurring in the fan blades is aggravated in sinter plants having wet pollution-control systems because the dust that is carried over to the fan is moist, and has a greater tendency to accumulate on the blades. The imbalance problem has been reported to be caused by uneven buildup of the dust and also by the breaking off of large amounts of built-up dust which places severe unbalanced loads on the blades. Both situations have caused severe vibrations and sometimes major breakdowns in the blowers. This situation is minimized by constant preventive maintenance to remove the dust buildup.

Application of Wet Scrubbers to Blast Furnaces

During 1967, about 170 blast furnaces were producing hot metal, and of this number about 51 were using wet scrubbers as the principal method of cleaning blast-furnace gas. Of these, about 33 were high-energy scrubbers. In addition, about 35 blast furnaces were equipped with high-energy scrubbers as cleaning units preceeding electrostatic precipitators which serve as final cleaning units.

The first high-energy scrubbers were installed in 1955. They were simple, fixed-orifice plates installed in the gas lines, with water introduced into the main at some distance upstream from the orifice plate. These scrubbers operated at pressure drops of 30 to 50 inches of water, with resulting output loadings varying from 0.01 to 0.03 grain per cubic foot.(41, 42, 43) The orifice scrubber, however, had the major disadvantage that it could not handle the variations in gas flow, and consequently could not meet the required emission limits during certain phases of blast-furnace operation when the velocity of the gases coming from the blast furnace was lowered.

The need for high-energy wet scrubbers that could handle variations in gas flow from a blast furnace led to the development of variable-orifice scrubbers that attempted to cope with the variability of gas flow by adjusting the size of the orifice opening. The performances of a variable-orifice scrubber and a fixed-orifice scrubber are illustrated in Figure VI-12.(44) The effect of a reduction in wind rate on the two types of equipment is quite evident.

During the same period that the orifice and variable-orifice scrubbers were receiving attention from blast-furnace technologists, the venturi scrubber was also under investigation as a possible means of cleaning blast-furnace gases. The first application of venturi scrubbers to blast-furnace gas was reported in 1955(45), with other installations reported in 1956(46) and 1960(47). Technical data relating the output dust loading to the water rate and pressure drop of a blast-furnace venturi scrubber are shown in Figure VI-13(45). The relationship between clean-gas dust loading and pressure drop is shown in Figure VI-14(47), that illustrates the low output dust loadings that can be achieved with this equipment. This high performance, however, can be achieved only if the blast furnace is operating at a high-enough top pressure to provide the required pressure drop. This level of high top pressure has not been achieved, as evidenced by the large number of blast furnaces operating with electrostatic precipitators as the final gas-cleaning unit. (See Table VI-1 that shows 108 blast furnaces operating with electrostatic precipitators.)

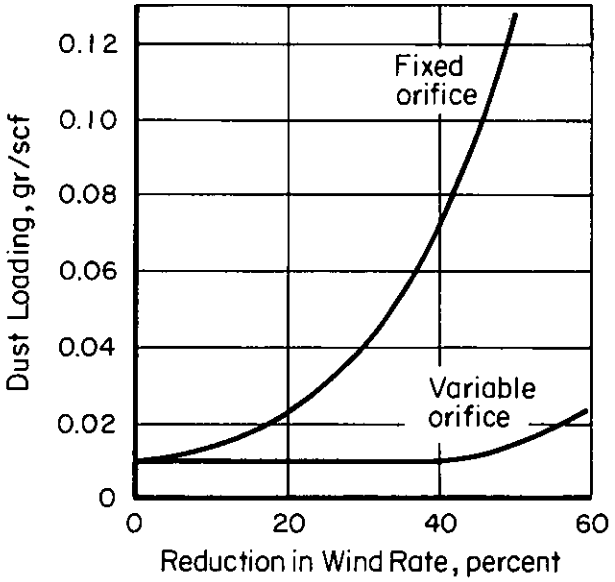


FIGURE VI-12. EFFECTIVENESS OF GAS CLEANING BY A FIXED-ORIFICE SCRUBBER AND A VARIABLE-ORIFICE SCRUBBER WHEN GAS-FLOW RATE IS VARIED

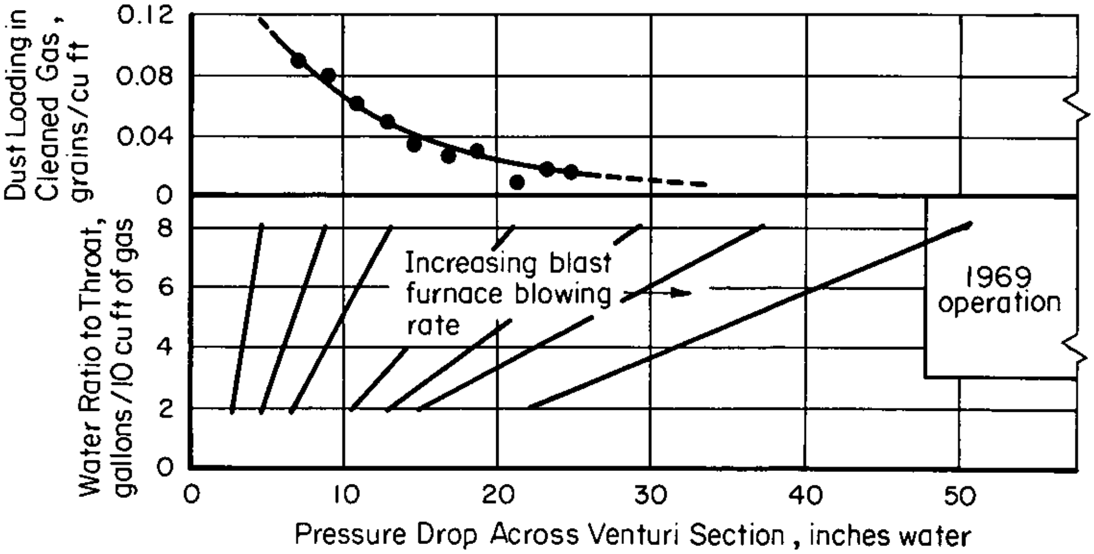


FIGURE VI-13. OPERATING CHARACTERISTICS OF A BLAST-FURNACE VENTURI SCRUBBER

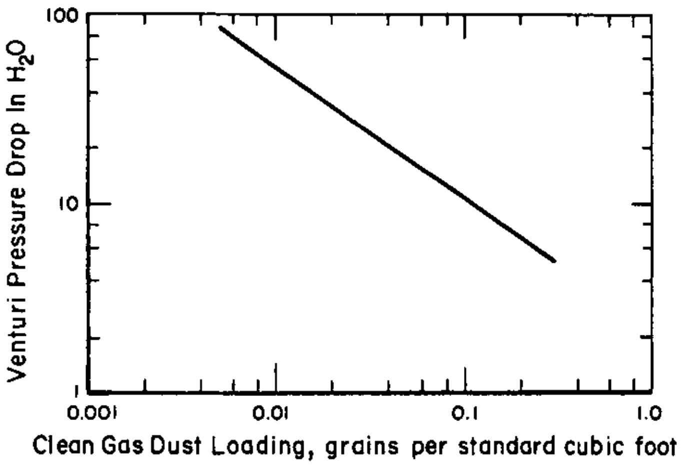


FIGURE VI-14. CALIBRATION CURVE FOR A BLAST-FURNACE VENTURI SCRUBBER

Application of Wet Scrubbers to Open-Hearth Furnaces

Wet washing of open-hearth gases was first considered to be economically expedient for shops that were to be operated only during high peak demands for steel, under which conditions the low capital cost for the wet system was considered an advantage.(48) However, some open-hearth shops that were considered to be fairly new found that wet scrubbers were economically attractive when the shop either had no waste heat boilers or the existing boilers could not lower the gas temperatures enough to warrant the installation of electrostatic precipitators or bag houses.(49, 50) The first open hearth installation was made in 1959(48) at U. S. Steel's Edgar Thomson Works, and others subsequently followed. Output gas loadings of 0.01 to 0.05 grain per cubic foot have been reported for the installations, again with the cleaning efficiency relating directly to the pressure drop of the scrubber. The relationship between clean-gas dust loadings and pressure drop for an operating open hearth installation is illustrated in Figure VI-15(48). Oxygen lancing was used during the refining period. The figure is representative of open-hearth practice with low oxygen-blowing rates and is not necessarily representative of present-day practice using higher oxygen-blowing rates.

Application of Wet Scrubbers to Basic Oxygen Furnaces

Wet scrubbers were first installed in 1954 on a basic oxygen furnace at the Hamilton Plant, Dominion Foundries and Steel Ltd., Ontario, Canada. The first installations in the United States was made at the Duquesne Plant of the U. S. Steel Corporation in 1963. The number of high-energy wet scrubbers installed over the years as compared to the number of electrostatic precipitators is shown in Figure VI-16. One of the principal reasons for selecting electrostatic precipitators over high-energy wet scrubbers is the existence of a water-treatment problem in a plant. Problems can include inadequate water-treatment facilities, or the lack of sufficient water. Even though there are 15 BOF plants in the United States with high-energy scrubbers as the primary pollution-control equipment, there is a notable lack of published information concerning their operation. It appears that problems associated with wet scrubbers in other applications apply also to BOF installations.

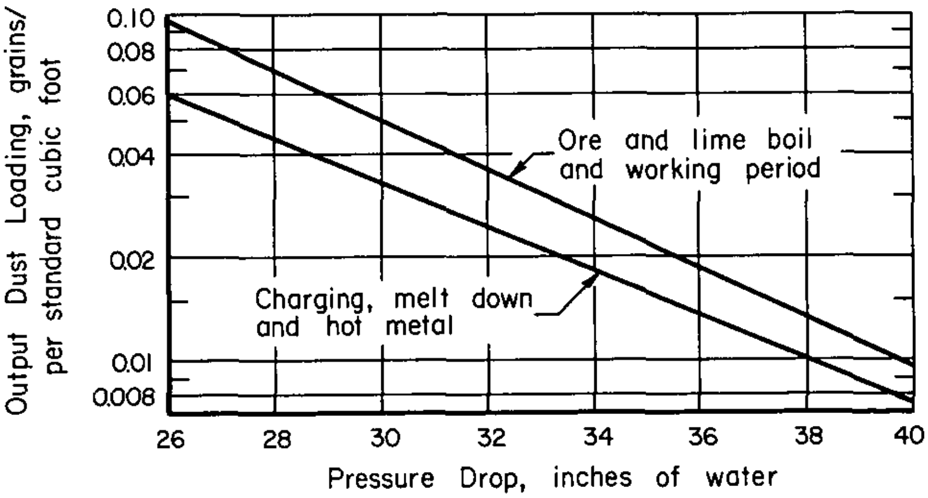


FIGURE VI-15. RELATIONSHIP BETWEEN CLEAN-GAS DUST LOADING AND PRESSURE DROP FOR A WET SCRUBBER ON AN OPEN-HEARTH FURNACE (OXYGEN LANCING USED DURING THE REFINING PERIOD)

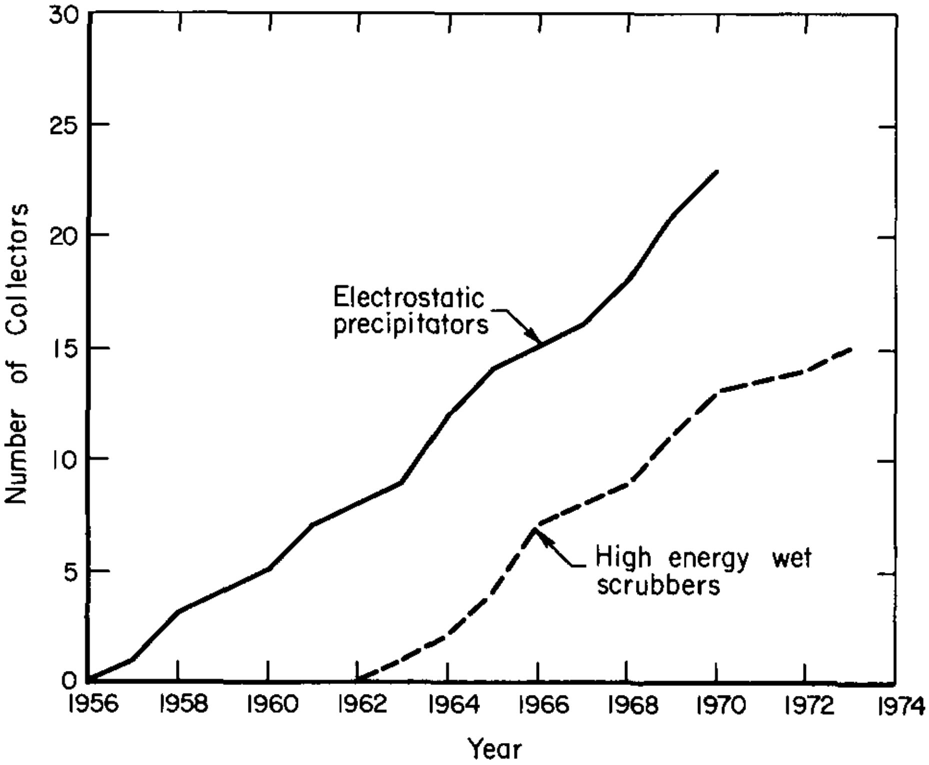


FIGURE VI-16. INSTALLATION OF ELECTROSTATIC PRECIPITATORS AND HIGH-ENERGY SCRUBBERS FOR AIR-POLLUTION CONTROL AT BOF STEELMAKING PLANTS

Problems associated with improper performance of wet scrubbers can be attributed to a lack of materials to withstand the abrasive and corrosive nature of the dust-laden water, or a misapplication of construction materials. Design of wet scrubbers does not appear to be a contributing factor to deficiencies in scrubber performance.

Application of Wet Scrubbers to Electric Furnaces

High-energy scrubbers for electric steelmaking furnaces are known to be used in only two shops; both owned by the Armco Steel Corporation. The first installation was made at the Butler, Pa., plant on a 70-ton furnace in 1958(51), and the second the Armco plant in Houston, Texas. The Butler plant (currently in the process of expansion) will soon include three 150-ton furnaces(52) that probably will be serviced with high-energy wet scrubbers. When expansion plans are completed in 1969, the Houston plant will be equipped with high-energy wet scrubbers operating at a pressure drop of 60 inches.(53) No other electric furnace shops are known to be using high-energy wet scrubbers.

Fabric Filters

Fabric-filter installations (or baghouses as they are more commonly called) have their biggest steel-industry application in the control of emissions from electric furnaces -- a total of 29 installations. There also are three known applications at sinter plants, and two applications on scarfing machines. Fabric filters are used on BOF's in Europe(54), but no installations of this type have been made in the United States.

The performance of fabric filters has been well developed on the basis of theoretical principles, and numerous descriptions are available in the published literature. A reduction of the theoretical concepts to a simplified mathematical form results in the following equation(55):

$$H' = \frac{rLt'v^2}{7000} ,$$

where

H' = filter resistance increase in inches of water
r = specific resistance of the dust (determined experimentally) in inches of water gage per pound of dust per square foot of filter cloth area per foot per minute of filtering velocity
L = input dust loading to the filter in grains per cubic foot of air
t' = operational time in minutes
v = filtration velocity in feet per minute.

This equation leads to the conclusion that resistance of the filter to flow is directly proportional to (1) the square of the superficial face velocity, (2) the weight of the dust collected on the fabric, and (3) the time of operation since the last cleaning.(54)

A more recent method of evaluating fabric-filter performance is based on "filter-drag". The development of the method is based on similarity to electrical circuitry and to heat transfer. The equation for filter-drag evaluation is as follows:

$$V = \frac{\Delta P}{S}, \text{ or in electrical analogy } I = \frac{E}{R}$$

where

V = velocity in feet per minute
ΔP = pressure drop in inches of water
S = filter drag in inches of water per foot per minute.

The factor V is similar to the air-to-cloth ratio of more common usage. Filter drag is independent of the size of the unit, the filter ratio, the type of dust, the style of fabric, and all other specifics of application.(56) The method has been used to evaluate the performance of fabric materials prior to full-scale installation in a bag house.

Application of Fabric Filters to Sinter Plants

Typical of the use of fabric filters in sintering plants is the collection of dust generated at the discharge and screening locations at the Bethlehem Steel Corporation's plant at Bethlehem, Pennsylvania(57), and the U. S. Steel Corporation's plant at Gary, Indiana(17). Both units are sectionalized, with sufficient capacity to permit shutting down sections for maintenance without affecting the cleaning efficiency of the units. Pertinent statistics for the two units are given in Table VI-3.

Application of Fabric Filters to Open-Hearth Furnaces

An experimental baghouse was installed at the Lackawanna plant of the Bethlehem Steel Corporation in February, 1960.(58) The development work was done with an oxygen-lanced open-hearth furnace, and results were satisfactory. A production baghouse was placed into operation by Bethlehem Steel at the No. 2 Open-Hearth Shop at Sparrows Point in 1963.(59) The only change that had to be made in melting practice was the elimination of fluorspar as a flux. The baghouse had 10 hoppers of 80 bags each. The bags were 11.5 inches in diameter and 34 feet long. Design capacity was 145,000 cfm at 500 F. With an input dust loading of 1.4 grains per cubic foot, the output loading was 0.0007 grain per cubic foot, for an efficiency of 99.95 percent. The open-hearth furnace and baghouse were operational in January, 1966, but the results of subsequent operations are unknown.

Application of Fabric Filters to Electric Furnaces

Fabric filters have been successfully applied to the control of emissions from electric furnaces ranging up to 100 and 150-net-tons capacity, and for multiple-furnace shops as well as one-furnace shops.(60, 61, 62, 63, 64) However, because electric

TABLE VI-3. DESIGN AND OPERATING DATA FOR SINTER-PLANT FABRIC FILTERS ON SINTER STRAND DISCHARGE

Design or Operating Variable	U. S. Steel Corp., Gary, Indiana	Bethlehem Steel Corp., Bethlehem, Pa.
Volume of Air, cubic feet per minute:	172,000 at 255 F	240,000 at 350 F
Suction, inches of water:	12	n.a.
Pressure Drop Across Bags, inches of water	4	n.a.
Hoppers in Unit, number	10	16
Bags per Hopper, number	88	72
Total Bags, number	880	1152
Bag size:		
Diameter, inches	11.5	12
Length, feet	32.2	28
Bag Type	Fiberglass	Fiberglass
Bag Life, months	17	36
Bag Permeability, cfm per foot^2 of cloth	12 - 20	n.a.
Air-to-Cloth Ratio (Normal), cfm per ft^2 of cloth	2.17	2.29
Air-to-Cloth Ratio (One Compartment Cleaning), cfm per ft^2 of cloth	2.41	2.44
Air Temperature, F	175 to 300	200 to 500
Theoretical Design Efficiency, percent	99+	99+

n.a. - not available.

furnaces have design and operating characteristics that can vary from furnace to furnace and shop to shop, the development of pollution-control facilities is not as straight-forward as for other steelmaking operations. One of the major problems in the design of electric-furnace pollution-control systems is the design of methods that will completely capture the fumes. The majority of electric-arc furnaces are top charged, which means the roof is removed during charging. As a result, the emissions generated during the charging operation are difficult to capture and contain. Capture of fumes by hoods and by direct-extraction techniques during melting and refining have not completely solved the problems of collection and containment, and extraction of fumes through the plant roof has been developed to control emissions through the entire plant.(64, 64)

Cyclone Dust Collectors

One other type of dust cleaning equipment that has found extensive use in the control of emissions from ironmaking and steelmaking operations is the cyclone dust collector. The cyclone separates particles from the gas by means of a centrifugal force exerted on the particles in a vortex flow that drives the particles toward the wall of the body of the collector. The particles at the wall move toward the discharge opening of the cyclone as a result of an axial component of the vortex flow, aided in the case of cyclones used in the iron and steel industry by the force of gravity. The magnitude of the radial forces acting on the particles depends on the nature of the vortex flow in the different sections of the cyclone. Radial gas velocities tend to act as counteracting forces, and tend to offset the separating forces generated in the cyclone.

Cyclones are suitable for collecting medium and coarse dusts, but are not suited for very fine dusts or metallurgical fumes. Their advantages are that there are no moving parts, there is a wide choice of construction materials, and maintenance costs are low. Power costs can be quite high because a high degree of efficiency is required.

Cyclones find their principal application as precleaners for other types of emission-control equipment. Some of the applications apparently are deliberate, while others occurred in a transition from lower to higher collection efficiencies.

Cyclones find application in pelletizing plants and in limestone plants for the collection of the large-size dust generated in certain of the operations. As precleaners, they are used in series with dust catchers, wet scrubbers, and electrostatic precipitators for cleaning blast-furnace gas; as precleaners for electrostatic precipitators handling the dust and gas from a sinter-plant wind box; and as part of the series of equipment used in open-hearth-furnace-emission control. No information has been located in the literature or during this study concerning the efficiencies of cyclones in the various iron and steel plant operations, or concerning any particular problems that have arisen with their use.

Cost of Applied Control Equipment

As part of the companion study for the Division of Economic Effects Research of NAPCA, estimates were made of the capital costs and operating costs of the principal types of emission-control equipment used in the integrated iron and steel industry. The types of equipment considered were electrostatic precipitators, high-energy wet scrubbers, and fabric filters. Cost estimates were based on established industrial estimating techniques, with cost information supplied by certain steel companies and equipment manufacturers.

For the purposes of the estimates made, a control system was considered to be made up of all the items of equipment and their auxiliaries which are used solely for the general abatement of atmospheric pollution in the neighborhood of the steel works. Typically this will include a collecting hood or gas-collecting pipe at the furnace, ductwork, spray cooler, dust collector, fan and motor, and stack. Included also will be structural steel, foundations, control instruments, insulation, piping, water treatment, and electric power supply facilities for the entire gas-cleaning system. Excluded are those equipment items which, while they may contribute to the functioning of pollution-control equipment, would be used for process or economic reasons even if there were no pollution-control requirements. For example, an open hearth furnace is usually connected to a stack whose primary task is to supply draft for causing gas flow through the heat regenerative stoves. In this study, the cost of the original stack is attributed to the steelmaking process because the furnace cannot operate without it. However, any increase in stack height, or other modifications necessary when air pollution equipment is installed, is charged as a cost of pollution equipment.

The cost of land occupied by pollution-control equipment has not been included. It is recognized that such land has a real value, but a satisfactory method for estimating it has not been established. Costs associated with preparation of the site, start-up operations, and working capital also are not included. Certain portions of a control system occupy or utilize parts of steel plant buildings and, therefore, might be charged with a share of general building costs. This item has not been estimated here. In calculating operating costs, no attempt was made to allocate a portion of general overhead to control systems.

Capital and operating costs in the estimates are based upon collectors whose efficiency can be relied upon to produce an outlet dust loading of 0.05 grain/scf of gas.

The estimates of capital costs include facilities for loading the collected dust or sludge into trucks for transportation elsewhere. No by-product values have been assigned. Central engineering costs, overheads, and fees were based upon a standard sliding scale generally used by contract engineers. Labor cost was calculated at the nominal value of $5.00/man hour, including all welfare and fringe costs.

It is believed that the general precision of the capital cost estimates is such that most specific plant situations will fall within ±15 percent of the estimated values. In more statistical terminology, it might be suggested that the standard deviation is about ±10 to 12 percent. It is to be expected that any specific plant location which presents unusual cost problems associated with layout, structure, power supply, etc. might fall outside these limits. In such cases, a detailed plant design and estimate must be prepared if accurate capital cost data are required. The accuracy of operating cost values is influenced by many factors which may vary considerably from one company to another. The selection of control equipment should not be based upon small differences in estimates of operating cost.

Operating cost estimates include costs for the following items:

(1) Electric Power

(2) Maintenance

(3) Depreciation

(4) Capital Charges

(5) Operating Labor.

Electric energy is calculated at a standardized rate of 1¢ per kilowatt hour. Maintenance is taken at a nominal cost of 4 percent of the total investment. Depreciation is calculated on a straight-line method using total investment with an expected life of ten years. Other studies of depreciation have suggested longer service life times, but these are considered to be greater than average plant experience will confirm. Advancing technology and rising standards give importance to the factor of technical obsolescence.

Capital charges are taken at 10 percent per annum. It is believed that this will be reasonable in the light of rising interest rates and local taxes.

Annual calculations are based on 330 operating days per year, 24 hours per day. This gives a total of 7,920 operating hours per year.

The estimated capital and operating costs are summarized in the form of graphs in Figures VI-17 through VI-24. For further details on these estimates, reference should be made to the companion report (A Cost Analyses of Air Pollution Controls in the Integrated Iron and Steel Industry); especially to Appendix C of that report.

Cost-Effectiveness of Applied Systems

The three principal types of equipment used to control iron oxide fumes from the various process segments in the integrated iron and steel industry can meet current air-quality requirements. This holds if the equipment has been correctly designed and constructed and is properly maintained. The particular equipment selected must perform its designed function at a cost that will not create an excessive increase in the cost of the finished steel products. Many factors are involved in determining the actual cost of air-pollution control to any given steel plant. Factors such as the local level of allowable emissions, power costs, availability of water, ease of dust disposal, and possible reclamation or marketing of the recovered iron oxide dust enter into the final determination of costs. Estimated operating costs for air-pollution-control equipment on open-hearth furnaces, basic oxygen furnaces, and electric furnaces are illustrated in Figure VI-25. The wide range possible in these costs is quite evident.

As regulations governing allowable emissions become stricter, the costs for control increase, but not as a simple direct relationship. This can be illustrated in the case of electrostatic precipitators as shown in Figure VI-26.(66) As collection efficiencies increase beyond 95 percent, the cost increases at a rapid rate. The effect of collection efficiency on the cost of electrostatic precipitators only, as well as installed cost, is shown in Figure VI-27 for installations in the iron and steel industry. Costs are 1968 costs. The one type of equipment whose costs are not drastically affected by increased requirements for efficiency is the fabric filter or baghouse.

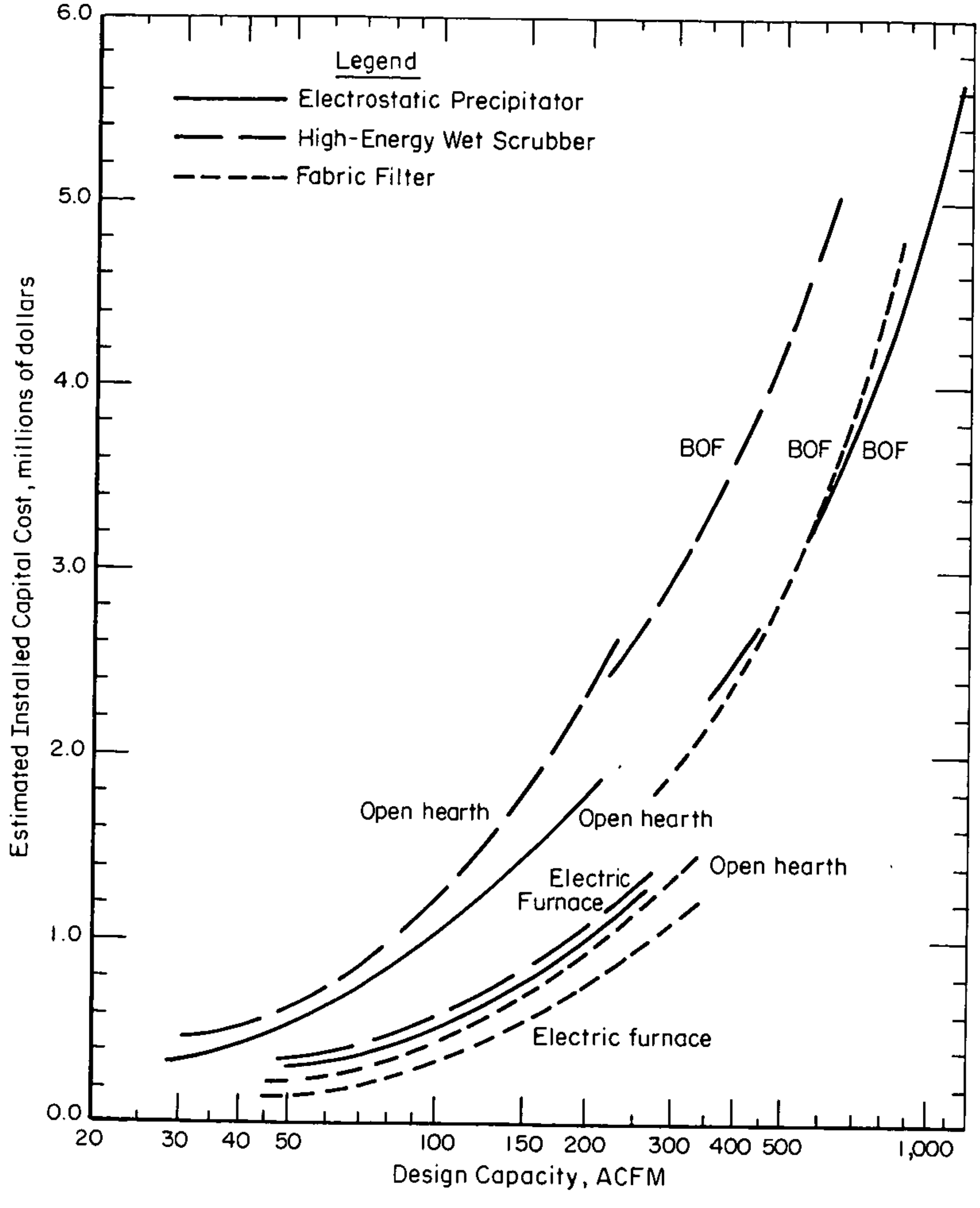


FIGURE VI-17. ESTIMATED INSTALLED CAPITAL COSTS (1968) OF AIR-POLLUTION-CONTROL EQUIPMENT AS RELATED TO DIFFERENT STEEL-MAKING PROCESSES, ON THE BASIS OF DESIGNED ACTUAL CUBIC FEET PER MINUTE (AT TEMPERATURE) OF GAS FLOW RATE

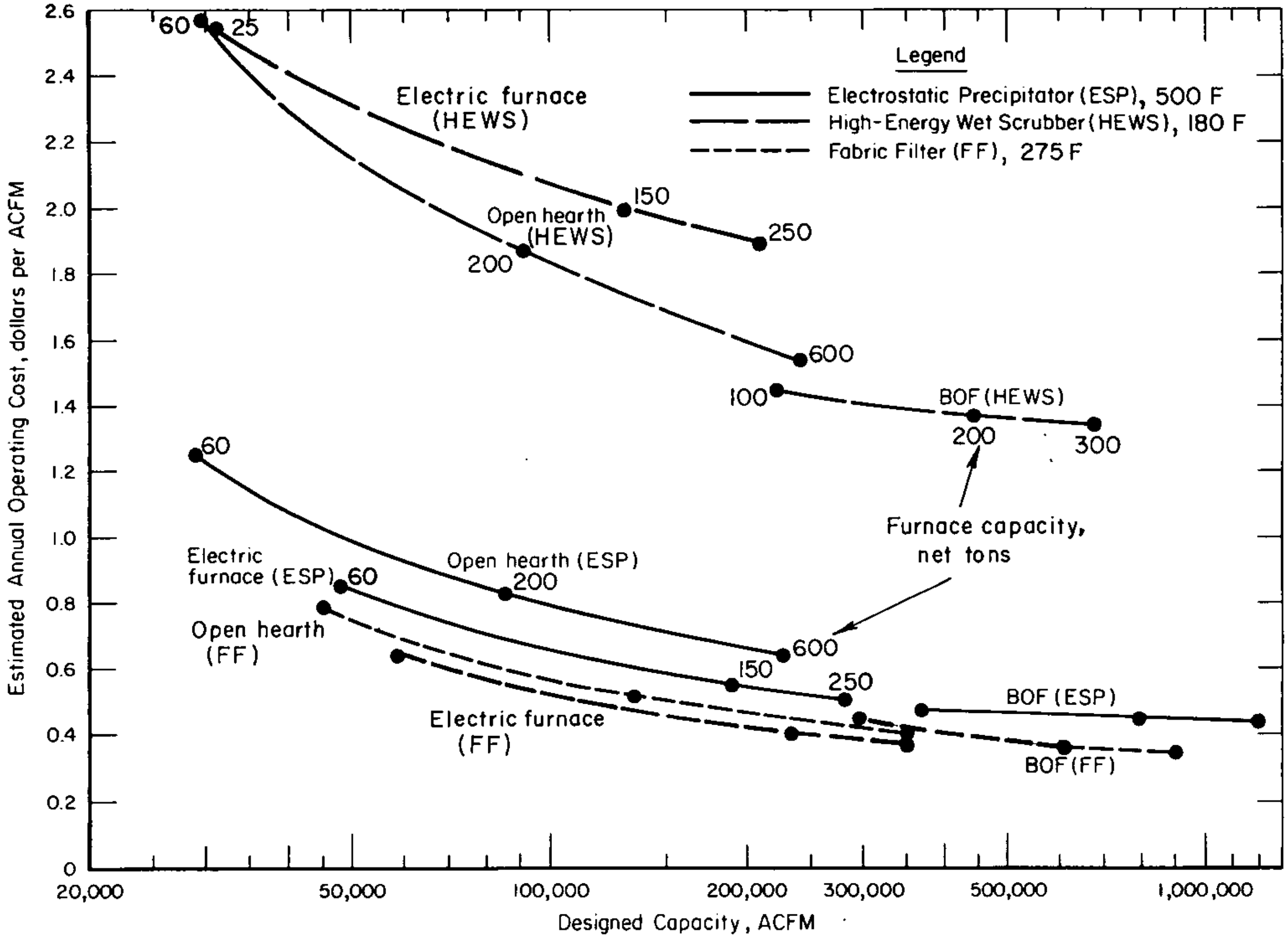


FIGURE VI-18. ESTIMATED ANNUAL OPERATING COSTS FOR AIR-POLLUTION-CONTROL EQUIPMENT FOR STEELMAKING PROCESSES (DEPRECIATION AND CAPITAL CHARGES ARE NOT INCLUDED)

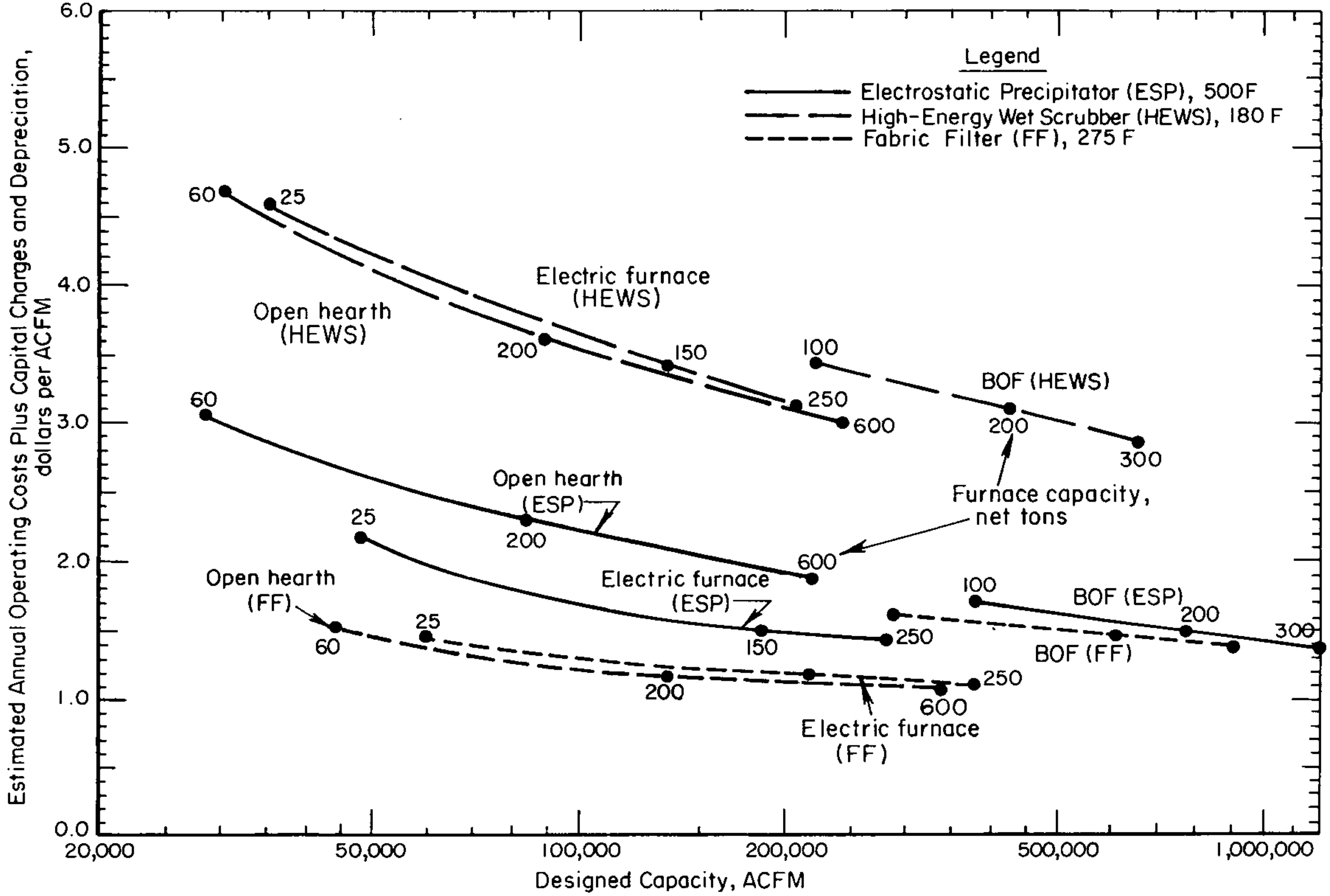


FIGURE VI-19. ESTIMATED ANNUAL OPERATING COSTS PLUS CAPITAL CHARGES AND DEPRECIATION FOR AIR-POLLUTION-CONTROL EQUIPMENT FOR STEELMAKING PROCESSES

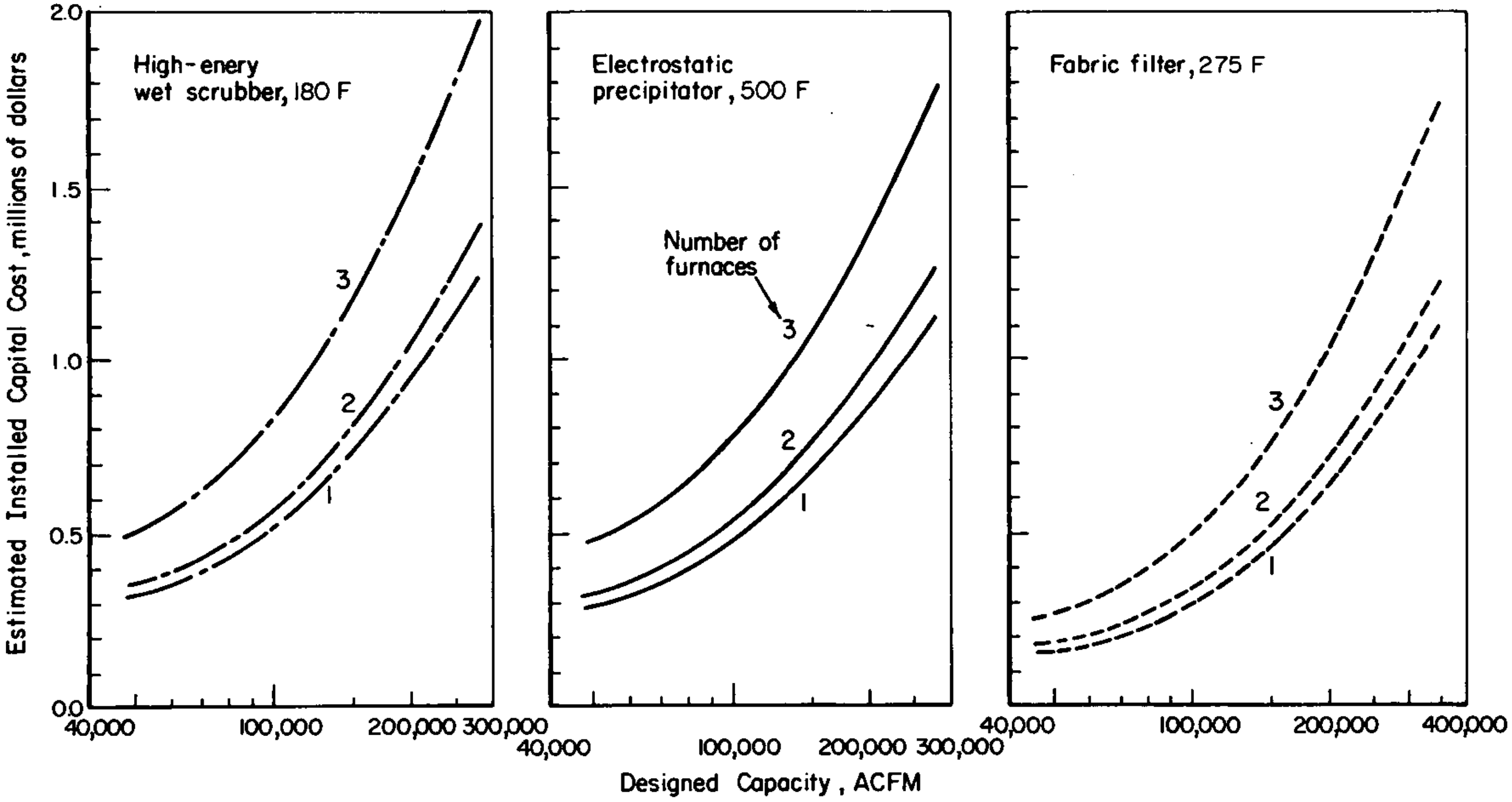


FIGURE VI-20. ESTIMATED INSTALLED CAPITAL COSTS OF AIR-POLLUTION-CONTROL EQUIPMENT INSTALLED ON ELECTRIC-ARC STEELMAKING FURNACES. CONTROL EQUIPMENT DESIGNED TO HANDLE EMISSIONS FROM ANY ONE FURNACE AT ONE TIME

