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AIR POLLUTION PROBLEMS *of the* STEEL INDUSTRY

Informative Report

Technical Committee TI-6

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Section II—Smoke in coke oven operation

Coke for smelting of iron ore in the blast furnace must meet particular specifications as to its physical qualities and composition and is especially produced in the coke oven plant from carefully selected types of bituminous coal.

The wasteful and outmoded beehive coke oven which is operated occasionally in some districts during periods of high demand for metallurgical coke, as in time of war, produces excessive amounts of smoke. Because of the inherent nature of this equipment such smoke cannot be reduced. The only measure of control, therefore, is in restrictions respecting location of such ovens in relation to built-up communities. The remainder of this discussion is confined to the modern by-product coke oven.

The selected coals are sized by crushing and pulverizing, blended according to formula, and transported to coal storage bins above the coke ovens. Measured quantities of the coal blend are removed from these bins into a larry car which runs on a track running along the top of the coke oven battery.

The larry car then moves to an empty oven and its measured contents discharged into the oven interior.

During the coking cycle, volatile gases released from the coal charged are conducted through a system of pipes to the by-product plant where, in a series of processes, constituents of value are recovered from the raw gases and the final, stripped coke-oven gas piped to some other equipment and burned as fuel.

At the end of the coking cycle, the coke formed in this carbonizing process is discharged from the oven into a quenching car whence it is transported to the quenching station where the incandescent mass is quenched with a very large quantity of water.

Subsequently the quenched coke is discharged onto the coke wharf, allowed to cool, and then transported to screening and crushing equipment.

Description of Coke Ovens

The large masonry structure recognized as coke ovens by the passing spectator is actually a battery of individual ovens varying in width from 15 to 20 in. A battery may include as many as 100 ovens side by side in a continuous structural unit. The average present-day oven is 30 to 40 ft long and 10 to 14 ft high. The over-all dimensions of the battery, however, exceed that indicated by the above dimensions due to the considerable volume occupied by the heating chambers in which gaseous fuel is burned for maintenance of the required temperatures and the mass of masonry below the ovens penetrated by an elaborate system of flues whose function is to recover heat values from the waste fuel gases.

Section I, Dust Problems in Blast Furnace Operation, was published in this *Journal* in May, 1957. It was edited by Wesley C. L. Hemeon.

Sources of Atmospheric Pollution

Visible smoke or other emissions around a by-product coke oven plant originate from the following operations: (*a*) charging of coal into the ovens; (*b*) leakage during carbonization; (*c*) pushing the coke out of the ovens; and (*d*) quenching the hot coke.

The following discussion does not include such purely in-plant problems as coal dust incident to the grinding and blending of coal, and steam and dust at the coke wharf. Also omitted from the discussion are the fuel-burning processes for the generation of steam, e.g., the burning of the coke breeze (the fine particles of coke too small for use in the blast furnace) and of the coke oven gas which, as a by-product, may be utilized as fuel in any of several other processes in the steel plant.

Smoke and Gases in Charging Coal into Ovens

Soon after an oven has been emptied of coke at the end of the coking cycle, it is refilled with a new charge of pulverized coal which may range in size from three-inch lumps down to pulverized material, and since the oven interior is at bright-red temperature, volatilization of gases from the coal mass begins at once and escapes to the exterior as visible clouds of yellow-brown smoke.

Considerable progress has been made over the years in reducing the quantity of such smoke partly in arrangements and practices for minimizing its escape from the interior and partly in shortening the time required for charging, since in the latter respect the sooner this is accomplished and the openings closed, the less is the total emission.

Some of the positive accomplishment is ascribable to improvements in coke-oven design and part to improved operating practices.

Coke Oven Design

It should be borne in mind that the fundamental features of a coke oven battery cannot be changed during its lifetime, which amounts to 20 to 30 years. At the end of its life it is completely razed and a new structure erected to replace it. At such times new features of design are inevitably incorporated both for improved economy of operation and air pollution control.

Steam Jet Aspiration

A number of newer design features have been under discussion in recent years on some of which there is general agreement and on others differences of opinion prevail within the industry. Leech[1] discusses a number of these and brings out the fact that one important improvement over older practice includes facilities for aspirating gases from the interior of the oven during charging by means of steam jet aspirators in the ascension pipe elbow, whereas in former times it was the practice to seal off the oven interior from the gas-collecting main during charging. This resulted in the emission of enormous quantities of smoke during this period in comparison with that under current practice.

Double Collecting Main

Even though a steam jet aspirator is

operated in the gas ascension pipe during charging, some smoke tends to escape from the openings at the opposite end of the oven due to the distance the gases must travel and partial obstruction caused by piling up of coal as portions of the oven become nearly filled.

One arrangement for minimizing this effect, available for incorporation in new plants, provides two gas collecting mains, with a gas ascension pipe with a steam jet aspirator at each end of the oven. Thus the length of gas travel to the point of exit is halved and escape of smoke is lessened.

It should be observed that effectiveness of smoke control with this arrangement is also greatly dependent on the charging operators who must manually open and close the steam valves supplying the jet aspirators.

Equalizing Main

Another design feature somewhat similar to the double main consists in a gas pressure equalizing main on the side opposite to the collecting main. The equalizing main serves simply to connect all ovens to each other through this main; it is not connected to the principal gas main flue. The equalizing main provides an avenue of egress for gas generated during the charging (which cannot leave through the ascension pipe into the principal collecting main) to pass into one of the nearby ovens that, due to its coking stage, is under lower pressure and can thus accommodate this gas. This arrangement is somewhat less positive and, therefore, less effective than the double main.

Special Duct By-Passes Attached to Larry Car

Various ideas have been advanced to provide additional gas passageway from the interior of ovens being charged supplementing that provided by a single ascension pipe leading to the gas main, i.e., to accomplish less expensively the effect of a double gas collecting main or an equalizing main. One of these proposes to take advantage of the lower pressure existing in adjacent partially coked ovens. To this end, a smoke duct fixed to the larry car assumes a position when the car is located for charging such that it provides a passage for gas from the end of the oven being charged that is farthest from the ascension pipe (and hence more likely to permit escape of smoke) to the top interior of an adjacent oven which is under lower pressure. In this arrangement a steam aspirator in the gas uptake of the adjacent oven would be turned on to increase the flow of gases. Leech, discussing this arrangement, draws attention to the disadvantages: the "smoke pipe is difficult to keep clean and its use requires opening one more coal-charging hole." In other words, it requires an additional manipulation on the part of the workman with all of the implied disadvantages concerned with the human factor. Improvements in this arrangement may be hoped for in the future since its simplicity otherwise is basically attractive.

Another device which has been tried involves attachment of a bustle pipe to the larry car to provide an exterior passage for gases from the end opposite to the ascension pipe, around the coal blocking the gas space in the top of the oven, to the interior space of the same oven nearest the gas exit. This arrangement also is subject to the difficulties mentioned above, i.e., keeping the bustle pipe free of tarry deposits tending to plug it. Here again future development may overcome these difficulties.

Charging Hole Spacing

One of the coke oven design elements that minimizes the escape of smoke from the oven interior during charging is in appropriate spacing of the charging holes in relation to oven volume. The objective in this respect is to avoid piling up of coal anywhere in the oven in such manner as to create a barrier to the free passage of gases from any part of the oven toward the gas take-off flue. This condition is attained by calculated spacing of the charging holes in relation to the volume of the oven, a feature discussed by Wilputte and Wethly[2] and also by Leech.[1] The latter refers also in this same connection to the advantage resulting from the design arrangement in which the bottom ends of the charging holes where they enter the oven chamber are flared outward, thus providing more gas space between the coal charge and the top of the oven for free passage of gases.

