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FLARE SYSTEMS STUDY

by

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SECTION I

INTRODUCTION AND SUMMARY

1.1 Introduction

This report presents the results of a study of emissions from flare systems. Flares are used for the control of gaseous combustible emissions from stationary sources. The scope of the study includes an evaluation of existing flare systems, an examination of flare design and sizing criteria, recommended design methods and features, an assessment of present emission problems and a recommended research program for flare emissions control. Information was obtained from the published literature, equipment manufacturers, equipment users, air pollution control agencies and universities. Visits were made to many of these sources of information in order to hold detailed technical discussions about the design and performance of flare systems.

Flaring is intended primarily as a safety measure for disposing of large quantities of gases during plant emergencies. Flows are typically intermittent with flow rates of several million cubic feet an hour during major upsets. Continuous flaring is generally limited to flows not greater than a few hundred cubic feet an hour. Since flaring is relatively inexpensive, this technique has been suggested for the control of gaseous combustible emissions from stationary sources. However, emissions from flares could also create a potential problem. This study was carried out with two objectives in mind. One was to determine the potential of flares as a control system and the second was to assess the emission hazards of present industrial flares.

Section II of this report explains the different applications of flaring waste gases. Section III describes the commercially available flare systems and gives comparative cost data. Section IV discusses flare design criteria including in some detail the two main problem areas of flare emissions and safety. Section V presents recommended design methods; Section VII discusses present flare loadings for various industries and their impact on emissions; Section VIII contains a recommended flare research program.

1.2 Summary

Commercially available flare systems are of two basic types — elevated and ground flares. Presently, these serve separate functions; elevated flares are used primarily for disposal of gaseous wastes generated during plant emergencies such as during power failure, plant fires, component failure and other overpressure situations in which discharge directly to the atmosphere could result in explosion hazards. Elevated flares are therefore used primarily in conjunction with vapor relief collection systems in large-scale chemical manufacturing or petroleum refining operations. Other limited applications include venting of storage tanks and loading platforms.

Although steam, water and air are frequently injected into the elevated flare burner to reduce smoke and luminosity, expedient vapor disposal rather than pollution control has been the design emphasis. Recently developed low-level flare systems represent a departure from conventional design. With recent emphasis reducing noise, chemical emissions, heat and luminosity, low-level flares have become increasing popular for disposing of routine discharges. These include disposal of flammable gases leaking from process and relief valves, process waste streams, and excess or off-specification product.

1.2.1 Elevated Flares

Elevated flare systems provide a means for disposal of gaseous waste streams with an almost unlimited range of flows and a minimal pressure drop of 0 to 60 inches H_2O. As such, elevated flares provide a unique function which cannot be duplicated by other types of combustion equipment.

Design criteria for elevated flare systems are oriented almost exclusively toward safe rather than efficient combustion of gaseous wastes. Accordingly, sizing calculations presently available are based on allowable pressure drop (Section 5.1.2) and dispersion of thermal radiation (Section 5.1.4) or the dispersion of toxic gases when a flare-out occurs (Section 4.1.7). Discharge of liquids into the flare system can cause problems, and "knock-out" or liquid disentrainment drums are required for liquid removal.

1.2.2 Low-Level Enclosed Flares

Low-level flares with enclosed combustion are being used in conjunction with the elevated flare in response to recent emphasis on pollution. These are described in detail in Section III. The study indicates that low-level flares, although relatively expensive to build and maintain, are effective in reducing noise and thermal emissions.

Relatively little information has been found on sizing and design of low-level flares. The normal configuration for construction of a low-level flare involves a steel outer shell, lined with refractory material. The outer shell serves to conceal the flame and prevent thermal and luminous radiation. As in other types of combustion equipment, the refractory also protects the steel shell from direct exposure to the effects of high temperatures and corrosive materials, and to improve combustion efficiency by minimizing heat losses. Refractory thicknesses typically varies from about 4 to 8 inches. The refractory used results in a sluggish response to abrupt changes in gas flow and adds considerably to the construction and maintenance costs of a low-level flare. Because of the slow heatup associated with refractory construction, the low-level flare is normally used only for low or continuous flow rates, with an elevated flare of conventional design used to accommodate sudden upsets. An elevated flare must be associated with low-level flare applications in most conventional designs.