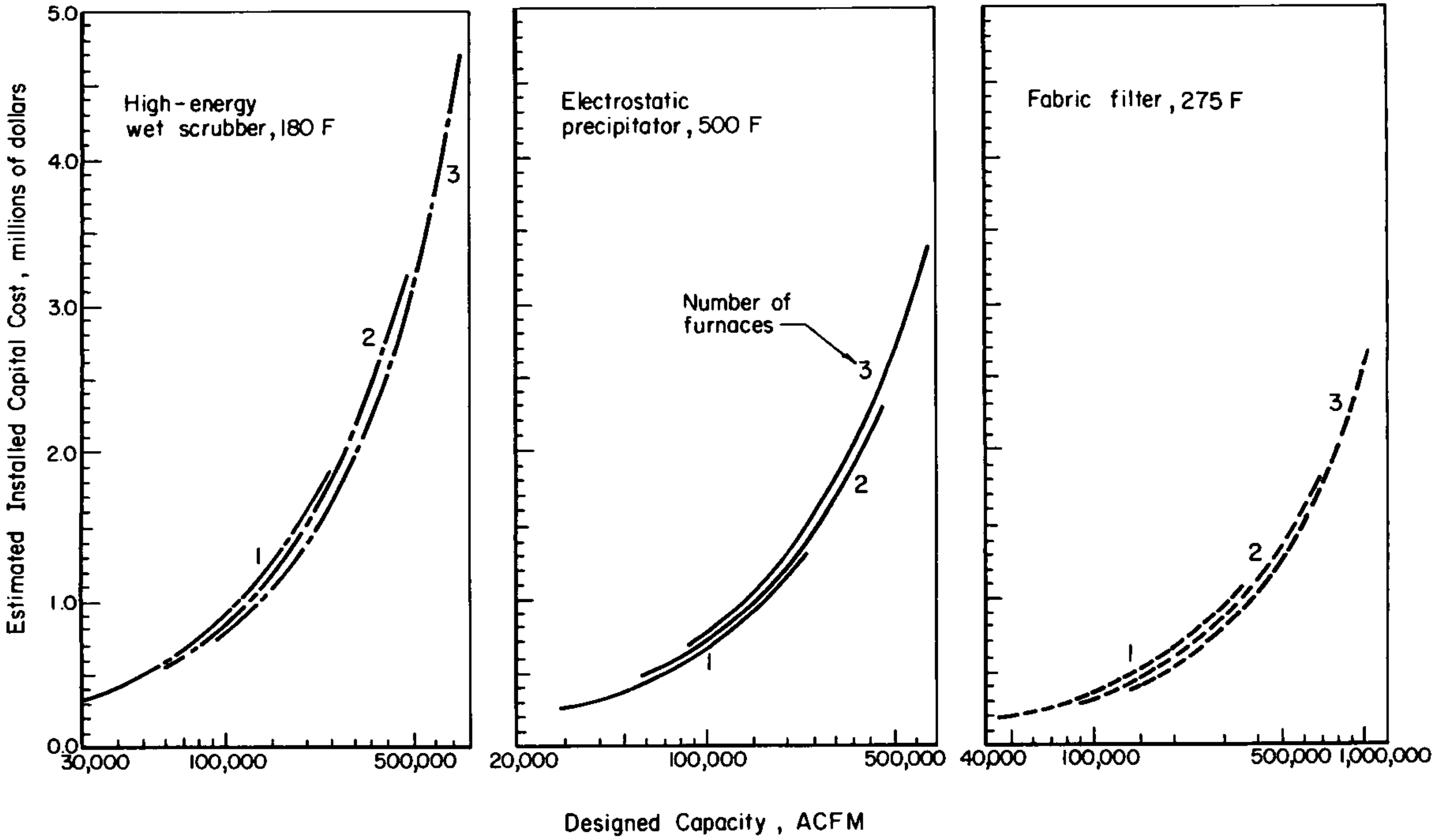


FIGURE VI-21. ESTIMATED INSTALLED CAPITAL COSTS OF AIR-POLLUTION-CONTROL EQUIPMENT INSTALLED ON OPEN-HEARTH FURNACES. CONTROL EQUIPMENT DESIGNED TO HANDLE EMISSIONS FROM FURNACES OPERATING AT THE SAME TIME

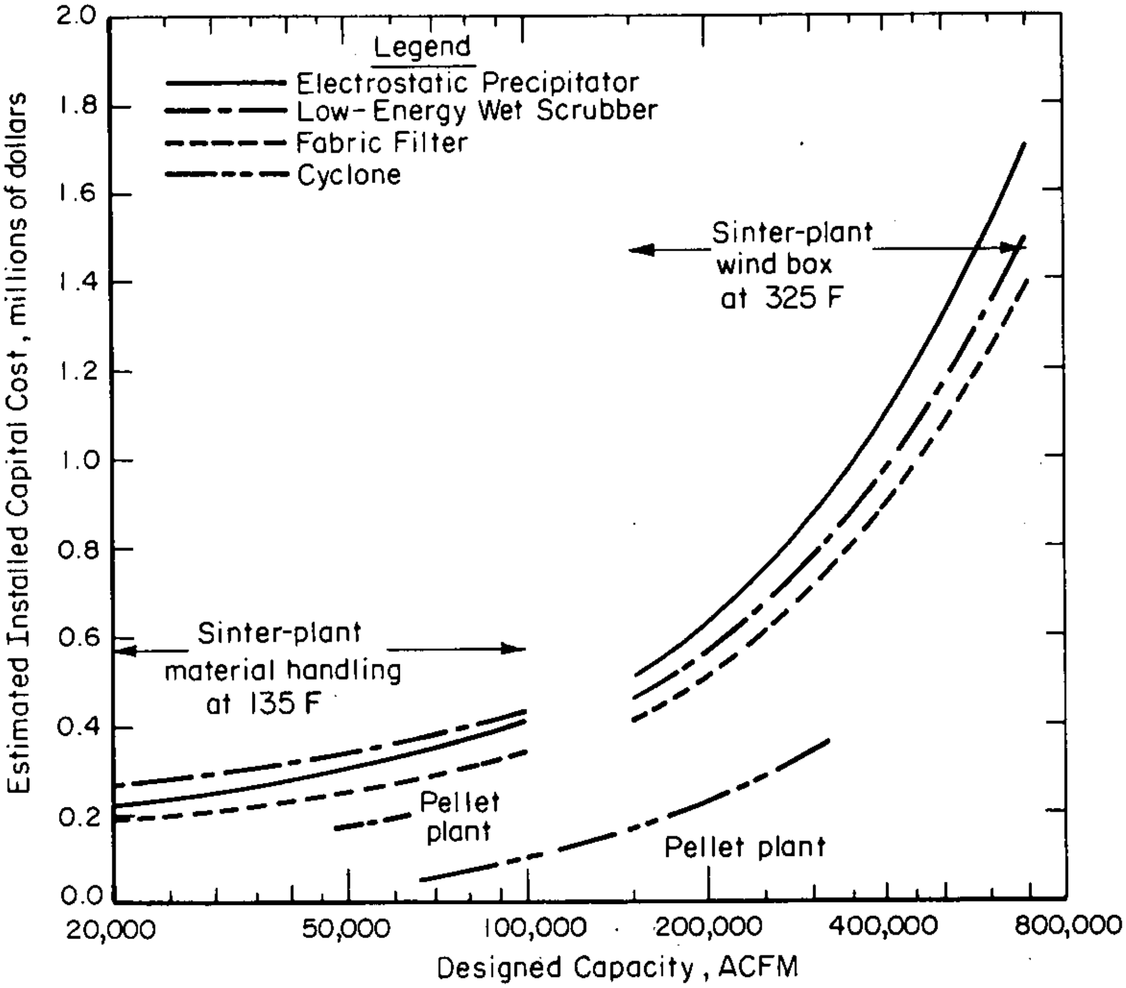


FIGURE VI-22. ESTIMATED INSTALLED CAPITAL COSTS OF AIR-POLLUTION-CONTROL EQUIPMENT USED IN SINTER AND PELLET PLANTS

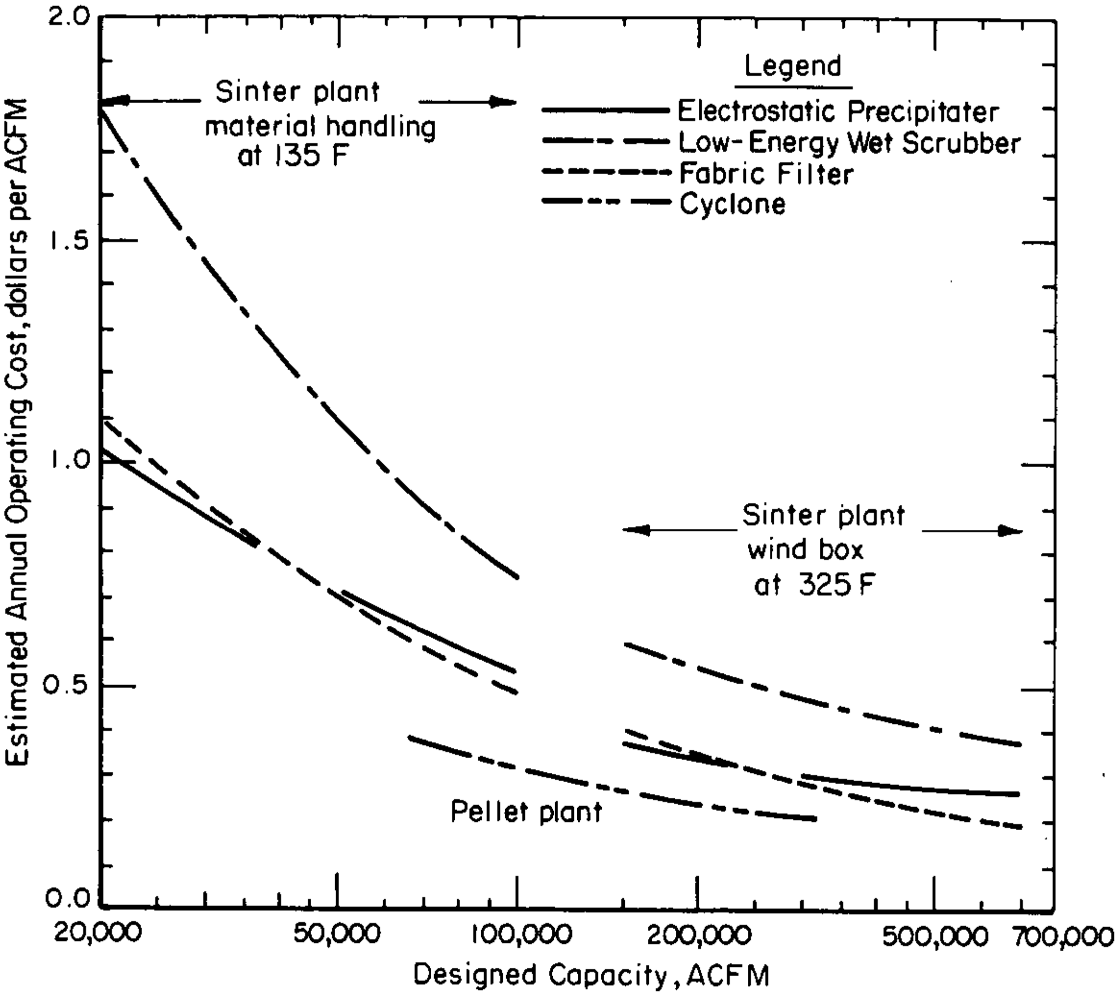


FIGURE VI-23. ESTIMATED ANNUAL OPERATING COSTS FOR AIR-POLLUTION-CONTROL EQUIPMENT USED IN SINTER AND PELLET PLANTS (DEPRECIATION AND CAPITAL CHARGES ARE NOT INCLUDED)

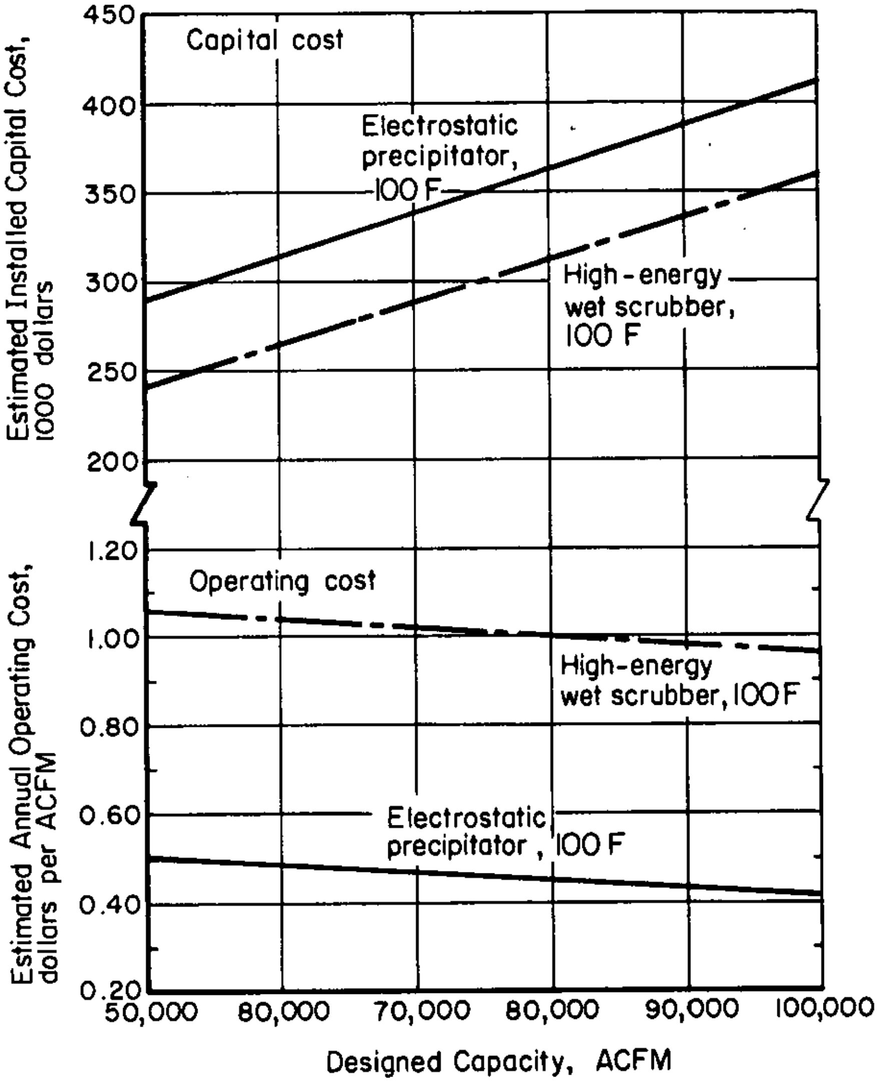


FIGURE VI-24. ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR AIR-POLLUTION-CONTROL EQUIPMENT USED ON SCARFING MACHINES (DEPRECIATION AND CAPITAL CHARGES ARE NOT INCLUDED IN THE OPERATING COSTS)

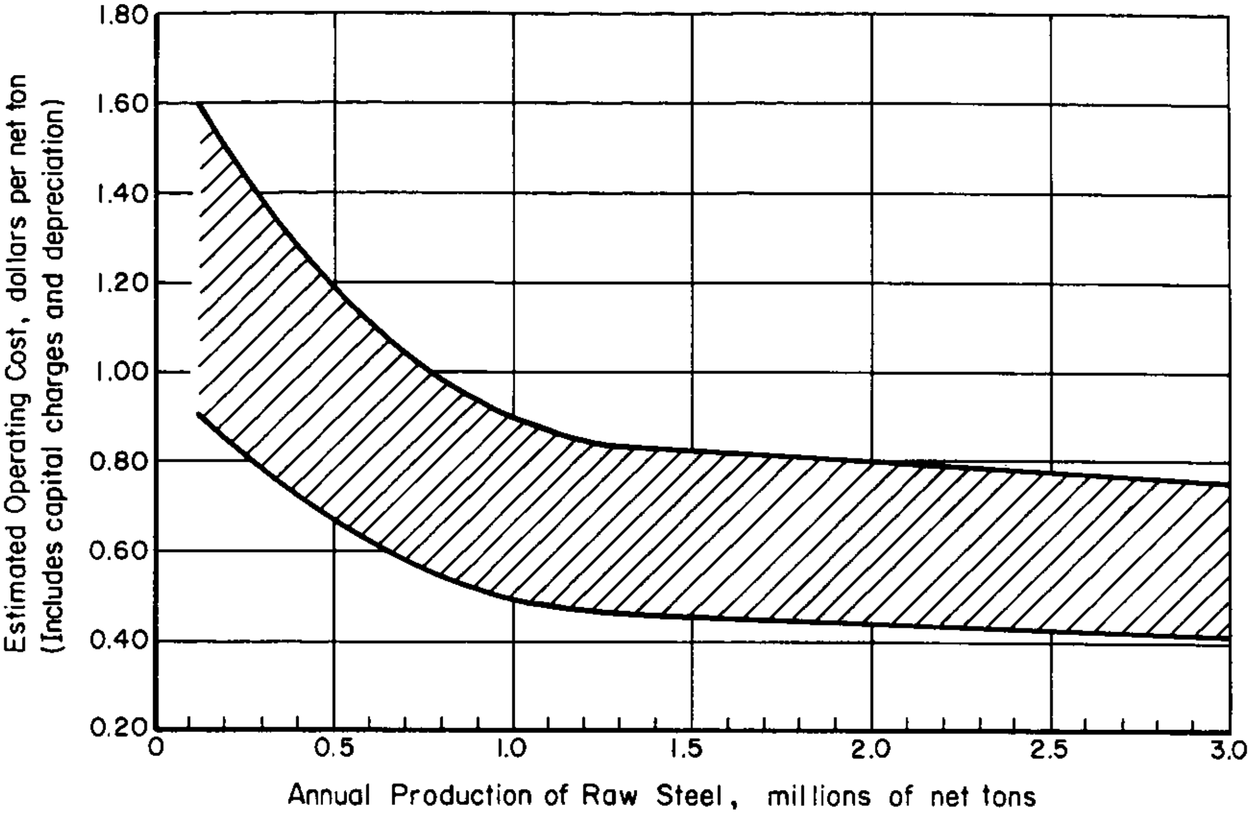


FIGURE VI-25. RANGE OF ESTIMATED OPERATING COSTS FOR AIR-POLLUTION-CONTROL EQUIPMENT PER NET TON OF RAW STEEL - OPEN-HEARTH FURNACES, BOFS, AND ELECTRIC FURNACES (TWO-FURNACE OPERATIONS)

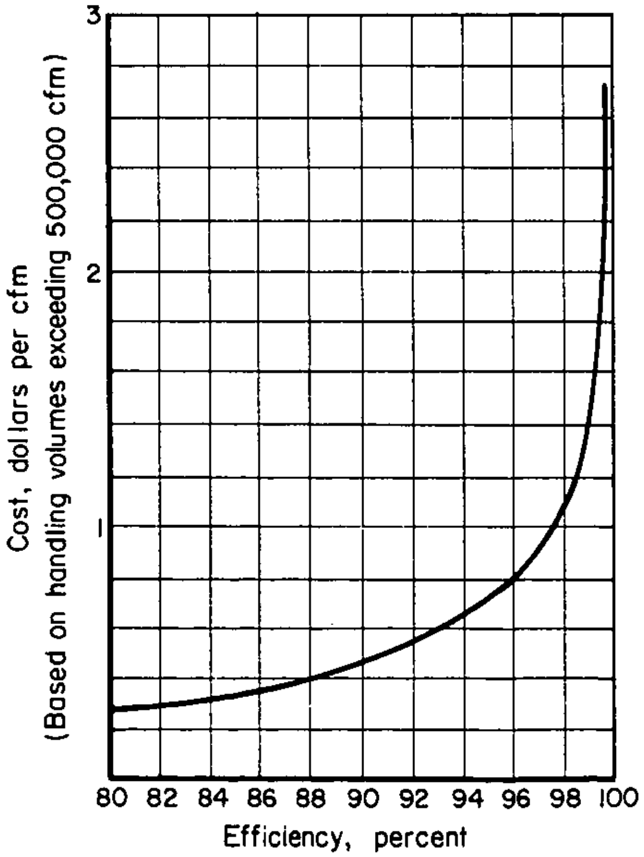


FIGURE VI-26. ELECTROSTATIC-PRECIPITATOR COSTS AS AFFECTED BY COLLECTION EFFICIENCY

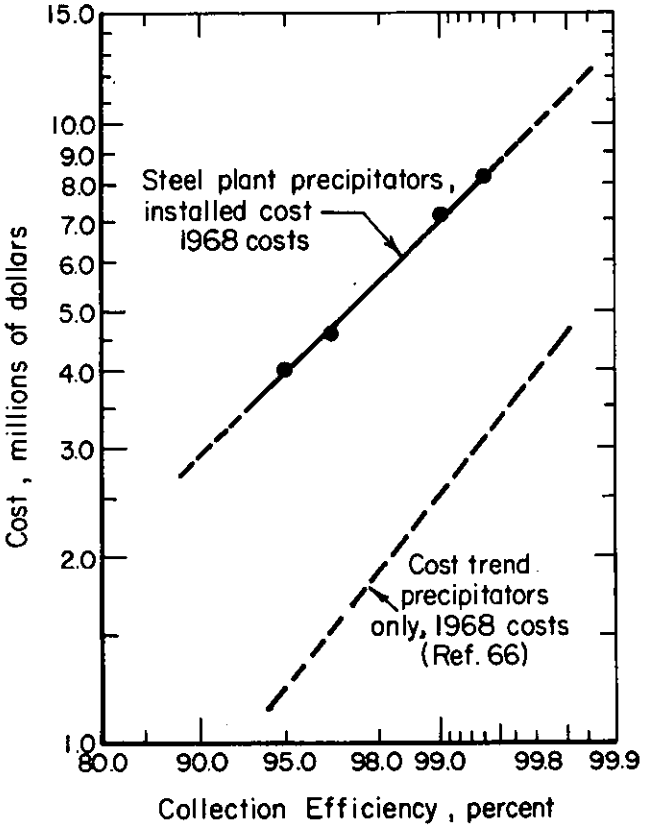


FIGURE VI-27. INSTALLED COST FOR STEEL PLANT ELECTROSTATIC PRECIPITATORS AS AFFECTED BY COLLECTION EFFICIENCY

Effect of Efficiency Specifications Greater Than Current Legal Requirements on the Cost of Air-Pollution Control Equipment

The remainder of Section VI is adapted from Appendix C in the companion report, "Final Economic Report on A Cost Analysis of Air-Pollution Controls in the Integrated Iron and Steel Industry", dated May 15, 1969, and is a result of work done by the Swindell-Dressler Company, Division of Pullman Incorporated, the subcontractor on the study.

Because of the dearth of experimental and empirical data on the relationship between collection efficiency and the cost of air-pollution control equipment, resort was taken to estimation of this relationship from theoretical considerations. The estimates based on theoretical considerations then were evaluated against the limited amount of empirical data that could be obtained.

In many localities, current legal requirements specify a permissible particulate emission at the stack of not more than 0.05 grain per dry standard cubic foot of gas (or equivalent) exhausted to the atmosphere. Some facilities have met this requirement (or even exceeded it) with even fine, submicron sized steelmaking dust by using high-efficiency filters, scrubbers, and precipitators. Manufacturers have been able to guarantee this performance with their equipment in a variety of applications. Also it is noted that blast-furnace gas has been cleaned to as low as 0.005 grain/DSCF* when necessary for reuse of the gas in high-energy burners and fine checkerwork of the blast stoves (although this is a coarser dust than from steelmaking).

This index "0.05" is not necessarily an ultimate measure of the effluent quality that can be obtained. It came into use in the early 1960's, on the basis that an open hearth furnace stack plume containing fume at such a concentration had an "acceptable" appearance in many steelmaking areas. The value "0.05" correlated approximately with the maximum efficiency of electrostatic precipitators normally offered by manufacturers at that time for collecting this fume. However, the rapid growth in the use of oxygen lancing of steelmaking furnaces has led to larger quantities of finer fume in their waste gases today.

A stack plume cleaned to this level is not an invisible plume. The very fine steelmaking fume escaping at the stack causes a larger degree of scatter of transmitted light than the larger particles previously encountered(13), and thus may be visible even in low concentrations. Yet, visibility of an exhaust plume persists as a means of checking collector performance, because it involves a simple comparison of "equivalent opacity" of the plume against the Ringelmann Smoke Chart.

Local code limitations based on Ringelmann opacity judgments may find a concentration of 0.05 grain/DSCF of steelmaking fume unsatisfactory. Where local codes are based on a schedule of allowable fume emission weight per ton throughput of processed material, the permissible fume rate customarily decreases for larger production equipment, so that above 30 to 40 tons of process weight per hour, the 0.05 level of control may not be adequate.

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*DSCF = dry standard cubic foot.

Thus, the widespread use of 0.05 grain/DSCF as a general limiting level for emissions led to its choice as a basis for calculating the size and cost of collectors for each process in the tabulations in Appendix D of this report. But, in recognition of the use of more restrictive enforcement methods in some steelmaking areas, and because of the trend in promulgating air-quality criteria which may suppress the emission sources in an area to an increasing degree, the following indications are drawn of the difference in cost for fume-collecting systems capable of an efficiency beyond the currently practiced or currently attainable level.

Performance Equations

The performance equations of gas cleaners, as currently understood and applied to select the size and operating parameters for a particular cleaning application have this in common – they are of the form:

$$\eta = 1 - e^{-F(x)} \quad ,$$

where

η = collection efficiency

or $1-\eta$ = penetration, dust loss, or outlet concentration as a fraction of the inlet concentration to the gas cleaner. It corresponds to some figure like 0.05, for example;

$$1-\eta = \frac{0.05 \quad \text{(grains/DSCF)}}{\text{inlet conc.} \quad \text{(grains/DSCF)}}$$

$\ln(1-\eta) = -F(x)$

$F(x)$ is a function of the size and operating parameters of the collector.

Fabric Filters. The equation for the performance of fabric (bag) filters, has been shown to be of the form(67):

$$\eta = 1 - e^{-S_o \frac{D'}{D}} \quad .$$

$\frac{D'}{D}$ is the target efficiency and is a function of $\frac{Dg}{Vf}$,

where

D = fiber diameter

g = gravitational constant

V = velocity of gas at filter face

$$= \frac{Q}{A} = \frac{\text{flow rate of gas}}{\text{area normal to flow}} = \text{face velocity}$$

f = settling velocity of particle, as from Stoke's Law.

$$S_o = \frac{\text{total projected area of all fibers in the filter}}{\text{cross section of filter bed}},$$

both normal to the gas flow.

The relationship between the target efficiency $\frac{D'}{D}$ and the function $\frac{Dg}{Vf}$ is shown in Figure VI-28.

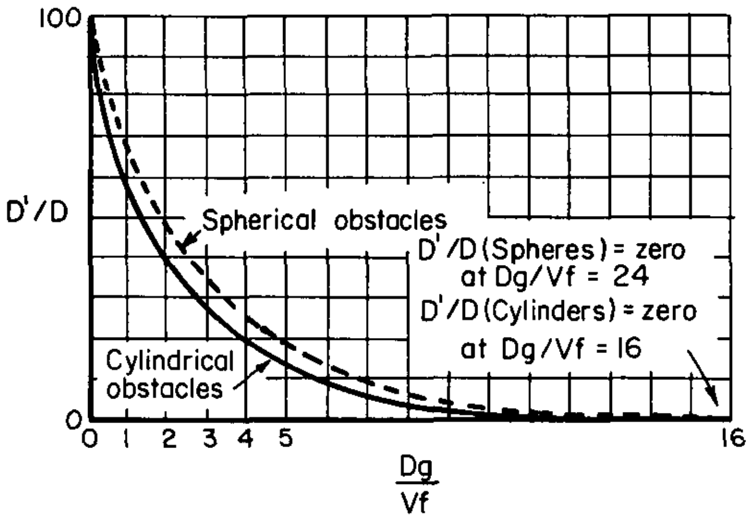


FIGURE VI-28. RELATIONSHIP BETWEEN TARGET EFFICIENCY $\left(\frac{D'}{D}\right)$ AND $\frac{Dg}{Vf}$ FOR FABRIC FILTERS

Electrostatic Precipitators. The equation for the performance of an electrostatic precipitator takes the form of the Deutsch equation$^{(15, 68)}$:

$$\eta = 1 - e^{-A'f'/Q} \quad ,$$

where

A' = collecting surface area

$$f' = \left[1 + \frac{2(k-1)}{(k+2)}\right] \frac{rE^2}{6\pi\mu} = \text{drift velocity}$$

k = dielectric constant of particles

E = electric field strength

r = particle radius

μ = gas viscosity at temperature.

Wet Scrubbers. A correlation established for wet scrubbers is as follows(69):

$$\eta = 1 - e^{-\alpha\left(P_G + P_L\right)^{\gamma}} = 1 - e^{-\alpha\left(P_T\right)^{\gamma}}$$

where

P_G = contacting power of gas stream

$= 0.157\ F_S$

F_S = pressure loss across scrubber, in. water, exclusive of loss due only to velocity changes or friction losses across dry portions of the equipment

P_L = contacting power of liquid stream

$= 0.583 p_F \dfrac{q_L}{Q}$

P_F = liquid feed pressure, psig

q_L = liquid feed rate, g.p.m.

$P_T = P_G + P_L$ = HP/1000 CFM, based on Q

Q = actual gas flow at the scrubber, CFM

α, γ = constants for a particular dust, related to particle size and size distribution.

Theoretical Factors Affecting Performance

To increase the efficiency of a collector, whose performance is describable by this logarithmic-decay-type function, it is necessary to increase F(X). The variable flow and equipment parameters comprising F(X) for a particular dust are respectively:

Bag Filter $S_\circ, \dfrac{D}{V} = S_\circ, \dfrac{DA}{Q}$

Precipitator $\dfrac{A'E^2}{Q\mu} = \dfrac{2L\,W\,n\,E^2}{A\,V\,\mu} = \dfrac{2L\,W\,n\,E^2}{n\,b\,W\,V\,\mu} = \dfrac{2LE^2}{bV\mu}$

where

W = collector surface span normal to flow

L = collector surface length in direction of flow

n = number of collecting ducts

b = separation of collecting surfaces

Scrubber F_S and $P_F(q_L/Q')$

where

q_L/Q' is the liquid/gas ratio (gal/1000 CF).

Effects of Properties of Particles

(1) Increasing f increases $\eta_{\text{bag filter}}$

$$f = \frac{4g\, r^2 \rho}{18\mu} \quad ,$$

where ρ is the density of particle.
So larger, denser particles are collected more easily.

(2) Increasing r increases $\eta_{\text{precipitator}}$. Again, larger particles are more easily attracted to the collector. Increasing the dielectric constant of the particulate, and decreasing resistivity by pre-conditioning via temperature and humidity (or SO_2 addition) increases $\eta_{\text{precipitator}}$.

(3) Increasing α or γ increases η_{scrubber}, as can be established(69). Both increase with particle size.

Effects of Geometry of Dust Collector

(1) Increasing filter thickness or mat density, or decreasing air/cloth ratio by using larger bag surfaces will increase $\eta_{\text{bag filter}}$.

(2) Increasing precipitator length in the flow direction, or decreasing plate spacing or tube diameter (within limits of electrical stability) will increase $\eta_{\text{precipitator}}$. Because the dust loading decreases in the flow direction, it is possible to achieve an economy by successive stages of precipitation, each optimized electrically for maximum efficiency at the respective loading it will see, rather than simply extending the first-stage field.

(3) Decreasing the throat area of a scrubber increases its pressure drop and increases η_{scrubber}. This can be done by variable geometric arrangement or by increased water rate.

Effects of Utility Parameters

(1) A partially blinded filter will be more efficient, but at a cost of higher pressure drop and higher fan horsepower.

(2) Increasing electric field strength increases $\eta_{\text{precipitator}}$ within the limits imposed by the geometry of the collector and dust properties with respect to sparking. This limit can be approached more closely with safety if automatic controls are used to regulate the discharge. Energy use rises.

(3) Venturi Scrubber. Increasing water usage or delivery pressure in a scrubber increases η_{scrubber}. Increased gas-pressure drop gives improved efficiency at the cost of higher fan horsepower.

Effects of Flow

(1) Even though an increase in face velocity $\left(\frac{Q}{A}\right)$ gives a higher theoretical efficiency in the inertial effect range, the effect is reversed in dealing with small particles ($<1\mu$). For a filter with a fixed pressure drop and fixed cleaning routine, the dust buildup will dominate, so that if increased loading blinds the filter, causing spillage and less net cleaning, then the following holds. Decreasing the quantity of gas treated or using a larger filter for lower face velocity increases $\eta_{\text{bag filter}}$.

(2) Decreasing the amount of gas treated by lowering precipitator velocity and increasing residence time increases $\eta_{\text{precipitator}}$ if distribution of the gas is maintained uniform between the plates.

(3) Increasing the quantity of gas treated or increasing throat velocity increases η_{scrubber} by increasing pressure loss across the constriction, with an increase in P_G and fan horsepower.

Effect of Temperature on Viscosity

(1) Increasing temperature increases μ gas, decreases $\eta_{\text{bag filter}}$, and decreases $\eta_{\text{precipitator}}$.

(2) Increasing temperature increases the quantity of gas handled, again lowering these efficiencies.

(3) Besides altering flow and settling or drift velocity, temperature also endangers the bags, structures, and mechanisms of the collectors. Filters and dry precipitators must have an inlet temperature above the water vapor (and sulfuric acid) dew point to avoid corrosion and dust caking on the collector, and causing dust handling problems in disposal conveyors.

(4) Temperature affects the scrubber mainly in increasing the gas flow and increasing the saturation-water requirement.

Control System Cost Changes

It is a property of decay functions of the aforementioned type that, at high efficiency, an increasingly large change in the exponent is required for a small incremental increase in efficiency.

Electrostatic Precipitators. For example, for an electrostatic precipitator, it has been stated that the precipitator unit size increases with respect to efficiency changes as follows(70):

Overall Efficiency for a Particular Dust	Outlet Loading With 5.0 Grains/DSCF Input Loading	Size of Precipitator Box and Unit Cost
90 percent	0.5	X
99 percent	0.05	2X
99.9 percent	0.005	3X

This tabulation excludes ductwork, water sprays, hood with its cooling auxiliaries, and stack; but includes the precipitator and its electrical components. The fan and motor size and cost, for a 1X increase in precipitator size would be affected by an increment corresponding to an increased static pressure (S. P.) of about 1-1/2 inches of water (the loss through Box X), with the volume remaining unchanged.

For a precipitator increment of X:

$$\text{Horsepower increment} = \frac{\text{S.P.} + 1.5}{\text{S.P.}} \times \text{H.P.}$$

$$\text{Fan-pressure increment} = \frac{\text{S.P.} + 1.5}{\text{S.P.}} \times \text{S.P.}$$

for the total system fan.

Fan volume unchanged.

The effect of increasing the size of an electrostatic precipitator on operating efficiency has also been reported in the literature for an electrostatic precipitator collecting open-hearth emissions.(71) The relationship developed between the collection efficiency and size of the precipitator (as shown by the square feet of collecting surface) is shown in Figure VI-29.(71) The results of the study have shown that removing the dust from 315,000 cubic feet per minute of open-hearth waste gas required 58,300 square feet of collecting surface area for an efficiency of 95 percent. An increase in the collecting surface area to 96,500 square feet (an increase of 66 percent) resulted in an increase in efficiency of only 4.3 percent to 99.3 percent.

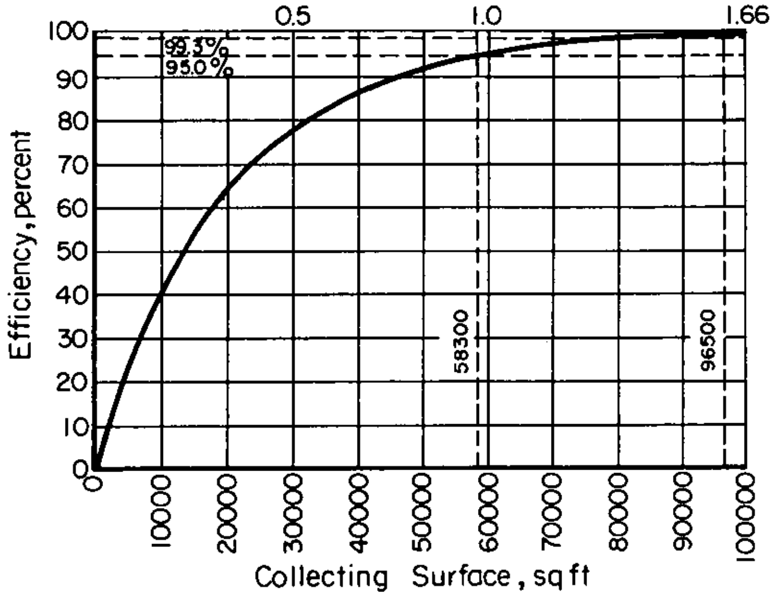


FIGURE VI-29. RELATIONSHIP OF ELECTROSTATIC PRECIPITATOR COLLECTING SURFACE TO COLLECTION EFFICIENCY FOR OPEN-HEARTH EMISSIONS

The above variation in size corresponds to Deutsch's Law:

$$(1-\eta) = e^{-\frac{A'f'}{Q}}$$

for a particulate of homogeneous size, shape, density, and composition.

$$\eta = \frac{\text{inlet loading } -R}{\text{inlet loading}} = 1 - \frac{R}{\text{I. L.}}\text{ , where } R = \text{the outlet loading.}$$

$$R = \text{constant}_1 \times e^{-\text{constant}_2 \times \text{length}}\ .$$

$$\log R = \text{constant}_3 + \text{constant}_4 \times \text{length}$$

for a given process and precipitator.

Case 1 Illustrative of Deutsch's Law

R:	$5\,\frac{\text{grains}}{\text{SCFD}}$ →	Box X	→ 0.5 →	Box X	→ 0.05 →	Box X	→ 0.005
η(percent):		90		90		90	
net η(percent):		90		99		99.9	
net size:		X		2X		3X	

However, real particulate varies in size, density, and susceptibility to charging (depending on surface and compositional variables), so that the least collectable particles remain after each treatment, lowering the efficiency of subsequent treatments.(72) Case 2 below illustrates this with arbitrary efficiencies:

Case 2. Illustrative of Deutsch's Law

R:	5 →	Box X	→ 0.5 →	Box X	→ 0.1 →	Box X	→ 0.03 →	Box X	→ 0.012 →	Box X	→ 0.006 →	Box 5/12X	→ 0.005
η(percent):		90		80		70		60		50		40	
net η (percent):		90		98		99.4		99.76		99.88		99.9	
net size:		X		2X		3X		4X		5X		5-5/12X	

A body of blast-furnace data(73) for a number of operating furnaces at various precipitator loadings yields the following progression, which shows this trend,

net η(percent):	90	95	98	99	99.5	99.9	99.99
net size:	0.55X	0.86X	1.4X	2X	2.65X	4.5X	7.5X

Cost data from precipitator manufacturers indicate a close correspondence to Case 1 in variation of cost (= constant x length) with efficiency. Guarantees are made on efficiency rather than outlet loading, because the precipitator is not adequately adjustable for cleaning a higher inlet dust concentration to the same outlet level (say 0.05). In fact, the higher loading may reach a point where spark-over occurs; so automatic electrical controls are used to maintain the highest collection efficiency just short of spark-over. (Large loading differences require design selection of plate spacing and voltage optimized for the loading and dust properties of the individual process effluent). The maximum guarantee is presently about 99.5 percent, although higher efficiencies (around 99.7 percent) can be reached.

The successive lowering of efficiency found with addition of identical precipitation units can be compensated for. Because each successive unit sees a lower dust loading, plates can be spaced more closely, and voltage optimized in each succeeding section, while avoiding spark-over. Still, each type of dust must be tested to determine its collectability as a function of precipitator length.

Tables VI-4 through VI-9 show some estimated cost changes for processes cleaned by electrostatic precipitation to various outlet dust concentrations. The variation is based on the Deutsch Law. Capital cost changes include:

Materials: precipitator + fraction of electrical.

Labor: corresponding to each of above at standard factors.

Engineering: scaled fraction materials plus labor.

Annual operating cost changes include 0.24 (Capital change) + fraction of electric power for precipitator and horsepower increments. Only small variations were noted for capacity of the cleaner, so that only the central size of cleaners is included for processes estimated in Appendix D at 0.05 grain per SCFD.

TABLE VI-4. ESTIMATED COST DIFFERENCES FOR A SINTER PLANT ELECTROSTATIC PRECIPITATOR AS AFFECTED BY THE OUTPUT DUST LOADING FROM THE WINDBOX

Plant Capacity : 6,000 net tons per day
Gas Volume : 630,000 ACFM at 325 F
Input Dust Loading: 0.8 grain per SCF[(a)]

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 29	- 23	- 17.5
0.050	0	0	0.0
0.020	+ 29	+ 23	+ 17.5

$$\frac{\log_{10}\left(\frac{R}{R_{0.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{18\%} = \frac{-\Delta C_R}{15\%} = \frac{-\Delta D_R}{10\%}$$

(a) 4 grains per SCF effluent precleaned by 80 percent efficient recovery cyclones.