Sleeves and Shear Gates

Another feature that has received attention in recent years aims to provide an enclosure between the hopper of the larry car and the top of the charging opening to prevent the escape of smoke-laden gases from the oven interior during the charging. This takes the form of drop sleeves and shear gates, which allow the operator to lower the sleeve to the top of the oven preparatory to charging the coal and to close the gate of each hopper as soon as it has been emptied, the latter to prevent the passage of gases upward through the hopper.[3] Immediately following this operation the operator will trip the drop-sleeve to raise it and quickly replace the lid. Then the leaks around the charging-hole lid are sealed either by luting or by dry seal.

Coal Measuring Sleeves

Since a part of the problem of allowing free passage of gas from one end of the oven to the other, during charging, is related to the volume of coal charged from a given hopper, attention has been given to means for better control and that has resulted in the development of volumetric sleeves on the top of the larry car hoppers which make it possible to adjust the bulk of coal in each hopper to match the requirements of ovens of different cubical capacity. This device makes it possible to charge the correct volume of coal and thus minimize the gas passage difficulties discussed above.

Mechanical Feed from Car to Oven

Any arrangements which reduce the time required for transfer of the coal charge from larry car hopper to oven interior will reduce the total escape of smoke and several mechanical devices have been advanced toward this end, including hopper vibrating mechanisms in conjunction with smooth stainless steel liners, cylindrical hoppers and bottom turn-table feeders, and a screw feed mechanism. The industry is attentive to these new developments and can be expected to adopt one or another as experience points the way to the best of these.

Control of Coal Bulk Density

Control of the bulk density of the coal mass is one of the factors contributing to coal feed rate as well as to certain production aspects. In those operations where the coal is pulverized and blended it has become increasingly common to control the moisture content and, by addition of small quantities of oil to the coal, to modify the bulk density further. Leech observes that oil-sprayed coal moves out of the larry car hoppers with much greater facility, thus reducing time required for charging.

Leveling

During the oven-charging process, the leveling operation ensues which involves operation of the leveling bar, a mechanism that is an element of the coke pusher equipment, operating through the leveling bar opening on the pusher side, near the top of each oven. Operation of the steam jet aspirator in the ascension pipe of the oven being serviced tends to prevent the escape of much smoke from the oven interior but it is not entirely successful. To perfect the control of smoke at this point, each oven can be equipped with a smoke seal box surrounding the leveler bar opening and which, in conjunction with the effect of the steam jet aspirator, and which, in conjunction with the effect of the steam jet aspirator, will greatly reduce the escape of gas from this opening, and on batteries having a gas-collecting main on the pusher side, practically eliminates all escape of smoky gases.

Carbonization Period

During the 18- to 20-hr carbonization period, leakage of smoke from the interior of an oven may occur around the doors unless measures are adopted to minimize it.

Sealing of Oven Doors

In older designs the joint between the coke oven door and the jamb is sealed by luting, in a hand-troweling process, a wet mixture of clay and coke breeze into a channel between the door and the jamb. In recent years a number of self-sealing door designs have appeared in which metal-to-metal contact between a machined surface and a knife edge, together with mechanical arrangements for exerting pressure, provides the seal and avoids the disadvantages of the older luting method which is so dependent for its effectiveness on the attitude of the workmen having this responsibility. It is, however, necessary that a superior maintenance program be applied to this equipment since wear and tear inevitably allows the development of leakage.

An optimum maintenance program for self-sealing doors, as proposed by coke oven operators of Allegheny County, Pennsylvania[3] includes changing the knife-edge material to stainless steel; adoption of a numerical system whereby a complete history of each door is kept, and of a system of tagging of doors by the operators to inform the maintenance force of the reason a particular door was taken out of service.

As to luted doors, it is advocated that tamping of the luting after completion of charging be practiced to minimize smoke emission from that source.

Pushing

At the end of the coking cycle the incandescent coke is transferred from the oven by pushing equipment into the coke-quenching car. The quantity of smoke arising from the mass during the period required for transport to the quenching station is dependent on the degree of coking. Incompletely carbonized coke ("green" coke) gives rise to considerable quantities of smoke; and conversely, if thoroughly carbonized, very little smoke is produced.

Coke Quenching

In the quenching process a car of incandescent coke, holding as much as 14 tons, fresh from the oven, is transported rapidly to the quenching station where the mass is quenched with some 4000–6000 gal of water in a short period of a minute and a half. Vast clouds of resulting steam soar upward from the tower and are visible for great distances.

Some liquid water droplets are entrained in the high velocity currents of air and steam inside the tower and are often perceptible as a light rain or mist within a radius of a few hundred feet. There is also the possibility of entrainment of fine particles of coke but the quantity is small, and, like the water droplets, tend to be deposited on the ground within a short distance of the tower. Contrary, therefore, to common opinion, the coke quenching tower is not a significant source of air pollution insofar as the neighborhood is concerned even though it may cause metal corrosion problems within the plant where contaminated water is employed for the quenching liquid.

Section III—The open hearth furnace

The open hearth furnace is the unit in which some 90% of the steel made in the country is produced. In a process which is superficially simple but intrinsically rather complicated, the pig iron produced in the blast furnace is transformed into steel by means which reduces the carbon content of four to five percent in the pig iron to a fraction of one percent and, equally essential in modern steel-making practice, controls the content of ever-present phosphorous, sulfur, manganese, and silicon.

Groups of furnaces up to a dozen or so arranged in a row comprise an open hearth shop. The open hearth shop is completely housed in a mill building identifiable from the outside by its row of steel stacks relatively closely spaced, looming some 50 to 100 ft above the roof line of the main building emitting vari-colored smoke ranging from white through various shades of tan.

The 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. A tap-hole at the base of the opposite wall above the pit is provided to drain the finished molten steel into the ladles.

Fuel in the form of oil, tar, coke oven, or natural gas, or producer gas 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. The hot gases on leaving the furnace interior are conducted in a flue downward to a regenerative chamber for heat recovery consisting in a mass of refractory brick systematically laid to provide a large number of small passageways for the hot gas called checkerwork or checkers. In passing through the checkerwork the brick mass absorbs heat, cooling the gases to around 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 pre-heated air for combustion. A system of valves in the flue effects the gas reversal so that the heat stored up in checkers is subsequently given up to a reverse direction stream of air flowing to the burners.

In some plants, the gases leaving the checkerwork pass to a waste heat boiler for further extraction of heat which reduces the temperature from around 1200°F to an average of 500° or 600°F.

Operation

Open hearth furnace capacities span a wide range. The median is between 100 to 200 tons per heat but there are many of smaller capacity and an increasing number of larger capacity. Time required to produce a heat is commonly between eight and 12 hours.

Raw materials charged to the open hearth furnace besides pig iron include iron ore, limestone, scrap iron, and scrap steel; and each of these is employed in different forms. The pig iron may be molten or in the form of cold pigs. The iron ore may be fine or in lumps and the scrap metal in a considerable variety of forms. The proportions of various ingredients vary with economic circumstances, with the characteristics of material supply and numerous other factors that need not be detailed here. The proportioning of metals and auxiliary materials, the order and the timing of their addition is complex and dependent for example, on the kinds of materials available, the kind of steel to be produced, characteristics of the fuel and of the furnace, and calls for a high order of skill from the open hearth furnace operator.