1.2.3 Auxiliary Equipment

Auxiliary equipment for the flare system includes igniters, pilots and safety-oriented equipment described in Sections 3.1, 4.4 and 5.1.6.

Knockout drums are normally provided for removal of liquids from the flared stream. Water seals and, less frequently, flame arrestors are used to isolate the flare stack from the vent collection system. Purge gas generators and vapor traps serve to prevent the formation of explosive mixtures within the flare stack. Maintenance of the liquid level in water seals and disentrainment drums is critical; liquid level control and alarm systems are available for these systems. Pilot burners are also frequently equipped with flame detection and alarm systems.

1.2.4 Costs

Capital costs for low-level flares and various types of elevated flares are given in Section 3.4. This information is based on discussions with flare vendors and users.

Elevated flare equipment costs vary considerably because of the disproportionate costs for auxiliary and control equipment and the relatively low cost of the flare stack and burner. As a result, equipment costs are rarely diameter-dependent. Typical installed costs range from $30,000 to about $100,000. Low-level flares are approximately ten times more expensive for similar capacity ranges.

Operating costs are determined chiefly by fuel costs for purge gas and pilot burners, and by steam required for smokeless flaring. Steam and other requirements are discussed in Sections 5.1.3 and 5.1.7. On the basis of 30 cents per million Btu's fuel requirements, typical elevated flare stack operating costs (2-foot-diameter stack) are about $1,500 per year.

1.2.5 Flare Performance and Emissions

Since flaring has traditionally been used for the safe disposal of gases discharged under emergency conditions, performance standards relating to combustion efficiency and gaseous emissions are limited. Probable air pollutants from elevated flares include CO, unburned hydrocarbons, aldehydes, and particulates as expected from any combustion process involving large, turbulent diffusion flames. These emissions result from flame quenching. Relatively low flame temperatures are typically observed for both elevated and low-level flares, probably resulting in low NO_x emission factors compared to other types of industrial combustion equipment.

Results of a survey to determine flare loadings and estimated flare emissions are discussed in Section VII. It was found that the average yearly emissions from flares constitute just a small fraction, less than 1%, of the average yearly plant* emissions. Total flare emissions over a year's time therefore probably only have a small impact on total plant

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*Representative plants include U.S. petroleum refineries, iron and steel mills and chemical manufacturing facilities.

emissions. However, because of the intermittent nature of flaring, the majority of flare emissions are concentrated into just a few minutes of actual flaring. During this time five or more times the normal plant emissions are released into the atmosphere.

1.2.6 Proposed Research and Development Programs

Programs have been developed to provide technology where deficiencies exist, to generate the data required to evaluate combustion modifications and extend the application of flaring to air pollution control.

Since little quantitative performance data were found in this study, field testing of elevated and enclosed ground level flare systems is recommended. Testing should be done to determine the concentration and characteristics of flare combustion products as well as the mass rate of emissions in order to evaluate the efficiency of flare systems as a control device.

A combustion research program is recommended to fill the gaps existing in the technology of large diffusion flames. For this study, construction of a large scale flare burner and combustion chamber is recommended. Part of the rationale and incentive for this program is that many industrial flames are of the turbulent-diffusion-flame type.

SECTION II

BACKGROUND

In many industrial operations, and particularly in chemical plants and petroleum refineries, large volumes of combustible waste gases are produced. These gases result from undetected leaks in the operating equipment, from upset conditions in the normal operation of a plant where gases must be vented to avoid dangerously high pressures in operating equipment, from plant start ups and from emergency shut downs. Large quantities of gases may also result from "off-spec" product or excess product which cannot be sold. Flows are typically intermittent with flow rates during major upsets of several million cubic feet per hour.

The preferred control method for excess gases and vapors is to recover them in a blowdown recovery system. However, large quantities of gas, especially those produced during upset and emergency conditions, are difficult to contain and reprocess. In the past all waste gases were vented directly into the atmosphere. However, widespread venting caused safety and environmental problems. In practice, therefore, it is now customary to collect such gases in a closed flare system and to burn these gases as they are discharged from an elevated flare stack or alternately the gases may be discharged and burned at ground level usually with shielding for the flame.