TABLE VI-5. ESTIMATED COST DIFFERENCES FOR A SINTER PLANT ELECTROSTATIC PRECIPITATOR AS AFFECTED BY THE OUTPUT DUST LOADING FROM MATERIAL HANDLING

Plant Capacity : 6,000 net tons per day
Gas Volume : 250,000 ACFM at 135 F
Input Dust Loading: 1.0 grain per SCF

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 18	- 15	- 10
0.050	0	0	0
0.020	+ 18	+ 15	+ 10

$$\frac{\log_{10}\left(\frac{R}{R_{0.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{18\%} = \frac{-\Delta C_R}{15\%} = \frac{-\Delta D_R}{10\%}$$

TABLE VI-6. ESTIMATED COST DIFFERENCES FOR A BOF ELECTROSTATIC PRECIPITATOR AS AFFECTED BY OUTPUT DUST LOADING

Furnace Size : 200 net tons
Gas Volume : 785,000 ACFM at 500 F
Input Dust Loading: 4.0 grains per SCF

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 9	- 10	- 11
0.050	0	0	0
0.020	+ 9	+ 10	+ 11

$$\frac{\log_{10}\left(\frac{R}{R_{0.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{9\%} = \frac{-\Delta C_R}{10\%} = \frac{-\Delta D_R}{11\%}$$

TABLE VI-7. ESTIMATED COST DIFFERENCES FOR AN OPEN HEARTH ELECTROSTATIC PRECIPITATOR AS AFFECTED BY OUTPUT DUST LOADING

Furnace Size : 200 net tons
Gas Volume : 85,000 ACFM at 500 F
Input Dust Loading: 5.0 grains per SCF

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 10	- 9	- 7
0.050	0	0	0
0.020	+ 10	+ 9	+ 7

$$\frac{\log_{10}\left(\frac{R}{R_{0.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{10\%} = \frac{-\Delta C_R}{9\%} = \frac{-\Delta D_R}{7\%}$$

TABLE VI-8. ESTIMATED COST DIFFERENCES FOR AN ELECTRIC FURNACE ELECTROSTATIC PRECIPITATOR AS AFFECTED BY OUTPUT DUST LOADING

Furnace Size : 150 net tons(a)
Gas Volume : 185,000 ACFM at 500 F(b)
Input Dust Loading: 3.0 grains per SCF

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 10	- 10	- 9
0.050	0	0	0
0.020	+ 10	+ 10	+ 9

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{10\%} = \frac{-\Delta C_R}{10\%} = \frac{-\Delta D_R}{9\%}$$

(a) Two-furnace system.

(b) Assumes humidification of process fume is capable of maintaining particle resistivity in satisfactory collection range.

TABLE VI-9. ESTIMATED COST DIFFERENCES FOR A SCARFING MACHINE ELECTROSTATIC PRECIPITATOR AS AFFECTED BY OUTPUT DUST LOADING

Gas Volume : 100,000 ACFM at 100 F
Input Dust Loading: 1.0 grain per SCF

Outlet Loading (R)	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	- 19	- 18	- 17
0.050	0	0	0
0.020	+ 19	+ 18	+ 17

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{19\%} = \frac{-\Delta C_R}{18\%} = \frac{-\Delta D_R}{17\%}$$

Wet Scrubbers. In the case of the venturi scrubber, it has been stated that the following relates capital cost to efficiency(70):

Overall Efficiency for a Given Dust at Inlet Load of Inlet Grain/DSCF, percent				Outlet Loading Grains/DSCF	Capital Cost
1.0	3.8	5.0	10		
90	97.4	98	99	0.10	X
96.2	99	99.24	99.62	0.038	1.43X

The operating expenses vary similarly for a venturi scrubber as efficiency is increased. This is shown in Figure VI-30(48) for an open-hearth application where a decrease in outlet loading from 0.1 to 0.01 grain/SCFD results in more than doubling the annual operating cost of the fan. For a given size adjustable venturi, the increased efficiency requires an increase in available horsepower to the fan and selection of a higher pressure fan. Operating power consumption increases directly with the pressure drop.

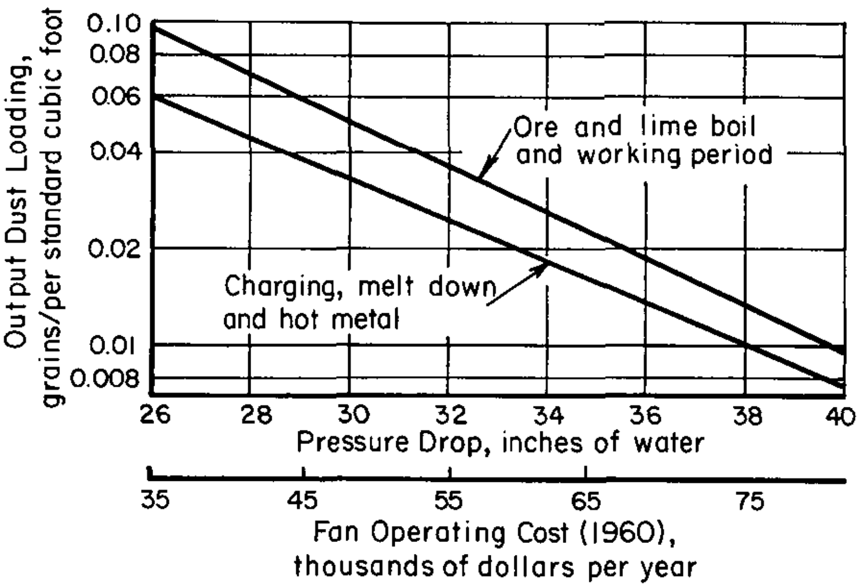


FIGURE VI-30. RELATIONSHIP OF OUTPUT DUST LOADING TO PRESSURE DROP AND FAN OPERATING COST FOR A VENTURI SCRUBBER OPERATING ON AN OPEN-HEARTH FURNACE(48)

The above venturi-cleaned open-hearth application involves oxygen lancing during the periods noted on the upper curve. Dust loading was low (0.82 to 0.87 grain/SCFD during oxygen periods, and 0.35 to 0.45 grain/SCFD during the charging, melting and hot-metal addition periods). When these data are corrected to a typical peak of 5 grains/SCFD loading for today's oxygen-lanced furnaces, it yields the following correlation:

R, outlet loading $\left(\frac{\text{grains}}{\text{SCFD}}\right)$	ΔP, venturi pressure drop (in. w.)
0.125	34.7
0.05	41.0
0.02	48.2

$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-0.178}$$

However, the contacting power concept(69) has been applied for the regression line of a plot of nonlanced open hearth gas-cleaning efficiency versus pressure drop at various operation conditions(46). This gives for a peak 5 grains/SCFD inlet loading:

R (grains/SCFD)	ΔP (in. w.)
0.125	44
0.05	78
0.02	136

$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-0.62}$$

The numerically higher exponent seems more in line with results from other steelmaking fume.

Blast-furnace data give the following(46):

R, outlet loading $\left(\frac{\text{grains}}{\text{SCFD}}\right)$	ΔP, venturi pressure drop (in. w.)
0.125	15.8
0.05	23.0
0.02	33.2

$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-0.403}$$

Data for an electric furnace making 20 percent ferrosilicon show(46):

$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-1.53}$$

For the typical scrap-charged electric-arc furnace, wet scrubbing applications are sparse, and data are not available for a scrubbing power-efficiency correlation.

Venturi gas cleaning data on the basic oxygen furnace have been developed as follows(74):

R, outlet loading $\left(\frac{\text{grains}}{\text{SCFD}}\right)$	ΔP, venturi pressure drop (in. w.)
0.125	27
0.05	41
0.02	60

giving
$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-0.417}$$

Data from a pilot-size conventional venturi scrubber applied to clean scarfing-machine effluent have been published as follows(75):

R, outlet loading $\left(\frac{\text{grains}}{\text{SCFD}}\right)$	ΔP, venturi pressure drop (in. w.)
0.125	34
0.05	60
0.02	108

$$\frac{\Delta P_R}{\Delta P_{0.05}} = \left(\frac{R}{0.05}\right)^{-0.631}$$

Tables VI-10 through VI-12 give some estimated cost differences for processes cleaned by wet scrubbers of the high-energy types. The variation is based on the preceding scrubber-application data. Capital cost changes include:

Materials: Fan and motor + fraction of electrical. The venturi itself is assumed adjustable and of sufficient strength for the higher pressure difference across its walls. Water rates are unchanged.

Labor: Corresponds to each of above at standard factors.

Engineering: Scaled fraction of materials plus labor.

Annual operating cost changes include 0.24 (capital change) plus electric power for horsepower increments.

An empirical relationship is indicated as follows:

$$\frac{\Delta K_R}{5.5\%} = \frac{\Delta C_R}{9\%} = \frac{\Delta D_R}{12\%} = \frac{\Delta P_R - \Delta P_{0.05}}{60-41} = \frac{\Delta P_{0.05}}{19}\left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \frac{41}{19}\left[\left(\frac{R}{0.05}\right)^{-0.417} - 1\right]$$

$$\frac{\Delta K_R}{11.8\%} = \frac{\Delta C_R}{19.4\%} = \frac{\Delta D_R}{25.9\%} = \left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \left[\left(\frac{R}{0.05}\right)^{-0.417} - 1\right]$$

TABLE VI-10. ESTIMATED COST DIFFERENCES FOR A BOF WET SCRUBBER AS AFFECTED BY OUTPUT DUST LOADING

Furnace Size : 200 net tons(a)
Gas Volume : 440,000 ACFM at 180 F
Input Dust Loading: 4.0 grains per SCF

Outlet Loading (R)	Venturi Pressure Drop (ΔP), inches of water	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.125	27.5	- 4.0	- 6	- 8
0.050	41.0	0.0	0	0
0.020	60.0	+ 5.5	+ 9	+ 12

(a) One furnace system.

TABLE VI-11. ESTIMATED COST DIFFERENCES FOR AN OPEN-HEARTH WET SCRUBBER AS AFFECTED BY OUTPUT DUST LOADING

Furnace Size : 200 net tons(a)
Gas Volume : 90,000 ACFM at 180 F
Input Dust Loading: 5.0 grains per SCF

Outlet Loading (R)	Venturi Pressure Drop (ΔP), inches of water	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.20	32.6	- 11.0	- 15.5	- 19.5
0.10	50.2	- 6.5	- 9.0	- 12.0
0.05	78.0	0.0	0.0	0.0

$$\frac{\Delta K_R}{-6.5\%} = \frac{\Delta C_R}{-9\%} = \frac{\Delta D_R}{-12\%} = \frac{\Delta P_R - \Delta P_{0.05}}{50.2-78} = \frac{\Delta P_{0.05}}{-27.8} \cdot \left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \frac{78}{-27.8}\left[\left(\frac{R}{0.05}\right)^{-0.62} - 1\right]$$

$$\frac{\Delta K_R}{18.2\%} = \frac{\Delta C_R}{25.1\%} = \frac{\Delta D_R}{33.5\%} = \left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \left[\left(\frac{R}{0.05}\right)^{-0.62} - 1\right]$$

(a) One-furnace system.

TABLE VI-12. ESTIMATED COST DIFFERENCES FOR A SCARFING MACHINE WET SCRUBBER AS AFFECTED BY OUTPUT DUST LOADING

Gas Volume : 100,000 ACFM at 100 F
Input Dust Loading: 1.0 grain per SCF

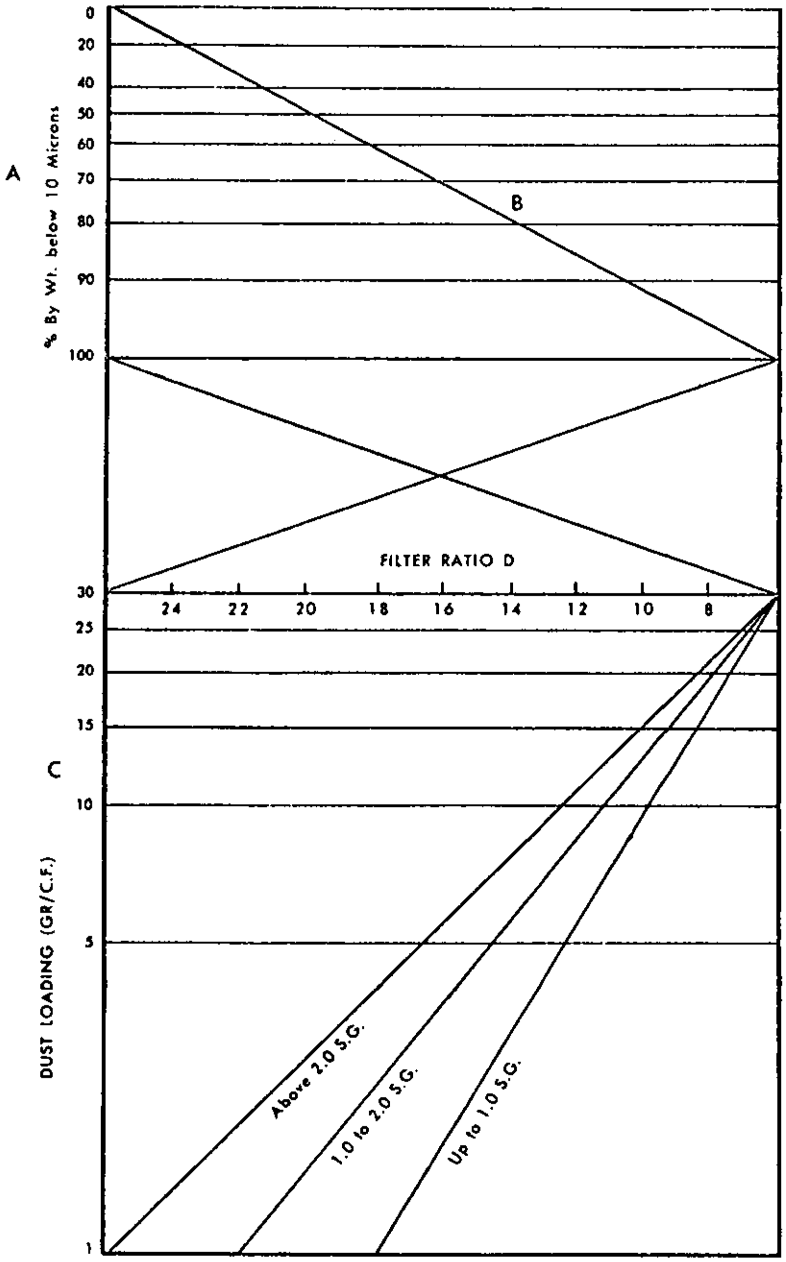
Outlet Loading (R)	Venturi Pressure Drop (ΔP) inches of water	Capital Cost Difference (ΔK_R) $K_{0.05}$, percent	Annual Operating Cost Difference (ΔC_R) $C_{0.05}$, percent	Annual Direct Operating Cost Difference (ΔD_R) $D_{0.05}$, percent
0.083	44.3	- 9	- 17	- 23
0.050	61.0	0	0	0
0.030	81.5	+ 11	+ 21	+ 28

$$\frac{\Delta K_R}{11\%} = \frac{\Delta C_R}{21\%} = \frac{\Delta D_R}{28\%} = \frac{\Delta P_R - \Delta P_{0.05}}{81.5-61} = \frac{\Delta P_{0.05}}{20.5}\left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \frac{61}{20.5}\left[\left(\frac{R}{0.05}\right)^{-0.631} - 1\right]$$

$$\frac{\Delta K_R}{32.6\%} = \frac{\Delta C_R}{62.5\%} = \frac{\Delta D_R}{83.4\%} = \left[\frac{\Delta P_R}{\Delta P_{0.05}} - 1\right] = \left[\left(\frac{R}{0.05}\right)^{-0.631} - 1\right]$$

Doubling the venturi pressure drop would cause a 25.9 percent increase in direct operating costs. Venturi loss of 41 in. w. is 85 percent of system loss, which accounts for 40 percent of total horsepower (including an unchanged water pumping and treatment system) in this case. Power cost is about 72 percent of direct operating costs.

Fabric Filtration. For an acceptable constant dust penetration through a fabric filter, the face velocity or air volume-to-cloth area ratio must decrease with decreasing particle size and density or with increased inlet loading. For a lower allowable penetration, the face velocity would similarly decrease. Thus, a more difficult or more thori thorough cleaning job would involve increased cost to provide more filter surface area. This is exemplified in the extreme case of a reverse jet-cleaned filter where face velocities are the highest encountered. Nomograms that can be used to estimate the size of reverse jet filters are shown in Figure VI-31 and VI-32.(76)



The following nomograph is presented as a convenient means of selecting Filter Ratio for preliminary determination of the size Aeroturn Dust Collector that will best satisfy the needs of your installation.

In many instances the nomograph will provide determination of the optimum Filter Ratio. Because of the great variety of possible service conditions and the effect of the characteristics of specific dusts, final determinations of Filter Ratio will be made by Buffalo Forge Company. This procedure provides the greatest assurance of correct and economic selection of equipment for your installation.

HOW TO USE

In order to select Filter Ratio, three conditions pertaining to your specific dust collection job are needed. They are:

a. The approximate percentage, by weight, of dust particles 10 microns or smaller.

b. Dust content of the air entering the Aeroturn Collector expressed in terms of grains (7000 per lb.) per cubic foot. Use average or normal values for both dust and air quantities.

c. Specific gravity of the material to be collected.

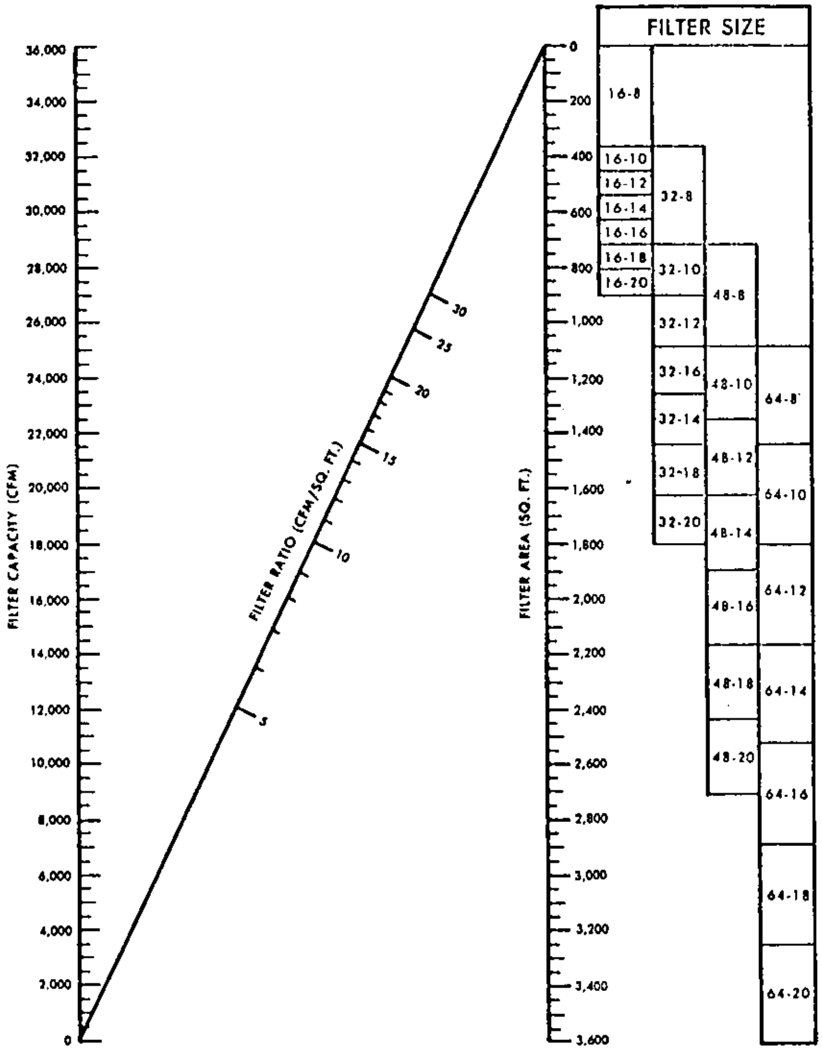
TO USE:

1. From appropriate point on vertical scale **A** draw horizontal line intersecting sloping line **B**.

2. From appropriate point on vertical scale **C** draw horizontal line intersecting the sloping line which represents the proper specific gravity range for the material to be collected.

3. Now, draw a straight line between points selected in steps 1 and 2 above. The intersection of this line with horizontal scale **D** gives the Filter Ratio. This value may now be used in the Size Selection Chart, on the next page, to determine the Aeroturn Dust Collectors applicable to your requirement.

FIGURE VI-31. NOMOGRAM FOR ESTIMATING THE FILTER RATIO OF A REVERSE-JET FILTER



HOW TO USE

This chart provides a convenient and accurate means for selecting the applicable size or sizes of Aeroturn Dust Collectors when Filter Ratio and required Air Cleaning Capacity are known.

1) Draw a line from the required Capacity through the applicable Filter Ratio to intersect the Filter Area scale.

2) From this point of intersection, draw a horizontal line through blocks designating Filter Size selections for desired Capacity.

3) If horizontal line passes through more than one Filter Size, first size intersected will be most economical. Subsequent selections will be less economical.

4) For capacities larger than shown: Use ½ the required capacity in the above procedure. Filter Size thus selected must be doubled for full capacity.

FIGURE VI-32. NOMOGRAM FOR ESTIMATING THE SIZE OF A REVERSE-JET FILTER

A reverse-jet cleaned fabric filter calculated from the nomograms shown in Figures VI-31 and VI-32 for dust having 70 percent of its weight less than 10 microns in size and a specific gravity above 2.0 yields the following information on sizing of the filter:

Inlet Dust Loading, grains/DSCF	Efficiency Required for 0.05 Grain/DSCF Outlet, percent	Filter Ratio, cfm/sq ft	Q/A Filter Area
5	99	16.4	X
10	99.5	13.7	1.2X
20	99.75	9.6	1.7X
25	99.8	7.6	2.1X

The effective filtering body is the dust cake layer on the bags. This does not at this time seem amenable to treatment which will improve efficiency. However, the bag, when new, and to a lesser extent when cleaned, holds little dust cake so that the fabric, with its small, dust-laden fibers is the basic filter until the filter cake layer reforms. As the small fibers break in service, the bag loses filtration capability. Additionally, the lower flow resistance of a cleaned bag passes a greater volume of air at reduced cleaning efficiency than when it is dust-coated; but at a higher velocity, which improves the collectability of larger particles and worsens the diffusional efficiency dominating small-particle collection.

An adequately designed baghouse will have a bag-cleaning cycle suited to the inlet dust loading from the process to which it is applied. This cycle is often automatically adjustable, so that the filter maintains the same average (time-wise) efficiency with variations in inlet dust loading and gas volume. The bag-cleaning period will begin when the collected dust causes the pressure drop through the filter to reach a set-point pressure.

In addition, the fabric weave and material are chosen with the special character of the process effluent in mind (such as particle size distribution). Economic factors (bag life and initial cost differences) also enter this choice, but increased efficiency can be achieved only by choosing from a group of fabrics which will give cleaning to the projected required level. Present practice usually gives efficiencies of 99 percent +, and bag filters frequently give the highest efficiencies of the applicable cleaning devices considered for a process. Therefore, this selective optimization does not offer much potential except as research may reveal new materials and weaves.

As a case in point, a process having a generally large particulate may be adequately cleaned by a certain bag to 0.05 grain/SCFD. If lower outlet loading is required, a suitable bag which gives similar results on a process with finer effluent may be substituted. The overall cost may or may not be larger. The choices are presently limited by limited test results on filtration properties of fabrics, and state-of-the-art in fabric technology with regard to dust abrasion, flexural durability, and chemical and temperature resistance. Electrostatic interactions of various fabrics with dust particles may prove to be significant.

No clear correlation has been advanced relating efficiency to operating parameters. However:

> A higher pressure drop may be expected to increase filtration action at the cost of additional power, but the trend of such variation is not known.
>
> A higher filter-face velocity (higher air/cloth ratio) theoretically yields a higher efficiency of collection for particles large enough to be governed by inertial laws, but these are ordinarily cleaned to nearly 100 percent efficiency, so the filter size is governed by loading. The small particles which escape collection migrate under diffusional impulses, and efficiency here would increase with residence time (lower face velocity, lower air/cloth ratio, thicker filter media). The relative effects of these coacting collection mechanisms is not sufficiently understood at present for use in practical design.

These foregoing factors are insufficiently defined at present for a useful definition of the effect on costs of changed efficiency requirements of fabric filters.

Conclusions

A situation of diminishing returns is indicated by performance equations of the exponential type. In many cases a 0.05 grain/SCFD outlet concentration becomes a practical maximum level for improving efficiency, even though it is by no means an absolute limit.

The state of the art, then, allows the gas-cleaner manufacturer to predict performance, design a collector, and guarantee it with some confidence up to about 0.05 grain/SCFD outlet loading for particles greater than 2 microns in size. At lower output levels, his experience is limited. The large change in size or operating parameters required for further small increases in efficiency would magnify the uncertainties known to exist in these simplified exponential relations with their empirical constants.

Measurement techniques used to determine dust loading in the ducted stream before and after the collector leave much to be desired, especially where small concentrations and even smaller changes in concentration are to be used as evidence of guaranteed performance. Lack of homogeneity of most dusts from iron and steel processes make the use of monitored data (light scattering or transmission, for example) difficult to interpret, or the equipment difficult to calibrate, for all the variations in dust composition, size, gas flow rate, etc. caused by process changes during a heat cycle, or from heat to heat. Isokinetic sampling (sampling at stream velocity) with traversing probes involves much averaging (in time and space) with calculation and readjustment continuing during the traverse. This is costly and of questionable accuracy. Null probes, too, operate with a significant degree of error in trying to balance small pressure differences. Neither approach to isokineticity can give a time history of emission rate during the course of a rapidly changing heat cycle because only two or three traverses can be run at best in an hour. Gas density (composition and state) and moisture content data should be monitored continuously and used as input to sampling-rate determinations during the course of a sampling test. Deviations here can seriously affect the loading measured as grains of dust per dry standard cubic foot of carrier gas.

From such quantitative data as can be obtained, control equipment is designed (often with a costly excess performance factor built in) and guaranteed somewhat conservatively. The guarantee is proven (or indicated) by standard sampling tests, and no assurance is given that any particular level of Ringleman chart greyness will not be exceeded. Research is needed to find a method to measure dust concentrations inexpensively; and agreement is needed to correlate design and enforcement bases of measurement.

Very fine particulate matter, because of greatly extended surface area, causes a much greater scattering of light, even in small concentration. A Ringelmann comparison should thus in some way account for the nature of the emission being sampled. If this correlation can be made, then this economical method of testing might be used to obtain adequate design data.

In the case of very fine steelmaking dusts from open hearth, electric arc, and basic oxygen furnaces; the collector performance is difficult to predict because of the following:

(1) The particle-size distribution is difficult to quantify with present methods for sampled dust, and the correlation of these data to "in situ" dust in the furnace effluent gas is in doubt. (Large discrepancies in reported BOF dust sizing are a case in point.) The smaller the size, the greater the difficulty.

(2) Agglomerative properties of the dust are not well established and the effect of this on sampled dust sizing and on collection mechanisms in the gas cleaners is not well understood.

(3) The mechanism of collection upon which the performance equations are based (inertial and electrostatic forces) tend toward zero efficiency in the size range of the bulk of steelmaking dusts (<2 microns), where molecular interactions dominate the motion of particles.

Any attractive interactions or agglomerative tendency would be beneficial to particle collection on a clean collecting element, but joining of particles into larger interadhesive masses would tend to blind a filter matrix (lessening gas handling capacity), or to interrupt electrostatic precipitator field propagation about the wires and plates, and make the collector surface difficult to clean and the dust hard to handle. This in some cases necessitates close control of temperature and humidity.

For low-velocity collectors (inherently large and thus economically inefficient for large-particle collection), a diffusional mechanism can give significantly high collecting efficiencies. (The effect is greatest, in theory, near zero-micron size, and decreases with increasing particle size.) A middle ground exists around 0.9 micron in a bag filter where minimum efficiency can be as low as 10 percent; exactly in the center of concentration of some 70 percent of steelmaking dust. This is shown in an efficiency-particle size relationship in Figure VI-33. Reference should also be made to Figure VI-35 for a fabric filter, and to Figure VI-38 for an electrostatic precipitator, where this effect also seems to be indicated.

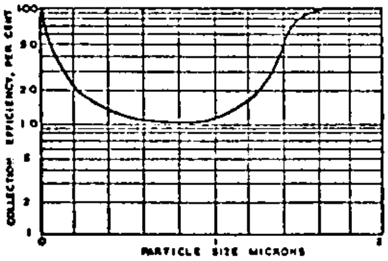


FIGURE VI-33. RELATIONSHIP OF PARTICLE SIZE TO COLLECTION EFFICIENCY FOR A FABRIC FILTER(78)

Further research is needed to:

(1) Develop techniques for reliable particle-size-distribution data representing the dust as it exists in the effluent gas

(2) Determine the extent of agglomerative effects and their effect in gas cleaning and effluent sampling mechanisms

(3) Utilize the diffusion mechanism for small particles in an optimum way while retaining economical and efficient inertial mechanisms for large-particle collection. (If the valley of low efficiency between the size ranges where diffusion and inertia are effective cannot be narrowed by this development, then another tack at development must investigate other gas-solid interaction phenomena for possible use in gas cleaning. Particle-interaction effects may be important here.)

(4) Develop economical methods to measure dust concentrations. (Methods should be adequate for design purposes and well correlated to methods used for obtaining enforcement data.)

In view of the foregoing difficulties, it is concluded that changes in legally required efficiency levels (to outlet loadings below about 0.05 grain/DSCF) would at this time have to be based on questionable design measurement and theory (whose extension into this range is also questionable.) The cost of such changes, as indicated by present understanding of the mechanisms of collection with proven equipment, would become increasingly great for collection efficiency changes of very small magnitude i.e., changes which can only be measured with an error of the same order as the change sought.

Technological Factors Affecting Gas-Cleaner Performance

(Adapted From Swindell-Dressler Report Given in Appendix C in Companion Final Economic Report on Cost Analyses)

The processes in the iron and steel industry can and do depart from design capacity and design operating conditions for a number of reasons that include the following:

(1) Economic pressures dictate the continued increase in productivity of an installed furnace.

(2) Technological improvements make possible significant increases in productivity (such as the introduction of oxygen blowing to open hearth and electric furnace steelmaking) of a new or existing facility.

(3) Batch handling of special heats, or runs of varying sizes and treatments.

(4) Slack market conditions may require cutbacks in output.

Changes in rate of production cause effluent quantities to increase or to diminish both in gas volume and loading. Operating conditions in the gas-cleaning system can vary with these conditions, as well as with the weather, gas-utilization program, raw material charge, etc. Also, noncontinuous or batch-type metallurgical processes vary during the course of a heat in both quantity and condition to the effluent.

To maintain satisfactory gas-cleaning performance under these conditions, it is necessary to have anticipated these factors in designing the pollution-abatement system, rather than specifying for average conditions. Maximum capacity should be anticipated, or adaptation to additional capacity provided. Adjustable equipment can often be used to optimize performance over a range of operations.

Provision should be made also in the initial installation to meet (or to add and adapt equipment to meet) expected future requirements of the pollution-control codes both as to dust content of effluent and treatment of objectional gas and solid chemicals in the effluent.

Assuming proper design and selection of equipment, any variation or variability in the process, control equipment, or performance would generally require an added cost. Any unique feature of a particular gas-cleaning application (particle size, dust loading, corrosion, etc.) would generally require a departure from a system designed for the general case.

The following exerpt from the British literature in 1963 summarizes the performance factors required for effective particulate removal(74):

> "The Clean Air Act and the increasingly wide use of oxygen in both the classical and the recently developed top-blown converter processes have combined to create an urgent need for highly efficient cleaning of high-temperature effluent gases containing submicron iron oxide fume to the visibility threshold of 0.05 grains per cubic foot. In order to satisfy this need, manufacturers of gas cleaning equipment had first to find how collectors which had already been well proved in other fields could be adapted to applications of which they had had no previous experience. This entailed not only the establishment of the empirical design parameters concerned with efficiency, but also a very close consideration of the ability of each type of collector to cope with unavoidable variations in gas volume, temperature, humidity, solids concentration, etc.
>
> The flexibility of any given type of collector (i.e. its ability to operate efficiently without breakdown over a wide range of conditions) is much more important in practice than its theoretical efficiency at constant flow-rate and temperature, etc., and the best unit for any given application will often not be the one which a comparison of efficiency and cost based on idealized operating conditions would indicate.
>
> Every manufacturer who can offer a complete range of equipment must weigh very many factors before finally offering one particular type of collector. He may be handicapped, particularly in the case of a completely new installation, by a shortage of basic process data, but he can usually arrive at a fairly accurate assessment of the relative strengths and weaknesses of the possible units.
>
> Although the size distribution and shape of dust or fume particles are of course the factors which determine the fundamental suitability or otherwise of any given design of collector for a particular application, other characteristics of the solids, the carrier gas, and the process itself must be also carefully considered and their effect on the collection device evaluated before a final selection is made.
>
> The agglomerating propensities of the solid particles are important because they determine the size distribution of the particles presented to the collector. The extent to which agglomeration into clusters or chains of particles will have proceeded, and hence what the effective particle size will be immediately before the process of final collection is begun, cannot be accurately predicted, and in practice allowance is made for it in the empirical design constants used by equipment manufacturers. Agglomeration after collection affects the caking properties of dry material, making it more easily released from filter fabrics, less liable to re-entrainment during precipitator rapping, and more easily settled from liquid effluent.

> The electrical resistivity of the material to be collected is of the utmost importance if a dry precipitator is to be used.
>
> If the collected material is not free-flowing when dry it may create dust handling problems. Hygroscopic dust will give rise to similar difficulties in 'dry' collectors, unless humidity and the temperature of solids and gas can be maintained at safe levels by control of the process, lagging, external heating, warm air purging, or by a combination of these.
>
> For the collection of dusts which are corrosive when wet the obvious choice is a dry type of unit, unless there is a risk of condensation. If the waste gases contain water vapour which comes from the process itself, or has been added for cooling or conditioning them, and sudden temperature surges are likely, elaborate precautions against condensation may be needed, and a more compact wet unit constructed from corrosion-resistant materials may be more economical as well as more reliable.
>
> The physical and chemical characteristics of the carrier gas must also be carefully considered when a collector is being chosen. The effect of variations in gas temperature and humidity, in particular, must be carefully investigated especially if, as is almost always the case, they accompany or cause changes in gas volume and dust characteristics during and after collection. These factors are affected by the method of hooding, cooling, and volume and temperature control, but no matter how carefully these are engineered the characteristics of the process may still cause the collector to be subjected to conditions which are far from ideal and impair its operation either directly by affecting the collection process, or indirectly by hindering dust discharge or causing structural damage. Collectors of different types are more or less susceptible to different non-ideal conditions, as shown in Table 1. The table is only intended to indicate some of the fundamental strengths and weaknesses of high-efficiency dedusters in relation to fluctuating operating conditions of one sort or another, and is not intended to be a comprehensive summary; it does, however, demonstrate the importance of factors which have nothing to do with the properties of particles."

Additionally, from the same literature source(79), the following Table I indicates operating conditions which affect the dust-collector efficiency at a peak level of equipment maintenance, and factors which require regular attention (cleaning the collector surface adequately to match dust loading, temperature control in dry collectors to minimize moisture and heat deterioration and maximize dust removal and handling properties) to insure peak efficiency throughout the life of the equipment.

The effect of operating conditions on the effective performance of the gas-cleaning function, the effect of those conditions which cause maintenance difficulties and shorten service life, and the effect of those conditions peculiar to a particular furnace type of process on the design and selection of gas cleaning equipment are best judged in the light of operating and design experience. The following quotations are discussions of emission cleaning for three iron and steel industry processes which present difficult problems of equipment selection, performance, and maintainability. These discussions were chosen for their concise and comprehensive consideration from an application point of view of the critical factors of equipment use. While they center on British practice (where raw materials, processes, codes, etc. have some variance from general American practice), the discussion of each factor remains pertinent (with perhaps some difference in degree) to a consideration of a corresponding American plant. After considering all the conditions existing on a particular job of equipment application, an engineer may find that the particular situation with which he is dealing is somewhat more difficult or less difficult than implied in the following quotations.

TABLE I **Effect on collector performance of fluctuating operating conditions** (a)

	Dry plate precipitator	Fabric filter	Scrubber	Irrigated precipitator
Temperature	Normally up to 650°F with standard construction but momentary peaks of 1 000°F can be tolerated. Temperature must be selected to suit electrical characteristics of dust.	Normal maximum temperature depends on fibre used. Up to say 275°F with organic synthetics, 600°F with fibreglass. Higher peaks tolerable but reduce bag-life disproportionately.	Normally below 200°F with presaturation. Surges can be prevented if maximum water rate always used in saturator.	
Humidity	Insufficient moisture may lower efficiency by increasing dust resistivity. High humidity with low temperature may cause condensation, possible corrosion, insulator and plate cleaning and dust disposal difficulties. Accurate control of spray cooling essential.	Operation below dew-point leads to bag-cleaning troubles. Chemical and physical damage to fabric likely. Dust disposal difficulties.	Efficiency unaffected by changes in humidity, providing gas remains near saturation.	
Flowrate	Efficiency increased if flowrate reduced, although gas distribution may deteriorate.	Efficiency little affected by flowrate. Pressure drop reduced as volume falls.	Water-rate and/or throat area must be adjusted to compensate for changes in inlet volume. Alternatively volume may be kept constant by air-addition.	Efficiency increased by operation at lower flowrates.
Corrosive solids or gas	Corrosion can be avoided by accurate temperature control, insulation, auxiliary heating, bypassing, or corrosion-resistant materials of construction.	Filter fabric may be damaged.	Special materials of construction will prevent corrosion. High-pressure (high top speed) stainless steel fan impellers can give trouble.	Special materials of construction eliminate corrosion but price may rule out.
Inlet concentration	Initial design must be based on peak loading.	Efficiency not affected by increased loadings: effect on pressure drop depends on duration of surges, but can be reduced by temporary increase in cleaning intensity.	Initial design must be based on peak loading.	Initial design must be based on peak loading.

(a) Table I taken from Reference 79.

"SINTER PLANT

MAIN STRAND GASES

The gases withdrawn from the main strand of a sinter machine present a fairly difficult gas cleaning problem, not, as in most other iron-and steelmaking applications, because high efficiencies must be achieved on very fine particles, but because of other characteristics of the dust and the gases themselves.

Volumes are great and the use of medium and high pressure drop collectors would involve large nonproductive power consumption.

The waste gases contain large quantities of both sulphur oxides and water vapour. Consequently they have a high (acid) dewpoint so that condensation and corrosion are a constant danger, aggravated by the wide fluctuations of temperature which occur from time to time.

The coarser fractions of the dust burden are exceedingly abrasive.

Hence, the ideal dust collector will have the following characteristics:

A pressure drop as low as possible.

Ability to operate efficiently over a wide range of temperatures without ill effect from occasional dampness of dust and collector internal surfaces.

A construction which minimizes condensation, lends itself to reasonably economical corrosion prevention, and is not susceptible to plugging during the occasional but inevitable periods of operation below dewpoint.

Freedom from abrasion troubles, preferably by complete avoidance of high velocities, otherwise by pre-collection of the coarse abrasive dust fractions prior to passing the gases through any collector in which high velocities are used.

DUST CHARACTERISTICS

The particle size analysis of the dust content of sinter strand gases can vary between quite wide limits. . . The type of dust to be dealt with depends on the mix fed to the strand, i.e. proportions of home and foreign ores and return fines, and also on whether or not the burden is conditioned in a pelletizing drum. It must be remembered that changes in dust composition occur as the rate of sintering alters and the relationship between temperature, flame-front penetration, and position on the strand varies.

DUST LOADINGS

The general level of dust concentration is affected greatly by the nature of the material fed to the machine and can vary from plant to plant between 0·1 and 1·0 grains per normal cubic foot and may occasionally reach 1·2. The rate of solids emission is very sensitive to variations in the progress of the sintering process along the length of the strand. Dust is mainly generated early in the sintering process and again when the flame-front reaches the bottom of the bed. It has been suggested that in the intermediate zone the increased moistness of the lower part of the bed causes it to act as a crude filter and hence to pass less dust. It has been found that as complete sintering approaches the discharge end of the strand, i.e. as the mean hottest windbox number increases, the dust loading rises noticeably.

GAS TEMPERATURE

Gas temperatures usually fluctuate between 60°C and 200°C but 100-150C is the most common range and 125 C may be taken as a reasonable average figure for UK practice.
(U.S. practice is in the range of 300 F to 400 F)

GAS COMPOSITION

The only constituents of the easte gases which are important from the gas cleaning point of view are water vapour and sulphur oxides, both of which affect the frequency and severity of condensation in the cleaning system. There will usually be about 10% water vapour by volume in the gases and the sulphur oxide content, expressed as SO_2, may be as high as 1·5 grains per normal cubic foot. Unfortunately, no acid dewpoint figures are available, but water dewpoints as high as 50°C are encountered and acid dewpoints considerably higher than this must therefore occur. So far as condensation and corrosion are concerned, the relatively high proportions of water vapour and oxides of sulphur in the gases complicate the design and selection of gas cleaning equipment. . . *(but they tend to facilitate electrostatic precipitation.)*

CHOICE OF DUST COLLECTOR

In the authors' opinion the sulphur oxide content of the gases rules out wet methods of collection, since these would result in difficult liquid effluent problems, and saturated gases having hardly any thermal lift and still containing some sulphur oxides would constitute an air pollution problem worse in some respects than the original one.

The choice of a dry collector will be dictated by the quantity and size range of the dust in the case under consideration, the space available, the pressure drop which can be tolerated and the outlet loading required. Generally speaking, particularly for dusts at the coarser end of the normal range and if an outlet concentration of 10· 15 grains per normal cubic foot is the highest acceptable outlet loading, or the dust is finer, or a settling chamber cannot be accommodated within the space available, cyclones may be used, but their pressure drop (up to 6 inwg) is a disadvantage and they must be specially constructed to withstand erosion by abrasive dust particles. For a stack loading of less than 0· 10 grains per normal cubic foot a more efficient type of collector must be used.

If outlet loadings down to 0· 05 grains per normal cubic foot are required, the only suitable device is the electrostatic precipitator. Were it not for the constant danger of condensation, the fabric filter would be a possibility, but a filter fabric would 'blind' when operated under moist conditions. It is true that the silicone-treated fibreglass fabric (which would have to be used in any case to withstand the high maximum temperature) is much less susceptible to plugging than are the natural and organic synthetic cloths, and has been found to regain its porosity on drying out, but there would always be a risk of the cloth becoming 'starched' with soluble salts and failing prematurely through what can only be described as cracking. Fibreglass, which has poor flex resistance in the first place, is exceptionally vulnerable to this sort of trouble. This type of collector also compares unfavourably with the precipitator from the points of view of pressure drop, space requirement, and maintenance cost, and would not be recommended for main strand gas cleaning.