Stack Emissions

The solids in the flue gases of open hearth furnaces include both coarse and fine particles and are continually emitted at highly variable rates throughout the eight to 12-hour cycle of an open hearth heat, variable in color appearance as well as in quantity. These particles originate from the mechanical and chemical reaction of hot gases inside the furnace on the charged materials, from the chemical reactions and agitation in the molten

Table I—Dust Collection Efficiency on Open Hearth Fumes of Several Inertial Type Dust Collectors (According to Vajda)

Type W Rotoclone	45%
Multiclone (6 in. tubes, 4 in. pressure drop)	43%
Type N Rotoclone (4 in. pressure drop)	50%
Pebble filter (Two 4 in. beds 1/4 in. to ½ in. pebbles 6 in. pressure drop	78%

bath itself, and from the combustion of the fuel. In addition to the dust and fume, gaseous emissions result in quantities determined by the composition and rate of fuel combustion.

Available data indicate that the highest rate of solids emission occurs in the first half hour after hot metal addition, and the period of one to two hours in the latter part of the ore boil. In the remaining period comprising more than 80% of the cycle, the solids emission rate is materially lower. The overall average concentration of solids in the flue gases is approximately 0.4 grain per cubic foot measured at standard conditions. This amounts to approximately five to 10 pounds of solids per ton of steel dependent upon the type of furnace operation. Over half the dust is less than one micron in size and a large part of this material has been measured at about 0.03 micron.

Flues and Checkers

During the course of furnace operation, coarser particles carried out of the furnace settle out in the flues and in the checkers. In order to avoid choking of these passages, it is necessary periodically to clear them and this is done by blowing with large volumes of steam for short periods of time, three or four times a month. The quantity of such dust is a minor proportion of total solids although it escapes into the open atmosphere in a relatively short period of time, and being composed of relatively coarse material would have a greater tendency to settle rapidly out of the atmosphere.

Fume Control

Engineering methods for the reduction of solids emission from open hearth furnaces have been the subject of extensive inquiry and investigation by the industry in recent years. This problem has been one of the most troublesome for the steel industry because of the design and operating difficulties encountered with precipitators, their high cost, and because many plants do not have adequate ground space near the open hearth stacks to permit installing such bulky equipment.

These difficulties have impelled the industry to support exploratory studies seeking possible alternatives. One of these was an extensive pilot investigation by Vajda[1] in Pittsburgh which included studies of the performance of various types of commercial scrubbers and inertial dust collectors. The findings indicated that a number of common types of equipment were capable of removing 50 to 60% by weight of these solids which, it should be pointed out, is that fraction which contributes to the dustfall nuisance of a community.

These are the efficiencies during furnace heats. The efficiency during blowing of flues and of checkers would be much higher because that dust consists mainly of coarse particles. No industrial installations of these types have been made.

Performance Criteria

What criteria of performance are properly applicable to open hearth flue gas cleaning?

One kind of criterion would cite the maximum permissible concentration of solids in the stack gases. Municipal regulations apply this basis widely to solid fuel burning equipment. When one comes to the consideration of an actual concentration figure to apply to open hearth furnace gases as a definition of good practice, there are various opinions as to what criteria should govern.

One view is summarized in the following. Decisions should not be based simply on the appearance of the stack plume. Specifications should rather be based on the concept that fume removal equipment ought to be of such efficiency that residents in the neighborhood are not subject to perceptible increments of dustfall on their premises. If such a standard were to be applied to the framing of a dust collection performance code for open hearth furnaces a number of inertial-type dust collectors and scrubbers would render acceptable service in many cases even though weight efficiencies would not exceed 50% during normal heats and perhaps over 90% during blowing of checkers and flues. The reason for this is that such collectors effectively remove the largest particles and these are the ones which may cause annoyance if they are deposited at ground level at a perceptible rate.

Another view expresses the conviction that the appearance of the stack plume should serve as the ultimate criterion. The argument in support of this is that unless fume is removed from the stack gases in amounts sufficient to dissolve the plume so that improvement is visually obvious to neighbors and passersby, the effort will have been wasted, since people are prone to complain on the basis of what they see at the stack even though there be no relationship to effects at ground level.

This attitude, representing as it does the line of least resistance, may be valid from the psychological viewpoint but not so from a scientific one. It is nevertheless widely held and was the basis on which Vajda rested his conclusions concerning the performance of various types of gas cleaner tested by him. He remarked, "Experiments... indicate that the outlet dust loading must be down to 0.05 grain per cubic foot to give a clear stack. Above this loading, a bystander cannot tell whether there is a cleaning unit on the stack or not."

Electric Precipitators

Electric precipitators have been installed (1959) for open hearth stack gas cleaning in steel plants at Geneva, Utah; Torrance and Fontana, Calif.; at Morrisville, Pa. and plans for installation have been announced by two companies in the Pittsburgh area. The Geneva installation differs from the other three in that provisions for supplemental fluoride control were incorporated in the design. This was accomplished by injection of lime into the gases to react with the gas-borne fluorides at a point preceding the precipitators. Therefore in this case the precipitators remove both particulate matter and the solid fluoride compounds formed by the above reaction.

Two points of importance need to be observed respecting electric precipitators. A visible, ever conspicuous plume is still apparent even when precipitators are operating at 90% efficiency and greater, a point having a bearing on the question of criteria discussed above.

The other point concerns the considerable experimental effort that is required after a precipitator is installed, to develop it to a stage of satisfactory performance. Electric precipitation of open hearth dust is still more of an art than a science. The engineering problems are well illustrated in the article by Akerlow[2] which details the development work over a period of several years that was involved in discovering causes of imperfect operation and designing corrective measures.

Filtration Research

Paralleling the developments described above, the American Iron and Steel Institute, recognizing the importance of this problem, in 1953 initiated research at the Harvard School of Public Health under Dr. Leslie Silverman seeking to ascertain the feasibility of filtration through slag wool in conjunction with a process for rejuvenation of the filtering media. A pilot unit has provided data leading to hopes that a gas cleaning apparatus might be developed requiring minimum ground area. This research is continuing.

Section IV—Bessemer and Top-blown Converters

Pneumatic converters serve basically the same function as that of open hearth furnaces, i.e., the transformation of pig iron to steel by lowering of the carbon, silicon, and manganese content according to the desired quality of the finished steel.

The refractory-lined steel vessel receives a charge of molten pig iron in quantities ranging from 25 to 30 tons in the case of the older Bessemer converters on up to double or more that quantity in more recently constructed units. Elimination of the dissolved carbon is effected by oxidation which results from intimate contact with a stream of air or oxygen. Since in a typical charge of pig iron the dissolved carbon, silicon, and other elements upon oxidation is equivalent in heating value to one ton or more of coal, no auxiliary fuel is required in this type of smelting; all that is required is a supply of oxygen to the molten charge.

Pneumatic converters of 30 tons capacity effect the complete oxidation reaction in a brief period of 10–15 min in contrast to the open hearth furnace where the melting and refining of 100–200 tons of steel requires periods ranging from eight to 12 hours. The advantages apparent in the preceding statement tend to be counteracted in some degree by a number of considerations. These include the composition of the resulting steel respecting such trace elements as phosphorus, sulfur, nitrogen, oxygen, etc. in relation to the metallurgical qualities of the resulting steel which in turn are determined by the physical qualities required in subsequent fabrication. These considerations in turn are related to the quality of raw materials, e.g., iron ore. A factor of importance in a comparison of the function of Bessemer converters vs. open hearth furnaces is in the limited extent to which these converters can melt scrap metal.