The flare system is used primarily as a safe method for disposing of excess waste gases. However, the flare system itself can present additional safety problems. These include the explosion potential of a flare, thermal radiation hazards from the flame, and the problem of toxic asphyxiation during flame-out. Aside from safety there are several other problems associated with flaring which must be dealt with during the design and operation of a flare system. These problems fall into the general area of emissions from flares and include the formation of smoke, the luminosity of the flame, noise during flaring and the possible emission of air pollutants during flaring.

2.1 Applications of Flaring for Waste Gas Disposal

There are three main considerations in deciding whether to flare a waste gas. These are: (1) the variability of the flow of the waste stream, (2) the expected maximum volume of the stream to be flared, and (3) the heat content of the waste stream.

A high variability of flow of the waste stream is probably the most important factor. A flare is designed to operate for practically an infinite "turndown" range of flows. Alternate waste gas disposal systems such as incinerators or afterburners need an adequate control on the flow of waste gases and can only be used for continuous or at least fairly continuous gas flows.

The volume of the waste stream to be disposed is also an important factor. With very large volumes of gas, direct flame combustion by incineration or a flame afterburner device becomes impractical due to the size of equipment needed. However, capacity for an elevated flare can be increased easily by increasing the diameter of the stack. A typical small flare with a four-inch diameter stack has a capacity of 30,000 scfh. A normal refinery flare with a capacity of 5,000,000 scfh would need only a 36-inch diameter flare stack.

The heat content of a waste gas falls into two classes. The gases can either maintain their own combustion or they cannot maintain their own combustion. In general, a waste gas with a heating value greater than 200 Btu/ft^3 can be flared successfully. The heating value is based on the lower heating value of the waste gas at the flare. Below 200 Btu/ft^3 enriching the waste gas by injecting a gas with a high heating value may be necessary. The addition of such a rich gas is called endothermic flaring. Gases with a heating value as low as 60 Btu/ft^3 have been flared but at a significant fuel demand (Ref. 1). It is usually not feasible to flare a gas with a heating value below 100 Btu/ft^3 (Ref. 2). If the flow of low BTU gas is continuous, incineration can be used to dispose of the gas. For intermittent flows, endothermic flaring is the only possibility.

Flares are well suited for disposing of intermittent flows of large and small volumes of waste gases that have an adequate heat value to sustain combustion. For intermittent flows of low heating value waste gases, additional fuel must be added to the waste stream in order to flare. Since the value of the additional fuel can become considerable and is completely lost during flaring, endothermic flaring can become expensive. However, if intermittent flows of low heat waste gases are in large volumes, the only practical alternative to flaring is to vent the gases directly to the atmosphere. This is usually unacceptable for environmental reasons.

Most flares are used to dispose of the intermittent flow of waste gases. There are some continuous flares but they are used generally for small volumes of gases on the order of 500 cfm or less. The heating value of larger continuous flows of a high heat waste stream is usually too valuable to waste in a flare. Vapor recovery or the use of the vapor as fuel in a process heater is preferred over flaring. For large continuous flows of a low heating value gas, auxiliary fuel must be added to the gas in order to flare. It is much more efficient to burn the gas in an enclosed incinerator rather than in the flame of a flare. For small continuous flow of gases, flares are sometimes used even though fuel or heat is either lost or wasted. In these cases the equipment costs are sometimes more important than fuel savings and a flare is more economical to use.

Flares are mostly used for the disposal of hydrocarbons. Waste gases composed of natural gas, propane, ethylene, propylene, butadiene and butane probably constitute over 95% of the material flared. Flares have been used successfully to control malodorous gases such as mercaptans and amines (Ref. 3). However, care must be taken when flaring these gases. Unless the flare is very efficient and gives good combustion, obnoxious fumes can escape unburned and cause a nuisance (Ref. 4).

Flaring of hydrogen sulfide should be avoided because of its toxicity and low odor threshold. In addition, burning relatively small amounts of hydrogen sulfide can create enough sulfur dioxide to cause crop damage or local nuisance (Ref. 5). In recent years gases whose combustion products may cause problems, such as those containing hydrogen sulfide or chlorinated hydrocarbons, have not been recommended for flaring.

2.2 Flaring Methods

The elevated flare is the most common type of flare system in use today. In this flare, gas is discharged without substantial premixing, and ignited and burned at the point of discharge. Combustion of the discharged gases takes place in the ambient atmospheric air by means of a diffusion flame. This type of combustion often results in an insufficient supply of air and thus a smoky flame. A smokeless flame can be obtained when an adequate amount of combustion air is mixed sufficiently with the gas so that it burns completely. Smokeless burning is usually accomplished by injecting steam into the flame. The modern elevated flare allows large volumes of waste gases to be burned safely and inexpensively. However, the elevated flare can also present other emission problems including the emission of noise, light and chemical air pollutants into the atmosphere.