Although, in common with all other collectors, a precipitator for this application has to contend with occasional condensation, its operation is not unduly affected by moist conditions, providing precautions are taken against corrosion and providing it has efficient rapping gear which will clear any. . . build-up and prevent progressive deterioration in its performance. The water vapour and sulphur oxides in the waste gases 'condition' the dust and, together with the relative coarseness of the dust,. . . *(assist the precipitation process.)*

The Head Wrightson sinter machine installed at the works of the Skinningrove Iron Co. Ltd., Saltburn-by-the-Sea, is provided with a Head Wrightson/Research Cottrell dry plate precipitator. The machine was designed to process a wide variety of home and foreign ore mixes, and experience indicated that the dust burden in the waste gases could be reduced by a simple settling chamber from 1. 0 to 0. 3 grains per normal cubic foot. *(This is lower than typical American loading.)* The gas valume from the 16 x 6ft square windbox machine is 180000 per normal cubic foot. The precipitator has two treatment zones, energized by a 15 kVA 230 mA transformer-rectifier set and operates at a treatment velocity of 6· 8 ft/s. In view of the expected intermittent operation, it was thought advisable to fabricate the collector plates in copper-bearing 'Corten' steel (0· 1%C max., 0. 1-0. 3%Si, 0. 5-1. 0%Mn, 0. 3-0. 5%Cu, 0. 5-1. 5%Cr, 0. 1-0. 2% P) and these have withstood the adverse conditions very well without noticeable deterioration. The interior of the precipitator shell is protected with gunned aluminous cement and the whole unit is thermally insulated to minimize condensation. The precipitator. . . was designed to operate at an average temperature of 300°F, and at an efficiency of 86· 7%, corresponding to an outlet loading of 0· 04 grains per normal cubic foot The design performance has been . . . achieved and, although the sinter plant has worked on a one or two shift per day basis and the precipitator has undergone an abnormal number of start-ups, there has been no deterioration of its internals. The sinter fan was inspected in August 1963, 20 months after commissioning and showed no sign of wear other than a general smoothness over the faces of the blades; it is estimated that it will operate for at least another 3-4 years without requiring maintenance. The machine had produced 250000 tons up to the time of the inspection. Reduced fan maintenance and plant downtime are two useful indirect benefits of efficient main strand gas cleaning.

The dust discharged from the precipitator hoppers is conditioned in a pelletizing drum and the pellets produced are returned to the process via the return fines conveyor.

DISCHARGE END EXHAUST SYSTEM

The whole of the discharge end of the sinter machine is usually completely enclosed; 100 tons or more of dust per day may be released by the equipment in this area (i. e. the end of the strand itself, the breaker, hot screen, and discharge to cooler). Air volumes vary with the size of sinter machine and the completeness of hooding, and are between 30000 and 150000 cubic feet per minute. Gas temperatures are usually between 40° and 150°C. Both the loading and the size range of the entrained dust are affected by the designs of hoods employed, and the exhaust volumes allocated to them, but dust burdens are typically in the range 4-6 grains per normal cubic foot of which 80% might be <100 μm and 10% <10 μm.

Careful hood design, combined with adjustment of individual exhaust rates during commissioning, can reduce both grain loadings and the proportion of coarse abrasive particles carried in the gases. It is relatively easy to obtain collection efficiencies of 90-95% by means of simple high-efficiency cyclones, and the stack discharge in such cases will contain about 0.5 grains per normal cubic foot of dust, 90% of which is <10 μm. At this sort of grain loading the stack plume does not appear offensive; all the same it represents a very high rate of solids emission (up to 700 pounds per hour on a large plant), and more and more interest is being shown in alternative higher-efficiency collection methods.

For cleaning the tip end emission the fabric filter and dry plate electrostatic precipitator are two obvious possibilities. Wet methods can be employed (self-induced spray units are fairly often used in the USA), but are not to be recommended because they introduce a secondary (liquid) effluent problem, and are liable to suffer from wet-dry interface troubles and sometimes from sludge discharge problems. At first sight, the fabric filter would appear to be ideally suited to this application, providing it is designed so as to avoid excessive scouring of the bags by the abrasive dust, and properly maintained so that a small leak in one bag cannot 'grit-blast' a hole into an adjacent one and start a rapid and messy chain reaction. The first requirement is quite easily satisfied, but the second is not so straightforward and a short period of neglect could have expensive and inconvenient consequences in the form of extensive bag replacements and operation at reduced capacity. From the point of view of efficiency and capital cost, the fabric filter is a 'good buy', but running costs are a most important factor, and cannot be accurately forecast.

While the operating characteristics of the dry plate precipitator are quite predictable for this application, discharge end precipitation is difficult because of the high resistivity of the dust at the gas temperatures normally encountered, when the moisture content is less than about 1.5 % by volume. In cold, dry weather the water vapour content may be as low as 0.5% by volume, and under these conditions unstable precipitator conditions are liable to occur at temperatures around 60°C.

The addition of relatively small quantities of water vapour, sifficient to raise the volume percentage to 2·0, leads to a marked improvement in precipitator performance, as does the addition of 100 ppm of SO_2. If a guaranteed efficiency is to be maintained under every circumstance, and at all times, and if water vapour or SO_2 cannot be added, the precipitator will be perhaps three times as large as a unit which will operate satisfactorily under all but the driest conditions. It is therefore well worthwhile either to mix in gases from some other part of the sinter system or to add steam. If the problem of conditioning can be overcome this is a very straightforward precipitator application,. . . *(Application of a dry system at the discharge end when water cooling at the sinter strand is employed could lead to the reintroduction of moisture control problems.)*

QUENCH GASES

The quenching of hot fines in pug mill or drum gives rise to large quantities of fine dust, particularly during periods of erratic plant operation.

In a typical installation the volume of gas vented from the drum was 7600 normal cubic feet per minute at 40-120°C, containing between 5% and 24= water vapour by volume. It was found that the dust loading was greatly affected, not only by the quantity and distribution of spray water, but also by the quality of sinter being made. During normal operation of the machine the loading was found to vary between 1.3 grains per normal cubic foot when sintering was complete, and 4·7 grains per normal cubic foot when incompletely sintered material was being discharged from the strand. Shortly after commissioning, before the sprays had been adjusted and while the operation of the machine was abnormally erratic, the mean dust concentration had been 4·8 grains per normal cubic foot (corresponding to a rate of discharge of nearly 400 pounds per hour) and the peak loading 33·2 grains per normal cubic feet in gas volumes of 8500-11000 normal cubic feet per minute. This illustrates the effect of plant operation on stack emissions. The final emission rate averaged 140 pounds per hour compared to 280 pounds per hour from the main stack and 135 pounds per hour from the tip end cyclone stack.

The quench stack dust is rather fine (99% <100 µm, 30% <10µm, 10% <3 µm). To date, to the best of the authors' knowledge, no attempt has been made to clean the gases, but if cleaning were required in an existing plant a self-induced spray washer or an orifice scrubber would be the best solution, unless the gases could be handled by an existing discharge end cleaning system. In a new plant the authors would recommend mixing the quench gases with the discharge end exhaust air to give a conditioned mixed gas stream capable of being cleaned in a precipitator of . . . *(conservative size to 0.05 grains per normal cubic foot.)* The problem can be entirely avoided if the hot returns are conveyed direct to the mixer (preheating the mix often has much to commend it).

THE OPEN-HEARTH FURNACE

The open-hearth furnace emits waste gases equivalent to between 74000 and 134000 normal cubic feet per ton of crude steel. Volume rates of flow are usually within the range 170-280 normal cubic feet·minute per ton of furnace capacity. Fume loadings vary from one period of the melting cycle to another. During charging and melting down concentrations of less than 0.5 grains per normal cubic foot are usual, and during fettling they are even lower. The highest fuming rates occur during refining and lancing, and loadings of 6 grains per normal cubic foot are common during oxygen injection. The concentration of fume is of course affected by the volume of excess air which is allowed to enter the furnace as well as by the fuming rate.

The composition of the furnace waste gases depends on the fuel used. The most important constituents from the gas cleaning point of view are water vapour and sulphur oxides. The percentage of water vapour may be as low as 2% or as high as 25% and a concentration of sulphur oxides calculated as SO_2 of 3.52 grains per normal cubic foot has been reported for a producer gas fired furnace. A sulphur oxide concentration of 0.36 grains per normal cubic foot has been reported for furnaces using 70% coke-oven gas and 30% pitch-creosote. In general high acid dewpoints are to be expected and if dry collection is to be used condensation must be guarded against.

Providing suitable precautions are taken against condensation, a dry collector may be used, and numerous dry plate precipitators have been installed in OH melting shops in recent years. Purely from the precipitation point of view, OH fume collection is fairly straight-forward *(with automatic controls)*, due largely to the conditioning effect of the water vapour and sulphur oxides in the gases, but the fume tends to be 'sticky' and an efficient rapping system is essential. The collector casing must be well insulated to minimize condensation, and if the unit is to operate under pressure the top insulator housing must be pressurized with warm air to keep the insulators dry. Dust should preferably only be stored in the hoppers in an emergency because it tends to bridge, and it may be advisable to heat the hopper sides. Some condensation is bound to occur at start-up, and it is advisable to clear as much collected dust as possible from the interior of the precipitator while it is shut down. If this is not done conveyers and dust discharge valves may become clogged with moist dust. If possible the precipitator should only be energized when it has reached its normal operating temperature, so that little dust is collected in it when it is sweating. If these. . . precautions are observed the dry plate precipitator will operate continuously. . . if not, severe build-up, electrical and operating difficulties, and corrosion will be experienced.

A dry plate precipitator installation on a 250 ton tilting OH furnace. . . follows a waste heat boiler and ID fan, and is designed to clean 78900 cubic feet per minute of furnace gases at a maximum temperature of 280°C. The design inlet loading is 5 grains per normal cubic foot during oxygen lancing and the outlet cleanness 0·04 grains per normal cubic foot. The precipitator is insulated, the hoppers are steam-heated, and the insulator compartments on top of the unit are pressurized with 600 cubic feet per minute of air at 200°F to prevent outward leakage of dirty gas and to keep the insulators both dry and clean. The precipitator has three treatment zones each of which is energized by a 21 kVA, 250 mA transformer recitfier set. This is quite a good example of a precipitator fitted into a very restricted site, utilizing turning vanes to reduce inlet and outlet duct sizes without detriment to gas distribution.

The fabric filter may be used for OH gas cleaning but is more susceptible than the precipitator to condensation troubles, has a much higher power consumption, and requires more space. A filter serving one of the Ajax furnaces was reported to operate at a pressure drop of 8 inwg and to have a bag-life on only 20 weeks. There seems to be no reason why filters of modern design using improved high-temperature fabrics should not operate satisfactorily at a pressure drop of 4-5 inwg with a baglife of a year or more, but prolonged pilot-plant testing would be needed to prove the durability of the filter fabric.

Both the irrigated electrostatic precipitator and the high-energy scrubber are capable of cleaning OH fume to 0.05 grains per cubic foot or better, but they would have to be constructed from expensive corrosion-resistant materials and would create secondary problems of liquid effluent treatment and loss of stack gas buoyancy.

ARC FURNACES

FURNACE PRESSURE CONTROL

For consistently good fume control at minimum rates of extraction, automatic control of furnace pressure is essential. The indicated pressure which it is necessary to hold within the furnace depends on the position of the pressure pick-up. The accuracy of control required is of the order of ±1.0 nwg for furnaces melting OH grades of steel but may be as fine as ±0.03 inwg for a furnace producing alloy steels. The control system used must have a high speed of response if it is to cope with sudden fluctuations within the furnace.

GAS COOLING OR CONDITIONING

Temperature at the outlet of the combustion chamber may be upwards of 1000 C and the gases must be cooled before they can be cleaned. The methods available are air dilution, indirect cooling by heat exchanger, and evaporative cooling. It is considered that the latter is often the best compromise on the grounds of simplicity, final gas volume, space requirements, and initial cost.

However, the type of collection device used will often dictate the manner in which cooling is carried out. With wet methods of collection, a comparatively small spray tower may be used (without fine control of the cooling sprays) and air dilution or indirect cooling would be pointless. If dry precipitation is preferred, the gases must be conditioned (most simply with water) and if a spray conditioning tower is required for this reason the gas will be spray cooled to the desired precipitator operating temperature. The fabric filter does not require pre-humidification of the gases for efficient operation and is, moreover, exceptionally vulnerable to condensation. The preferred method of cooling in this case will depend upon whether the filter fabric is organic-synthetic (e. g. Orlon or Terylene) and therefore not suitable for operation at over 130°C, or fibreglass, which will withstand up to 250°C. In the former case air dilution or indirect cooling may be used, but in the latter spray cooling should present no difficulties providing a good control system is fitted.

SYSTEM CAPACITY AND SAFETY

. . . The details of safety require that . . . very conservative assumptions are made. The problem of explosion hazards has been considered in recent papers.

Air may enter the system at the air break between elbow and fixed fume pipe and at the combustion chamber, as well as through the furnace openings. The volume of air entering by each of these routes is unimportant providing (a) that control of fumes is obtained and (b) that the final waste gas volume is such that even if combustion has been incomplete an explosive mixture cannot be formed.

The combined effects of combustion and dilution have been calculated for the lancing period, and are shown in Table III. However, the rate of evolution of combustion, following the addition of oily scrap cannot be predicted, and it must be remembered that in practice the operation of a fume cleaning system must take second place to the production of steel; allowance must also be made for occasional deficiencies in the standard of both operation and maintenance of cleaning systems. Hence, although under ideal conditions an O_2 to waste gas ratio of 10:1 would no doubt be adequate, it is recommended that a ratio of not less than 15:1 be used.

TABLE III Effects of combustion and dilution[11]

Ratio of waste gas/oxygen injection flowrate	% Carbon monoxide if no combustion occurs	Approx. % combustion for safe operation (based on 100% oxygen utilization)
22:1	9·1	Nil
16:1	12·5	Nil
15:1	13·3	5%
14:1	14·3	10%
10:1	20·0	32%
6:1	33·3	50%
5:1	40·0	55%

Current understanding of the explosion problem is incomplete; explosions have been reported even in conservatively designed systems following errors in operation, and it is considered more prudent to use theory to predict the magnitude of apparent safety margins rather than to reduce these to the point where (due to the intrusion of incalculable factors) they do not exist, and a variation in the process or a mistake by an operator can cause an explosion.

GAS CLEANING

The furnace gases may be cleaned to 0.05 grains per cubic foot by precipitator (wet or dry), fabric filter, high-energy scrubber, or combination scrubber-precipitator.

Dry plate precipitation is relatively straightforward providing the gases are properly conditioned. It is therefore ideally suited to direct extraction systems but much less so for hood or conventional hood vent installations.

(A) 75 ton furnace. . . has been fitted with direct extraction fume control equipment and fume is to be collected by a dry-plate electrostatic precipitator ('B' unit referred to below). The lancing rate of this furnace is 1200 cubic feet per minute and the volume during lancing, after combustion and cooling 49200 cubic feet per minute. The precipitator is designed to clean a total of 83200 cubic feet per minute from the existing furnace and another which is to be added in the future, from 6.5 to 0.05 grains per normal cubic foot.

Furnace gases will pass through a water-cooled elbow and refractory-lined fixed duct connected by a power-operated movable sliding sleeve, into a gas burner followed by a combustion chamber. They will be cooled and conditioned in the rectangular spray tower and will enter the precipitator at a temperature of 500°F.

The fabric filter is theoretically ideal, having a uniformly high efficiency irrespective of throughput but it must be carefully designed and protected against condensation. Filtering velocities may be as low as two feet per minute so that space limitations will often exclude this type of cleaner.

The high-energy scrubber operating at a pressure drop of 30 inwg or more will do a satisfactory fume-cleaning job ***(U.S. air pollution regulations would require about 45 inches water gage.)*** and its compactness is a great advantage, particularly when the available space is limited. Power may be saved by regulating the fan in an efficient manner to suit the rate of exhaust required for fume control and the pressure drop needed at different periods of the melt to give the statutory final gas cleanliness, but this is only practicable if the pressure drop of the scrubber can be adjusted to the desired level over a wide range of flow-rates.

It must be stressed that in the long run regular maintenance and attention to operating conditions affect the cost and effectiveness of any gas-cleaning unit. The incorporation of automatic controls, operator-proof controls, scheduled preventive maintenance, anticipation of adverse process conditions and raw material possibilities are important to the continued performance of gas-cleaning equipment after the guarantee period.

Attention is now directed more specifically to the following parameters that affect gas cleaner performance:

(1) Effect of gas-volume changes on collection efficiency of a dust collector

(2) Effect of pressure drop within the gas cleaner on efficiency and capacity of the collector

(3) Effect of dust loading, and effect of collector-surface renewal on pressure drop, volume, and collecting efficiency

(4) Effect of particulate as generated in each metallurgical process (particle density, particle density, particle size, size distribution) on efficiency of each applicable dust-removal device

(5) Effect of temperature on efficiency of and gas volume to collector, and required gas conditioning for cooling and humidification before dust removal

   (a) Gas analysis as it affects conditioning required prior to cleaning and exhausting

   (b) Corrosion and the use of water

   (c) Abrasion and chemical effects of dust

(6) Adaptability of the particulate-removal system to removal of gaseous pollutants.

Effect of Gas Volume Changes

As previously indicated, the volume of effluent gas emitted by a metallurgical process may vary greatly during one heat, or according to changing production level of the process. Because the efficiency of dust removal changes when volume changes, it becomes necessary to

---operate at constant volume with air substituted for effluent gas deficiency,

---or, use a gas-cleaning device which adjusts itself to volume changes, or is adjustable to satisfactory efficiency over a range of volume.

Self-induced or orifice washers and certain fluidized-bed scrubbers can adjust themselves, essentially at constant efficiency. Adjustable-throat venturis, orifice-wedge and flooded disk scrubbers can be adjusted to suit a range of gas flow. These and other wet scrubbers can also be flooded (uneconomically) to achieve the same effect.

Multiple units (nested cyclones, parallel scrubbers, precipitator tubes or ducts, multiple venturis, baghouse filter tubes) can be partially blocked off to maintain high (design) efficiency at reduced volume, with economy of water and power use.

---or, design for maximum possible effluent volume, and "over-clean" at reduced volumes.

The following quotation from the British literature in 1964 illustrates one suggested method for determining good design in relation to gas flow(13):

> "It will be appreciated that the efficiency of a precipitator is greatest when the velocity of the gas through the cross-section of the electrode system is uniform, and no gas is bypassing the electrode system. This is ensured by the construction of ... models ... of the precipitator and inlet flue system. The flow conditions in the model are adjusted to give the same Reynolds number as the full-scale plant, allowance being made for scale factors, gas viscosity, and density. The flow pattern in the model is corrected using splitters and baffles, their position being determined by experiment. Such model tests permit requirements to be worked out in advance, and avoid the difficulties in carrying out such work on site on the finished plant."

Effect of Pressure Drop

Because of large cross section and control of build-up conditions (temperature and humidity) and regular rapping for dust removal, electrostatic precipitators usually will show negligible change in resistance to flow in operation.

Bag filters, when new, have low resistance and low efficiency. Sometimes a precoat of dust is applied to make the initial cleaning of process fume more effective. The buildup of dust increases both efficiency and pressure drop until the cleaning (by shaking or reverse flow of air) cycle is initiated (often by a pressure signal). Then efficiency will be at a lower (but still effective) level until the dust layer reforms on the fabric.(55)

Wet scrubbers increase in efficiency with increased resistance due to mechanical constriction of the throat area or added water input. The proportionality of change as attributed to Semrau's correlation is described later.

Efficiency of cyclones also depends upon pressure drop. Cyclones are used only with coarse, easily collected dusts, however, and usually with a view to product recovery as much as to gas cleaning. As such, they may usually be regarded as process equipment. The rules relating pressure drop, capacity, and efficiency are available in the Air Pollution Engineering Manual.(80)

Effect of Dust Loading

An electrostatic gas cleaner is essentially a constant-efficiency device, so that any change in inlet loading will be reflected proportionally in the outlet stream loading. However, in actuality, changes in dust build-up occur and adversly affect the propagation of a uniform electric field. Plate spacing must be designed to accommodate the condition of heaviest expected dust loading. Automatic controls are often required to maintain an optimum electric field without spark-over.

A well-designed bag filter will be unaffected by a change in inlet loading, except that automatic cycling of the bag-cleaning system will adjust to the change (within certain limits of variability).

A wet scrubber will yield constant efficiency for a given pressure drop. Therefore, a change in inlet loading will be reflected proportionately in the outlet loading. However, wet-scrubbing systems can be adaptable to changing conditions, provided sufficient power is applied. A venturi throat can be closed to maintain a given effluent level with increased dust generation in the process. A process whose fume output varies widely with time could be handled by making frequent adjustments of the cleaner to maintain a constant acceptable output of fume.

Particulate Characteristics From Different Process Segments

In Appendix C, "Characteristics of Emissions", of this report, some data are presented on the nature of particulate material generated by various processes and conveyed by gases emitted from the process vicinity. This dust is generally nonuniform from one particle to another and from process to process. The differences may be categorized as particle size, shape, density, and composition.

The mechanisms of particle collection on which gas-cleaning equipment are based vary in collecting efficiency, generally with particle physical properties. The chemical nature of the dust may affect its susceptibility to electric charging. This would primarily affect electrostatic precipitation, but could be a second-order effect in wet scrubbing and in fabric filtration. Solubility and chemical activity in water would affect the water cycling, dust handling, and collector-surface maintenance in wet collectors.

Some general variations in the efficiency of collectors with these particle properties can be drawn. Grade-efficiency curves typical of industrial collectors in the mid-1950's have been presented for various types of dust-collecting equipment.(78) These show the efficiency of collecting particles of a given size. The curves were based on test results using a standard dust (Table VI-13) with a 2.7 specific gravity. These curves can be used to indicate in a general way the relative applicability of each type of equipment to different process fumes. As shown in Figure VI-33, the efficiencies generally are lower (often dropping abruptly) for finer grades of dust. Some devices are more economical to operate, but they generally do not clean fine particles from gases as well as others.

TABLE VI-13. GRADING OF W.C.3 TEST DUST[(a)]

Size of Grade, microns	Percentage by Weight in Grade	Percentage by Weight Smaller Than Top Size of Grade
104-150	3	100
75-104	7	97
60-75	10	90
40-60	15	80
30-40	10	65
20-30	10	55
15-20	7	45
10-15	8	38
7-1/2-10	4	30
5-7-1/2	6	26
2-1/2-5	8	20
2-1/2	21	12

(a) From Reference 78.

Relationship of Particulate as Generated by Different Processes to Collecting Efficiency

Stairmand(78) has presented grade efficiency curves for various cleaning equipment at specific conditions using a standard dust. These curves indicate the relative applicability of each type of equipment to different dusts. Some devices are more economical to operate but do not clean fine particulate from gases as well as others.

The curves are applied to various processes with their given particulate size distributions.

By making a density correction, the curves can be applied to dusts for which particle-size distribution data (as in Table VI-13) are known. Some distribution data are given in Appendix C to this report. No quantitative data are available upon which to base corrections for particle shape, composition, and surface differences; so such an application of the curves will not be quantitatively precise.

Particle-size-distribution data available for this kind of analysis are inadequate in some measure. The size ranges reported are usually too large and require excessive averaging in the region of greatest variation in efficiency on the grade-efficiency curve (the fine-particle-size region). Steelmaking dust is largely concentrated in this region. Whether or not averaging according to the log-probability distribution would be applicable to distributions having given data ranges such as 0-1 micron or 0-5 microns is not known.

The shape of the grade-efficiency curve may be affected somewhat by (1) process variables which alter the properties of the dust, (2) conditioning of the dust by humidity and temperature control (in the case of electrostatic precipitation), (3) collector geometry (affecting treatment time) and (4) energy input (see Table I). The development of a family of curves should be undertaken to develop grade-efficiency variations at different levels of pertinent operating variables (such as scrubbing-energy level or electrostatic-precipitation treatment duration). Note that steelmaking fume can generally be adequately removed with a scrubber pressure drop of 40 plus inches of water, or by electrostatic precipitators whose geometry, control, and energization are specifically selected for that application. Using the given curves, however, to analyze the effect of each type of treatment on actual process dusts will give a rough comparison of collectors for a given task, and a general comparison of dust-property effects on performance of each collector. At least, relative indications may be drawn. Efficiencies measured in the field of equipment that is collecting dust from the actual processes dusts whose properties would also be tested under the collecting conditions) would allow precise comparisons, more precise (and probably more economical) designing, and dependable predictions of performance. Such data generally are not available, not very good, or undisclosed. Therefore, the theoretical treatment while limited, is the best alternative available for relative comparisons.

The fabric-filter curve has been deleted from Figure VI-33 because it is based on a theoretical calculation for a new filter. A more typical practical grade-efficiency curve given in Figure VI-34(82) is based on actual test results. However, both indicate that the efficiency would not go to zero as particle size approaches zero. This is discussed in the literature(67) in terms of a diffusional collecting mechanism which comes into play at an increasing rate as particle size diminishes. The zero drop-off in the other grade-efficiency curves represents the failure of the inertial impaction mechanism to collect small particles. Discussions in the literature(67) include diffusion of particles to water-droplet targots as well as to filter media. Therefore, this effect should also apply to wet scrubbing. As indicated by the U-shape of curves in Figure VI-38, the mechanism of diffusion seems also to apply to electrostatic precipitation. This mechanism, then, would suggest an upward alteration of the grade-efficiency curves.

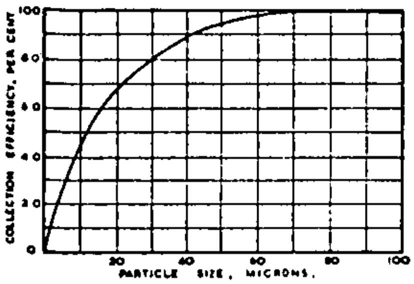


Fig. 14
Medium efficiency, high-throughput cyclone.
Efficiency at 5 microns = 27%

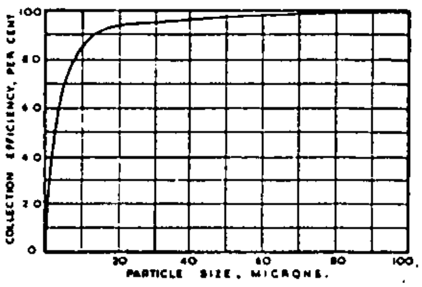


Fig. 15
High efficiency (long cone) cyclone.
Efficiency at 5 microns = 73%

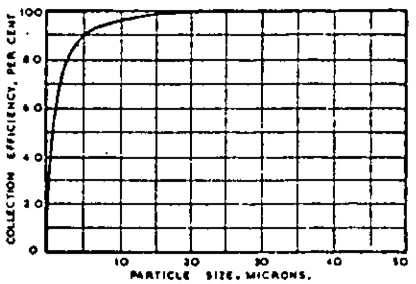


Fig. 16
Small diameter, tubular cyclones.
Efficiency at 5 microns = 89%

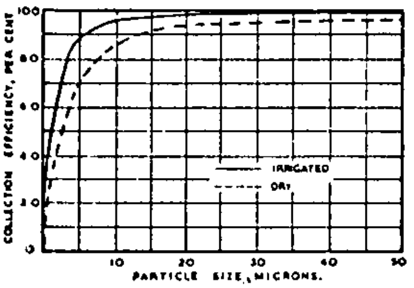


Fig. 17
Large diameter dry and irrigated cyclone.
Efficiency at 5 microns = 87%

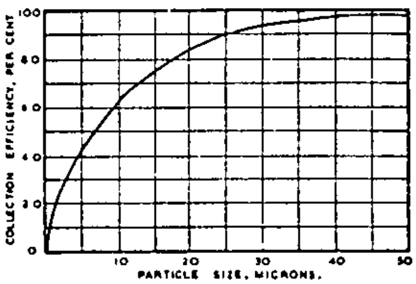


Fig. 18
Low pressure drop cellular cyclone.
Efficiency at 5 microns = 42%

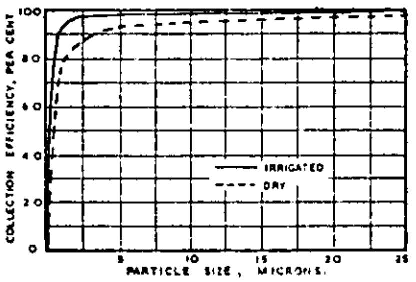


Fig. 19
Electrostatic precipitator. Irrigated—efficiency at 5 microns = 98%
Dry—efficiency at 5 microns = 92%

Fabric filter
curve omitted
for reasons
given in the
text.

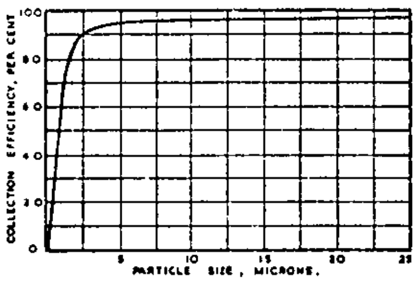


Fig. 21
Spray tower.
Efficiency at 5 microns = 94%

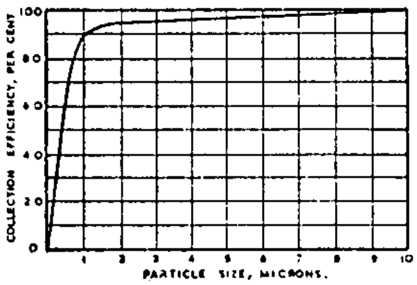


Fig. 22
Wet impingement scrubber.
Efficiency at 5 microns = 97%

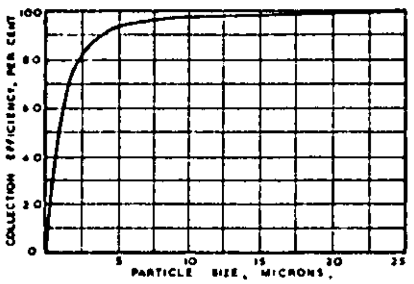


Fig. 23
Self-induced spray collector.
Efficiency at 5 microns = 93%

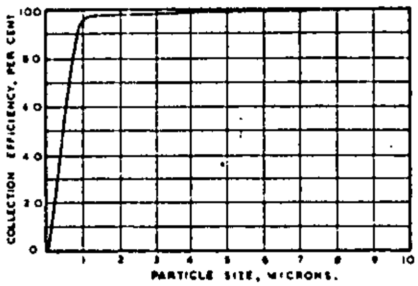


Fig. 24
Venturi scrubber.
Efficiency at 5 microns = 99.6%

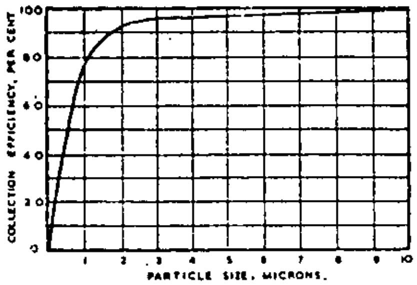


Fig. 25
Disintegrator gas washer.
Efficiency at 5 microns = 98%

FIGURE VI-34. GRADE-EFFICIENCY CURVES FOR DIFFERENT TYPES OF AIR-POLLUTION CONTROL EQUIPMENT(78)

(These curves were determined on the relatively coarse dust described in the text, and do not necessarily apply directly to metallurgical fume.)

Variations in this effect will occur with temperature and particle concentration. By designing low-flow-rate collectors, and by optimizing inlet conditions, one could take advantage of this mechanism with fine dusts.

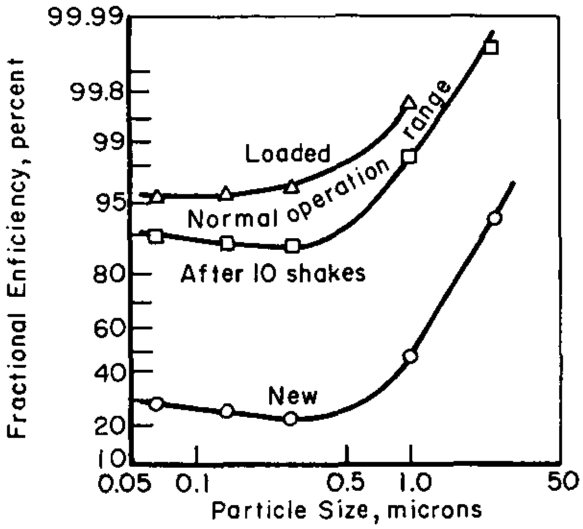


FIGURE VI-35. COLLECTION EFFICIENCY AS AFFECTED BY PARTICLE SIZE IN A FABRIC FILTER(81)

The investigation of this diffusional mechanism, the testing and sampling techniques which contribute to the dearth of data, and filling of the data gaps should be undertaken to assist in future proper design of collectors and prediction of capital and operating costs.

The grade-efficiency data shown in Figure VI-34 are applied in Table VI-14 to various process dusts with assumed particle-size distributions. By multiplying each of the size-range limits of these distributions by the square root of the ratio

$$\frac{\text{specific gravity of process dust}}{\text{standard-dust specific gravity}},$$

the curves can be used to estimate the average efficiency of collection for the weight fraction of dust within those corrected size range limits. By multiplying each such fractional efficiency by the corresponding weight fraction, and summing, the net efficiency for the collector and dust combination is estimated. But, note that this yields only a relative indication of efficiency, and is not to be taken absolutely and compared to a measured efficiency from the field. Experience suggests that precipitator efficiencies calculated in this way are low, and calculated wet-scrubber efficiencies (using extrapolations to the reported 22 in. w. pressure-drop situation(67)) are high for open-hearth dust and are low for BOF dust.

Effect of Temperature

From the gas laws, volumes vary directly with absolute temperature. This has several implications for the gas cleaning system:

TABLE VI-14. CALCULATED RELATIVE EFFICIENCY OF COLLECTING EQUIPMENT FOR VARIOUS PROCESS DUSTS AND COLLECTORS

(Results reported here are subject to the limitations given in the text.)

	Sinter Strand	Flux Fraction (as in self-fluxing sinter making)	Basic Oxygen Furnace	Open Hearth	Electric Arc Furnace	Pressure Drop (in. water)
Particle Specific Gravity	4.0	2.7	5.0	5.2	3.93	--
Inlet Loading, $\frac{\text{grains}}{\text{SCFD}}$	4		4-8	2-7	3-6	--
Required Efficiency to Attain 0.05 Grain per Standard Cubic Foot, %	98.73		98.9-99.38	97.5-99.28	98.33-99.17	--
Computed Efficiency, %, for:						
Cyclones						
High Throughput	65	59	Not Applicable			3.7
High Efficiency	91	90	"	"	"	4.9
Multicyclone	98.5	98	"	"	"	4.3
Wet	97	96	"	"	"	3.9
Wet Scrubber						
Low Energy						
Spray	97	97	"	"	"	1.4
Wet Impingement	99.75	99.52	"	"	"	6.1
Self-Induced	98.25	98	"	"	"	6.1
High Energy						
Disintegrator	99.32	98.95	72	88	86	--
Venturi	99.98	99.95	85[(a)]	94.5[(a)]	94[(a)]	22[(a)]
Electrostatic Precipitator						
Dry	99.00	95.5	64[(b)]	83[(b)]	81[(c)]	0.6
Wet	99.86	98.95	--	--	86[(b)]	0.6
Fabric Filter	99.99	99.99	(97.8)	99.5	99.5	4.0

(a) A pressure drop of 40+ inches of water gage normally is required to clean steelmaking fume to the specified 0.05 grain per standard cubic foot with a venturi scrubber.

(b) The codes in the mid-1950's (when these grade-efficiency data were typical in Britain) were less restrictive. Precipitator designs today can be guaranteed to 99.5 percent efficiency if required, but the curves in Figure VI-34 still can be used for comparative collection efficiencies.

(c) With proper humidification.

(d) Underlined values for computed efficiencies meet the required efficiency for outlet bonding of 0.05 grain per standard cubic foot.

(1) The fan-power requirement is proportional to volume because of this, many systems cool the gases to a minimum practical temperature before entry into the fan, unless thermal lift must be maintained to get rid of noxious gases in the effluent. Since positive pressure ordinarily makes for simpler structure in a precipitator, and best efficiency requires several hundred degrees of temperature, this benefit is ordinarily not available for a forced-draft precipitator fan. However, in the wet scrubber, where efficiency depends on a high gas-stream energy, at a high power-consumption level, the cooling of gases is particularly beneficial.

(2) Precipitators and especially bag filters are limited in the temperature at which they operate. Thus, cooling as a preconditioning step is required before entry to the gas cleaner on many processes. The method of cooling also affects the volume of gas to be handled, as shown in Figures VI-36(13) and VI-37(82).

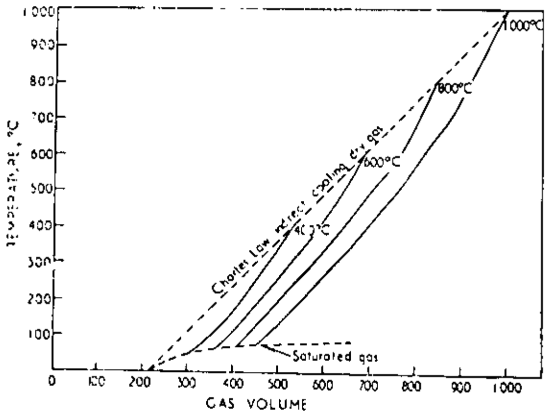


FIGURE VI-36. VARIATION OF VOLUME WITH TEMPERATURE WHEN GASES ARE COOLED BY THE EVAPORATION OF WATER

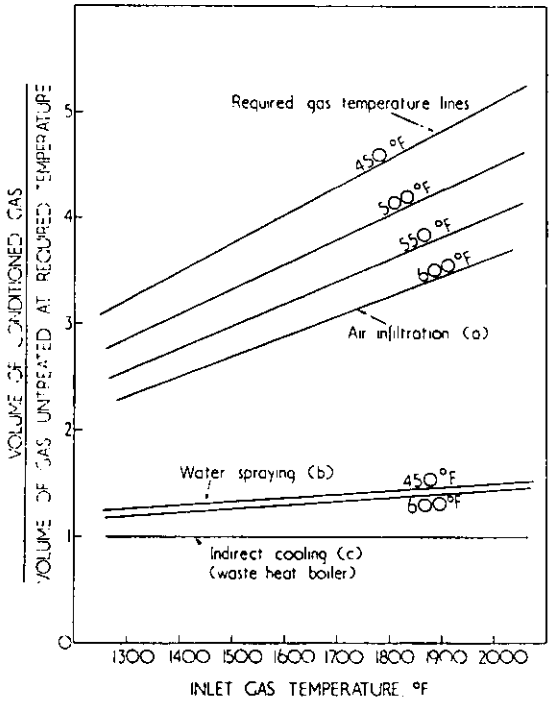


FIGURE VI-37. WASTE GAS VOLUME VARIATION FOR DIFFERENT GAS CONDITIONED TEMPERATURES BY AIR INFILTRATION AND WATER SPRAYING

Effect of Humidity

Additions of water to the gas stream or to the gas-cleaner system is a frequently required preconditioning step. The humidity of the gas entering a baghouse must be sufficiently below the dewpoint to preclude corrosion of the structure and clogging of the bags with moist cake. On the other hand, quenching is an economical way to cool, avoiding expensive radiation ducting or excessively large components to handle dilution air.

Humidity is sometimes critical in the electrostatic precipitation of certain dusts of high resistivity. Again, it can be coupled with cooling quench in the pre-conditioning zone, but care must be taken to stay above the dew point temperature. No liquid effluent results from these cases. It should be noted that in both of the above systems, the acid dew point is also critical from a corrosion point of view in those cases where sulfur dioxide is a significant process effluent component, such as the open hearth and some coal-burning processes. While it has been noted that sulfur dioxide can be beneficial in the precipitation of some process dusts, this benefit is likely to be lost as sulfur dioxide regulations take effect.

Water flushing of elbows, fan blades, and other parts of the systems has been effectively used to inhibit impingement abrasion and to prevent dust buildup.

Corrosion, abrasion, dust buildup and excessive temperature are the most frequent maintenance problems on a gas-cleaning system. Where water is used as a remedy, careful pH control is important, as is control of solids buildup in a recirculating-water system.

Except for this preventive maintenance, water effluents usually are the result of wet scrubbing or wetted-surface precipitation. This later finds application to electric-arc-furnace fume-cleaning where satisfactory particle resistivity for collection is difficult to achieve, and in sinter plant and blast furnace applications where coarse, abrasive dust must be removed.

Effect of Electrical Resistivity of Dust

The effect of electrical resistivity on the collection of dust is discussed as follows in a British source published in 1964(13):

> Much has been written on the subject of the effect of the resistivity of the dust on precipitator efficiency and it is not proposed to go deeply into this aspect of the subject;... It can be shown, however, that for dust of a very high resistivity, precipitation efficiency can be seriously reduced (see Figure VI-38 and section on particle sizing), and, for resistivities higher than 10^{11} ohm-cm, difficulties are likely to be encountered. There is some divergence of opinion between different investigators on the value of resistivity at which difficulty is likely to be encountered and it is thought that this is due to a number of factors difficult to control, such as the degree of packing of the dust, so that in practice different forms of apparatus can disagree to a considerable extent. At the same time resistivities measured by any one form of apparatus, when used by an experienced operator, can be related to precipitator performance.
>
> The electrical resistivity of most dusts and fume depends on the nature and condition of the surface of the dust particles, rather than on the material of which the dust is composed; the resistivity is in practice often determined by adsorbed layers of vapour, such as water, sulphuric acid, or ammonia. These usually arise from reactions taking place in the furnace or vessel to

which the precipitator is attached; for instance, high-sulphur fuel oil used in firing OH furnaces can produce sulphuric acid, and this in turn is adsorbed by the dust. Where the dust resistivity is high, suitable layers to reduce the resistivity of the dust can be provided by the injection of one of the conditioning agents listed above into the flue before the precipitators. In practice, however, in this country, it has not so far been found necessary to supply any artificial conditioning agent to red oxide dust plant, although difficulties have been reported from abroad. Figure VI-39 shows the resistivity plotted against temperature for fume originating from LD converters, OH furnaces, arc furnaces, and ladle desiliconization processes.

It will be seen that the resistivity is below 10^{11} ohm-cm in all cases except for fume from the arc furnace. In the case of OH furnaces the dust is normally 'conditioned' by the water vapour and sulphur trioxide resulting from the combustion of the fuel used to fire the furnace.