The relatively low capital investment required for pneumatic converters in combination with their other advantages has led recently to a period of extensive engineering and metallurgical research to find ways of more effectively exploiting these advantages.

Bessemer Converters

Bessemer converters are those spectacular steel-making units whose brilliant yellow flame dramatically illuminates the sky around some steel plants at night and which discharge volumes of high-soaring clouds of orange-brownish iron oxide fumes prominently visible in daytime.

They are cylindrical steel vessels with a spout or nose surmounting the top at an angle with the main axis, mounted on trunnions on which they can rotate. One of the trunnions is hollow and serves as an air duct for passage of air from a blower to a chamber at the bottom of the vessel known as the wind box.

Air passes upward (when the converter is vertical) into the molten metal through holes (tuyeres) in the refractory barrier separating the wind box from the molten metal bath. Air pressure prevents metal from trickling downward through the tuyeres into the wind box. When the converter is tilted 90° on its side the surface of the molten metal is below all tuyeres and the air blast can be shut off when it is in this position. In fact this is the position of the converter when it is charged with molten pig iron.

The sequence of operations in the operation of a Bessemer converter is well outlined in the following extract:[6]

"After completion of the previous blow, the vessel is turned on its trunnions until it assumes an almost horizontal position and scrap, scale, or ore is dumped into the vessel if desired. The molten pig iron is then poured in from the transfer ladle. In this horizontal position the metal is contained in the belly of the converter and does not come in contact with the tuyeres. The blast is started and the vessel turned to a vertical position and remains in this position throughout the balance of the blowing period, unless 'side-blowing' is resorted to for increasing temperature.

"The Bessemer blow is usually thought of as being divided into three parts, the first period, the second period, and the after blow.

"The first period, or the *silicon blow*, as it is commonly called, begins as the blast is turned on and the vessel turned up. During this period of the blow, a short transparent flame extends from the mouth of the vessel. As the blowing continues the flame starts to lengthen after about four minutes and the second period or *carbon blow* begins.

"It is during the second period that the flame attains its full brilliance and length, extending as much as 30 feet beyond the mouth of the converter. This flame results from the evolved carbon monoxide burning to carbon dioxide as it comes in contact with the air at the mouth of the converter. It is at this time that the blower carefully studies the flame to determine if his judgment regarding temperature control, and in estimating the amount of scrap needed, initially was correct.

"The long, brilliant flame which is characteristic of the carbon blow continues until the elimination of carbon approaches completion, whereupon there is a definite change in the appearance of the flame. The length of the flame gradually drops and it seems to fan out. . . .

"After the blower has made the decision that the blow should be terminated, the vessel is turned down and the blast turned off."

Dust and Fume Emissions from the Bessemer Converter

In the operation of the ordinary Bessemer converter two kinds of particulate matter are discharged to the atmosphere. Pellets of metal and slag are mechanically ejected due to the violence of the air blast bubbling through the molten metal. These are known as spittings composed, as they are, of relatively coarse particles which tend to settle out on the premises close to the source. The other type is the visible orange-colored fume of iron oxide resulting from volatilization in the converter of some of the iron and its subsequent oxidation in the open air. These particles are suspended in the hot gases which, because of their buoyancy rise to great heights transporting the visible fume with them.

If these tendencies were absolute there would be no air pollution problem outside the plant area (except where the converters were located immediately adjacent to places of residence near the plant boundary), because of the limited distance travel of coarse spittings on the one hand, and on the other hand, the buoyant transport of the visible fumes to such heights as to avoid contamination at ground level.

Departure from these absolute tendencies doubtless occurs in that some smaller droplets of metal and slag, small enough to be transported upwardly in the buoyant cloud of visible fume but large enough to settle out of the cloud later by gravity, may be generated. To what extent this is a significant contributor to dustfall at different distances from a converter plant is not known. It is quite certain, however, that the visible fume portion of the emission cannot cause soiling of property at ground level when soaring away at high altitudes.

In spite of these uncertainties covering the magnitude of the air pollution potential of the converter at a distance, the problem of fume suppression has received considerable attention. The difficulties are well summarized by Trinks[3]:

". . . The gases which leave the Bessemer converter have a temperature of about 3000°F, and they are still burning after they have left the mouth of the converter vessel. These flaming gases are not confined and cannot be confined, for several reasons. The mouth of the converter is not stationary during the blow. The vessel is tilted from horizontal to vertical position at the beginning of the blow, and is laid down again before the end of the blow. And that is not all. During the main part of the blow, the position of the converter is not always the same. The blowers have a surprisingly keen ability to locate thin spots in the bottom. They tilt the vessel in such a manner that the depth of iron or steel is greater over the thin spot than elsewhere.

"Additional features exist which make any dust-catching device near the converter mouth an impossibility. A crane-way must be provided over the converter for transporting ladles which contain up to 50 tons of iron or steel. Converter vessels are removed for relining, and repair jobs must be done.

"Last, not least, the converter spits pellets of iron and steel. The yield of a converter is commonly considered to be in the neighborhood of 88%. For every 100 pounds charged into the vessel, about four pounds of carbon burn to CO in the converter and to CO_2 after leaving the vessel. Eight pounds are thrown out as pellets or as metallic oxides. The pellets are troublesome, because they are shot out with high velocity. Some rise to a height of 50 or even 60 feet. When impinging upon a solid object such as a wall or girder, or roof, the pellets flatten and stick. The action is very similar to that of the metal-spray. In time, heavy masses of iron and steel are formed. Unless removed at regular intervals, they drop off and endanger those who are working below.

"The combination of all of these facts makes the problem of dedusting the Bessemer converter an extremely difficult one. The most obvious, but very expensive solution consists in total enclosure, with a roof at least 70 feet above ground level. At that height very few pellets can stick to the roof. The fan which draws the gases from the converter chamber must suck in enough volume of cold air to reduce the temperature of the gases to about 800°F, in order to prevent sealing. The diluting air may be drawn in from outside for instance through louvres. The cooled gases can be sent into cyclone cleaners or other known dust-separators.

"The gases which have passed through dry separators are not entirely free from smoke. The hot gases contain fumes which solidify upon being cooled in the open. If that portion of the total smoke is likewise to be eliminated, the gases must be sent through a spray tower and then through an electrostatic precipitator. The cooling water removes some of the dust and must, according to the latest laws, be filtered, before it is allowed to re-enter the river or the lake.

"A complete total-enclosure installation for several converters runs into fabulous sums. So far as the author knows, complete enclosure for the purpose of dust elimination has never been attempted in a steel plant . . . .

"Complete enclosure was observed by the author in Germany, where it had been installed as a war measure for the purpose of blacking out the light which converters emit. Much of the converter dust was deposited in the flame tower and was removed at regular intervals through a door in the funnel-shaped bottom. Only a light brown haze was visible at the top of the tower. . . .

"The rate of discharge of dust from a converter is not constant during the period of the blow. The thinner the bath, the greater is the rate of dust production, presumably because the metal is more thoroughly atomized and, for that reason, offers a greater surface to the air stream . . . .