A second type of flare often found is the ground flare. A ground flare consists of a burner and auxiliaries located at or near ground level. The burner may be with or without shielding but it must allow for the free escape of the flame and combustion products. Ground flares have the advantage of being able to have the flame shielded. Compared to elevated flares they either require more land if unshielded or the burners, controls and shielding may be more expensive than a stack. Also if the ignition or pilot system fails, the ground flare cannot disperse the gases as well as an elevated flare.

A third system which has been recently developed and is being employed more frequently, particularly where noise luminosity and smoke formation are severely criticized by local residents, is an enclosed "low-level" ground flare used in conjunction with an elevated flare. In more than 90% of the flare occurrences the load to the flare is less than 10% of design capacity of a flare stack (Ref. 2). The "low-level" ground flare is designed to handle most of the flare occurrences, and the remaining large releases use both systems. This system, called an integrated flare, although expensive can greatly reduce smoke, noise and light emissions that cause complaints from local residents.

Forced draft flaring, where combustion air is mechanically blown to premix with the gas before igniting, is ideal as far as combustion is concerned. This type of flare achieves smokeless burning without the use of steam injection. However, this method has a limited turndown ratio and requires a much larger flare stack for the added combustion air. While this approach has been utilized for some special applications, mostly in places where smokeless burning is required but steam is not available, it has generally been found uneconomical for most uses.

The use of air-inspirating burners for premixed air has also been attempted with flares. This type of operation requires the gas to be supplied at substantially constant rate and pressure of the order of 1 to 4 psig. In many cases such pressure cannot be made available because limitations of the vent gas collecting system. For air-inspirating installations it is also generally necessary to provide a numberof burners of different capacities to handle the wide range of venting rates normally encountered. Flare systems based on this principle have been largely unsuccessful.

Usually, if there is a continuous flow of gas, a vapor recovery system is considered. While the collection, storage, and return of gas is expensive, the continuous wasting of gas may be much more expensive. The capital expenditures to store and recompress immense volumes released intermittently and irregularly usually exceeds the operating expense of flaring the gas. Many plants are now using their flare system in conjunction with a vapor recovery system. They have a triad system for control of waste gases which consists of a vapor recovery system, a low-level flare for most of the flare occurrences which overload the vapor recovery system and an elevated flare for large releases which overload the low-level flare.

Horton et al., (Ref. 6) have discussed what they feel is the future answer to reducing the possible load to a flare. The nuclear power industry has installed highly reliable instrumented systems to eliminate the need for relief valves and still protect a system from overpressure (Ref. 7). However, these systems have not achieved wide use in the chemical or petroleum industry.

The real source of most pressure in gas-liquid systems is heat. Fired heaters and heat exchangers create large volumes of gas which must be relieved. A highly reliable means for automatically cutting off heat, when the pressure reaches a specified value, would decrease or eliminate the need for a safety relief valve. It would therefore decrease the quantity of gas sent to the flare. Reliability is usually assured by independent and redundant instrumentation (Ref. 7).

The high integrity protection system can never totally eliminate all safety relief valves in a plant and thus the need for a flare. However, the load to the flare would be greatly reduced with the flare being used only in major emergency situations.

SECTION III

COMMERCIALLY AVAILABLE FLARE SYSTEMS

In general there are three types of flare systems in use today, the elevated, ground and forced draft flare. This section will describe the equipment available for flaring waste gases by these systems and will also present relative cost data for the different systems.

3.1 Elevated Flares

The modern elevated flare system is made up of several components including the flare tip, some type of gas trap directly below the tip, a pilot and ignition system at the top of the flare tip, and the stack and its support. When smokeless burning is required, a steam injection system must also be provided at the top of the flare. Water seals and knockout drums are also usually required for safety reasons. Figure 3-1 shows a schematic of a typical elevated flare system.