In the case of the arc furnace, there is normally no such supply of conditioning agent in the gases leaving the furnace as curve 1, which is the resistivity of a dust sample taken immediately at the furnace outlet and is typical of a highly resistive dust without the conditioning surface layer. When a precipitator is attached to an arc furnace it is necessary, in view of the high temperatures involved, to cool the gases, usually by means of a water spray tower, to an economical level for the precipitator. This has the effect of reducing the gas volume to be treated; and at the same time, the dust is 'conditioned' by water vapour and the resistivity curve assumes the shape shown for the other fume with the peak value below the limit for efficient precipitation.

Effect of Particle Size on Precipitator Efficiency

The same British report(13) describes the following:

It can be shown from calculations on the forces acting on charged particles that the efficiency of an electrostatic precipitator should decrease with decreasing particle size; this, however, is not normally borne out in practice and many commercial applications of precipitation are on processes in which much of the fume is submicron, as for instance, blast-furnace gas cleaning and the red oxide fume evolved from oxygen blowing processes.

Figure VI-37 shows the relationship with precipitation efficiency and particle size for a number of dusts, the first three relating to dry precipitation, and number 4 to a wet precipitator. Curve No. 1 was obtained on a dust whose electrical resistivity was of the order of 10^{13} ohm-cm, and the precipitator was exhibiting signs of severe reverse ionization; it is interesting to note that the fall-off in efficiency becomes increasingly serious for particle sizings below 20 μm. Curve No. 2 was obtained upon the same dust when the resistivity had been decreased by the use of a conditioning agent, while curve No. 3 was obtained on a dust whose resistivity was well below the limit of 10^{11} ohm-cm quoted in the section on resistivity.

Curve No. 4, obtained on the wet electrofilter, has a fall-off comparable with the lowest resistivity dry dust (curve No. 3); in this case, although the dust was initially highly resistive, the resistivity of the dust in the precipitator was reduced to a safe level by the cooling and natural conditioning effect of the spray tower preceding the precipitator; in addition, since the particles were deposited on a moving flow of water, the effect of high resistivity would be of no consequence in any case. Since this fume consisted of non-magnetic particles of spherical form it was possible, using the electron microscope, to continue the grading beyond the limit of most forms of grading apparatus; these gradings indicated that there was no serious fall-off of precipitator efficiency for particle sizings down to the order of $\frac{1}{100}$ μm.

While the theory of the motion of the dust particles under the effect of the electric field assumes that the dust is deposited as individual particles, there is in practice a strong tendency for very fine fume to agglomerate into masses consisting of hundreds of fine particles, such agglomerates behaving as single, much larger particles in the electric field, with the result that efficiency is higher than would be theoretically calculated for such a fume. This is normally considered to be one of the explanations why the precipitator fails to obey the basic theory. It is also one of the difficulties of carrying out dust gradings and limits their value, since clearly what is required of a dust grading apparatus is the grading including the effect of agglomeration, and one of the debatable points in dust grading methods is the energy which should be used to disperse the agglomerates formed in the precipitators in a dust grading apparatus. An interesting feature is the action of the conditioning agent, as illustrated by curves 1 and 2, since it would appear that, in addition to reducing the resistivity of the dust, the agglomerating properties are also materially improved. The authors consider that for efficient precipitation it is necessary, particularly in a dry precipitator, for the dust to have the correct agglomerating properties in addition to a suitable electrical resistivity value.

Adaptability of Particulate Removal Systems to Removal of Gaseous Pollutants

Studies on the injection of dry, powdered limestone, dolomite, maganese dioxide, alumina, and other metal oxides to process gases containing sulfur dioxide indicate that some 30 to 60 percent of the SO_2 can be absorbed by the additive and removed in the particulate-removal system (as an added inlet loading).

A bag filter could do this effectively. A wet scrubber system gives the added benefit of a liquid-absorbtion stage, and has yielded good test results. Alkaline solutions may be used without the powder injection.

A catalytic oxidation process unit could be inserted in series following a precipitator so the high temperature at which the precipitator operates could be used in the oxidation. The process scrubbing would preclude following with a baghouse or precipitator.

These systems are in the development phase, and their use is contingent on economics and competitive-process developments.

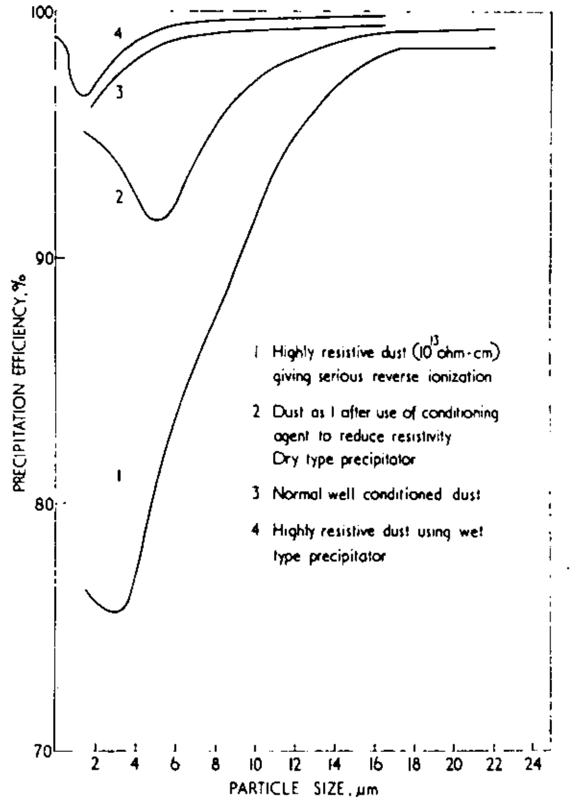


FIGURE VI-38. VARIATION OF PRECIPITATION EFFICIENCY WITH PARTICLE SIZE

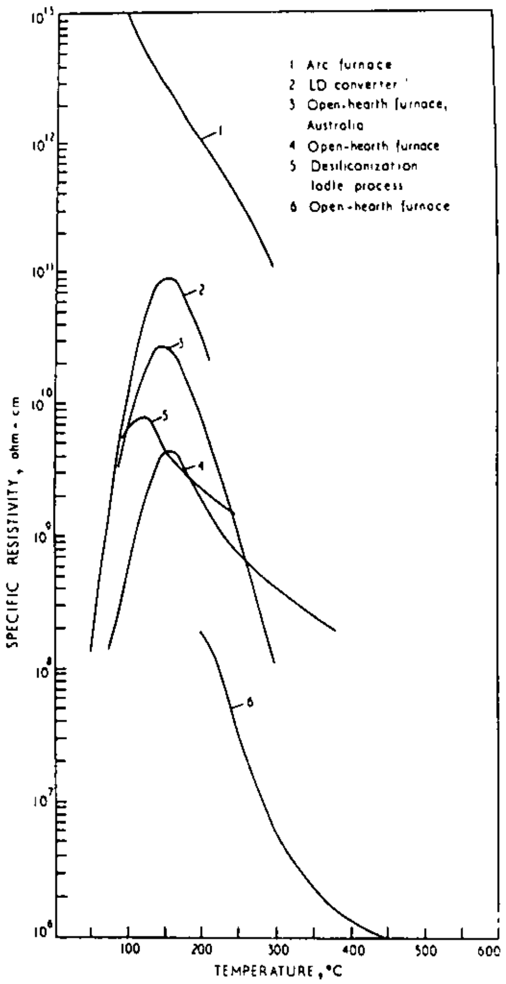


FIGURE VI-39. ELECTRICAL RESISTIVITY OF RED OXIDE FUME FROM VARIOUS OXYGEN-BLOWN STEELMAKING PROCESSES

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VI-85 and VI-86

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SECTION VII

PROBLEMS AND ASSOCIATED OPPORTUNITIES FOR RESEARCH

An objective of this study is to determine where research and development may be undertaken to achieve the desired control of emissions to the air from the integrated iron and steel industry. As a means for screening the various process segments with respect to research needs, an identification key was developed to select the subjects requiring research effort to resolve its air-quality problems, and to establish some indication of priority. The key is given in Table VII-1.

TABLE VII-1. IDENTIFICATION KEY FOR PROBLEM IDENTIFICATION

Factor	Key			
	■	▨	□	?
Level of emission	Severe	Moderate	Minimal	
Is it controlled?	No	Partially	Yes	
Can it be controlled?		Partially	Yes	Uncertain

The key is explained as follows:

Level of emission -

Severe - Emission is (1) large in volume, (2) detrimental regardless of the volume, or (3) particularly obnoxious with respect to odor. As examples: (1) a large volume of emissions would be the iron-oxide fume generated in uncontrolled BOF operation, (2) detrimental in small amounts would be applied to fluoride emissions, and (3) the evolution of hydrogen sulphide from quenched blast-furnace slag would be an example of a particularly obnoxious odor.

Moderate - Emission is (1) modest in volume, (2) somewhat detrimental regardless of volume, or (3) slightly obnoxious or disagreeable with respect to odor. As examples: (1) the particulates generated during the quenching of coke, (2) acid fumes from partially hooded pickling operations, and (3) benzol odors downwind from a coke plant.

Minimal - Emission is (1) at a low volume, (2) slightly detrimental when in large volumes, but generally tolerable, and (3) any odors classed as a minor nuisance. As examples: (1) particulates generated during the indurating of pellets, and (2) gases from mold coatings during ingot pouring.

Is it controlled? - This factor in the identification key is concerned with the apparent average for the entire integrated iron and steel industry.

No - The industry on the average does not control emissions to the air from the process or from the process segment.

Partially - The steel industry generally does some control of emissions to the air.

Yes - The process or process segment usually appears to be controlled adequately.

Can it be controlled? -

No - Present pollution-control technology is not adequate for successful control.

Partially - Present pollution-control technology has some limitations that interfere with successful control.

Yes - Emissions can be controlled with present control-equipment and technology.

Uncertain - Insufficient information available to determine if control is possible.

It should be pointed out that under the factor "Can it be controlled? ", no process or process segment is considered as absolutely uncontrollable with respect to emissions.

Priority for the conduct of research and development was evaluated on the basis shown in Table VII-2. The priority rating is based on a combination of the level of emission, whether it is controlled, and whether it can be controlled. The first priority is for processes or process segments having a severe level of emissions, no control or only partial control, and the control technology is, for practical purposes, unknown or only partially effective. Second or third priority is determined on the basis of emission level, with the same considerations for control and the possibility of control. Any process or process segment listed as controllable with respect to emissions by use of present technology is not considered as an appropriate area for research and development activities.

Ratings for the various process segments considered in this study are shown in Tables VII-3 through VII-8. Research and development priorities are determined on the basis of the indicated ratings. Emissions from the process segments are designated as follows: $\boxed{\text{P}}$ - particulates, $\boxed{\text{G}}$ - gaseous, and $\boxed{\text{A}}$ - aerosols.

TABLE VII-2. PRIORITY FOR RESEARCH AND DEVELOPMENT EFFORTS

Level of Emission	Is It Controlled?	Can It Be Controlled?	Priority Rating
■	■	?	First
■	■	▩	
■	▩	?	
▩	■	?	Second
▩	■	▩	
▩	▩	?	
▩	▩	▩	
□	■	?	Third
□	■	▩	
□	▩	?	

TABLE VII-3. RESEARCH AND DEVELOPMENT EVALUATION FOR MAKING PELLETS AND FOR RAW-MATERIAL HANDLING

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Making Pellets	Crushing and grinding	P	Process	▨	☐		III-41, IV-9, A-3
	Pelletizing	P	Process	☐	☐		III-41, IV-9, C-10
	Indurating	G	Process	☐	☐		III-41, V-6, VI-29, VI-32, C-9
Ore	Unloading - boat - coarse ore	P	Wind	▨	■	?	III-41, III-42, IV-6, V-1, A-1, C-2
	- fine ore	P	Wind	■	■	?	C-2
	- pellets	P	Wind	■	■	?	III-41
	Unloading - railroad - coarse ore	P	Handling	▨	■	?	C-2
	- fine ore	P	Handling	■	■	?	C-2
	- pellets	P	Handling	■	■	?	C-2
	Transfer to storage - coarse ore	P	Handling	☐	■	?	III-42
	- fine ore	P	Handling	■	■	?	III-42, IV-9
	- pellets	P	Handling	☐	■	?	III-42
Flux	Blast-furnace limestone - unloading boat or barge	P	Wind	☐	■	?	III-41, A-4, C-11
	- unloading railroad	P	Handling	☐	■	☐	C-13
	- transfer to storage	P	Handling	☐	■	?	C-13
	Sinter-plant limestone - unloading boat or barge	P	Wind	☐	■	?	A-4, C-13
	- unloading railroad	P	Handling	☐	■	?	C-13
	BOF lime - unloading and transfer to storage	P	Handling	☐	☐		C-13
Coal	Unloading - boat or barge	P	Wind	■	■	?	III-41, V-1
	- railroad	P	Handling	■	■	?	C-16
	Transfer to storage	P	Wind	■	■	?	C-16

TABLE VII-4. RESEARCH AND DEVELOPMENT EVALUATION FOR COKE MAKING

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Coke Plant	Coal transfer - storage to coke plant	P	Wind	■	■	?	III-41, V-2, VII-12, A-4, C-16, C-26
	Internal transfer to crushing plant	P	Handling	■	▨	☐	III-41, VII-12, C-16
	Crushing and grinding	P	Process	■	▨	☐	III-41, IV-10, VII-12, C-16
	Internal transfer to storage	P	Handling	■	▨	☐	III-41, VII-12, C-16, C-26
	Coal transfer - storage to larry car	P	Handling	■	▨	☐	III-41, V-3, VII-12, C-16
	- larry car to coke oven	P	Handling	■	▨	?	III-41, IV-10, V-3, VII-12
		G	Open oven	■	▨	?	V-3, C-16
	Coking operation - oven	G	Lids and door seals	▨	▨	▨	III-41, IV-10, IV-11, V-2, VII-12, C-14, C-18, C-27
	- underfiring	G	Fuel	▨	▨	☐	III-41, V-2, V-31, C-18
	Pushing coke	P	Abrasion, thermal draft	■	■	?	III-41, IV-10, V-3, VII-12, C-19
		G	Incomplete coking	■	▨	☐	C-19
	Quenching coke	P	Thermal draft	▨	■	▨	III-41, V-3, VII-12
	Transfer to storage	P	Handling	☐	▨	?	III-41, V-4, C-20
	Crushing and screening	P	Process	▨	▨	☐	III-41, VII-12, C-20
	Coke-oven gas system	G	Leaks	☐	☐		III-41, VII-12, C-21
	By-product plant	G	Leaks	■	▨	☐	III-41, V-4, VII-12, C-21

TABLE VII-5. RESEARCH AND DEVELOPMENT EVALUATION FOR MAKING SINTER AND MAKING IRON

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Making Sinter	Crushing and grinding of materials	P	Process	▨	□		III-41, V-5, A-2, C-5
	Material transfer to sintering machine	P	Handling	□	□		III-41, V-5, C-2
	Ignition and sintering	P	Process	■	▨	?	V-5, V-33, VI-7, VI-15, VI-21, VI-29, VI-32, C-2, C-5
		G	Fuel	▨	■	?	V-5, V-33
	Cooling, crushing, and screening	P	Process	■	▨	□	C-2
	Transfer to storage	P	Handling	□	▨	?	
Making Iron	Transfer - ore, sinter, pellets, flux and coke - storage to stockhouse	P		▨	▨	?	III-42 IV-11, IV-12, IV-13, C-38
	Material transfer - internal stockhouse to skip hoist	P		▨	□		III-42, C-38
	- skip hoist to blast-furnace top	P		□	■	?	III-42, C-38
	Ironmaking - chemical reactions	G	Process	▨	□		III-42, V-6, VI-7, VI-16, A-9, C-30, C-39, C-43, C-47
	- burden degradation	P	Process	▨	□		III-42, V-7, C-43
	- casting iron	P	Chemistry	■	■	?	III-42, V-8, V-9, C-40
	- flushing slag	G	Chemistry	■	■	?	III-42, C-40
	- slag disposal	G	Chemistry	■	■	?	III-42

TABLE VII-6. RESEARCH AND DEVELOPMENT EVALUATION FOR MAKING STEEL AND POURING INGOTS

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Open-Hearth Steelmaking	Refractory maintenance	P	Handling	☐	▨	☐	V-11
	Charging scrap	P	Handling	▨	▨	☐	III-43, V-10, C-54
	Preheating and melting	P	Material	▨	▨	☐	III-43, V-10, V-38, VI-8, VI-18, VI-21, VI-26, VI-27, VI-28, A-13, C-62, C-66
		G	Fuel	▨	▨	☐	III-43, V-10, C-62
	Hot-metal addition	P	Chemistry	■	▨	☐	III-43, V-10, C-62
	Oxygen lancing	P	Process	■	▨	☐	III-43, V-11, C-64
		G	Process	▨	▨	☐	V-11
	Tapping	P	Handling	▨	■	☐	V-12
BOF Steelmaking	Charging scrap	P	Handling	▨	☐		III-43, IV-15, VI-9, VI-11, VI-18, VI-26, VI-27, VI-28, A-16, C-66
	Charging hot metal	P	Chemistry	■	▨	☐	III-43, V-12
	Oxygen lancing	P	Process	■	▨	☐	III-43, V-12, C-69, C-70, C-71, C-73
		G	Process	■	▨	☐	V-12, C-70, C-73, C-77
Electric-Furnace Steelmaking	Charging scrap	P	Handling	▨	▨	☐	III-43, IV-16, IV-17, IV-18, V-14, VI-21, A-18, C-79, C-88
	Charging hot metal (if used)	P	Chemistry	■	▨	☐	III-43, C-91
	Melting	P	Process	▨	▨	☐	III-43, V-14, VI-12, VI-20, VI-26, VI-27, VI-28, VI-29, C-91
	Oxygen lancing	P	Process	■	▨	☐	III-43, C-83
		G	Process	▨	▨	☐	V-15, C-84
Pouring Ingots	Pouring without hot tops	P	Oxidation	☐	■	☐	III-43, III-44, C-104, C-106
		G	Mold coating	▨	■	☐	V-12, A-24, C-106
		G	Process	☐	■	☐	V-12, C-106
	Pouring with hot tops	G	Material	▨	■	☐	C-106, C-112
		P	Material	▨	■	☐	C-106
	Leaded steel additions	P	Material	■	☐		C-108
	Ingot stripping	P	Process	☐	■	☐	C-108

TABLE VII-7. RESEARCH AND DEVELOPMENT EVALUATION FOR PRIMARY ROLLING, CONTINUOUS CASTING, PRESSURE CASTING, AND CONDITIONING

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Rolling Billets, Blooms, and Slabs	Maintenance - soaking pits	P	Handling	▨	▨	☐	
	Firing - soaking pits	G	Fuel	▨	▨	☐	
	Charging and removing ingots	P	Process	☐	■	?	
	Primary rolling	P	Oxidation	☐	☐		
Continuous Casting	Flow of molten steel into machine	P	Oxidation	☐	▨	☐	IV-19
		G	Oxidation	☐	☐		
	Torch cutoff	P	Process	☐	■	☐	C-110
		G	Process	☐	■	☐	
Pressure Casting	Flow of metal into mold	P		☐	☐		IV-19, C-112
	Flow of metal into hot top	P	Material	☐	■	☐	
		G	Material	☐	■	☐	C-112
	Torch cutting to remove riser	P	Process	☐	■	☐	C-113
Auxiliary Operations	Preparation of ingot molds	P	Process	▨	■	?	
		P	Material	▨	■	?	C-106
	Preparation of pressure casting mold	P	Process	☐	☐		
		A	Material	☐	■	?	
	Pigging of molten iron	P	Chemistry	■	▨	?	
Conditioning Semifinished Products	Grinding and chipping	P	Process	☐	▨	☐	
	Spot scarfing	P	Process	▨	▨	☐	

TABLE VII-8. RESEARCH AND DEVELOPMENT EVALUATION FOR HOT ROLLING, COLD ROLLING, COATING OF FINISHED PRODUCTS, WASTE INCINERATION, AND POWER GENERATION

		Type	Controlling Factor	Level	Is It Controlled?	Can It Be Controlled?	Report References
Finished Products	Heating for rolling	G	Fuel	▨	☐		III-44, III-45, IV-23, V-41, V-18, C-114
	Hot scarfing prior to rolling	P	Process	■	▨	☐	III-44, V-18, VI-33, A-27, C-114, C-116, C-117
	Hot rolling	P	Oxidation	▨	▨	☐	III-45, IV-20, V-18, A-27, C-114, C-117
	Pickling for scale removal	A	Acid mist	▨	☐		IV-23, V-18, C-117, C-118
	Shotblasting for scale removal	P	Process	▨	☐		C-115
	Cold rolling	A	Rolling oil	☐	▨	☐	III-45, IV-22, V-18, C-117
	Hot galvanizing	P	Cover flux	▨	☐		III-45, IV-22, V-19, C-121
	Electro-galvanizing	P	Cover flux	☐	☐		IV-23, V-20, C-120
	Electro-tin plate	P		☐	☐		III-45, IV-22, V-20
	Paint coating	A	Process	▨	☐		III-45, IV-22
	Plastic coating	A	Process	▨	☐		III-45, IV-22
Waste Incineration	Disposal of in-plant generated wastes	P		▨	▨	☐	A-28, A-29, C-124
		G		▨	▨	☐	
Power Generation	In-plant generation of electric energy	P		▨	▨	☐	
		G		▨	▨	?	

First Priority for Research and Development

Process or process segments rated to warrant first-priority efforts are characterized by the following key designations:

Level of Emission	Is It Controlled?	Can It Be Controlled?
■	■	?
■	■	▩
■	▩	?

Examination of the processes in the tables shows the following to fall into the first-priority classification:

(1) Unloading and transfer to storage of fine ore or pellets
(2) Unloading and transfer to storage of coal
(3) Coke plant - oven charging (particulates and gases)
(4) Coke plant - pushing coke
(5) Sinter plant - ignition and firing of sinter
(6) Ironmaking - (a) casting iron, (b) flushing slag, (c) slag disposal
(7) Pigging of molten iron.

Second Priority for Research and Development

Process or process segments rated to warrant second-priority efforts are characterized by the following key designations:

Level of Emission	Is It Controlled?	Can It Be Controlled?
▩	■	?
▩	■	▩
▩	▩	?
▩	▩	▩

Examination of the processes in the tables shows the following to fall into the second-priority designation:

(1) Unloading coarse ore

(2) Coke plant - gaseous emissions from lids and door seals

(3) Coke plant - particulates during quenching of coke

(4) Sinter plant - gaseous emissions from fuel

(5) Making iron - transfer of bulk materials from storage to stockhouse

(6) Preparation of ingot molds

(7) Gaseous emissions from in-plant generation of electric energy.

Third Priority for Research and Development

Process or process segments rated to warrant only third-priority efforts are characterized by the following key designations:

Level of Emission	Is It Controlled?	Can It Be Controlled?
☐	■	⍰
☐	■	▩
☐	▩	⍰

Examination of the processes listed shows the following to fall into the third-priority designation:

(1) Transfer of coarse ore

(2) Unloading and transferring of limestone

(3) Coke plant - handling of coke

(4) Coke plant - coke-oven-gas system

(5) Sinter plant - transfer of sinter to storage

(6) Making iron - charging from skip hoist to blast-furnace top

(7) Charging and removing ingots from soaking pits

(8) Preparation of pressure-casting molds.

Evaluation of Research and Development Priorities

The problems, possible solutions, and implications of the changes that are required and which may occur as a result of research and development, are discussed in Table VII-9. Making of coke is considered first because it presents major problems requiring solution at three levels of priority. Sinter-plant operation is considered second because it also presents problems at all three levels of priority, but these appear, overall, less severe than those for coke making.

Coke Making

The unloading of coal from barges and movement of coal to the storage areas presents a serious particulate-emission problem because of the fineness of the coal dust and the ease with which it can become airborne once it is in a stockpile. The unloading operation can possibly be improved by the development of continuous bucket unloaders that would transfer the coal to shrouded conveyor belts for transport to storage areas. Such an approach would keep the particulates contained, but in all probability the shrouded conveyor belts would also have to be hooded and exhausted to remove any airborne particulates from the system. If this were not done, excessive wear of the conveyor-belt rollers would probably occur, with resulting high maintenance costs. This type of system would also have a tendency to restrict the expanse of storage space. Moisture additions at the first transfer point, which would be stationary, should tend to minimize dust generation at subsequent transfer points.

The containment of coal in the stockpiles and prevention of coal dust from becoming airborne is a serious problem. Attempts have been made to keep dust down by moisture additions to the piles, as well as by spraying the piles with plastic films. Neither method has proved to be satisfactory. An ideal additive to the coal stockpiles would be one that would keep a protective film over the stockpile, would heal itself if broken, would not be detrimental to the crushing, grinding, and coking of coal, and could be used to control the bulk density of the coal.

The transfer of coal from storage to the coal-grinding plant is a problem similar to that of unloading and transfer of coal to stockpiles. The Japanese have reportedly resorted to a reclamation system that utilizes underground systems to recover the coal from the stockpiles, thereby eliminating the problem of agitating the coal pile.

Particulate emissions from the crushing, grinding, and transport of coal to the storage bins above the larry cars usually are under control, and particulate emissions from this source should not be present. Grinding mills and conveyor systems can be serviced with efficient emission-control equipment. The recovered coal dust is a plus, because any lost dust would mean a loss in yield for each ton of coal ground, with an attendant increase in the cost of coke.

Charging of the coke ovens from the larry car is a persistent problem, and one of constant concern to the coke-oven operator. All lids must be open during the charging operation, with the result that dust which becomes airborne inside the coke oven due to the thermal draft finds an easy path to the atmosphere via any of the open ports. Constant maintenance of automated lid-lifting and closing equipment and rapid charging have been the major means of minimizing emissions from this source. The new

TABLE VII-9. ANALYSIS AND POSSIBLE SOLUTIONS TO COKE-PLANT AIR-POLLUTION PROBLEMS

Process Segment	Problem	Possible Solution	Advantages	Technological Disadvantages	Process and Equipment Factors Requiring Solution
Making coke	Insufficient control of particulate and gaseous emissions	Complete enclosure and building ventilation	Centralized control and exhausting of emissions to allowable limits	Create industrial hygiene problems Possible explosion hazard	Design, construction, safety, and industrial hygiene problems
Unloading of coal from barges and transfer to storage	Particulate emissions caused by clam-shell unloading, free-fall dumping, and wind	Continuous bucket unloading and discharge to shrouded belt	Contain and minimize particulates Permit all-weather operation	Restrict area of operation and extent of storage area	Design and construction
Unloading of coal from railroad cars, and transfer to storage	Particulate emissions caused by car dumping or bottom dumping	Enclosure and exhausting of car-dumping or bottom-dumping area, and shrouded belt to storage	Contain and minimize particulates	Restrict area of operation and extent of storage area	Design and construction
Storage of coal	Particulate emissions generated by wind	Unknown			Retention of particulates in storage piles
Transfer of coal from storage to coal crushing and grinding plant	Particulate emissions generated by clamshell recovery and free-fall loading of cars	Underground recovery and conveyor transfer to grinding plant	Minimize or even eliminate emissions due to coal recovery	Extensive rebuilding of coal-storage facilities	Design and construction
Coke-oven charging	Particulate and gaseous emissions generated during charging	Double aspiration lines	Reduce emissions during charging	Unknown	New charging methods
		Shrouded charging pipes and collection equipment on larry car	Reduce emissions during charging	Possible explosion or fire hazard	
		Pipe-line charging	Eliminate emissions		
Coking	Leakage of gaseous emissions around doors, seals, and lids	Improved maintenance	Reduce emissions	None	Design, construction, and maintenance
		Improved design in lids, seals, and doors	Minimize emissions	None	
Pushing of coke	Particulate generated by abrasive action of coke on oven brick, and thermal draft causing dispersion of particulates	Hooded exhaust over push side	Contain and exhaust particulate and gaseous emissions	Possible interference with pushing operation	Method and/or equipment for capturing and collecting emissions
		Fine spray nozzles to spray coke and reduce temperature	Reduce temperature of the coke as it is pushed, reduce the intensity of the thermal draft, and minimize dispersion of particulates	Possible interference with pushing operations and create a safety problem	Mechanics of quenching and particulate emission
Quenching of coke	Emission of particulates during the quenching of hot coke	Use of baffles	Reduce particulates		Quench tower operation and characteristics
		Redesigned quench tower	Minimize or even eliminate particulates		
Coke-oven-gas recovery system	Leakage of gas	Improved gas-plant components	Minimize leakage		Design and maintenance
	High H_2S content in coke-oven gas	Develop economical method of removing H_2S	Minimize or even eliminate sulfur oxide due to burning of coke-oven gas		
By-product recovery plant	Leakage of gas and aerosols	Improved by-product-plant components	Reduce emissions		Design and maintenance
Making coke	Insufficient control of particulate and gaseous emissions in present coke plants	Develop new coke-making process	Eliminate emissions	Unknown	New process and equipment

European larry car which exhausts the emissions into a scrubber system located on the larry car has not been fully successful because of fire and explosions which have reportedly occurred in two Canadian installations.* It has been reported that cooperative work among several steel companies on the improved larry car-emission control system has been somewhat successful. Details are not yet available, but are expected to be disclosed to NAPCA soon, probably by the AISI, which has informally expressed its intention to request research funding from NAPCA on this subject.

An American company (Allied Chemical Corporation, Wilputte Division) that designs and builds coke ovens has under development a method of preheating coal followed by charging into the coke oven by means of a pipeline system. The developers feel that the method will control completely the emissions of particulates and gases to the atmosphere during charging. The company is installing the system on a commercial battery of coke ovens of its Semet-Solvay Division at Ironton, Ohio. Further information has not yet been released by the company, but is expected to be released soon. The commercial installation probably will be operational about mid-1970, unless unexpected difficulties are encountered. Assessment of the advantages and disadvantages of the system must await operation on a commercial scale.

Leakage of gaseous emissions around the lids, doors, and seals is a problem that can be minimized only through constant maintenance. As coke ovens become older, the leakage problem becomes aggravated. Coke-plant-construction companies have been working on the development of improved designs, but under the conditions imposed by the coking process, there has not yet been a substantial return on the effort put into this part of coke-oven construction.

Pushing of coke results in particulates generated by the abrasive action of the stove refractories on the coke as it is pushed from the oven. The thermal draft created by the exposure of the hot coke to the atmosphere carries the particulates into the atmosphere. Various types of hoods and exhaust systems have been tried on the European continent, but none have operated successfully. The possibility of a prequenching operation between the coke oven and quench car may be a means of reducing the temperature of the coke, and thereby reducing the intensity of the thermal draft.

The quenching of coke is also a source of particulates; installation of baffles in the quench tower has reduced this emission from 60 to 80 percent. Further work is being carried out on this aspect of particulate control. Another subject of research could concern itself with new designs for quench towers that would be a combination of quench tower and heat exchanger to (1) prevent the steam generated from going into the atmosphere, and (2) contain the particulates within the restricted area of the quench tower itself.

New coking processes have been under development for many years, but none have been able to compete with the existing by-product coke plant. However, the fact that the coke by-product market has to a great extent been usurped by the petrochemical industry, and markets for coal by-products have deteriorated, the attraction of the by-product coke plant has diminished. Coking processes that do not recover the by-products are of considerable interest in the integrated iron and steel industry today, and a number of new coke-oven installations may in the future dispense with much of the by-product recovery that has been traditional until now.

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*This report has not been confirmed.

When new coking processes are developed, evaluation of them and of the usefulness of the metallurgical coke they produce is usually hampered by two facets of scale. First, the coking pilot plant often is too small to produce large amounts of coke for commercial-scale evaluation, and second, the integrated steel industry includes only extremely limited capability to evaluate the performance of the new coke sufficiently to qualify it for acceptance on a commercial scale. Without such acceptance, it usually is impractical to authorize construction of a multimillion dollar coking plant based on a new process. The blast-furnace operators usually are not satisfied with anything less than full-scale evaluation of a new coke. Experience has shown that such a test must be carried out for a minimum of 1 week to provide valid results for comparison to existing practice. This means that a blast furnace producing 2000 net tons per day of hot metal at a coke rate of 1200 pounds per net ton requires 1200 net tons of usable coke per day, which is 8400 net tons for the complete test. Pilot facilities are seldom in a position to supply such requirements. An experimental blast furnace operated by the Bureau of Mines was available for such tests and required only about 300 tons of coke to carry out the required trial. Unfortunately, this furnace is no longer operative, and probably will soon be declared surplus. This will leave in the United States only one small experimental blast furnace suitable for such evaluations – the furnace owned by United States Steel.

For about a decade or more, the FMC Corporation has had under development a new process for making coke, and at various times has operated a pilot plant at Kemmerer, Wyoming, to produce their FMC coke.[1] This coke is made by a continuous process involving fluidized beds and briquetting. One application of the coke has been as a reducing agent in phosphorus furnaces – an application less demanding than the blast furnace in terms of mechanical strength of the coke. Recognizing the need for new methods to produce coke for blast furnaces, United States Steel cooperated with FMC to manufacture some metallurgical coke by this process and evaluate it in one of the small experimental blast furnaces. The results were reasonably good, but were not sufficiently convincing with respect to performance and cost to encourage U.S. Steel or other steel companies to invest the much larger amounts of money needed to expand this evaluation to a larger scale. Subsequently the Kemmerer pilot plant was closed down, but there are today unconfirmed rumors that some thought is being given to reopening of that plant for purposes that are unknown at this time.

At least one American coal company (probably two) have developed new methods for making coke or char on a continuous basis under conditions that are thought to control emissions much better than those for conventional coke ovens. Island Creek Coal Company is thought to have a process that might be of interest for application to the steel industry, but little is known about this process at the present time. The activities of Peabody Coal Company along these lines are of more interest. Peabody has a process that involves pretreatment of coal on a traveling grate in a dutch oven, followed by treatment in a shaft furnace. The coke is self-agglomerating during the process (like coke in a conventional oven), rather than briquetted as is done for FMC coke. Throughput time is understood to be between 1 and 2 hours, rather than about 16 hours as in a conventional oven. Peabody installed in 1961 a demonstration plant rated at 100 tons per day at Columbia, Tennessee; they use the plant for process development and sell the coke for chemical purposes in the vicinity. Most of this coke was not intended to be a metallurgical grade, but it is understood that some work was done on blast-furnace coke. The results appeared good to Peabody, but have not been evaluated by blast-furnace tests. The process looked good enough for some purposes that Monsanto Chemical Company built a plant in 1966 at Decatur, Alabama. This plant is rated at 500 tons per day; and the coke is used as a reducing agent in phosphorus furnaces.

Making Sinter

Problems, possible solutions, and implications of changes in sinter-plant operations are given in Table VII-10. Particulate and gaseous emissions are a problem in the operation of a sinter plant, because each of the various process segments that are included in the over-all operation has its own particular air-pollution problem that must be handled. Sinter plants will undoubtedly be in use for many years to come, if for no other reason than to recover the iron values that are generated as dusts in steelworks operations.

Crushing and grinding operations associated with the preparation of materials for sintering are straightforward, and particulate emissions can be controlled with presently available equipment. The transport of materials to and from sintering plants falls into the same category. The areas of major importance in minimizing emissions is in the ignition and sintering operation of the sinter strand. Particulates are drawn from the sinter bed by the strong air flow required by the sintering operation. The primary fuel used to make the sinter is coke in the form of fines. The sulfur content of the coke is a major source of sulfur emissions to the atmosphere. Coke is the usual fuel in this particular application, because the coke fines are to a great extent generated during the crushing and sizing of the coke for blast furnace use. The fines are, therefore, available at a reasonable cost for the production of sinter. Major problems exist in the development of existing air-pollution control equipment to handle high-lime particulates that are generated in the production of highly-fluxed sinters required to meet increased demands for higher blast-furnace productivity. Wet scrubbers offer a possible solution to the recovery of the high-lime particulates, as do bag houses. Wet scrubbers also offer the possibility of recovering the sulfur gases, because the lime content of the particulates may act somewhat as a scavenger for the sulfur dioxide. The possibilities could be explored as a combined method for recovering particulates and sulfur gases in the same equipment. Work also is advisable to determine if other additives can be introduced into the water to improve the recovery of sulfur dioxide by the lime. Particulates generated during cooling, crushing, and screening of the sinter can be handled by existing air-pollution control equipment, and probably do not require further development in their application. However, all of the foregoing depends to a considerable degree on better knowledge of the nature and characteristics of particulates and gases evolved from sintering plants. Therefore, the first step in further research aimed at better control of emissions from sintering plants is improved characterization of the amount and nature of the emissions. This improved characterization will require measurement, sampling, analysis, and evaluation of emissions from several sintering plants being operated on a commercial scale.

Raw Material Storage and Handling

Problems, possible solutions, and implications of change in the handling and storage of the vast amounts of raw materials required in making iron and steel are given in Table VII-11. The problem here is one of the most difficult to solve. Generation of particulates during the handling of raw materials from receiving to final transfer for processing is a never-ending air-pollution problem. Particulates become air-borne from the storage piles due to dry and windy weather conditions. The more-apparent solutions such as complete enclosure and underground recovery systems are certainly technically feasible, but appear to be economically impractical at this point in time. Research and development may fruitfully be carried out to produce some type of wetting

TABLE VII-10. ANALYSIS AND POSSIBLE SOLUTIONS TO SINTER-PLANT AIR-POLLUTION PROBLEMS

Process Segment	Problem	Possible Solution	Advantages	Technological Disadvantages	Process and Equipment Factors Requiring Solution
Making sinter	Insufficient control of particulate and gaseous emissions	Complete enclosure and building evacuation	Centralized control and exhausting of emissions to allowable limits	Limited access for maintenance Industrial hygiene problem for working personnel	Design, construction, and maintenance Industrial hygiene problem
Crushing and grinding	Collection of iron oxide, limestone, and coke dust				
Transport to sinter strand	Iron oxide, limestone, and coke dusts generated at transfer points	Use of water sprays and detergents at transfer points	Minimize generation of particulates	Actual level of control subject to variation	Design, construction, and maintenance
		Complete enclosure and evacuation of transfer system	Collection of particulates to allowable limits	Creates secondary dust-handling problem	
Ignition and sintering	Iron oxide, limestone, and lime dusts	Ducted control of combustion air to strand	Possible reduction of the volume of air handled with resulting increased collection efficiency	Restrict direct observation of sinter strand-probably require remote monitoring	Redesign of sinter strand
		Oxygen enrichment of combustion air	Further reduction in volume of air handled and further improvement in collection efficiency	Increase maintenance requirements Space restrictions around sinter strand	Effect of oxygen enrichment on process
	Sulfur dioxide generated by burning coke	Reduce sulfur content of coke	Corresponding reduction in SO_2	No known method for reducing sulfur in coke	Reduction of sulfur in coal used to make coke
		Wet recovery system with additives to combine with SO_2	Minimize or eliminate SO_2 emissions to atmosphere	Corrosion resistant materials required	Mechanism of SO_2 removal
		Fabric collectors with additives that combine with SO_2	Minimize or eliminate SO_2 emissions to atmosphere	Close control required to monitor additions	Mechanism of SO_2 entrapment
Cooling, crushing, and screening	Generation of particulates	Can be controlled by application of existing equipment			Design and construction
Transfer to storage	Generation of particulates	Enclosure and evacuation of transfer system	Eliminate particulate emissions	Increased maintenance problems	Design, construction, and maintenance

TABLE VII-11. ANALYSIS AND POSSIBLE SOLUTIONS TO RAW MATERIAL STORAGE AND HANDLING AIR-POLLUTION PROBLEMS

Process Segment	Problem	Possible Solution	Advantages	Technological Disadvantages	Process and Equipment Factors Requiring Solution
Unloading and transfer to storage of coal, fine ore, and pellets	Generation of particulates due to handling	Better methods of unloading boats and barges	Minimize particulate emissions		Design and construction
		Enclosure and evacuation of railroad car dumps	Minimize particulate emissions	Increased maintenance, secondary dust handling problem	
Storage	Generation of particulates due to drying of materials and windy weather	Complete enclosure	Eliminate emissions to the atmosphere	None	Retention of particulates in storage piles
		Self-healing coating	Minimize emissions	Unknown	
Recovery from storage	Generation of particulates due to handling	Underground recovery systems	Minimize particulates	Increased maintenance	Design and construction

agent that will minimize the generation of air-borne particulates during storage and handling. Fortunately, gaseous emissions are not a problem during handling and storage, except for the handling and storage of blast-furnace slag, which is a special problem now receiving research attention by the AISI, and which is discussed in the next paragraph under "Iron Making".

Iron Making

Problems, possible solutions, and implications of change for emissions generated during the making of iron are given in Table VII-12. The most pressing problems deserving of attention in the making of iron are (1) the generation of hydrogen sulfide from the quenching of slag, and (2) improved methods for the control of "kish".

Some research has been conducted on the mechanisms controlling the generation of hydrogen sulfide from quenched blast furnace slags. However, the problem is far from solved, partially because of the limited funding that has been available to carry out the research. Further research is required on rapid analytical methods for determining the concentration of hydrogen sulfide in the air, as well as continued work to further investigate the mechanisms of formation and possible methods for control.

The evolution of "kish" during the cooling of hot metal is a persistent problem in the handling of hot metal. The greasy platelets of graphite are difficult to collect and equally difficult to remove from collecting equipment. The only available solution appears to involve hooding of the areas where kish is evolved, and connection of these hoods to high-velocity ducts connected in turn to particulate-collection equipment.