"Thin baths are found at different times, for instance, while the vessel is righted and while it is being laid down. During both periods, the blast is on, so as to keep the iron or steel from running down through the tuyeres. In a partly tilted vessel, the edge of the bath is very thin. In consequence, very thick and heavy brown smoke is emitted while the vessel is being tilted up or down. The shorter the time of tilting, the shorter is the period of producing heavy smoke . . . .

"The greatest smoke producer in the operation of a converter is the so-called 'green bottom.' After a certain number of blows (never more than 20) the bottom has been worn thin and uneven. The blower decides, when it is time to change bottoms. The so-called green bottom is actually not green. It has been thoroughly baked. The green part comes in from the fact that the edge or rim of the bottom is smeared with clay and graphite. The new bottom is pushed up against the lower end of the vessel and is quickly fastened by swinging bolts and wedges. A charge is then run into the vessel. However, the new charge is only about 35% of the weight of a regular charge, which means that the bath is thin. If the light charge is blown for three or four minutes with full pressure, extremely dense and heavy smoke is discharged. The extreme heat of this blow dries the luting between bottom and vessel quickly. If a leak should occur, the loss would be comparatively small. If no leak is discovered during the short blow, the vessel is filled to the regular weight of charge and the blow is finished. . . ."

Fume Control Investigations by U. S. Steel Industry

In 1952 (?) the steel companies in the Pittsburgh area sponsored studies on fume control issuing from Bessemer converters. The findings[4] confirmed the engineering complexity of the problem and produced also some interesting data. The experimental assembly included a steel framework erected in the space above an operating Bessemer converter which permitted mounting of steel plates for experiments with air jet and water spray systems to see if such arrangements would prevent the accumulation of spittings on the steel surface. These spittings, as observed by Trinks, consist of small globules of molten iron and slag which are discharged through the converter nozzles at high velocity and on impingement adhere strongly to steel surfaces until the accumulation of a thick mass heavy enough to drop off spontaneously. This condition has always complicated consideration of enclosures for confinement of the converter effluents prior to removal from the gas stream.

These experiments were conducted at a height of 55 ft above the converter mouth and included attempts to prevent accumulation of spittings by the sweep of air jets from high pressure nozzles tangential to the steel surface. All these attempts were unsuccessful.

The application of water sprays to the steel surface was successful in preventing such accumulations so long as the surface was maintained wet at all times during the exposure.

Measurement of air velocities and of temperatures in the plume at a distance of 55 ft from the converter mouth indicated that the total flow of flue gas (including the air which had become turbulently entrained in the 55-ft distance) amounted to 250,000 to 300,000 cu ft a minute at temperatures between 450 and 550°F. These values are of the same order of magnitude as those indicated from German studies cited later on.

Another experiment in which a curving steel plate was mounted 80 feet above the converter mouth also accumulated spittings in spite of the play of high pressure air jets against the surface.

Some experimental studies on dust collectors were also carried out. A 1200-cfm portion of hot dust-laden gases from the main stream was aspirated through a small-diameter cyclone. The cyclone efficiency ranged from 66 to 76%. The effluent in the cyclone was markedly different in appearance from the main cloud. It appeared as a very light gray emission; the brown fume apparently disappeared. In one worst condition, the cyclone effluent was a light tan color. Some electric precipitator studies on a 400-cfm portion of gases showed the expected high efficiency.

Current Investigations

The importance of the Bessemer converter in the melting of special types of steel and a recognition of the desirability of finding means for fume control has led to the sponsorship by the American Iron and Steel Institute of a program at Battelle Memorial Institute. This project, just getting under way at the time of this writing, will seek by studies on a laboratory model of a Bessemer converter to determine the cause of fume formation and, hopefully, means for its prevention.

German Research

The American steel industry in addition to its own investigations has been following with keen interest experimental developments in Germany where the Bessemer converter plays an even more vital role in the refining of pig iron to steel than in this country. Because of this fact and also because the increased use of oxygen to accelerate the refining process results in even denser clouds of brown fume, the German industry has in recent years conducted some experimental work toward the suppression and removal of particulate matter.

In some German plants the converter flue gases are discharged into a chimney of very large cross-sectional area and of varying height (an arrangement instituted in World War II for protection for aircraft). This has facilitated certain experimental observations on dust collection.

Data on experiments reported by Dehne[8] supplement usefully information available from American practice. He reports on experiments on a 30-ton converter. Dust measurements indicated an average emission of solids of 132 lb/min or 1320 lb/melt is indicated. These weight figures include all very coarse material, a measured proportion of which would settle out rapidly on the premises immediately surrounding the installation. This is illustrated by the particle size data reported by Dehne whereby it is shown that about three-fourths of the particulate matter by weight is larger than 100 microns.

These facts regarding particle size are related to an installation described by Dehne known as the Bamag chimney which consists of water cooled steel plate chimney walls, rounded cross section, with cyclone dust collectors disposed around the periphery at the top. This dust collection arrangement was reported to remove 500 lb of dust per melt which in relation to the total dust quantity, 1320 lb/melt, indicates a collection efficiency of 42%.

Further along these lines he reports on the results of experiments in which well atomized water was sprayed into the chimney space and was found to remove up to 1540 lb of dust per melt with a water consumption rate of 800 to 1000 gpm. The physical conditions, however, accompanying such use of water, e.g., escape of a mud spray and accumulations of water at the base of the chimney and at points close to the converter mouth, were found to be intolerable.

The results are interesting in the indication that on a weight basis collection efficiencies approached 100%. At the same time the visual impression of particulate removal which pertains to the very fine particulate matter was not significantly improved. In this connection Dehne offers some observations of fundamental importance in relation to this problem, as follows:

"Therefore one's visual impression of the smoke cloud which is still strikingly brown even at lowest dust concentrations by weight is not an absolutely perfect scale for measuring the efficiency of dust removal. But if the acceptability of the smoke emission is to be judged by its color, then it must be cleaned to at least 0.035 gr/ft^3. Such a criterion . . .eliminates from consideration all those dust-removing processes feasible from a cost standpoint but whose limits of efficiency would result in outlet concentrations far above the said figure."

Certainly it can be observed as a comment on these observations that there can be serious question as to the necessity for removal of all of the almost weightless fine particulate matter.

Dehne cites other experimental work involving use of water scrubbing, some of which were "more or less satisfactory but no complete success was achieved."

He shows in some detail an arrangement in which the greatest success was realized, in terms of coarse dust removal, involving the use of a short conical flue inside which water was atomized, the assembly being anchored to the converter with an open space between the converter mouth and entrance to the cones of about 13 ft. In this arrangement the high velocity gases issuing from the mouth of the converter caused the gases and their load of particulate matter to pass right through the cone and water spray. This arrangement in combination with supplementary water sprays downstream from the cone unit and with mist eliminators, resulted in a dust collection efficiency superior to the Bamag-chimney cyclone combination and had the advantage of lower cost.

Various other experimental studies were conducted on a pilot scale (7000 cfm) involving several other types of scrubbers, cloth filters, packed towers, and injection of steam into the issuing stream of gases. Their experiments also included exploration of audible sound energy in an 1800-cfm pilot plant. They were able to coagulate the fumes but the flocs disintegrated in passage through a cyclone and were not effectively caught.

Electrical precipitation was also the subject of trial on a pilot scale (7000 cfm) and the results even on a visual basis were appraised as satisfactory. However, he observes that while this apparatus performed well, it has not received as serious attention "because one could not get accustomed to the idea of having to build an electrostatic filter or precipitator of the size of the steel mill bay." This concern is entirely understandable from an inspection of the drawing illustrating the size of the gas-cleaning unit that would be required in comparison with the size of the converter itself.