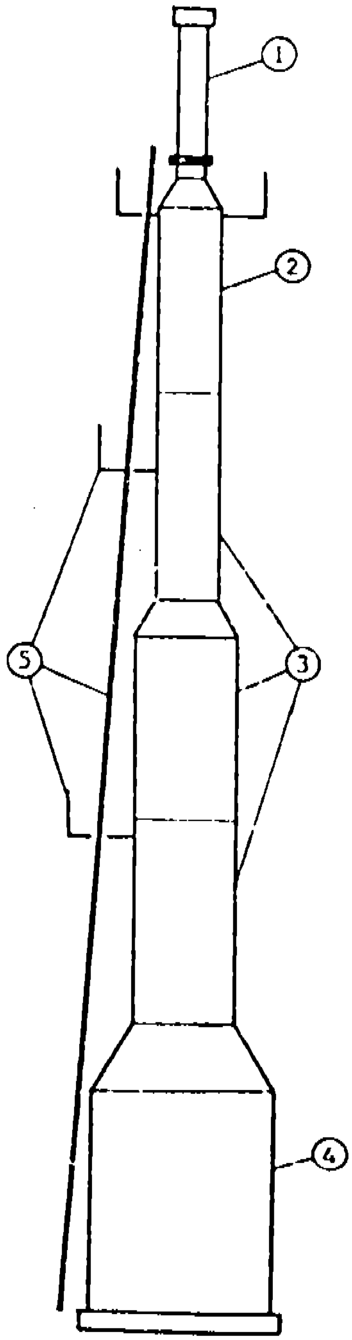
3.1.1 Flare Tips

A flare tip must be capable of operating over a wide range of turndown ratios. To achieve this, the flare must have excellent flame holding ability and mixing characteristics. Flameholding is ensured by providing multiple continuous pilots around the combustion tip and by providing a flame stabilization ring on the combustion tip. Figure 3-2 shows the standard flare tips available from John Zink Company. The flare tip is usually made of stainless steel or some other high temperature and corrosion-resistant alloy.

Smokeless burning can be achieved with special flare tips which inject water, natural gas or steam into the flame thereby increasing air-gas mixing to ensure complete combustion. Water injection has many disadvantages including ice formation in the winter, a mist in the summer, the tremendous pressure head needed for an elevated flare and a turndown ratio much less than steam, making control very difficult with the possibility of quenching the flame. Natural gas has also been used to inject into the flame for smokeless burning but only in the case where the gas itself has no value since it is also burned during flaring. For these reasons steam is the most common utility used for smokeless burning.

There are two basic steam injection techniques used in elevated flares. In one method steam is injected from nozzles on an external ring around the top of the tip. In the second method the steam is injected by a single nozzle located concentrically within the burner tip. Vendors use various types of nozzles to create a circular, swirl, fan, jet or Coanda effect.

In recent years environmental regulations have required flares to be smokeless for large turndown ratios. To ensure satisfactory operation under varied flow conditions, the two types of steam injection have been combined into one tip. The internal nozzle provides steam at low flow



①	Flare Burner and Location of Fluidic Seal
②	Gas Trap
③	Riser Sections
④	Entry, Disentrainment or Water Seal
⑤	Ladders and Platforms