TABLE VII-12. ANALYSIS AND POSSIBLE SOLUTIONS TO IRON MAKING AIR-POLLUTION PROBLEMS

Process Segment	Problem	Possible Solution	Advantages	Technological Disadvantages	Process and Equipment Factors Requiring Solution
Transfer of bulk materials from storage to stockhouse	Generation of particulates due to handling	Underground recovery	Minimize emissions	Increased maintenance	Design, construction, and maintenance
Stockhouse internal material transfer to shiphoist	Generation of particulate emissions due to handling	More complete application of available equipment	Minimize particulate emissions	Secondary dust handling problem	Design and installation
Material transfer shiphoist to blast furnace top	Generation of particulate emissions due to handling	Enclosure and evacuation of blast furnace top	Minimize emissions	Increased maintenance, secondary dust handling problem, and potential explosion hazard	Redesign of blast furnace top, dust handling, and safety problems
Casting of iron	Evolution of "kish" from cooling iron	Shorter troughs	Reduction in time of iron exposure to atmosphere	None	Redesign and reconstruction of cast house
Flushing of slag	Evolution of hydrogen sulfide	Unknown			Mechanism of hydrogen sulfide evolution and means of control
Slag disposal	Evolution of hydrogen sulfide	Unknown			Mechanism of hydrogen sulfide evolution and means of control
Transfer of iron to steelmaking furnace	Evolution of "kish" from cooling iron	Application of existing equipment	Minimize particulate emissions	None	Design and construction
Pigging of molten iron	Evolution of "kish" from cooling iron	Redesign of pig machines machines and application of available pollution control equipment	Minimize particulate emissions	None	Design and construction

APPENDIX A

PROCESSES IN THE INTEGRATED IRON AND STEEL INDUSTRY

Because the manufacture of many products depends on the use of steel, the iron and steel industry has grown to be one of the largest basic industries in the United States and the World. The production of steel consists of making metallic iron from iron ores, converting the iron into steel, casting the molten steel into shapes that are solidified, and then further processing of the solid shapes into semifinished products such as sheet, strip, bar, rod, plate, slab, billet, bloom, or ingot. The following section provides a description of the various processes involved in the production of steel.

Manufacture of Iron and Steel

The principal steps in the manufacture of iron and steel are (1) preparation of raw materials, (2) making iron, (3) making steel, (4) casting of steel, (5) rolling into semifinished products, and (6) manufacture of finished products. Some of the descriptive material in this section is taken from the work of J. J. Schueneman, et al.(1)* For more detailed descriptive information on the various processes, it is recommended that such well-established references such as "The Making, Shaping and Treating of Steel"(2) be consulted.

Preparation of Raw Materials

The major raw materials used in the production of iron are iron ore (or agglomerates such as pellets and sinter made from ores), limestone, coke, air, and energy in the form of heat. One factor that contributes to the economy of the integrated production of iron and steel is that gases produced in the making of iron and coke frequently are used to meet other energy requirements in the plant.

Iron Ore. Prior to the end of World War II, the United States iron and steel industry was essentially self-sufficient in high-grade iron ores. However, because of the high demand for steel, these high-grade ore deposits were depleted. The industry instituted research to develop methods of utilizing low-grade taconite ores for blast-furnace use. These developments were instrumental in the adoption of highly beneficiated burdens in blast furnaces. The change in the makeup of iron constituents charged to blast furnaces in the United States in the period from 1957 to 1966 is shown in Figure A-1. During 1967 the iron and steel industry consumed a total of about 136 million net tons** of iron ore and recycled mill scale and dust in the making of pig iron.(3) Agglomerated materials such as pellets, sinter, and briquettes accounted for about 97 million net tons, and the remaining 39 million net tons was in the form of lump ore, most of which was imported.

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*References for this appendix are given at the end of Appendix A.

**Net ton = 2000 pounds.

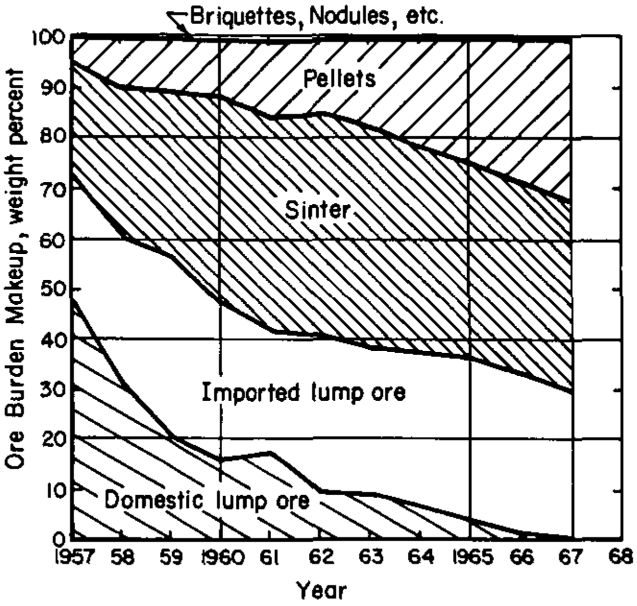

FIGURE A-1. CHANGE IN BURDEN CHARACTERISTICS FOR UNITED STATES BLAST FURNACES

Very little crushing and grinding of ore is done at the blast-furnace plant. Usually the only crushing and grinding located at the steel-plant site is associated with sinter-plant operations. Pellets are made in plants located at the mine sites. High-grade ores are crushed and sized at the mines within very narrow size ranges for shipment to the blast-furnace plants(4). Fine materials that cannot economically be processed further and used in the production of pellets near the mines are shipped to steel plants for use in the manufacture of sinter.

Sinter. Sintering plants are designed to convert iron ore fines and blast-furnace flue dust into a product more acceptable for charging into the blast furnace. This is achieved by burning a mixture of ore-bearing fines plus a fuel consisting of coke dust or coal. Combustion air is drawn through the flat porous bed of the mixture. The principle of sintering is to supply just enough fuel to the material to be sintered so that a sticky mass will be produced, but the material will not be melted sufficiently to run. The bed is formed on a slow-moving grate composed of receptacle elements with perforated bottoms, known as pallets. The assembly of such pallets end to end in a hinged or linked arrangement comprises an endless metal belt with large sprockets at either end. The ignition furnace is either gas or oil fired, and its purpose is to bring the fuel in the charge to its kindling temperature, after which the down draft of air through the bed keeps it burning.

The sintered material is dumped from the grate as it passes over the head sprocket upon a screen, the undersized material becoming the return fines, and the oversized material, which is still at a red heat in the center, passing to a sinter cooler. The cooler can be a large rotating apron or a linear grate upon which the sinter is deposited while cool air is blown through louvers located in the apron or grate.

As the cooler reaches a certain position, stationary scraper bars push the sinter off the apron into cars or conveyors. A sinter plant is illustrated schematically in Figure A-2.

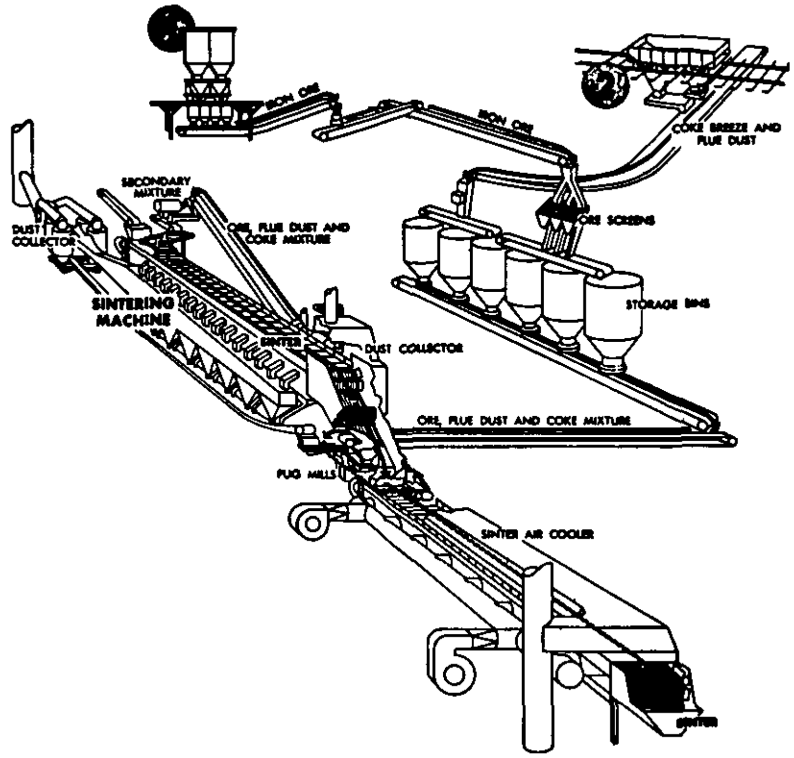

FIGURE A-2. SINTER PLANT

Modern sintering plants have capacities ranging from 2000 to more than 6000 tons of sinter per day. One plant of the latter capacity has a sinter-bed width of 12 feet and a bed length of about 150 feet. In 1967 a total of about 51 million net tons of sinter were made in the United States for use in the blast furnaces. By far the largest portion of this sinter was made within the perimeter of blast-furnace plants. In contrast to fired oxide pellets (which are very strong), sinter is relatively friable and does not stand up well physically during shipment for long distances.

Oxide Pellets. The recovery of the iron components from taconite ores can only be done if the ores are ground to a very fine powder. Sintering of the fine taconite concentrates was unsuitable as a method of agglomeration, so extensive efforts were directed toward the development of pelletizing processes to agglomerate the concentrates into useful sizes. The first successful commercial pelletizing plant was placed into operation by the Reserve Mining Company in 1955. The estimated annual pellet-making capacity in the United States in 1968 was 56.3 million net tons.

The pelletizing process was originally developed to agglomerate the fine magnetite concentrates, but since its initial development the process has been used for the hematite ores as well. The process consists of two main operations: (1) rolling the fine concentrates into damp balls of a suitable size (much like making a tiny snowball), and (2) drying and firing the balls to make hard pellets. The pellets made are roughly spherical in shape and about 1/2 inch in diameter. The types of equipment for making the balls and for hardening them vary from plant to plant. One type of pellet plant, such as used at the Empire Mine in Palmer, Michigan, is illustrated in Figure A-3(5).

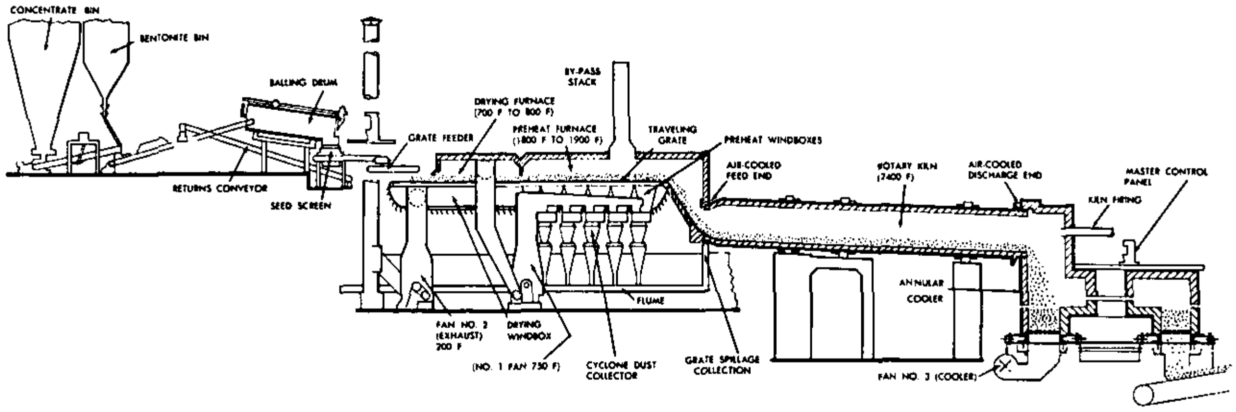

FIGURE A-3. GRATE-KILN PELLETIZING PLANT AT THE EMPIRE MINE

Limestone and Lime. Limestone (commercial $CaCO_3$) is the major fluxing material used in producing metallic iron in a blast furnace. It is also used in some open-hearth furnaces. The major role of limestone is to flux silica from ores, and to combine with sulfur to lower the sulfur content of the iron or steel. To reduce the amount of energy required to achieve the desired chemical reactions in the making of iron and steel, technologists have adopted the use of burnt lime (commercial CaO) as an additive in many steelmaking processes, but not in the blast-furnace process.

Limestone is crushed and screened to the desired size at the quarry site and only the correctly sized stone is shipped to the blast-furnace plants. Burnt lime is also prepared, usually at the quarry, by calcining the limestone to produce a high-quality lime for use in basic oxygen furnaces, open hearths, and electric furnaces. There are about eight different processes for making lime for use in the steel industry.(6) Many steel companies have their own limestone quarries and related lime-producing facilities, while others purchase their requirements from commercial operators.

Coke. Coke, the chief fuel used in blast furnaces, is the residue after distillation of certain grades of bituminous coal. It is made in two types of ovens: (1) the beehive, and (2) the recuperative or by-product oven. In either type of oven, the distillation or coking process consists mainly of driving off certain volatile matter, leaving in the residue a high percentage of carbon mixed with relatively small amounts of impurities.

The beehive oven is the older of the two types of oven, and on a national scale is unimportant in comparison to by-product ovens. On a local scale in several small areas, however, beehive ovens can be a matter of local concern. Their use at iron and steel works has nearly disappeared, although a few are used occasionally during times of maximum steel production when supplies of by-product coke may be in short supply at the blast furnaces. The dome-like structure is built of refractory brick. It has a flat floor sloping slightly toward the front. In the roof is an opening through which coal is charged and the products of distillation and combustion escape. A door in the front permits both the regulation of the amount of air admitted during the coking process and the discharge of the coke after the process has been completed. A typical beehive oven is about 12 feet in diameter by 8 feet high, and will hold about 6.5 tons of coal. It is insulated with loam or clay to prevent loss of heat.

Beehive coke ovens are operated continuously to conserve the heat that has been absorbed by the oven refractories. The ovens are charged as soon as practicable after the coke from the previous cycle has been removed or "drawn" from the oven. The heat stored in the oven refractories is enough to start the coking cycle for the following charge of coal. The door to the beehive oven is partially bricked up and the coal charged into the oven through an opening ("trunnel head") in the top of the oven. After the total charge is in the oven, the coal is leveled to provide more or less uniform treatment of the coal. The heat stored in the oven refractories starts the coking process very soon after the charge has been leveled. Volatile matter from the coal is driven off by the heat and starts to burn, thereby providing more heat to continue the coking process. Coking takes place from the top to the bottom of the coal in the oven. The rate of evolution of volatile materials and their subsequent combustion is controlled by regulating the amount of air entering through the opening in the oven door. After the coking process has been completed, the door is opened by removing the sealing brickwork, and water is sprayed over the coke to quench or "water it out". By-products are not recovered in the beehive process. Beehive ovens almost invariably are located in coal fields; not within the perimeters of integrated steel plants.

In the by-product coking process, coal is heated in the absence of air. The volatile matter is not allowed to burn away, but is piped to special equipment that extracts its valuable ingredients. After the extraction process, some of the gas (heating value about 550 Btu per cubic foot) returns to the ovens for use in heating the coking chambers and for heating in other processes in the steel plant. These ovens are rectangular in shape. Older ovens may be from 30 to 40 feet long, 6 to 14 feet high, and 11 to 22 inches wide. Coke ovens built since 1967 are usually about 50 feet long, 16 to 17 feet high, with coking chambers having an average width of 18 inches. As many as 100 of them may be set together in a battery for ease in charging and discharging the coal and coke. A modern by-product oven can receive a charge of 16 to 20 tons of coal through ports at the top. The ports are then sealed and coal begins to fuse, starting at the walls of the oven, which may generate heat from 1600 to 2100 F. The fusing works toward the center of the charge from both walls, and meets in the center, causing a crack down the middle of the mass. This crack and the porous structure of the by-product coke are its distinguishing features. When coking is finished (16 to 20-hour carbonizing period), doors at the ends of the oven chamber are opened, and the pusher ram shoves the entire charge of coke into railway cars. The load is taken to a quenching station, where it is watered by an overhead spray. After this, it is taken to a wharf to cool prior to screening.

The volatile products that have passed out of the ovens are piped to the chemical plant where they are treated to yield gas, tar, ammonia liquor, and light oil. Further refinement of the light oil produces benzol, toluol, and other complex chemical compounds. However, in recent years, competition from the petrochemical industry has made the recovery of coke by-product chemicals marginally economical or uneconomical, unless coke-plant installations are of such a large size that processing costs can compete with petrochemicals.

The fundamental features of a coke battery cannot be changed during its lifetime, which amounts to 20, 30 or more years. At the end of its life it is completely razed and a new structure embodying current technological ideas is erected to replace it.

Fuels. An integrated iron and steel plant uses a great variety of fuels, some of which are generated as part of the plant's own operations and some of which are purchased.

Coke-oven gas is produced during the manufacture of coke from coal in the coke ovens. The exhausted gas does not contain any particulates and does not require separate cleaning because particulates are trapped in the by-product recovery system. The major impurity is hydrogen sulfide, which in burning is changed to sulfur oxides. For some in-plant use, the hydrogen sulfide is removed. Coke-oven gas typically has a heat content of about 500 to 550 Btu per cubic foot.

Blast-furnace gas is a product from the ironmaking process in the blast furnace. It is a rather low-heat-content gas, with an average value of about 80 Btu per cubic foot. The gas when exhausted from the top of the blast furnace, is laden with particulate materials which are cleaned from the gas before its use in the steel plant. Blast-furnace gas is usually burned to heat blast-furnace stoves, normalizing and annealing furnaces, foundry core ovens, gas engines for blowing, firing of boilers, and gas engines and gas turbines for power generation. Preheated blast-furnace gas combined with preheated air has been used successfully for heating coke ovens, soaking pits, and reheating furnaces.(2) The present trend in the use of higher blast temperature for blast furnaces has increased the requirement for cleaner blast-furnace gas in the heating of blast stoves. A cleaner gas is required to prevent clogging of the checker work in the blast stoves, because clogging decreases stove efficiency and increases maintenance problems.

Tar, one of the by-products of the production of coke, is often used as a fuel for firing open-hearth furnaces. The tar that is burned is not cleaned, and the sulfur contained in it (usually about 0.60 percent) becomes sulfur oxide in the combustion process.

Commercial fuels (principally oil and natural gas) are used in the as-received condition at the steel plant.

Air. Air is a necessary material in the production of metallic iron in the blast furnace. It is used as it exists in the surrounding atmosphere without any treatment except for preheating to temperatures varying from 1000 to 2000 F, before it is blown into the blast furnace. Air requirements for the blast furnace may vary from 45,000 cubic feet to 60,000 cubic feet per ton of iron, depending on the type of practice used. Heated air is used to supply thermal energy to the blast furnace, but it can also act as a direct replacement for coke that would normally be burned to supply this thermal energy inside the blast furnace. A typical blast stove is illustrated in Figure A-4, with various types of checker brick used in it.

The use of high blast temperatures permits the blast-furnace operator to inject auxiliary fuels (such as oil, natural gas, coal, or coke-oven gas) through the tuyeres. The injection of these auxiliary fuels results in the generation of increased amounts of carbon monoxide in the blast furnace. (Carbon monoxide is the active reducing gas in

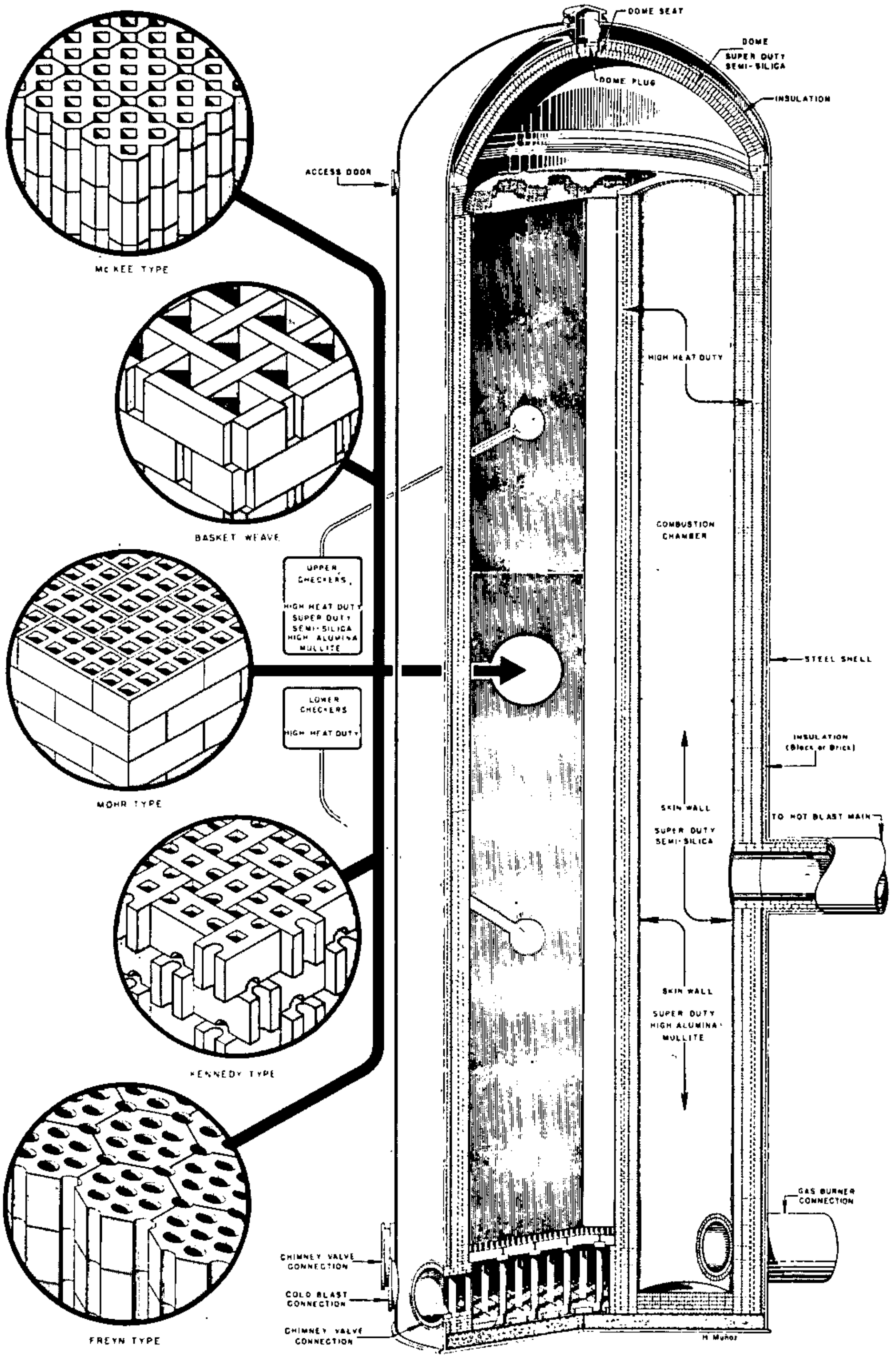

FIGURE A-4. TYPICAL BLAST FURNACE STOVE

the blast-furnace process.) This use of injected fuels also results in a lowering of the amount of coke that must be charged to a blast furnace. Typical effects of fuel-oil injection and coal injection on the amount of coke required to make one net ton of pig iron is shown in Figure A-5[(7)] and Figure A-6[(8)]. The injection of auxiliary fuels into the blast furnace is economically attractive to blast-furnace operators. In 1968 in the United States, about 50 blast furnaces were using injection of natural gas; about 15 were using fuel oil; about 3 were using coke-oven gas; 3 were using tar; and 1 was using injection of coal.

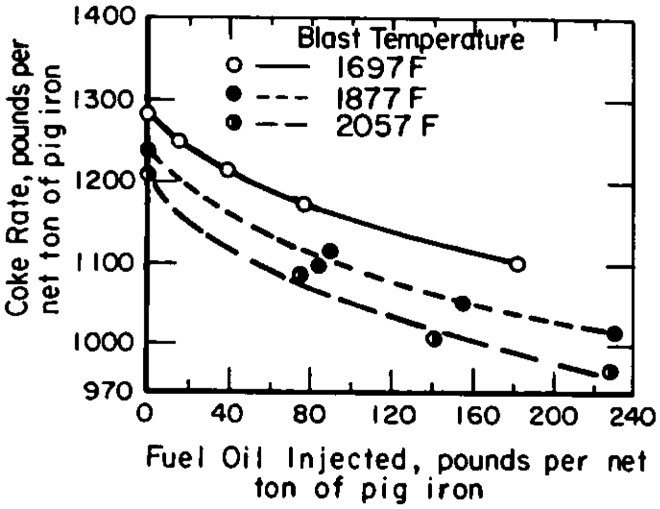

FIGURE A-5. EFFECT OF FUEL-OIL INJECTION AND BLAST TEMPERATURE ON COKE RATE

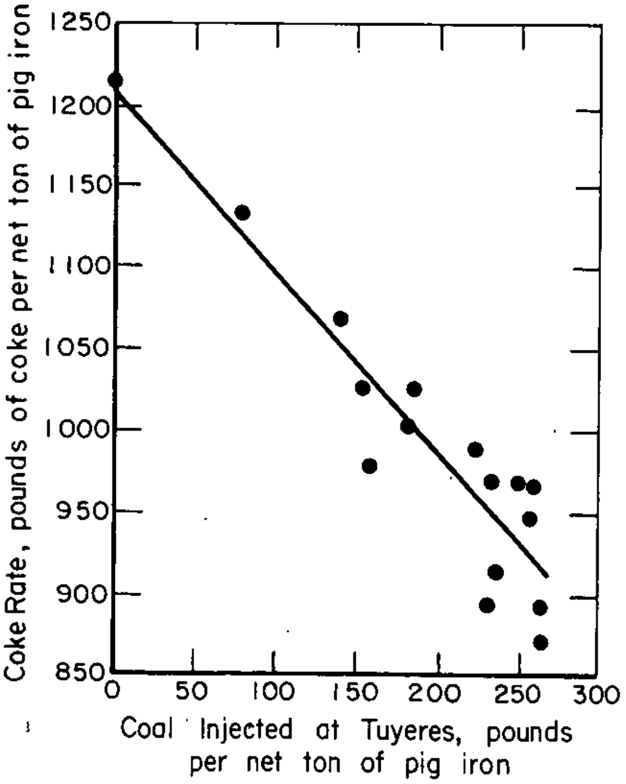

FIGURE A-6. EFFECT OF COAL INJECTED AT THE TUYERES ON COKE RATE

Making Pig Iron

Pig iron has been manufactured in the United States for a great many years in blast furnaces, and this is still the process used to make almost 100 percent of the pig iron. Pig iron from a blast furnace is saturated with about 4 percent carbon. The iron is tapped while molten from the blast furnace and usually is not allowed to solidify before it is delivered to the steelmaking process. The molten iron in steelmaking parlance usually is called "hot metal". Only a small portion of molten iron from blast furnaces is allowed to solidify into "pigs" for distribution in the solid state. The name "pig iron" is generic and includes "hot metal" and "iron pigs". Much research has been directed toward the development of processes that would bypass the blast furnace as an iron producer. The first such direct-reduction process for pig iron is expected to be operational in the United States in 1969 near Mobile, Alabama.

Blast-Furnace Practice. The first step in the conversion of iron ore into steel takes place in the blast furnace. The blast furnace is a large cylindrical structure about 100 feet high, lined with heat-resistant bricks. A blast furnace is shown schematically in Figure A-7. Iron ore, coke, and limestone are charged through sealing "bells" at the top, and heated air under pressure is blown into the lower section through the tuyeres to burn the coke. The air is heated in stoves (described in the section on Air and illustrated in Figure A-4), which typically are 26 to 28 feet in diameter and over 100 feet high. Three or four blast stoves are used per blast furnace, depending on the method of blast heating developed in the various plants. As the solid materials (known collectively as the "burden") pass down the furnace from the top to the bottom, the reducing gases (carbon monoxide and hydrogen) rising through the burden react with oxygen in the ore to start the formation of iron. This reaction continues as the burden materials flow toward the middle of the furnace, at which point the coke acts to take out still more of the oxygen in the ore, and the limestone begins to crumble and react with impurities in the ore and coke to form a molten slag. As the charge enters the zone of fusion, all the materials but the coke become pasty or fused. The iron becomes a porous mass. It then passes through the melting zone and becomes liquid. In this zone the ash from the burned coke is absorbed by the liquid slag, while the iron absorbs silicon from the slag and carbon from the coke.

The iron and slag form a molten mass in the hearth, the slag floating on a pool of iron 4 or 5 feet deep. About every 4 or 5 hours iron and slag are drawn off. The slag is removed more frequently than the iron. From 100 to 300 (or more) tons of iron are drawn off at each time. The hot-metal or ladle cars which receive the iron range in capacity from 40 to 160 tons. The ladle car usually is a special type of tank car that makes it possible to deliver hotter iron to the steel works, even though it may be 20 miles away. Most of the metal produced in the blast furnace is used in molten form for the manufacture of steel in open hearth and other types of steelmaking furnaces.

To produce 1 ton of pig iron requires, on the average, 1.7 tons of iron ore, 0.9 ton of coke, 0.4 ton of limestone, 0.2 ton of sinter, scale, and scrap, and 4.0 to 4.5 tons of air. In addition to the pig iron, the furnace yields about 0.5 ton of slag and about 6 tons of gases per ton of pig iron produced. Air constitutes over one-half of the material entering the furnace, whereas gases constitute more than three-quarters of the materials leaving the furnace. The difference is due to the fact that much of the carbon and oxygen entering as solids, in the coke and ore, respectively, emerge as

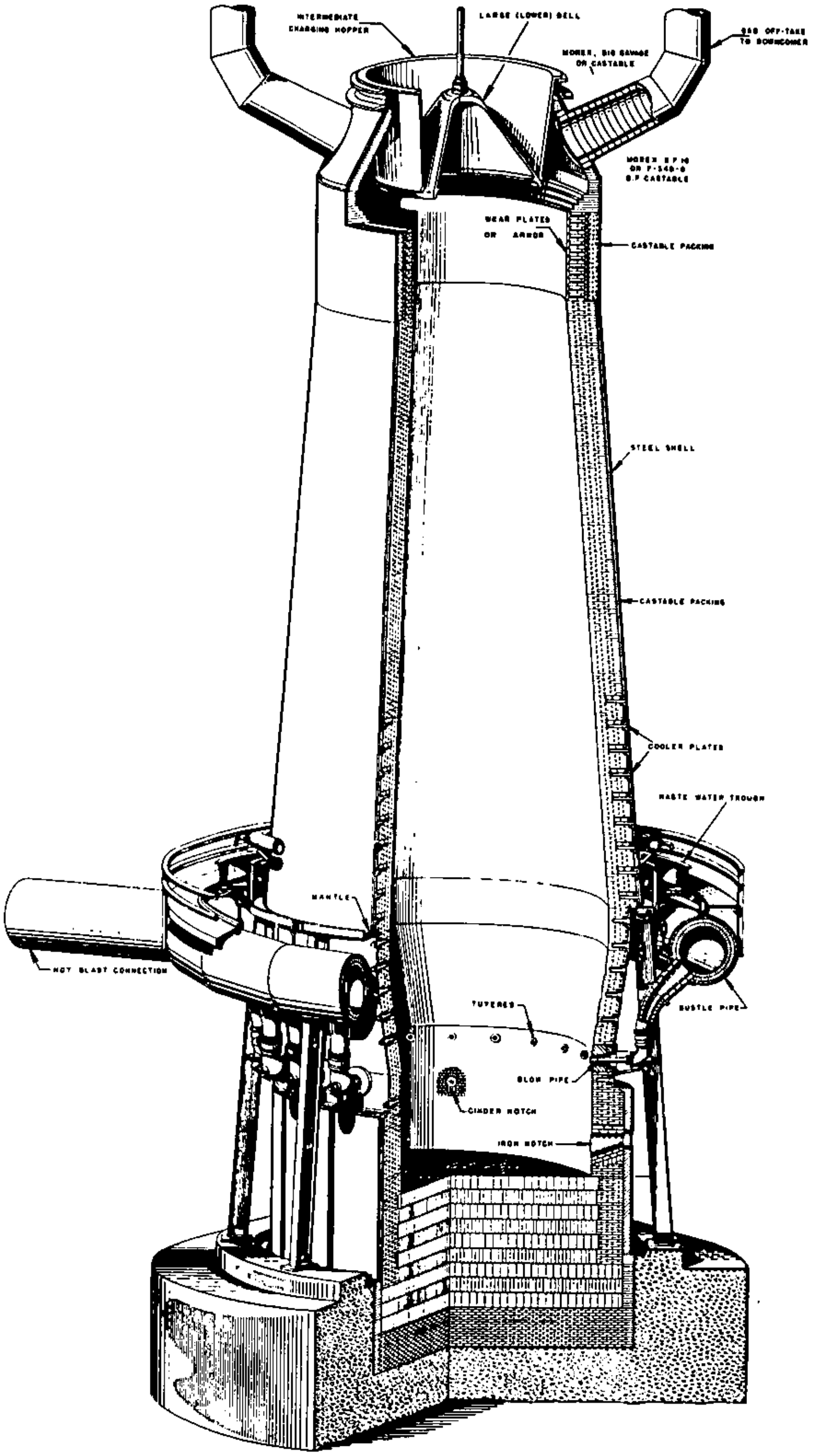

FIGURE A-7. TYPICAL BLAST FURNACE

gases. These gases, piped from the top of the furnace, are rich in carbon monoxide, which can be burned. They are used to heat stoves and generate power. About 30 percent of the gas is required to heat stoves, and the remainder is used for steam generation, underfiring of coke ovens, or heating soaking pits.

Direct Reduction. Processes which bypass the blast furnace as a means of producing pig iron usually make use of much smaller equipment and are not dependent on handling such large quantities of materials as required in blast-furnace plants. The first direct-reduction process to be constructed for commercial production of pig iron in the United States is the Dwight-Lloyd-McWane (D-LM) process. The plant (under construction near Mobile, Alabama) will be very small by steel-industry standards (only about 200,000 tons per year). A typical flow sheet for the process is shown in Figure A-8.

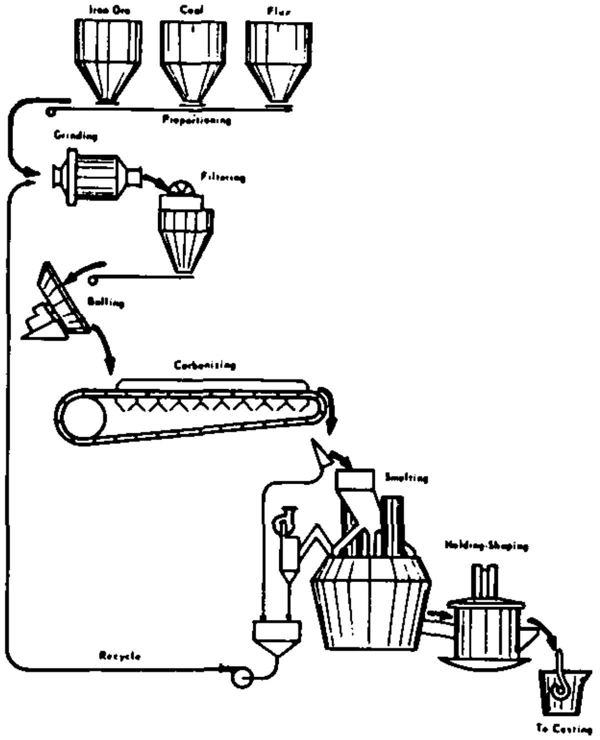

FIGURE A-8. DWIGHT-LLOYD-McWANE DIRECT REDUCTION PROCESS

The D-LM Process makes use of a balling operation to prepare powdered ore, coal, and flux for partial reduction on a sintering machine, after which the partially reduced pellets are charged into an electric smelting furnace where the pellets are further reduced and melted to make pig iron.

Although the D-LM Process is mentioned here by way of illustration, and because it is a "first" for the production of pig iron in the United States by a means other than the blast furnace, this particular process does not have any unique worldwide importance among processes of this general type. For example, by far most of the pig iron that is produced throughout the world by means other than the blast furnace is made in electric smelting furnaces of the Tysland-Hole type; sometimes with some type of preheating or pretreatment of the burden. The largest installations of this type are in Norway and Venezuela where prices of electrical energy are low in comparison to prices for coal. Such processes for pig iron have not yet been adopted in the United States, nor does there seem to be significant pressure to adopt them on a large scale in the near future.

In addition to direct-reduction processes that produce molten pig iron (as discussed in the preceding paragraph), other direct-reduction processes perform the reduction of ore to metallic iron without going through a melting step. Examples include (1) the HyL Process now operational in several plants in Mexico, which uses natural gas as the main source of heat and reductant, and (2) the SL-RN process now being implemented by plant construction in New Zealand and Korea, which uses coal as the main source of heat and reductant. Processes in this category produce "metallized ore" or "sponge iron" (without going through the pig iron stage), and these solid products are then melted and refined in steelmaking furnaces in a manner generally similar to melting and refining of scrap. The first plant of this general type in the United States presently is under construction near Portland, Oregon, using the Midland-Ross "Midrex" process, but as in the case of the D-LM plant, rated output will be small in comparison to even a small blast-furnace plant.

Making Steel

Steel in the United States is made by three major processes, (1) open-hearth practice, (2) basic oxygen (BOF) practice, and (3) electric-furnace practice. At one time, steelmaking in the Bessemer converter was one of the predominate processes used for making steel. By 1948, the production of Bessemer steel in the United States had decreased to about 4.2 million net tons per year. This production decreased further to about 1.4 million net tons by 1958, and by 1967 the total production of Bessemer steel was only 0.3 million net tons. During 1968, Jones and Laughlin Steel Corporation shut down the last Bessemer converters in the United States integrated iron and steel industry. These converters were located at their Aliquippa, Pa., plant. The only Bessemer converter remaining in operation in the United States is located at the A. M. Byers Company, Ambridge, Pa., and is used in the manufacture of wrought iron.[9] Bessemer converters are not considered in this study.

The production of carbon raw steel* from 1954 through 1968 is shown in Figure A-9. The rapid increase in production of carbon steel in basic oxygen furnaces (BOF) and the simultaneous decrease in tonnage made in open hearths is quite evident.

The relationship for the full year 1968 for the major steelmaking processes in the United States was as follows:

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*AISI definition. Raw steel is steel in the first solid state after melting and suitable for further processing or sale and includes ingots, steel castings, and continuous or pressure-cast blooms, billets, slabs, or other product forms.

Process	Production of Raw Steel in 1968 Millions of Net Tons	Percent of Total
Open hearth furnace	66.1	50.4
Basic Oxygen furnace (BOF)	48.6	37.1
Electric furnace	16.4	12.5
Total	131.1	100

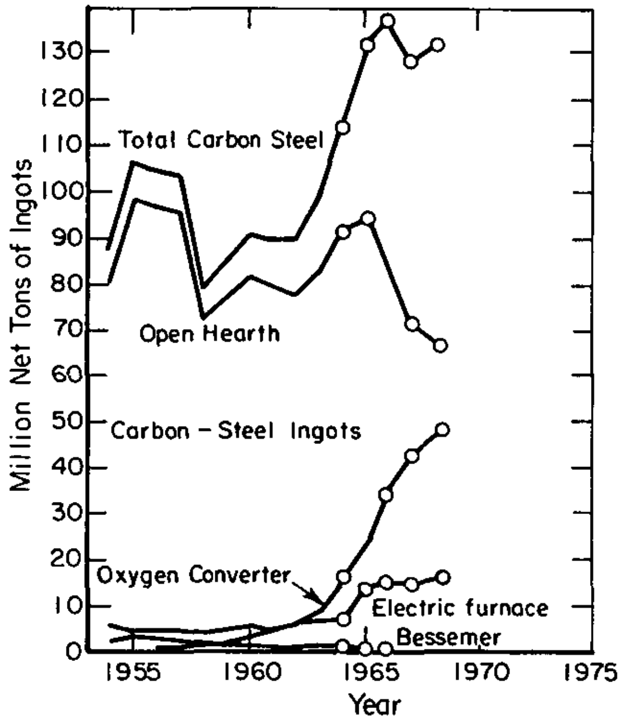


FIGURE A-9. PRODUCTION OF CARBON RAW STEEL IN THE UNITED STATES BY VARIOUS PROCESSES

Open-Hearth Steelmaking. The open hearth furnace at one time accounted for about 90 percent of the steel made in the United States. During recent years, increased use of the basic oxygen furnace and electric furnace has decreased the production of steel in open hearths to about 55 percent of the industry total by early 1968.

Open-hearth steel is made usually from a mixture of scrap and hot metal in varying proportions, depending on relative cost and availability of these two main raw materials. The object of the operation is to lower the impurities present in the scrap and pig iron, which consist of carbon, manganese, silicon, sulfur, and phosphorus, to the limits specified for the particular grade of steel. This refining operation is carried out by means of a slag that forms a continuous layer on the surface of the liquid metal. This slag consists essentially of lime combined with the oxides of silicon, phosphorus, manganese, and iron, which are formed or added during the operation.

Open-hearth furnaces are of two types, depending on the character of the refractory material that forms the basin holding the metal. Where the refractory material is mainly siliceous fireclay or another silica-rich refractory, the furnace is described as "acid", and where the basin is lined with dolomite (or magnesite), it is termed a "basic" furnace. Acid open hearths are used mainly for making steel castings in the foundry industry. Steel in the integrated iron and steel industry is made mostly in basic open hearths.