In all their experiments, the efficiency of fine particulate removal was seriously reduced during the final blowing period following decarburizing, which is that period when phosphorus is removed i.e., dephosphorizing. This smelting stage is a characteristic of European practice due to the high phosphorus content of their ores. It is not characteristic of American practice. For this stage of operations they devoted experimental effort to noting the effect of adding steam to the blast (22 lb of water per ton of pig iron). This resulted in a white waste-gas streamer, eliminating the dark-brown smoke clouds otherwise present. In addition to this advantage it was noted that clouds of smoke were no longer blown into the plant shed when the converter was tilted, a feature which is lacking in all dust-removing methods. The disadvantage was in the reduction of melting capacity—two tons per melt—i.e., from 30 tons to 28 tons or a six percent reduction.

In his final discussion pertaining to problems incident to the application of the electric precipitator which from a visual standpoint alone was superior to all methods, Dehne considers those aspects dealing with dilution of converter gases with air induced into the base of the chimney enclosure in relation to gas temperature. It would be absolutely essential to eliminate major infiltration of dilation air as occurs in their present installations and to cool the gases by other means. As to the latter he lays great stress on a waste heat boiler and concludes that it may then be possible to reduce the volume of gas flowing to the precipitator to a value of 212,000 cfm. This is the figure on which the dimensions of the enormous installation shown in a drawing accompanying his paper are based. He notes also in this connection that means would have to be provided for coarse dust removal as, for example, by the Banag round chimney, and that the chimney walls must be protected by cooling means discussed in his article.

Role of the Bessemer Converter in Steel-Making

Although use of the Bessemer converter has steadily declined relative to the open hearth furnace during the first half of the present century, it continues to serve an important role, partly for the special quality of steel it can produce and partly for economic reasons peculiar to particular plants. Some of the economic considerations are explained in the following:[2]

"The early use of converter steel in this country involved a considerable quantity of rail steel, and for many years this process was the principal method used for the production of steel . . . The rated converter capacity of the nation is approximately 12,000,000 tons of steel (1950) with a considerably greater potential capacity. Over half of this capacity represents blown metal for use in the open hearth or duplex process and the remainder Bessemer ingots. Although most of the steel in this country is manufactured by the open-hearth process, during the past few years many new converters have been installed and extensive experimental work on converter steel is in progress. The inherent advantages of the process involve economic considerations in times of peace and national security in times of war . . . .

"The cost of building a Bessemer plant is appreciably less compared with an open-hearth plant of equivalent capacity and the difference in cost depends, to some extent, upon the size of individual units. However, in the operation of a Bessemer plant, greater blast-furnace capacity is required as only a small amount of scrap is used in the process. Therefore, the investment in blast-furnace facilities for a Bessemer plant would be greater compared to an open-hearth plant and must be considered as part of the investment costs. This probably was a factor which, to some extent, was responsible for the shift from Bessemer to open-hearth production during the years between about 1910 and 1948.

"With proper facilities in an integrated plant, consisting of Bessemer converters and tilting or stationary open-hearth furnaces, the cost of producing Bessemer ingots over a period of years should be less than open-hearth ingots. When a shortage of scrap exists and the price is high, Bessemer facilities not only have an economic advantage, but are in a better position to meet market demands for steel products. This latter feature is of considerable importance in time of a national emergency . . . .

"The ratio of Bessemer to open-hearth production is influenced by the availability of steel scrap. The Bessemer process uses about 10% scrap. The duplex open-hearth process utilizes very little scrap while the stationary open-hearth process ordinarily employs 35% to 60%. Although the quantity of scrap used in the Bessemer process is small, this quantity may be increased appreciably in the future to approximately 25% by oxygen-enrichment of the blast. Further, the use of scrap in the blast furnace may be considered in the Bessemer situation.

"The Bessemer process is more than self-sufficient in scrap. The crop ends in the blooming mill alone produce about 15%, and additional scrap is produced in further processing of the material. The stationary open-hearth process produces a similar amount of scrap, but constantly uses more than it produces. The deficit is supplied by scrap originating from the Bessemer process and from sources outside the plant.

"The Bessemer process has certain economic advantages when scrap is scarce and costly, but there are periods in our economy when scrap is plentiful and cheap. Therefore, the economic pressure which exists over a period of years will be a controlling factor which influences the Bessemer steelmaking capacity of the nation . . . .

". . . Present trends in the use of oxygen and compressed air in the bath of open-hearth furnaces indicate clearly the future possibilities of a more widespread use of the basic principles of the pneumatic converter process."

Top-Blown Oxygen Converters

A smelting process that is superficially similar to the Bessemer converter is the top-blown oxygen converter or the basic oxygen furnace; it is also known by the term Linz-Donawitz, the latter deriving from the names of two Austrian towns where the early development work occurred.

The converter vessel in this process is similar to a Bessemer converter although considerably larger than most of them. A principal difference is in the means for the supply of oxygen to the molten metal. Instead of bubbling air under pressure upward through the bath, a stream of oxygen is supplied through a water-cooled pipe extending from an overhead position downward into the converter, the end being positioned at some distance above the surface of the bath. The high velocity of the oxygen results in impingement on the liquid metal surface which results in violet agitation and intimate mixing of the oxygen with the molten pig iron. Rapid oxidation of the dissolved carbon and silicon (and also of some of the iron) ensues.

Results of O_2 Concentration

The high concentration of oxygen results in the evolution of iron oxide fumes in considerably greater quantities than from the bottom-blown Bessemer converter and in a correspondingly more objectionable emission.

This problem was recognized in the initial consideration by American steel manufacturers who first considered adoption of the process and equipment for fume control was always a prime consideration in the design of the plant. As a result, the three plants now in operation on the North American continent are all equipped with effective dust-suppression equipment. One of these employs a Venturi scrubber, another one a disintegrator of the type that has long been applied to the cleaning of blast furnace gases, and the most recent one, with a Cottrell precipitator.

Control Problem Big

The latter installation illustrates the magnitude of the fume control problem and of the equipment for the purpose. A huge water-jacketed steel hood mounted above the mouth of the converter when in its normal vertical operating position, receives the fume-laden gases from the converter and also a much greater volume of room air drawn in to effect dilution of the hot gases. The stream totalling 250,000 cfm passes from the hood into a large settling chamber where large volumes of water are sprayed into it to effect cooling and also incidental removal of some of the particulate matter. The gases then pass through a flue to the Cottrell electric precipitator which removes the solids at a rate of more than one ton per hour at efficiencies of over 98%.

The dust collection system which in its physical dimensions dwarfs that of the converter proper represent more than 10% of the total plant investment.

Section V—Sintering plants

Sintering machines are those devices designed to convert fine iron ore, dust, and the like into lump form more suitable for charging into blast furnaces, by burning a mixture of this material with finely divided coke as air for combustion is drawn through a flat porous bed of the mixture. The resulting high temperatures induce a condition of incipient infusion of the iron ore particles comprising the bed and results in formation of a firm porous mass.

The bed is formed on a slow-moving grate composed of receptacle elements having perforated bottoms, known as pallets. The assembly of such pallets end to end in a hinged or linking arrangement comprises an endless metal belt with large sprockets at either end.