Fig. 3-1 - Integrated Flare Stack Components

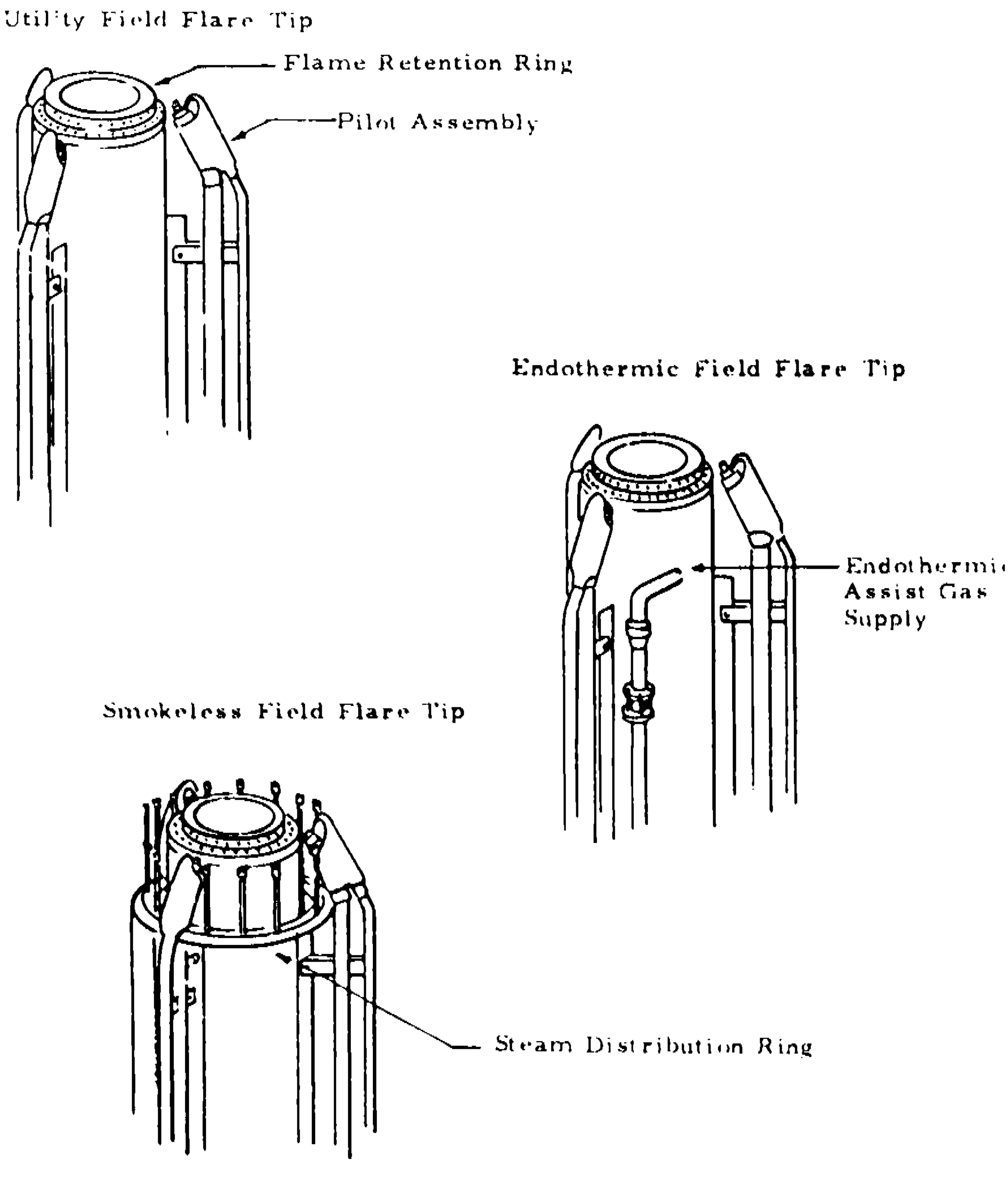


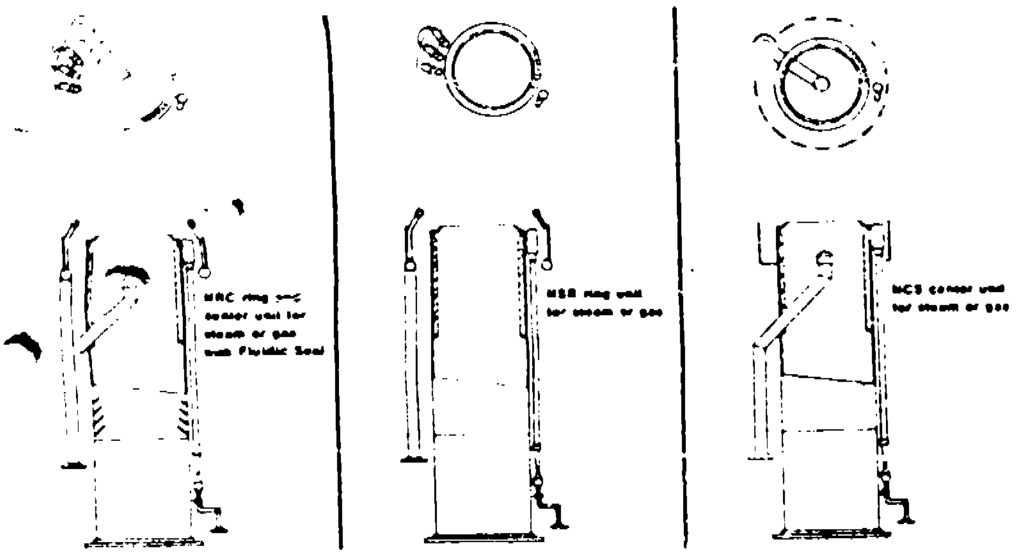
Fig. 3-2 - Flare Tips from John Zink Company rates while the external jets are available at large flow rates. Figure 3-3 shows a schematic of National AirOil flare tips illustrating the different steam injection methods.