Open-hearth furnaces in the integrated steel industry are large massive structures. The open-hearth furnace proper consists of a shallow rectangular basin or hearth enclosed by walls and roof, all constructed of refractory brick, and provided with access doors along one wall adjacent to the operating floor, as shown in Figure A-10. A tap hole at the base of the opposite wall above a pit is provided to drain the finished molten steel into ladles. Fuel in the form of oil, coke-oven or natural gas, tar from coke making, or producer gas (a gas rich in carbon monoxide manufactured by blowing a limited quantity of air through a hot bed of solid fuel) is burned at one end. The flame from combustion of the fuel travels the length of the furnace above the charge resting on the hearth. Upon leaving the furnace, the hot gases are conducted in a flue downward to a regenerative chamber called checkerwork or checkers. This mass of refractory brick is systematically laid to provide a large number of passageways for the hot gases. The brick mass absorbs heat, cooling the gases to about 1200 F. All the elements of the combustion system burners, checkerwork, and flues are duplicated at each end of the furnace, which permits frequent and systematic reversal of flow of the flame, flue gases, and preheated air for combustion. A system of valves in the flue effects the gas reversal so that the heat stored in checkers is subsequently given up to a reverse-direction stream of air flowing to the burners. In some plants, the

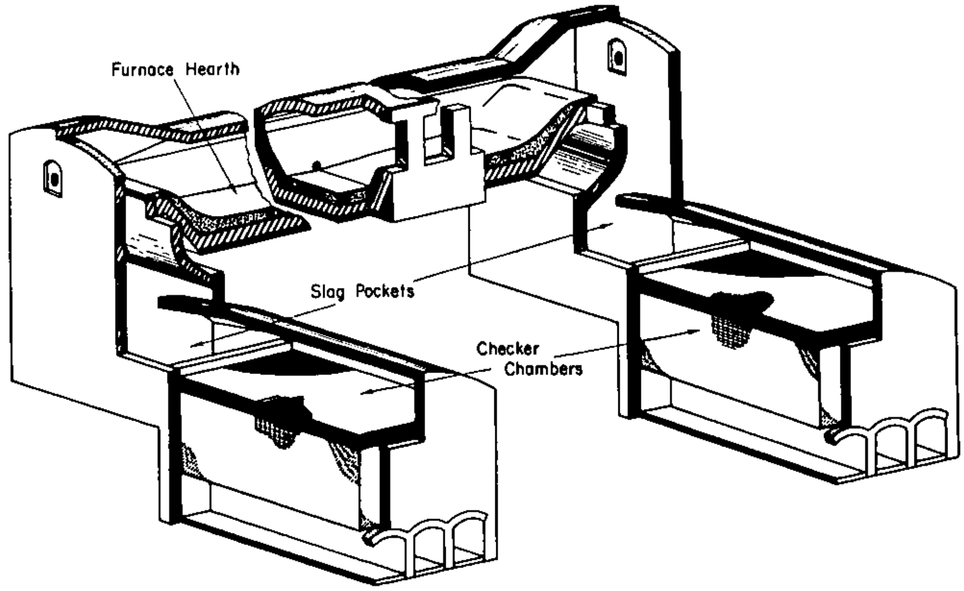


FIGURE A-10. CROSS SECTION OF A BASIC OPEN-HEARTH FURNACE gases leaving the checkerwork pass to a waste-heat boiler for further extraction of heat so as to lower the temperature from around 1200 F to an average of about 500 or 600 F. Open-hearth furnace capacities span a wide range. The median is between 100 and 200 tons per heat (batch of finished steel), but there are many of smaller capacity and an increasing number of larger capacity. Time required to produce a heat is commonly between 8 and 12 hours without the use of large amounts of oxygen.

The open-hearth process consists of several stages: (1) tap to start, (2) charging, (3) meltdown, (4) hot-metal addition, (5) ore and lime boil, (6) working (refining), (7) tapping, and (8) delay. The period between tap and start is spent on normal repairs to the hearth and plugging the tap hole used in the previous heat. During the charging period, the solid raw materials (which usually include a combination of pig iron, iron ore, limestone, scrap iron, and scrap steel) are dumped into the furnace by special charging machines. The melting period begins when the first scrap has been charged. The direction of the flame is reversed every 15 or 20 minutes. When the solid material has melted, a charge of molten pig iron is delivered direct from the blast furnace in large ladles and poured into the open hearth through a spout set temporarily in the furnace door. This is the normal sequence for a "hot-metal" furnace; but for a cold-metal furnace, only solid materials (pig iron and/or steel scrap) are added, usually in two batch charges.

The hot-metal addition is followed by the ore and lime boil, which is a bubbling action much like the boiling of water and is caused by the oxidized gases rising to the surface of the melt. Carbon monoxide is generated by oxidation of carbon and is characterized by a gentle boiling action called "ore boil". When carbon dioxide is released in the calcination of the limestone, the more violent turbulence is called the "lime boil".

The aims of the working period are (1) to lower the phosphorus and sulfur content to levels below the maximum level specified, (2) to eliminate carbon as rapidly as possible and still allow time for proper conditioning of slag and attainment of proper process temperature, and (3) to bring the heat to a condition ready for final deoxidation in the furnace or for tapping. At the end of the working period the furnace is tapped, with the temperature of the steel at approximately 3000 F.

The delay period includes waiting time during the heat cycle (e.g. equipment breakdown, tapping equipment in use on another furnace, etc.) plus repair work not usually done during the tap to start period. For normal operation of a 10-furnace shop as a whole, the following breakdown of the heat stages has been made:

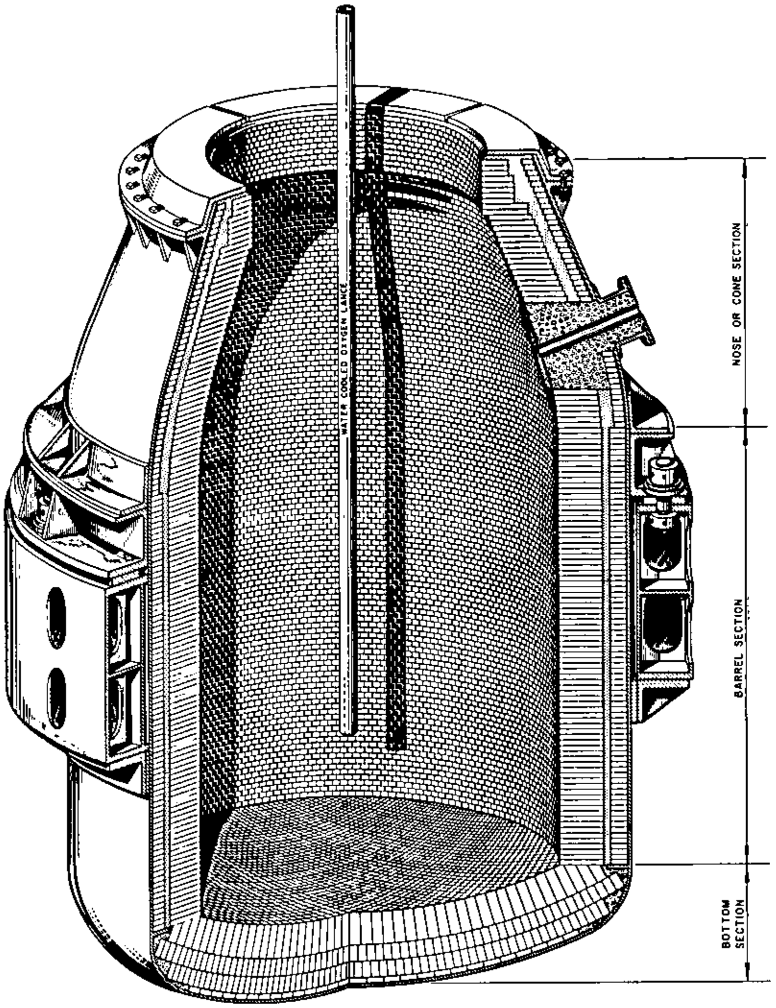
Period	Percent of Time in Indicated Period
Tap to start	6
Charging	12
Meltdown	12
Hot-metal addition	3
Ore and lime boil	38
Working (refining)	19
Tapping	2
Delay	8
	100

The use of consumable lances to inject gaseous oxygen into the bath during the refining period and speed the oxidation reactions, shorten heat time, save fuel, and increase production has become more or less standard practice over the last 10 to 12 years. Since 1957 water-cooled lances inserted through the furnace roof have come into prominent use. Frequently, oxygen lances are used throughout the heat with the exception of the charging and hot-metal-addition periods. By use of high oxygen flow rates from hot metal to tap, production rates of 90 to 100 tons per hour are conceivable in a 300-ton furnace. Oxygen consumption under these conditions ranges from 600 to 1000 cubic feet per ton (900 to 1667 scfm during the period oxygen is being added).

There has been some experimentation with oxy-fuel lances, i.e., the use of oxygen in combination with the fuel. This procedure plus the substitution of burned lime for limestone has increased the steel output of a 200-ton furnace from 20 to approximately 30 tons per hour.

Upright Basic Oxygen (BOF) Steelmaking. A process for refining molten pig iron ("hot metal") to make steel was developed in 1952 in Linz-Donawitz, Austria, in which a top-blown oxygen converter was used to refine the pig iron. Although there are now several variations in practice, the general technique worldwide is known as the "basic oxygen" or BOF process. The furnace is a pear-shaped steel shell lined with refractory brick as shown in Figure A-11. The usual charge for this type of furnace consists of hot metal (molten pig iron), steel scrap and flux. The ratio of hot metal to scrap conventionally is about 70/30. The steel scrap can be replaced with iron ore or prereduced iron pellets. A water-cooled lance is used to supply high-purity oxygen at high velocity to the surface of the metal bath. The high velocity of the oxygen results in impingement on the liquid-metal surface, which in turn produces violent agitation and intimate mixing of the oxygen with the molten iron. Rapid oxidation of the dissolved carbon, silicon, and manganese produces a heat of steel. In the blowing process, some of the iron is oxidized as well and passes off as fume. The BOF process differs from open-hearth practice in that external heat does not have to be supplied to facilitate the refining of the iron. The only sources of heat are (1) the sensible heat from the hot metal, and (2) the heat released by the exothermic reactions between the oxygen and metalloids in the charge (primarily silicon and carbon). In March, 1969, there were 27 steel plants in the United States with BOF installations with a total rated annual capacity of 57 million tons. The 60 existing vessels have capacity ratings from 75 to 325 tons per heat. An additional 19 million tons of annual capacity is under construction or planned for operation through 1970. The time required to make a heat of steel in the BOF is much shorter than in the open hearth. Heat time for a typical 150-ton BOF operation is as follows:

Charge scrap	1 minute
Charge hot metal	2 minutes
Oxygen blow	20 minutes
Chemical tests	5 minutes
Tapping time	5 minutes
Total time	33 minutes



TYPICAL BASIC OXYGEN FCE.
(B.O.F.)

FIGURE A-11. BASIC OXYGEN FURNACE

Rotary Basic-Oxygen Steelmaking. A steelmaking process developed in Sweden makes use of a rotating vessel that is operated in a nearly horizontal position as shown in Figure A-12(10). The process is known as the Stora-Kaldo Oxygen Process. Only one steel plant in the United States has a rotary-oxygen-furnace installation; Sharon Steel Corporation has two Kaldo vessels with a nominal capacity of 150 net tons of steel per heat. Operation of the Kaldo converters is somewhat similar in principle to that for the upright BOF vessels, but there are significant differences that increase heat time over that of the BOF and permit the use of more scrap than in the BOF.

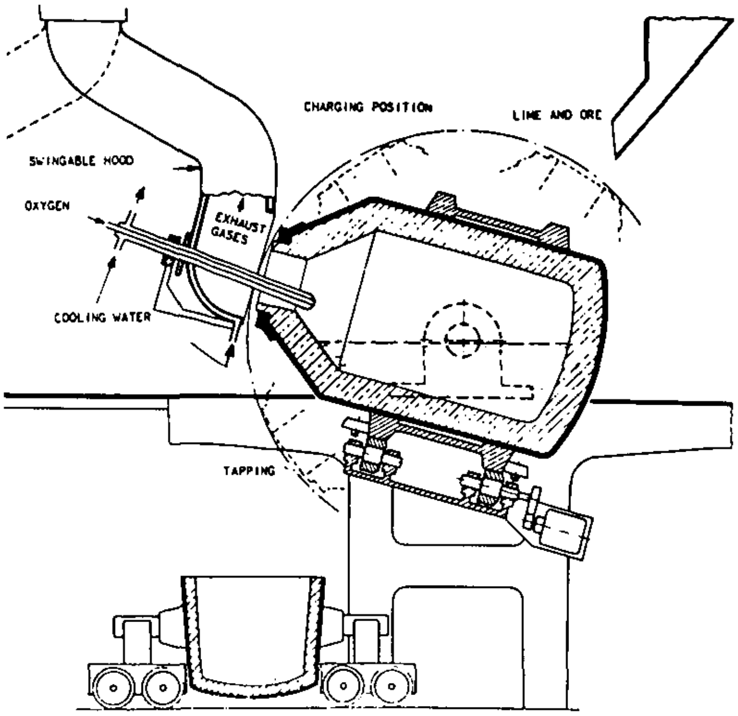


FIGURE A-12. STORA-KALDO ROTARY OXYGEN CONVERTER

Electric-Furnace Steelmaking. Whereas the open-hearth and BOF steelmaking processes conventionally use a charge that contains a high percentage of molten pig iron (hot metal) obtained from blast furnaces, electric steelmaking furnaces conventionally have no hot metal in their charge (although there has been some limited use of hot metal in electric steelmaking furnaces). Generally, electric steelmaking furnaces depend on metallic scrap for most of their charge. Because electric steelmaking furnaces permit a high degree of control over their operations, expecially with regard to ability to hold the steel for long refining periods and to control temperatures to high levels in the furnace, they are generally preferred for the manufacture of alloy and stainless steels. Although electric furnaces account for only about 12 percent of the total raw steel made in the United States in 1967, they accounted for about 36 percent of the alloy and stainless steel. Of the total steel made in electric furnaces in the United States in 1967, about 41 percent was in alloy and stainless grades. Comparable alloy and stainless fractions for the other two major types of furnaces were about 9 percent of open-hearth production and about 6 percent of BOF production.

The furnaces employed in electric-arc melting practices in the integrated steel industry are refractory-lined cylindrical vessels with large graphite electrodes passing through the furnace as shown in Figure A-13. Electric energy is supplied to the electrodes by transformers ranging in capacity from 4,000 to 85,000 kilovolt-amperes.(11, 12) The trend in recent years has been to provide electric-arc furnaces with larger transformers than previously thought feasible. By installing larger transformer capacity, the productivity of a given electric-arc furnace can be doubled. The largest installations to date are a 200-ton direct-arc electric furnace powered by a 76,000-kVA transformer at the Laclede Steel Company, Alton, Illinois(12); four 200-ton furnaces at the

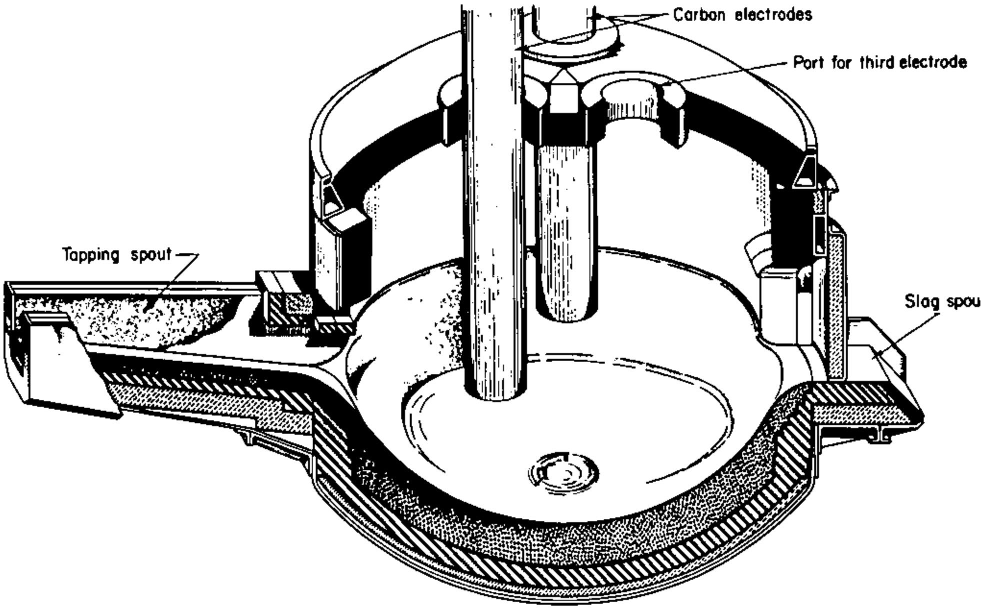


FIGURE A-13. DIRECT-ARC ELECTRIC FURNACE

Republic Steel Corp., Canton, Ohio, plant and a 250-ton furnace at Northwestern Steel and Wire Company which was placed in operation in early 1969. The relationship between melting capacity of direct-arc electric furnaces in the United States and their transformer capacities are shown in Figure A-14.(11, 12)

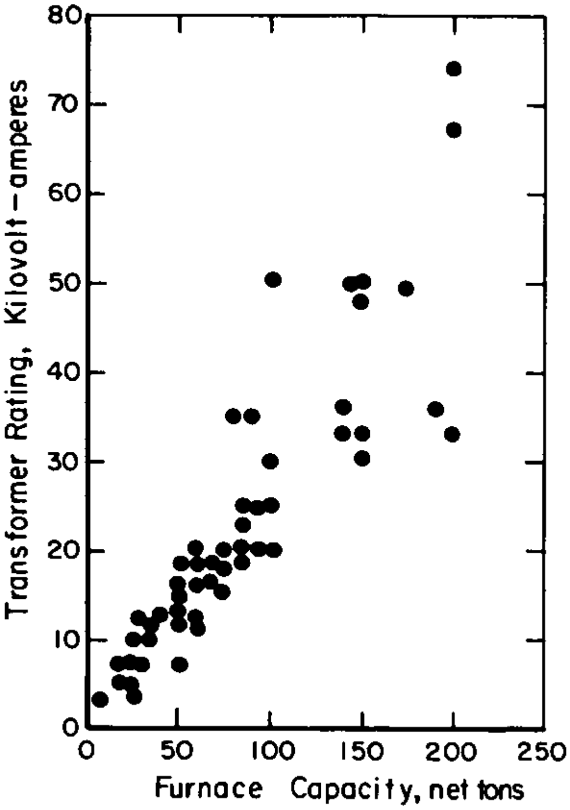


FIGURE A-14. RELATIONSHIP BETWEEN ELECTRIC-ARC FURNACE CAPACITY AND TRANSFORMER RATING

Only basic-lined electric-arc furnaces are used to make steel in the United States integrated iron and steel industry. Some acid-lined electric-arc furnaces are still in use in the United States, but these are used to produce special steels in the foundry industry.

The metallic charge for direct-arc electric-furnace melting of steel usually consists of mostly steel scrap, along with some cast-iron scrap or solid pig iron. Charge preparation consists of the selection of the proper grades of scrap for the steel to be made, and the addition of alloying elements to achieve the desired composition. High-purity gaseous oxygen usually is used today to carry out refining more rapidly than would be done with the older practice of using additions of iron ore as the source of oxygen.

Electric-induction furnaces are used in the integrated iron and steel industry only to melt special alloys and stainless steels on a scale that is very small and scattered when compared with methods for melting high-tonnage steels. Because induction-furnace melting involves no products of combustion, and lacks the high-temperature arc of the steelmaking electric-arc furnace, it is the cleanest method for melting steel. If the scrap placed into an induction furnace is clean, emission from the furnace is minor, with respect to both quantity and density, and is easily collected in simple equipment. Because induction furnaces are used only in specialty situations, the scrap charged to them almost invariably is selected with care as to composition and cleanliness. In those cases where contaminated (e.g., oily) scrap is charged, the scrap usually will emit fume and smoke until the contaminant is burned off. To minimize fume emission during melting in such furnaces, contaminated scrap sometimes is preheated, thus moving the point of evolution of fume from the melting operation back to the preheating operation. In general, however, induction-furnace melting of steel is a miniscule contributor to air-pollution problems.

Scrap Preheating. Preheating of steel scrap for charging into steelmaking furnaces is not a common practice, but when it is done it is accomplished by three techniques: (1) heat exchange by the removal of sensible heat from gases not undergoing combustion as part of the preheating cycle, (2) by the use of air-fuel burners, and (3) by the use of oxy-fuel burners. The use of air-fuel burners is most common. With the use of such burners (as with the employment of noncombustion processes), temperatures attained by the scrap are rarely above 1800 F. At these temperatures, the only appreciable potential for particulate emission from the preheating step rests in the presence of oil, paper, rubber, and other combustibles in the scrap. If the scrap contains such combustibles, a considerable amount of fume can be generated during preheating. In comparison to these first two methods of preheating, oxy-fuel preheating adds additional problems because of the higher temperatures that can be attained during preheating. These higher temperatures extend into and past the melting range of the steel.

A new steelmaking technique developed in the United Kingdom in 1962-63 made use of an oxygen-fuel burner instead of an oxygen lance to achieve melting and refining of low-carbon and low-alloy steels.(13) This fuel-oxygen scrap (FOS) process, has not gained acceptance in the United States, but the idea of fuel-fired burners and oxygen-fuel burners has been adapted to a limited degree in the United States for the preheating of scrap in open-hearth, BOF, and electric steelmaking practices.

Oxygen-fuel burners are used as preheaters to shorten the time required to melt scrap in the steelmaking furnace, and thereby reduce the overall tap-to-tap time in open-hearth practice, and to permit use of greater amounts of scrap in the BOF's. Tap-to-tap times in open hearths have been decreased by 12 percent with a corresponding production increase of 15 percent.(14) Scrap charges in BOF's have been increased from an average of 28 percent of the metal charge to 36 percent of the charge.(15) Republic Steel Corporation, at its Chicago Works, has four open hearths operating with oxygen – natural gas roof burners(16); Inland Steel Company at East Chicago, Indiana, has installed oxygen – natural gas burners in all open hearths of their No. 3 open-hearth shop.(14) Wisconsin Steel Works, Chicago, Illinois, has used oxygen – natural gas burners in their two 120-ton BOF's,(17) and the Pittsburgh Steel Company has used oxygen – oil burners in their 200-ton BOF.(15)

Vacuum Degassing of Molten Steel

In the early 1950's several catastrophic failures of large electric-generator turbine rotors were traced to the presence of hydrogen in the steel. These events were quickly followed by research and development efforts directed toward developing methods of eliminating hydrogen from steel. In the United States, the first vacuum degassing installations were placed into operation in 1956. Steel technologists were not long in finding that vacuum degassing could be used also as a means of deoxidizing steels. The rapid reaction between carbon and oxygen under reduced pressures produces a cleaner product than when oxygen is removed by use of conventional deoxidizing additions such as silicon and aluminum. This carbon-deoxidation technology was rapidly placed into practice by the steel industry, as evidenced by the number of units installed in the years that followed. The number of units installed from 1956 through 1967 is shown in Figure A-15.

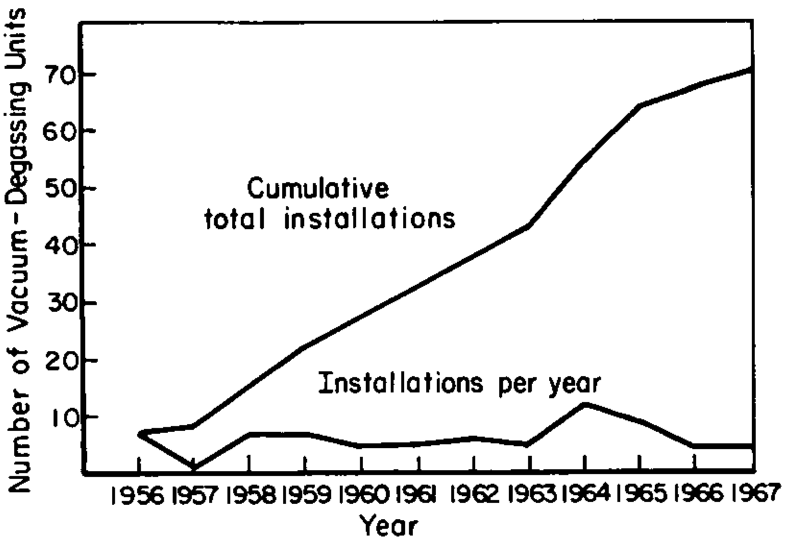


FIGURE A-15. NUMBER OF VACUUM DEGASSING INSTALLATIONS IN THE UNITED STATES

(Source: Battelle compilation.)

Vacuum degassing processes can be divided into three general groups: (1) stream degassing, (2) circulation degassing, and (3) ladle degassing.

Stream Degassing. The stream-degassing process was the first to be placed into operation for the treatment of steel that is cast into large ingots for subsequent forging into rotors for electric generators. In this process the vacuum-treated steel is collected directly in the ingot mold that is inside the vacuum chamber as shown in Figure A-16. If the degassed steel is collected in a ladle that is located inside the vacuum tank, the process (called ladle-stream degassing) is conducted, as illustrated in Figure A-17. The ladle of vacuum-treated steel is removed from the tank and transported to the ingot-pouring area where the steel is then cast into ingot molds. There are other variations that perform the same type of operation by slightly different mechanical means, but the end results are generally the same as for the processes illustrated.

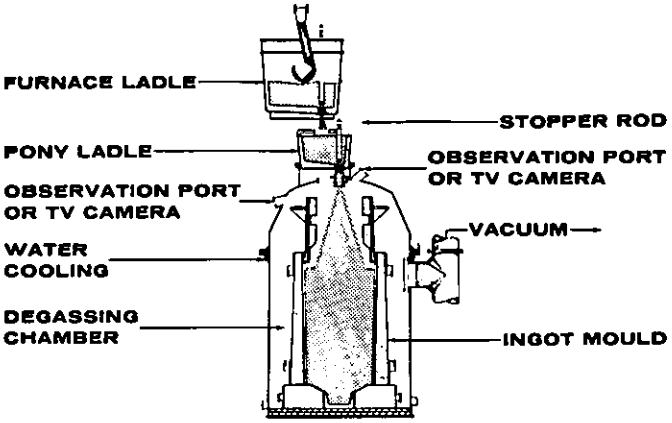


FIGURE A-16. INGOT STREAM DEGASSING

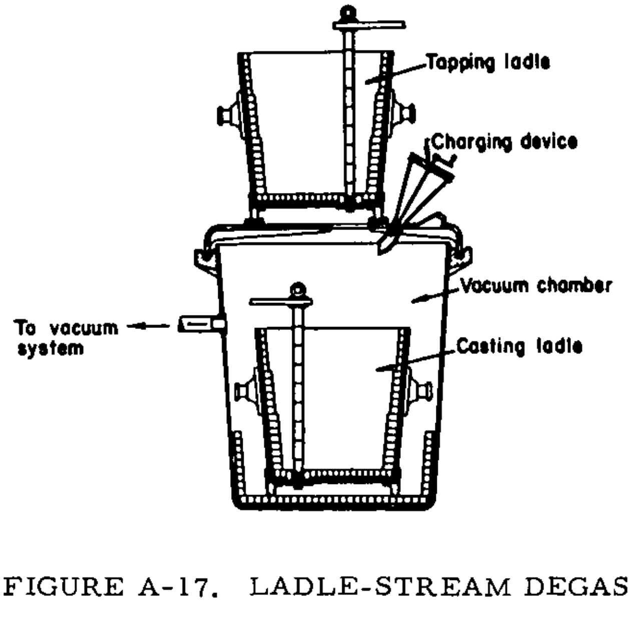
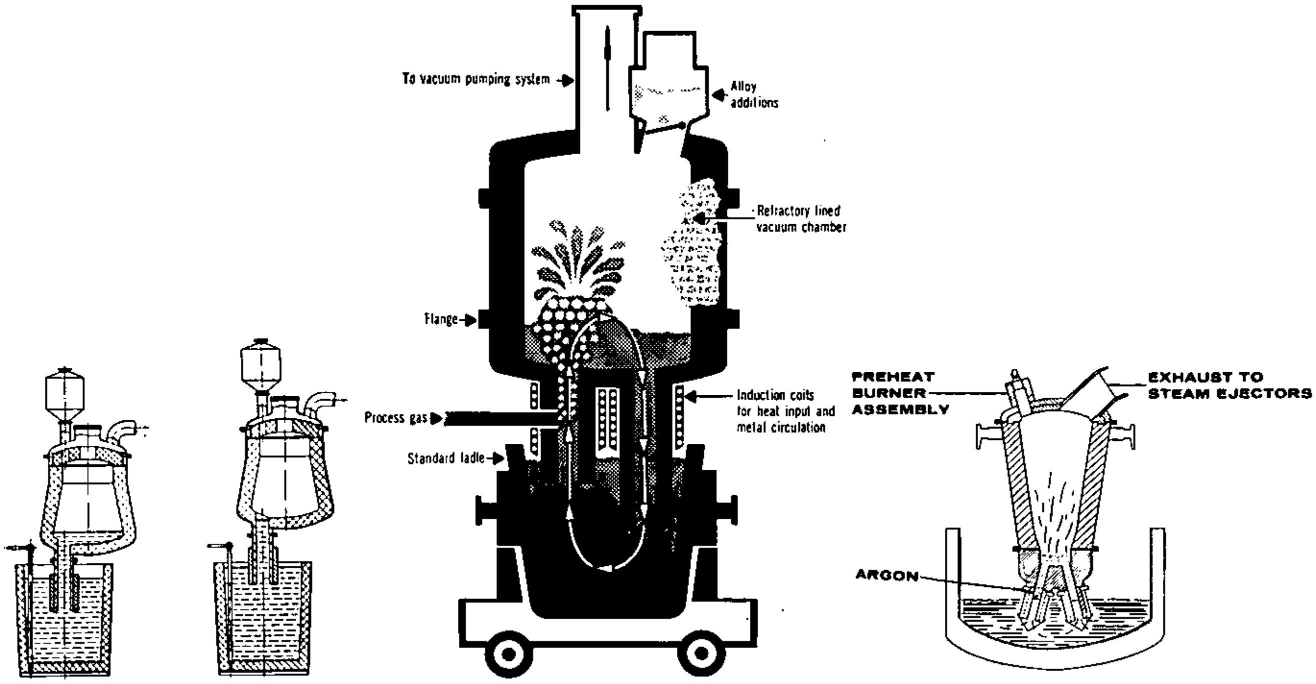


FIGURE A-17. LADLE-STREAM DEGASSING

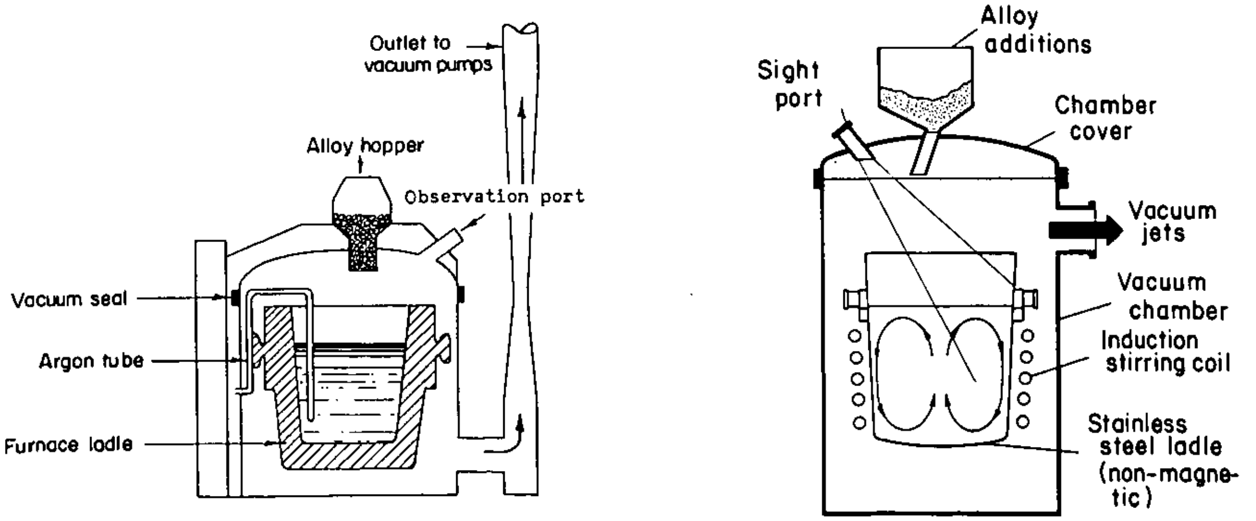
Circulation Degassing. Some steelmaking technologists believed that the treatment time in stream degassing was too short to take full advantage of the potential of vacuum degassing. Several processes were developed to extend the vacuum-degassing cycle and permit a longer treatment time. The circulation processes involve taking a part of the molten steel from the ladle into the vacuum treatment chamber for treatment and then returning the steel to the ladle. The cycle is repeated until the oxygen and hydrogen contents of the steel are reduced to acceptable levels. Representative circulation-degassing processes are shown in Figure A-18.



a. D-H Process b. Thermo-Flow Process c. R-H Process

FIGURE A-18. CIRCULATION-DEGASSING PROCESSES

Ladle Degassing. Ladle-degassing processes provide agitation or stirring the molten steel in the ladle that is positioned in a vacuum tank. One process bubbles argon gas through the steel to agitate the molten metal, and another process stirs the metal by means of an induction coil. These processes are illustrated in Figure A-19.



a. Purge Degassing b. Ladle-Induction Degassing

FIGURE A-19. LADLE-DEGASSING PROCESSES

Manufacture of Semifinished Products

An essential step in the preparation of molten steel for further processing into salable products is the solidification of the molten steel into shapes that can be processed into the desired products. The traditional method has been to pour (teem) the steel into ingot molds, permit the steel to solidify, remove the ingots from the mold, reheat the ingots, and roll them into the desired semifinished products such as billets, blooms, or slabs. In recent years, two new methods have been developed and placed into use by the integrated iron and steel industry. These processes are (1) continuous casting and (2) pressure casting, both of which eliminate much of the processing associated with conventional ingot practice. Conventional ingot practice accounted for about 94 percent of the raw steel produced in the United States in 1967. It is estimated that continuous casting accounted for 5.5 percent and pressure casting 0.5 percent.

The teeming of molten steel into conventional ingot molds at one time was accompanied by much evolution of smoke and fume, primarily because tar and other bitumens were used as mold coatings. During the last decade the use of such coatings has been drastically curtailed, so that visible emission during teeming is less than formerly. However, under some teeming practices, evolution of air contaminants is high enough to restrict visibility at the teeming station. This degree of evolution does not occur in the newer continuous-casting and pressure-casting processes.

Some grades of free-machining steels involve intentional additions of lead or sulfur to the steel shortly before or during teeming. Because of the volatility of these elements at the temperature of molten steel, fuming of the additives represents an emission problem. The tonnage of such steels represents a small fraction of total steel produced nationally, but can be substantial at particular steel plants that make such grades.

Conventional Ingot Practice. Conventional casting and rolling require a large amount of plant area to accommodate the teeming area, soaking pits, and roughing mill. In addition, extensive transport facilities are required to handle ingots and ingot molds. Conventional ingot-casting practice is illustrated in Figure A-20. Molten steel is transported in ladles to the teeming station for pouring of the ingots. Molds are transported to the same area on special cars holding two or three molds to the car. One string of cars holds enough ingots to receive all of the molten steel from the heat. After the teeming operation, the ingots are permitted to solidify in the mold and cool to a selected

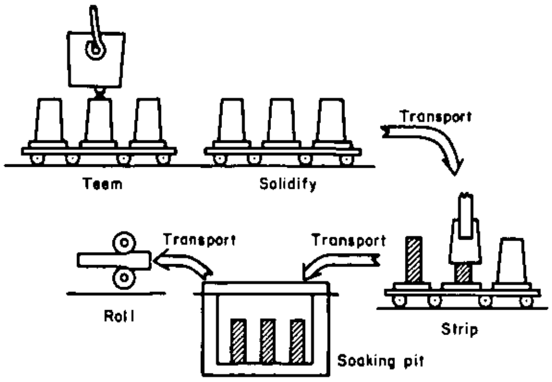


FIGURE A-20. CONVENTIONAL INGOT-CASTING PRACTICE temperature, which is dependent on the type of steel produced. After the proper holding time, the ingots are transported to the stripping station, where the molds are removed. The ingots are then transferred to soaking pits where they are soaked to equalize the temperature throughout the ingot and heated to the desired rolling temperature. The heated ingot is removed from the soaking pit and transported to a roughing mill where it is rolled into billets or blooms, or to a slabbing mill where it is rolled into slabs. Billets, blooms, and slabs differ in size and shape. Billets are usually square and measure 2 x 2 to 5 x 5 inches. Blooms are usually square or slightly oblong and measure 6 x 6 to 12 x 12 inches. Slabs are always oblong and measure 2 to 12 inches thick and 20 to 70 inches wide. Billets are used to produce bar and light merchant products, blooms to make heavier merchant products and structural products, and slabs to make strip, sheet, and plate products.

Continuous Casting. For many years, steel producers recognized that continuous casting was possibly the ultimate method for the conversion of molten steel to semi-finished products. The first United States patent was issued to Sir Henry Bessemer in 1865. There was a period of experimentation on a pilot-plant scale in the United States about 1940. Mechanical and material problems prevented early development of this process, and it was not until 1943 that the first continuous-casting installation was successfully operated in Germany. This was followed by further work in the United States in 1946, Austria in 1947, the United States again in 1949, and Germany in 1950. In the following years the Russian technologists devoted a great amount of effort to the process and succeeded in placing several commercial plants into operation. Efforts in Europe and the United States resulted in commercial installations in the 1950's. The estimated capacity for continuous casting of raw steel in the United States in 1968 was about 7 million net tons. Capacity now under construction is expected to increase this figure to an estimated 14 million net tons in 1969, and 16 million by 1971.

Continuous-casting machines are of three general types: (1) vertical machines, (2) vertical machines with bending rolls, and (3) curved-mold machines. These are illustrated in Figures A-21(18) and A-22(19).

Pressure Casting. Pressure casting is a relatively new method for converting molten steel into semi-finished products. The process was originally developed for the manufacture of cast-steel freight-car wheels. Additional research and development led to application of the process for making cast slabs. The first commercial installations were for the production of stainless steel slabs. Construction on the first plant designed to make plain-carbon-steel slabs was started in 1968 with start-up scheduled for early 1969. Total production of pressure-cast steel in 1967 is estimated to be 500,000 net tons, all of it essentially stainless steel. With the addition of the carbon-steel facility in 1969 this figure should increase to 1 million net tons annually.

The principal parts of a pressure-casting unit are shown schematically in Figure A-23. Operation consists of (1) placing a ladle of molten steel in the pressure tank, (2) covering the tank with a special cover that includes a special preheated ceramic tube, (3) positioning the mold over the tank and pouring tube, (4) introducing air pressure into the tank and forcing the molten steel up the ceramic tube into the mold cavity, (5) sealing the pouring tube with a refractory plug to prevent the flow of the molten steel from the mold back into the ladle, (6) releasing pressure in the tank, and (7) moving the mold from the tank and positioning another mold for another casting cycle. The mold is held

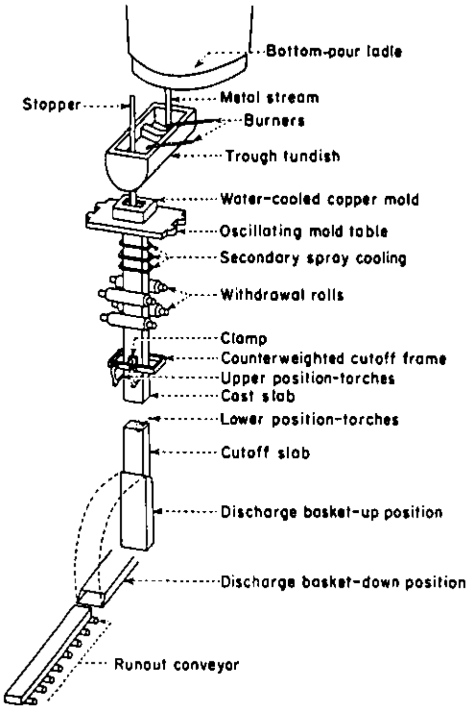


FIGURE A-21. TYPICAL VERTICAL CONTINUOUS-CASTING MACHINE FOR STEEL

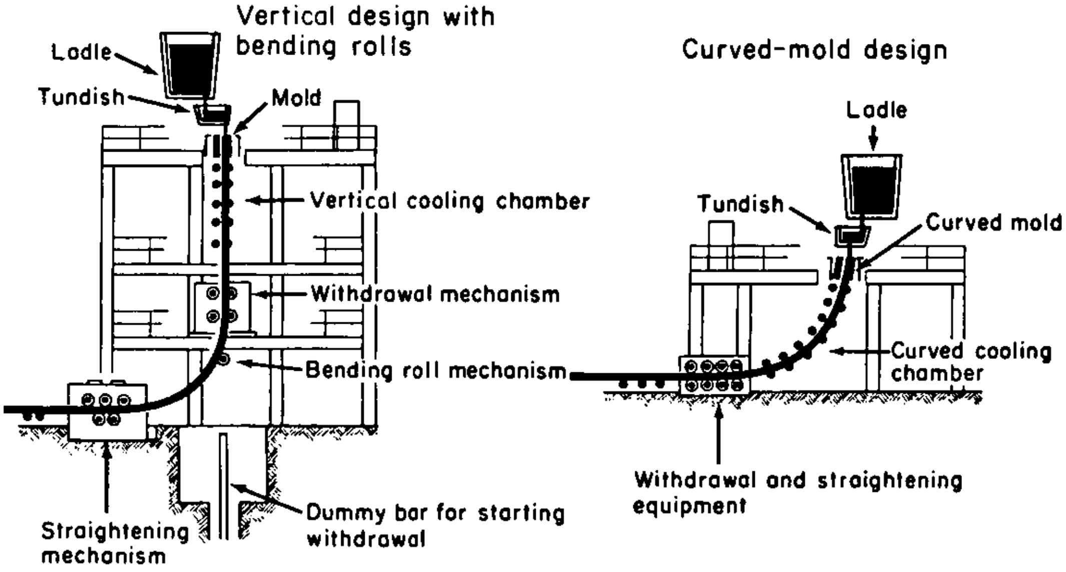


FIGURE A-22. LATER DESIGNS OF CONTINUOUS-CASTING MACHINES FOR STEEL in the closed position until the slab has solidified, after which the mold is opened, the hot slab removed, and the mold prepared for another cycle of casting.

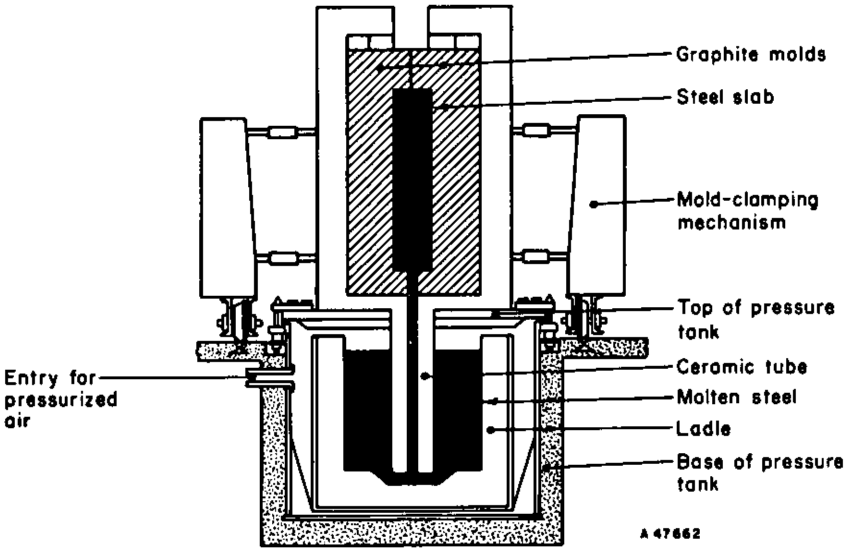


FIGURE A-23. INSTALLATION FOR PRESSURE CASTING A SLAB

Manufacture of Finished Products

Rolling of ingots into billets, blooms, or slabs rarely yields a defect-free product. Consequently, additional work must be done to condition the semifinished products before they are processed further. Conditioning is done by grinding, chipping, or scarfing, depending on the type of steel involved and the kinds of defects that must be removed. Grinding is done with conventional abrasive grinders, chipping with hand-held chipping hammers or special equipment known as "peelers", and scarfing can be done with hand torches, or with automated equipment that has recently become available. Slabs are generally scarfed automatically before they enter the hot-strip mill.