Just after the charge has been placed to form the bed, the coke in the mixture is ignited by the play of flames on the surface and a movement of air induced downward through the porous bed under the influence of the sintering machine exhaust fans connected to enclosures (wind boxes) underneath the top section of the endless linked pallet assembly. Thus combustion is maintained in a layer which slowly progresses downward and is completed before any given portion of the bed arrives at the end of the machine. At the end of the travel, the red hot sintered mass breaks off as the pallet elements turn downward around the tail sprocket. The hot mass of sinter is then passed to a cooler in which its temperature is reduced as cool air is drawn through it, frequently supplemented by water sprays.

There are two principal sources of dust in the operation of this process. One is in the combustion flue gases which contain some dust that has been mechanically entrained from the bed itself due to passage of air through the bed of material; it may also contain some fume due to volatilization of some of the constituents of the iron ore or dust in the mixture.

The quantity of solids in flue gases varies with type of ore and sintering machine design characteristics; the median is probably of the same order of magnitude as that issuing from a single open hearth furnace of average capacity. In the older plants no flue gas cleaning equipment was customarily included but all of the more recently constructed units are equipped with either mechanical dust collectors, scrubbers, or electrical precipitators.

The dust incident to crushing and screening operations of the resulting sinter is comparable to that resulting from any such operations characteristic of numerous other industries, e.g., rock crushing, although the quantity of dust is a small fraction of that encountered in some of these other industries. The crushing and classifying operations in the older plants are simple and few, and often not equipped with effective dust control systems. In the typical case where such plants were located well within the boundaries of a steel mill, it is probable that the resulting dust is more of a nuisance to adjoining departments of the steel plant than to the surrounding community.

In the newer plants, however, well designed exhaust systems in which hoods and exhausted enclosures are provided around crushing equipment, screens, and transfer points in the material handling system, are universally employed. High efficiency cyclones are commonly employed for dust removal and are effective in the removal of coarse particles which might otherwise be responsible for a local nuisance.

The first sintering machine in this country was installed in 1911 and such machines became increasingly a common item of equipment in years following although on a small scale in terms of later developments. They were primarily applied to the iron ore dust that blew out of blast furnaces into the flues and other gas passages. Stockpile accumulations of this dust represented an increasing nuisance until the sintering process was developed which transformed the material to lump form which would be recharged to the blast furnace, profitably.

The role of sintering machines in steel plant operations assumed a *new* stature following World War II. This was due to the changing character of iron ore supplies when, with the approaching exhaustion of the high grade lumpy ores of the Messabi ore deposits, new sources became available which had high properties of iron ore fines. This circumstance was accompanied by increasing evidence that any important reduction in the fines supplied to blast furnaces not only increased production but also reduced material costs due to decreased requirements for coke and limestone. As a result of these developments, sintering machines are being installed on a large scale in all segments of the steel industry. It is reported (Packard) that the sintering capacity of the steel industry in this country had attained a level of 60,000 tons per day at the end of 1958, a striking increase over the figure of 10,000 tons in 1939.

These economic developments respecting the distribution characteristics of ore charged to blast furnaces practically insure that the older, inefficiently designed sintering plants will be replaced by modern ones in coming years. This process is already taking place at the time of this writing.

Modern sintering plants have capacities ranging from 2000 to more than 6000 tons of sinter per day. The dimensions of one of the latter capacity are interesting. Having a bed width of 12 ft, it extends to a length of about 150 ft. Exhaust fans draw air through the bed of such a unit at a rate of more than 500,000 cfm measured at temperatures of 350°F. This is the flue gas volume which is subject to gas cleaning for removal of dust or fume.

The exhaust system for control of dust incident to crushing and screening of the finished sinter involves air flows in the vicinity of 150,000 cfm.

The fact that all new sintering plants are being provided with equipment for control of air pollution in combination with that respecting the high rate of obsolescence of the older ones constitutes firm assurance that this type of equipment is quite unlikely to be a source of future dissatisfaction.

Section VI—Electric Furnaces

The electric arc furnace for the making of steel, first employed in this country in 1906, has undergone marked development during the past 20 years. In 1935 it accounted for 1.3% of the total steel-making capacity of ingot-producing plants in the country and by 1954 the proportion had increased to 8.4%. The remaining capacity is accounted for in that of open hearth furnaces and Bessemer converters. The use of electric furnaces in steel foundries has also developed at a rapid rate during the same period, but the present discussion is largely confined to the integrated steel plants having also open hearth furnaces or pneumatic converters or both.

Role of Electric Furnaces

The function of electric furnaces is in general much more specialized than that of open hearth furnaces and pneumatic converters, in that they are especially adapted to and are primarily used for the production of special alloy steels.

". . . the electric-furnace products represent practically all of the stainless, constructional alloy, tool, and special many other important industries. While at the present time the electric-arc furnace cannot compete with the larger open-hearth furnace as to cost in the production of the commoner grades of steel, yet the electric furnace, if operated in a favorable scrap-producing area with favorable power rates, in many cases can produce ordinary carbon steels at costs comparable, and sometimes less than, open hearth costs."[19]

The furnaces in operation today for the manufacture of steel consist essentially of refractory-lined cylindrical vessels through the roof of which large carbon electrodes pass downward into the charge. The three electrodes supplying current at rates as high as 10,000 to 20,000 amperes generate great quantities of heat as the current arcs from one electrode to the bath, passes through the bath and arcs to one of the other electrodes. Since World War II many electric furnaces having a capacity of 10 tons of steel and with shells 20 ft in diameter have been placed in operation. Within the past few years, furnaces of 200 tons capacity with shells approaching 30 ft in diameter have been installed.

Electric furnaces are completely housed in mill buildings and therefore, unlike open hearth and Bessemer converter installations, the passer-by does not see the equipment or evidence of its operation other than in the appearance of brownish smoke issuing into the open atmosphere through roof ventilators of the buildings housing them.

Fume and Dust Emissions

The high temperature inside the furnace created a natural draft which induces a flow of air inward through spaces around charging doors and outward through the annular spaces in the roof surrounding the three electrodes, carrying with it variable quantities of fume and dust which are discharged into the atmosphere of the mill building housing the furnace. It escapes subsequently to the open atmosphere through openings provided by the roof ventilators.

During the melt-down stage, oxidizing conditions prevail and reactions occur that are similar to those in the bath of the basic open hearth furnace. Although the differing characteristics of the two processes indicate differences in the mechanism of fume generation they are not altogether dissimilar. Heat is applied to the charge in the electric furnace at a much higher rate per unit area of surface and therefore conditions are favorable for oxidation specting heat transfer and contact with oxygen are altogether different. In both processes a so-called boil occurs from escape of carbon monoxide resulting from reactions between carbon and iron oxide. Oxygen gas introduced to the bath through a pipe or lance is applicable to the electric furnace process as well as to the open hearth and the resulting metal oxide fumes, of course, have the same origin.

The quantity of escaping dust and fume has been variously estimated to range from five to 30 pounds per ton of steel melted, depending on size of furnace, and the character of scrap as to its content of fine dirt.

The magnitude of the resulting dust and fume emissions inside the mill building, especially to cranemen, is therefore roughly proportional to the size and number of the furnaces. As larger and larger furnaces have been developed and more of them installed in one building, the emissions have become intensified not only inside the building but in the immediate neighborhood, and extensive engineering efforts have been applied to the control of such fume during the past several years.

The Fume Control Problem

The characteristic distinguishing this problem of dust and fume control from other metallurgical furnaces has to do mainly with the development of means for channeling the stream of dust- and fume-laden gases through a flue leading to gas cleaning equipment without interference with proper function of the furnace. In this respect the problem is roughly analogous to that of the Bessemer furnace in that capture and transport of the fume-laden gas and air stream is the primary problem; after that point, treatment for removal of particulate matter in more or less conventional kinds of equipment can be considered.

Furnace Hoods

The first devices for fume control that were quite successfully applied to the small acid-lined furnaces of the steel casting industry consisted in steel enclosures mounted on the furnace roof which were connected to exhaust systems through suitably designed flexible linkages, e.g., swivel elbows, telescoping joints, and the like. An opening is provided in the central portion of the exhaust enclosure for free passage of the electrodes, and sections overhanging the roof above charging doors serve to withdraw fume-laden leakage air from those locations into the exhausted enclosures. For mechanical reasons, the application of such a method for

Interior Exhaust

In a move toward simplification of the mechanics of fume exhaust, some installations have been made in recent years whereby fume is withdrawn directly from the interior of the furnace through a hole in the roof while carefully controlling the rate of exhaust in relation to the internal negative pressure so as not to chill the interior of the furnace and its charge and to avoid exposing the steel to excessively oxidizing conditions.

This system can effect control of the fume emission at rates of air and gas exhaust much lower than in the roof top hood system previously mentioned although the gas temperatures issuing from the furnace are very much higher (2000–2500°F); this necessitates refractory-lined flues to the point where such gases enter the gas cooling unit.

Limitations of Direct Exhaust Method

The principal limitations of this system are related to metallurgical considerations. One of the particular advantages of electric furnaces in the refining of alloy steels is in the facility with which the oxidizing or reducing character of the slag can be controlled, and in the reducing furnace atmosphere that results from the non-oxidizing character of the electric heat source. Because of this circumstance high proportions of oxidizable metal elements in the making of high alloy steels can be melted with a minimum of loss from oxidation.

It has been felt in the industry that a system which controls escape of furnace fumes by inducing a flow of air into the furnace interior would make it difficult or impossible to maintain the essential reducing character of the slag in the later stages of two-slag (oxidizing and refining) process employed in the making of high alloy steel.

Recognizing that this opinion is based on inference rather than on actual experience, an experimental study was launched in 1958 by the Subcommittee on Electric Furnaces of Allegheny County, Pa. Their plan involves full-scale installation on an industrial electric furnace of a "water-cooled, hole-through-roof, emissions off-take which will be connected to a cooling system, fan, and stack. The purpose of the experiment is to determine what effect negative furnace pressure will have on the melting of certain alloy and stainless steels which require double slag practice . . . to determine whether its installation will interfere with furnace operation and production in any way . . . maintained in the production of alloy and stainless steels where the 'two-slag' process is employed."[11]

It is probable that a definitive report on these studies will be issued by this group by June, 1959.

The present status and future prospects for electric furnace fume control is well summarized in the same report:

". . . a general conclusion is that emission from electric furnaces to the atmosphere can be reduced.

"The problems are not ones for which simple solutions can be found. This applies especially to installations already made where buildings and furnaces were installed without planning emission control, and where vertical and horizontal space may not allow a practical installation of control equipment.

"Also, it will apparently be necessary to study each furnace or furnace group separately when considering an installation, since there will be different charges to and products from each one, different methods of fluxing, lancing, and operating . . . .

"Obviously the economies of each installation needs careful study, from the viewpoint of investment, operation, and repair of the control system, as well as to how its operation affects output and quality of product from the furnace. In some installations, an economic study may necessarily consider whether to abandon the present furnaces and build new ones on which controls may be more advantageously placed."

Section VII—Miscellaneous Processes

Besides the dust, smoke, and fume control problems treated in the earlier sections of this report, there are a number of miscellaneous operations which logically should be included in such a report as this, although their individual significance as sources of air pollution is relatively minor in comparison with some of those discussed previously.

Scarfing Machines

During the past 40 years, as the technology of steel fabrication developed requirements for still higher qualities, ever increasing attention has been devoted in one particular to the conditioning of semi-finished products. A major element in this area involves the need for removing surface defects of blooms, billets, and slabs prior to shaping, as by rolling, into a product for the market. Such defects as rolled seams, light seabs, checks, etc., terms describing imperfections like surface fissures, seabs that are inhomogeneous with respect to the main body of the metal piece, will generally retain their identity (although not shape) during subsequent forming processes and result in products of inferior quality.

In the earliest days of the development, pneumatic chisels were employed to remove such surface defects. About 25 to 30 years ago the scarfing process developed and today represents an important operation in the making of high grade steel products. It consists essentially in supplying streams of oxygen as jets to the surface of the steel product under treatment while maintaining high surface temperatues that result in rapid oxidation and localized melting of a thin layer of the metal. Originally the process was a manual one consisting in the continuous motion of an oxyacetylene torch along the length of the piece undergoing treatment. In recent years the so-called hot scarfing machine has come into wide use. This is a production machine adapted to remove a thin layer ($1/8$-in. thick or less) of metal from all four sides of red hot steel billets, blooms, or slabs as they travel through the machine in a manner analogous to the motion through rolling mills.

The process results in simultaneous generation of quantities of both dust and fume of such magnitude as to be quite intolerable inside the mill building. Such installations therefore are equipped with exhaust systems designed to remove this material at its source and to deliver the contaminated air stream to a dust collector before discharge to the atmosphere.

The exhaust system design is conventionally based upon the exhausting of 750 to 1500 cfm of air per scarfing nozzle and for machines now in common use, this results in exhaust systems ranging from 20,000 to 100,000 cfm.

The scarfing process involves the use of water jets adjacent to the oxy-acetylene torches and the steam to be generated is drawn off along with the fume and dust.

The scarfing process will typically remove two to three percent of the total metal but most of this material is in the form of coarse particles not fine enough to be categorized as dust. The fine material entrained in the air stream of the exhaust system will amount to approximately 36 grains per pound of metal removed and in typically heavy duty scarfing operations, this may amount to 50 to 75 lb of solids per hour.

The bulk of the particulate matter on a weight basis is represented by the non-fume fraction and various types of wet scrubbers as well as electrical precipitators have been successfully applied to the efficient removal of the entrained dust, although a visible plume due to the escape of very fine particulate matter will be noticeable as an emission from the stack. This material, however, represents only a few pounds per hour and has little or no tendency to settle out of the atmosphere and thus to contribute to dustfall nuisance.

Heating and Reheating Furnaces

The emission of smoke due to inefficient combustion of fuel (blast furnace gas, coke oven gas, natural gas, fuel oil and pitch, or tar from the coke oven by-product plant) represents another area of potential air pollution, although of diminishing significance. There are numerous operations throughout the steel plant involving the heating and re-heating of ingots, blooms, and billets in connection with the operation of the rolling mills and other finishing processes.

In the earlier days of the industry when the technology of furnace design was less well understood, there were frequent instances of smoking chimneys due to lack of automatic fuel-air ratio controls and to insufficient combustion space with the result that the fuel gases were incompletely consumed before coming in contact with the relatively cold steel, and black smoke resulted. With the almost universal use of instruments and automatic combustion controls, modern furnace designs avoid this error and one rarely sees the emission of black smoke from them. Some of the older heating and re-heating furnaces of poor design are still in operation but are rapidly becoming obsolete and being replaced with modern units, and it can therefore be concluded that such few smoking chimneys as remain in the steel industry will disappear before long.

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