The conditioned billets, blooms, or slabs are reheated to the required rolling temperatures in special furnaces that are fired with fuel gas. After being reheated to the desired temperature, the billets, blooms, or slabs are transferred out of the furnace and transported to the hot mills where the rolling is done.

Billets and blooms are processed into bar, wire products, and structurals of various weights and sizes. Air-borne emissions are not a problem in the production of these products. Iron-oxide scale is formed during the time the semifinished products are reheated for rolling, and is broken off by high-pressure water sprays as the steel enters the first rolling stand of the mill. This scale is collected in scale pits and sent to a reclamation plant for recycling (usually) to the blast furnace or sinter plant.

The processes that are of interest to this project are the surface-treatment operations such as acid-pickling lines, blast descaling, tin lines, galvanizing lines, plastic-coating lines, and other coating operations. These processes are carried out continuously with provision for the supply of steel via a "pay-off" coil at the process input end, and a similar provision for removing the finished, coiled product from the "re-coil" end. A horizontal continuous processing line that is typical of older plants is illustrated in Figure A-24, and the vertical type of processing line that is representative of newer processing lines is illustrated in Figure A-25(20). Equipment designs vary with the process, space available in the steel plant, and preferences of steel-plant personnel.

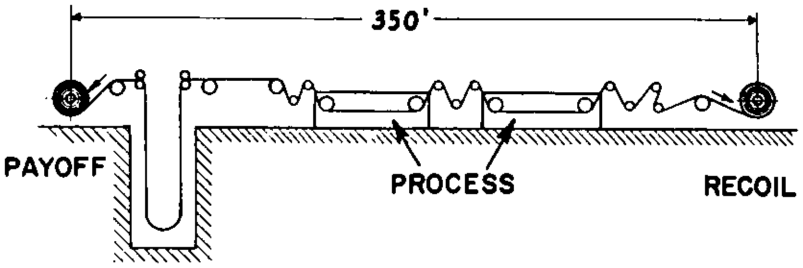


FIGURE A-24. NATURE OF HORIZONTAL PROCESSING LINE

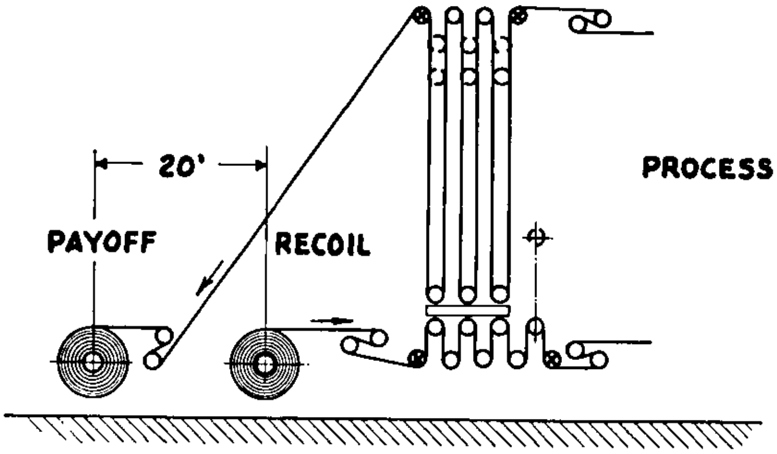


FIGURE A-25. NATURE OF VERTICAL PROCESSING LINE

Auxiliary Operations

Two operations that usually are not considered as process segments in the making or iron and steel, but nevertheless incidental to the manufacture of steel, are the foundries and incineration facilities associated with iron and steel plants.

Foundries. The foundry installations associated with iron and steel plants are primarily used as a means of supplying castings for maintenance purposes, and in this capacity are usually under the management of the maintenance department. In the large majority of steelworks installations, the captive foundries have modest facilities for the melting of nonferrous alloys such as aluminum, brass, and bronze. These facilities are usually well ventilated and their emissions collected. Molten steel or iron required for large castings sometimes is obtained from the existing facilities located at the steel plant. Iron can be obtained directly from the blast furnace. Additions of steel or alloying elements are made to obtain certain metallurgical properties. Molten steel is transported to the foundry for pouring into molds prepared for the purpose. Some steelworks foundries have cupolas or electric furnaces for melting ferrous metals for castings. Two major foundry items required for the production of steel may or may not be made within the steelmaking complex. These are (1) ingot molds required for the transformation of molten steel into a solid product for additional processing, and (2) iron and steel rolls necessary for rolling ingots into finished products.

Most steel companies purchase ingot molds from foundries that are in the business of supplying this specialized item to the steel industry. In some cases, the ingot-mold companies have facilities adjacent to the steel plant and obtain the iron for casting the molds from the steel-plant blast furnaces. If a single steel plant is large enough, or if several steel plants of one company are centrally located, and in the final case, if a steel plant is in an isolated location with respect to available outside ingot-mold sources, the company may have its own in-plant facilities for making ingot molds.

Iron and steel rolls used in the rolling of ingots to semifinished and finished products are continually replaced to maintain desirable quality standards. The manufacture of rolls is a much more specialized operation, technically and process-wise, than the making of ingot molds. Because of this highly specialized requirement, few steel companies make their own rolls, preferring to purchase them from companies specializing in this item.

Incineration Facilities

The making of iron and steel requires the use of many materials that are not a part of the ironmaking and steelmaking processes, but are necessary adjuncts. These materials include (1) wood from pallets used to ship refractory brick into a steel plant, (2) paper or plastic bags used in the shipping, storing, and handling of various required materials, (3) paper scraps that result from the various packaging and shipping operations, and (4) various other solid-waste materials that are generated in the iron and steel plants. Considering the large amounts of such materials that are used, the problem of disposal of solid waste is considerable in the iron and steel industry. Therefore, incineration is commonly practiced in most steelworks.

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APPENDIX B

GENERAL DESCRIPTION OF AIR-POLLUTION CONTROL EQUIPMENT

Many processes involved in the making of iron and steel create particulate and gaseous emissions that result in air-pollution problems of varying degrees. Some of the emissions are nothing more than simple dusts, occurring in rather small amounts, that can be removed by equipment of somewhat simple design. Other particulate emissions are more complicated in character and require more complicated equipment to achieve desired levels of discharge to the atmosphere. Capture of different particulate emissions generated in the making of iron and steel also requires different amounts of energy (and involves different operating costs) to achieve acceptable dust loadings to the atmosphere. One example of typical variations in energy requirements for various exit-dust loadings is shown in Figure B-1.(1)*

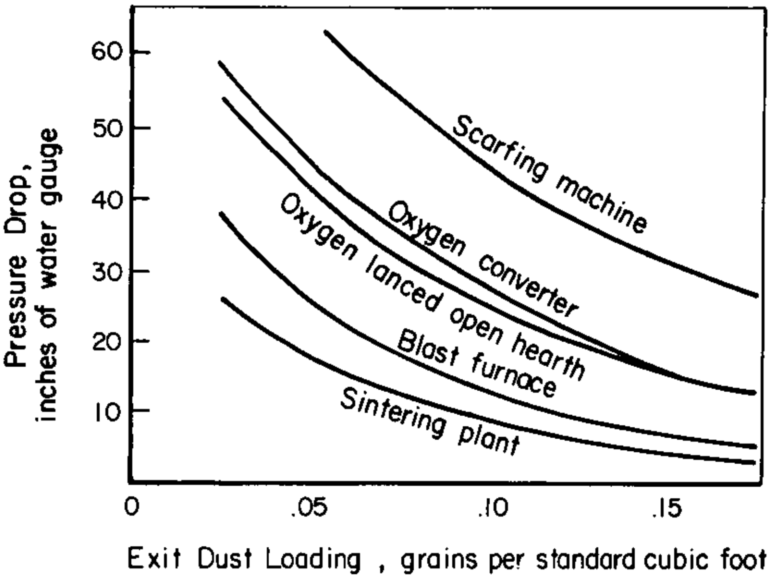

FIGURE B-1. EXAMPLE OF COMPARATIVE ENERGY LEVELS TO MAINTAIN TYPICAL EXIT-DUST LEVELS

In addition to particulate emissions, some processes in the steel industry produce gaseous emissions that require the application of chemical methods if they are to be captured.

One of the outstanding methods for control of emissions, especially for control of gaseous emissions, involves the installation and application of automatic controls on combustion equipment. This method attacks the problem by inhibiting the formation of some undesirable components rather than by collecting them after they are formed.

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*References cited in this appendix are listed at the end of Appendix B.

Although the design and nature of emission-control equipment is vitally important to the effectiveness of collection, the behavior and efficiency of even the best and most suitable equipment in a particular situation is affected drastically by factors such as the age and condition of the equipment, the skill and attitudes of its operators, and the degree of attention given to regular and sufficient maintenance.

Particulate emissions in the integrated iron and steel industry can be classified in three forms(2):

(1) Emissions containing particulate matter in the form of relatively coarse particles, a substantial portion in sizes above 10 microns.* This includes grit from combustion processes, kilns and calciners, grinding and screening operations, and from driers.

(2) Emissions in which the majority of the particles are between 1 micron and 10 microns, and arise from steelmaking processes. The fine airborne particles found in industrial atmospheres are in this size range.

(3) The third size range of emissions includes true fumes, which are predominantly below 1 micron. They may produce industrial haze, either alone, in combination with normal atmospheric fogs, or after interaction with other contaminants in the atmosphere. Typical of these are fumes from oxygen-blown open hearths, electric-arc furnaces, and basic-oxgyen (BOF) furnaces.

Equipment that can be used to control air pollution in the integrated iron and steel industry can be classified into four general groups which are: (1) cyclone dust collectors, (2) electrostatic precipitators, (3) bag filters, and (4) wet scrubbers, including spray scrubbers.(2,3)

Cyclone Dust Collectors

The principle of operation of cyclone separators is the imposition of a centrifugal acceleration on gas-borne particles. This is usually achieved by admitting the dust-laden gas tangentially to the periphery of a cylindrical vessel, resulting in a spiraling flow pattern that causes the solid particles to be thrown outwards to the wall of the vessel, where they fall to a conical discharge pipe. The clean-gas exit is located on the axis of the vessel. The configuration and relative size of the gas inlet and outlet pipes is governed by the required characteristics of the unit. High-throughput units differ from high-efficiency units by having larger inlet and exit areas for a vessel of a given diameter. High-efficiency and high-throughput cyclones are illustrated in Figure B-2. In theory, small-diameter cyclones will have an efficiency** superior to larger units of similar proportions. High throughput combined with high efficiency is sometimes achieved by nesting a number of small cyclones into a single unit as shown in Figure B-3. However, there is a hazard that units containing small nested cyclones can develop poor performance characteristics because of blocking of the small solids-discharge pipes, which results in uneven distribution of gas.

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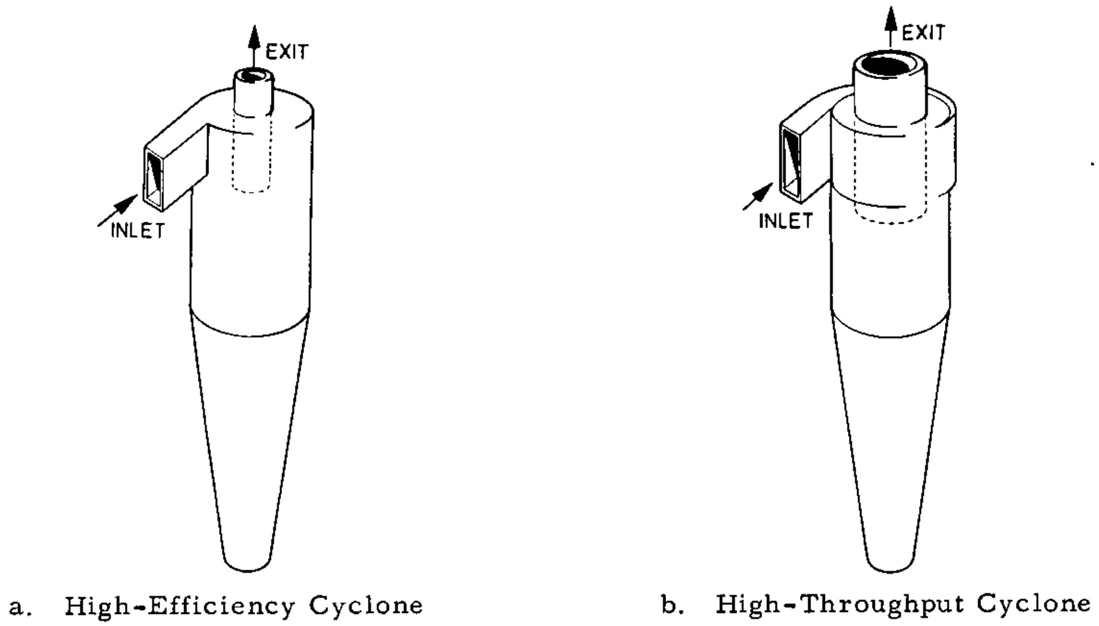
* 1 micron = 0.001 mm.

** Efficiency refers to the amount of particulate matter removed by the control system, expressed as a percentage of the amount of particulate matter in the entering gas.



a. High-Efficiency Cyclone b. High-Throughput Cyclone

FIGURE B-2. TYPICAL CYCLONE CONFIGURATIONS

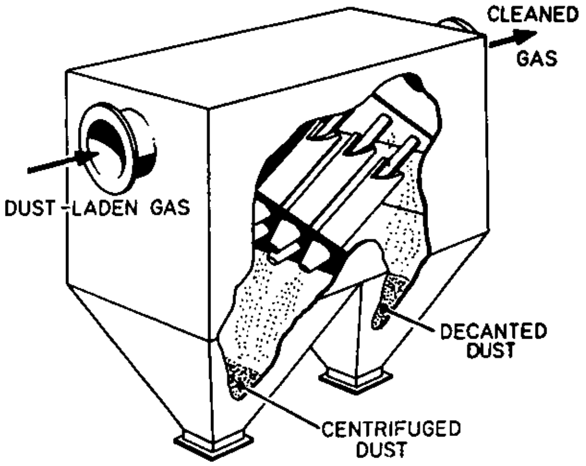


FIGURE B-3. NESTED TUBULAR CYCLONES

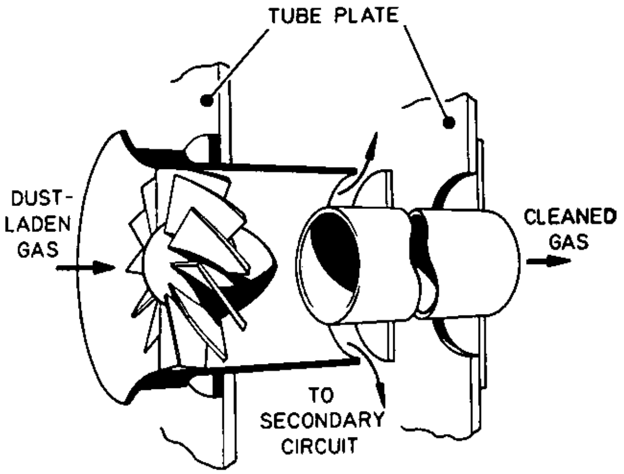


FIGURE B-4. CELLULAR CYCLONE

The efficiency of a cyclone can be increased by introducing water into the system. This is usually done with a ring main located just below the top cover plate of the cyclone.

Medium-efficiency cyclones (such as the cellular cyclone illustrated in Figure B-4) are sometimes used to reduce the load on subsequent dust-removal equipment. Swirling action is induced by passing the gas through pitched vanes.

Electrostatic Precipitators

The action of electrostatic precipitators is based on the passage of a dust-laden gas through an intense electrostatic field between electrodes of opposite polarity. The particles take up an electrical charge from the discharge electrodes, and are accelerated towards the grounded electrodes or collector plates, which are at opposite polarity. The dust particles give up their charge and are deposited as a layer on the collector plates. The layers of dust are usually removed from the collector plates by periodic rapping that causes the dust to fall into two collecting hoppers.

Two general types of electrodes are in general use: (1) the wire-in-tube system as shown in Figure B-5, and (2) the wire-and-plate type shown in Figure B-6. There are many refinements of electrode configuration employed by equipment manufacturers. A schematic illustration of a full-size wire-and-plate electrostatic precipitator is shown in Figure B-7.

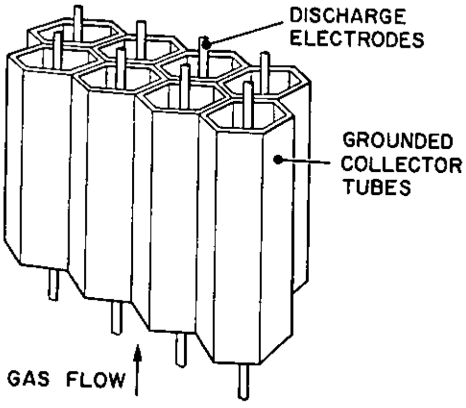


FIGURE B-5. WIRE-IN-TUBE ELECTROSTATIC PRECIPITATOR

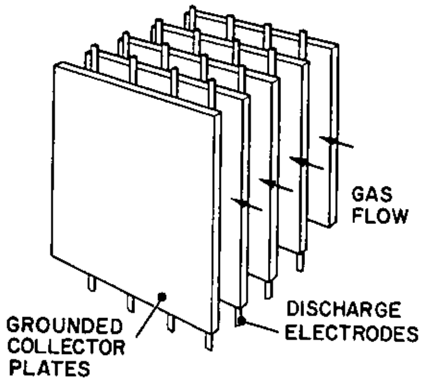


FIGURE B-6. WIRE-AND-PLATE ELECTROSTATIC PRECIPITATOR

When designing electrostatic precipitators, a great deal of attention must be paid to the quantities of dust that must be handled, and large-scale pilot-tests are often required to obtain accurate assessment of precipitator performance. Lack of attention to such items as the resistivity and stickiness of dusts has led to serious malfunctioning of precipitator installations, because of excessive buildup of the voltage gradient across the collected dust. This results in local areas of intense electrical discharge and leads to the effect known as "back ionization". This back ionization results in current requirements in excess of the capacity of the electrical equipment, which causes a drop in voltage and results in poor collection efficiency.

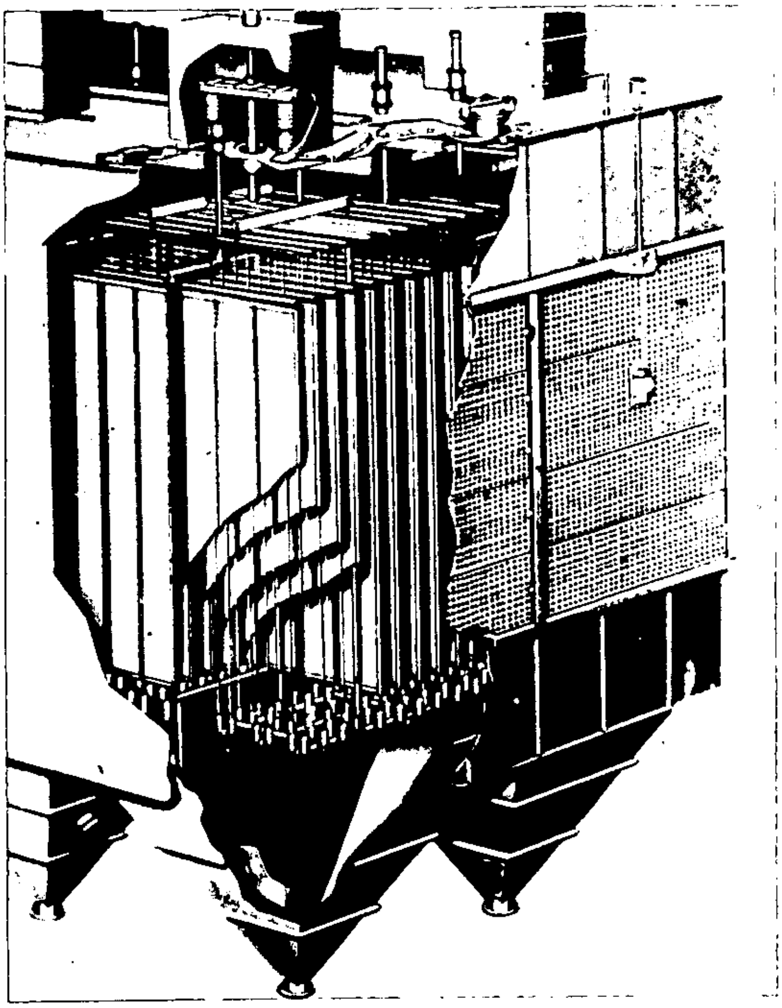


FIGURE B-7. INTERNAL CONSTRUCTION OF WIRE-AND-PLATE ELECTROSTATIC PRECIPITATOR

Bag Filters

The filter cloth of bag filters consists of threads about 500 microns in diameter which are spaced 100 to 200 microns apart, thereby forming a sieve with large openings. However, the openings are criss-crossed by fine fibers about 5 to 10 microns in diameter, which are the individual fabric fibers. The fine fibers form effective impingement targets and can remove a high portion of submicron particles.(4) A diagram of a typical filter fabric is illustrated in Figure B-8.

During the passage of a dusty gas through the fabric, particles will impinge upon, and be retained by, these fine fibers and cause a buildup of a layer of solid material on the fabric. If the gas velocity through the fabric is low enough, this solid accumulation will be in the form of a loose floc that will effectively trap even submicron-sized particles. The progressive accumulation of solid material on the fabric eventually leads to an excessively high pressure drop in the system, or to a local breakdown of the filter bed (i.e., the accumulated dust). The necessity for the periodic cleaning of the filter fabric results in a tendency for the efficiency to vary in a cycle-like manner, as the floc filter bed progressively builds up, and then cyclically is removed. The operation of multiple-bag units enables collection efficiency approaching 100 percent to be obtained. Care must be taken not to cool the entering gases to below their dew point. The condensation of moisture on the bags leads to rapid blinding of the fabric and usually forces shutting down the unit for cleaning.

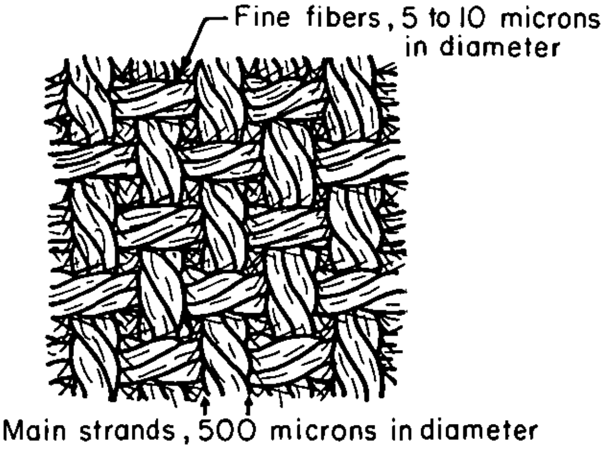


FIGURE B-8. DIAGRAM OF A TYPICAL FILTER FABRIC

Bag-filter fabrics must have properties that will permit them to operate in various atmospheres and at various temperatures. Operating atmospheres and temperature limitations for some representative bag-house fabrics are listed in Table B-1(5). The service life of fiberglass bags has been extended somewhat by treating the fabric with silicone compounds.

TABLE B-1. OPERATING CONDITIONS FOR TYPICAL BAGHOUSE FABRICS

Fabric	General Use	Maximum Temperature, F
Cotton	Noncorrosive or mildly alkaline dusts and gases	180
Wool	Mildly acid conditions	200-215
Nylon	Alkaline dusts or gases unsuitable for acid conditions	200-215
Dynel	More acid-resistant than wool or Orlon	200-215
Orlon	Widely used for corrosive gases	250-275
Terylene	Widely used for corrosive gases	275-300
Fiberglass	Resistant to most gases except hydrogen fluoride	500-650

Bag filters are capable of handling gases with medium to high dust concentrations. Three general types of bag filters are generally used: (1) low-velocity filters, (2) (2) shaker-type bag filters, and (3) the reverse-jet filters.

Low-Velocity Bag Filter

This type of bag filter consists of multiple fabric bags suspended vertically in a box housing as shown in Figure B-9. A relatively simple bag-shaking gear is used. A major disadvantage of the low-velocity bag filter is that, to prevent blinding of the fabric, gas velocities are low (about 3 feet per minute). Higher velocities tend to drive particles into the fabric making it difficult to remove the dust by simple shaking.

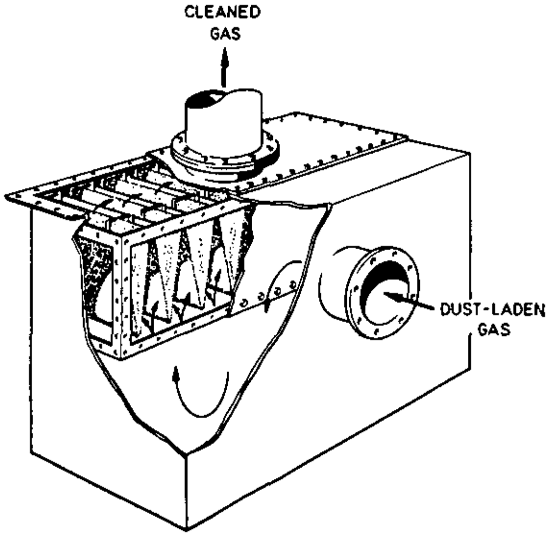


FIGURE B-9. LOW-VELOCITY BAG FILTER

Shaker-Type Bag Filter

The shaker-type filter is similar in configuration to the low-velocity bag filter except that it is equipped with an automatic rapping gear which may be actuated on a predetermined cycle, or on reaching a certain pressure drop across the filter. The shaker-type filter typically is able to tolerate a face velocity of about 6 feet per minute when dust loadings are low because of the more efficient method of bag cleaning. The more common face velocities for bag collectors used in the steel industry are 3 feet per minute or less. The shaker-type bag filter is illustrated in Figure B-10.

Reverse-Jet Filter

In order for normal bag filters to operate at high efficiency, it is necessary to provide large areas for filtration and avoid frequent cleaning, which in turn limits the maximum dust concentrations that can be handled. The reverse-jet filter has design and operating characteristics intended to overcome these limitations of normal bag filters. These characteristics of reverse-jet filters are as follows:

(1) A felt of compressed wool is used as the filter fabric and has a sufficiently close texture that it can act as an effective filter without the requirement that a floc must build up to aid in dust-retention capability.

(2) The deposited dust is removed by a reverse current of air from an external blow ring which traverses the length of the bag, usually continuously. The construction of a typical reverse-jet filter is illustrated in Figure B-11.

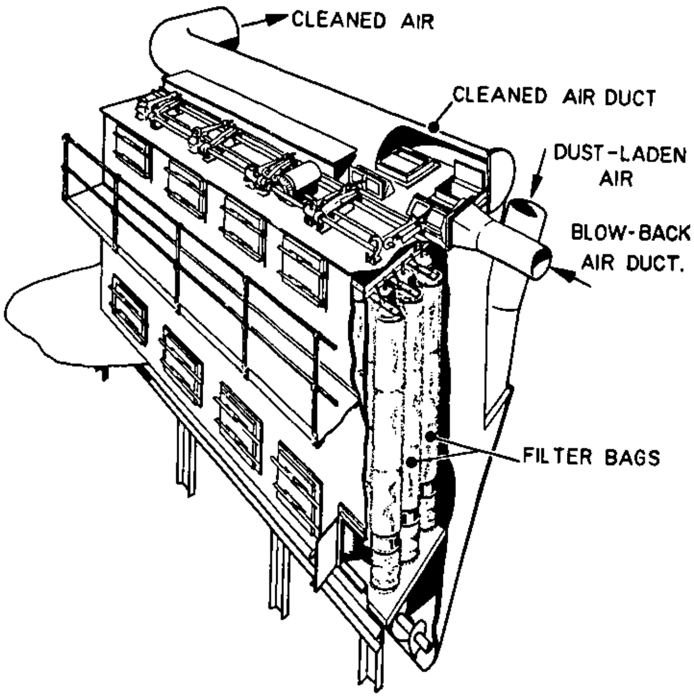


FIGURE B-10. SHAKER-TYPE BAG FILTER

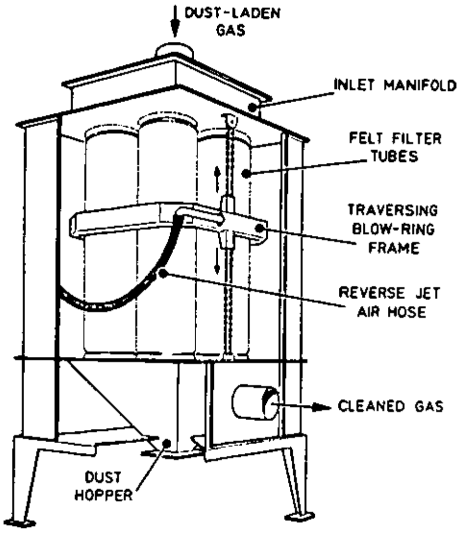


FIGURE B-11. REVERSE-JET BAG FILTER

Limitations on operating velocities are less than for normal bag filters, because the requirement for deposited dust to improve efficiency is eliminated. Face velocities of 10 feet per minute are common, and in some cases the face velocities can be as high as 15 to 20 feet per minute. Efficiencies are close to 100 percent for particles down to about 1 micron in size.

A modification that has been developed is called a "pulse-jet filter". Bag-cleaning is achieved by blowing strong jets of air into the bags from the "clean" side of the fabric, thus causing a reversal in air flow and agitation of the bags. The bags may be cleaned in sequence so as to maintain consistent collection efficiency. However, difficulty may be encountered in the removal of material from the fabric, and a progressive buildup of dust may result in an increased pressure drop in the system and a requirement for periodic removal of bags for cleaning.

Wet Scrubbers

Wet scrubbers can be divided into two categories, (1) wet-impingement scrubbers and (2) spray scrubbers. The principle of operation in these scrubbers is that when dust-laden gas impinges on a liquid body, the gas will be deflected around or away from the liquid body, but the dust particles (having greater inertia) will tend to collide with the surface of the liquid and be subject to a retaining force.

Wet-Impingement Scrubbers

Wet-impingement scrubbers are dependent on a layer of water as the entraining medium for dust particles. Irrigated-target scrubbers, orifice-plate scrubbers, and disintegrators fall in this category.

Irrigated-Target Scrubbers. This scrubber functions by passing a gas upward through a flooded perforated plate so that the liquid on the top of the plate is atomized at the edges of the orifices. This atomization creates a dust-trapping spray directed at targets located above the orifices, as illustrated in Figure B-12. An important feature of this design is its apparent freedom from choking of the holes in the orifice plate. Scrubbers of this type may incorporate several orifice plates in series, two or three being usual. Each plate imposes a pressure drop of about 3 inches of water gage.

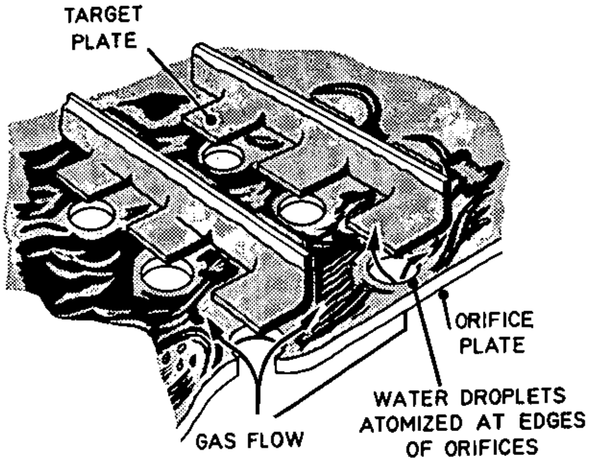


FIGURE B-12. IRRIGATED-TARGET SCRUBBER

Orifice-Plate Scrubbers. Scrubbers of this type operate on essentially the same principle as the irrigated-target scrubber, except for the omission of the target above each orifice. Scrubbers of this type have been used in the cleaning of blast-furnace gas.(6)

Disintegrators. Disintegrator scrubbers have found use in the past in cleaning blast-furnace gases.(7) In scrubbers in which a spray is generated, the energy required to atomize the liquid is obtained at the expense of a pressure drop or by pumping the liquid through nozzles. Because the collection efficiency increases with the increased relative velocity between the liquid droplet and particle, higher efficiencies are attained by increasing the energy input to the system. In the case of the disintegrator, this increased energy is obtained by passing both the dirty gas and the scrubbing liquid into the intermeshing vanes of a stator and high-speed rotor as shown in Figure B-13. Disintegrators are relatively inexpensive when their high performance is considered. However, their energy and water consumptions are high.

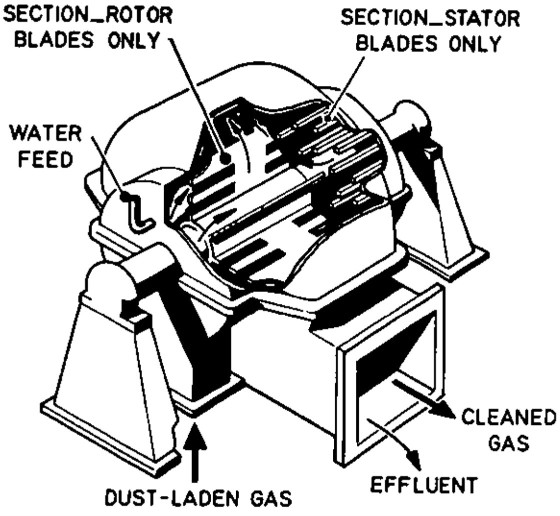


FIGURE B-13. DISINTEGRATOR

Spray Scrubbers

Spray scrubbers are those in which the scrubbing liquid is broken into a spray to form a large number of collection sites. The efficiency of spray scrubbers is improved by increasing the relative velocity between the spray droplets and dust particles, thus raising the collision rate between particles and droplets. Spray towers, venturi scrubbers, and flooded-disk scrubbers fall into this class.

Spray Towers. The spray tower (as illustrated in Figure B-14) has become somewhat obsolete because of its relatively high cost. However, where the structures exist as a part of original blast-furnace installation, the spray towers sometimes are used as precoolers for the large quantities of gas involved. Spray towers have the advantage that no very close clearances are involved, and as a result, the unit can handle relatively high dust concentrations without suffering from choking problems. In addition, because very fine spray is not involved, the spray generators do not require fine jets and reliability is improved. Also, the spray water often can be recirculated until it contains quite a high concentration of solids.

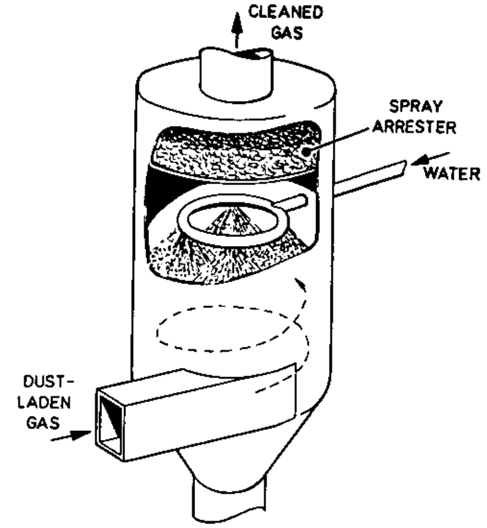


FIGURE B-14. SPRAY TOWER

Venturi Scrubbers. Venturi scrubbers are characterized by their high collection efficiency over a large range of particle sizes and their correspondingly high pressure drop.

Water is admitted from jets to the throat of a constriction in the duct carrying the dusty gas. The high gas velocity atomizes the water, and the rapid acceleration of the droplets of water leads to a very high particle-droplet collision rate. From the venturi, the gas is then passed to a cyclone where the agglomerated particles that are now relatively large can be separated easily. A simple venturi scrubber is illustrated in Figure B-15. Optimizing of the performance of high-energy scrubbers (such as venturi scrubbers) is important, because the power consumption of such scrubbers can be quite high. Optimizing of venturi-scrubber performance has led to the development of scrubbers whose pressure drop and performance can be controlled while the scrubber is operating, either to deal with varying gas rates or to maintain a given efficiency during a particular period of operation. A variable-throat venturi scrubber that operates in this manner is illustrated in Figure B-16. A scrubber of this type can be operated for short periods of time when the process requirements demand it, at a pressure drop that would be impractical or uneconomical for continuous operation.

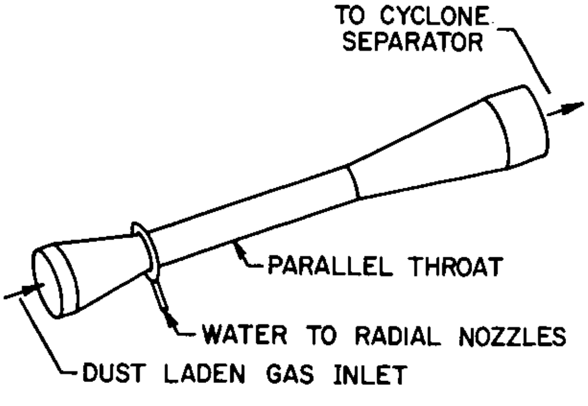


FIGURE B-15. VENTURI SCRUBBER

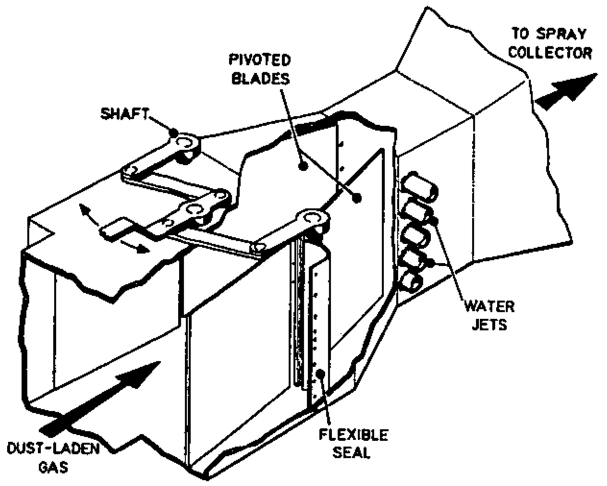


FIGURE B-16. VARIABLE-THROAT VENTURI SCRUBBER

Another modification of a venturi scrubber is shown in Figure B-17. Fine nozzles and jets are omitted, and slurries can be used as the cleaning medium. The liquid flows down the sides of the scrubber toward the venturi throat where it cascades and forms an atomized spray to perform the entrapping function on the particles.

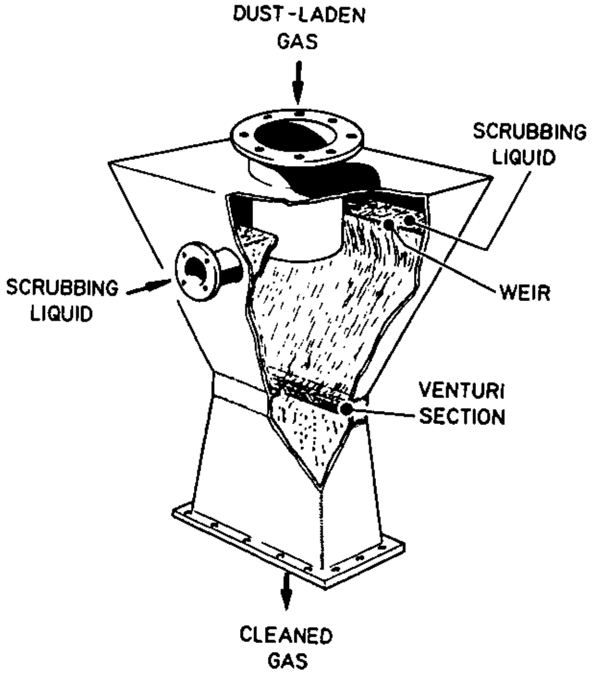


FIGURE B-17. VENTURI SCRUBBER USING SLURRIES

Flooded-Disk Scrubber. In the flooded-disk scrubber, an atomized spray is obtained by positioning a rotating disk in the path of a dusty gas and flooding the surface of the disk with water, as shown in Figure B-18. An atomized spray generated in this way has good particle-collection characteristics. Also it is possible to vary the position of the disk in the tapered throat and allow for fluctuations in gas throughput.

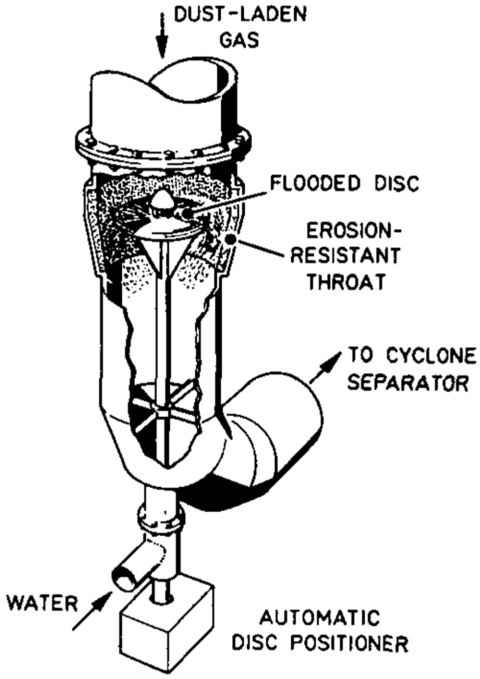


FIGURE B-18. FLOODED-DISK SCRUBBER

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