While these are the most common types of tips, there are several other mainly special purpose tips commercially available. A further modification of the steam injection tip is shown in Fig. 3-4. Here, an internal nozzle is used to inject both steam and air into the tip. The major disadvantage of this system is that a larger tip is needed because of the increased pressure drop. Under some circumstances, the gases may actually burn inside the tip. Figure 3-5 shows a tip using a Coanda effect of steam injection to achieve the required air gas mixture. While this method provides efficient mixing, the burning of the gas takes place inside the flare tip instead of outside or above as with the other tips. Burning inside the tip can drastically shorten the life of the tip. Figure 3-6 shows National AirOil's jet mix vortex tip. These can be used with relatively high pressure waste gases with little or no steam needed for smokless operations. Figure 3-7 shows the special purpose In-air flare tip which burns gases smokelessly without steam. It has limited use since it requires both high pressures and low pressure gas in the ratio of about three to one. Also its maximum turndown ratio is only about two. Other special purpose tips are available including endothermic tips that inject gas to raise the heat value of the waste stream and tips with added muffling for quiter flaring.

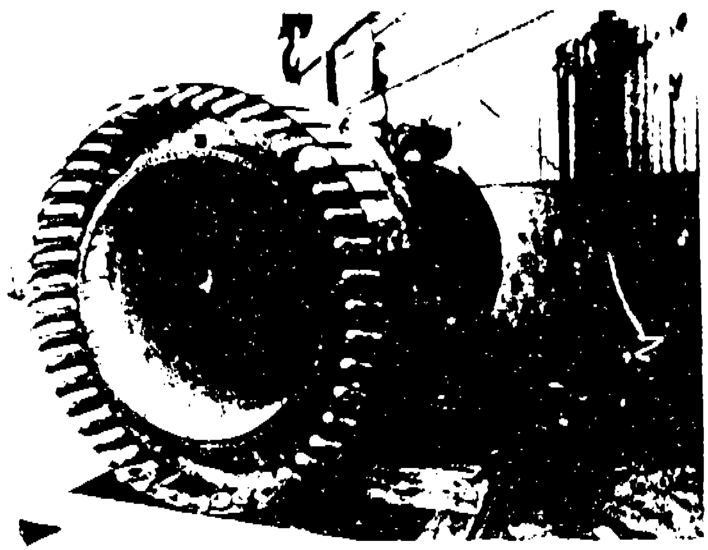
The rate of steam injection to the flare tip can be controlled manually or automatically. While automatic control is usually not mandatory, it is preferred because it reduces steam usage, greatly reduces the amount of smoking and minimizes noise. Automatic systems use flow measurement devices with ratio control on steam. Since the flow rate measurement cannot include the variables of degree of saturation and molecular weight, the ratio control is usually set for some average hydrocarbon composition. It is usually necessary to have a fixed quantity of steam flowing at all times to cool the distribution nozzles at the tip.

3.1.2 Gas Traps

To prevent air migration into the flare stack as a result of wind effects or density difference between air and flare gas, a continuous purge gas flow through the flare system is maintained. The system can be purged with natural gas, processed gas, inert gas or nitrogen. To reduce the amount of purge gas requirement and to keep air out of a flare system, gas trap devices are normally located in the stack directly under the flare tip. One type of gas trap commercially available is the molecular seal (Fig. 3-8). This type trap may not prevent air from getting in the stack as a result of gas cooling in the flare headers. Instrumentation systems are available to automatically increase the purge rate to prevent air from entering the stack during rapid gas cooling. A new development in gas traps is National AirOil's Fluidic Seal (Fig. 3-9). This seal weighs much less than a molecular seal and thus can be placed much closer to the flare tip.



a. Schematic of Ring or Center Unit for Steam



b. NAO 48-Inch Ring and Center Unit for Steam

Fig. 3-3 - Flare Tips Illustrating Ring and Center Steam Injection Units (from National AirOil)

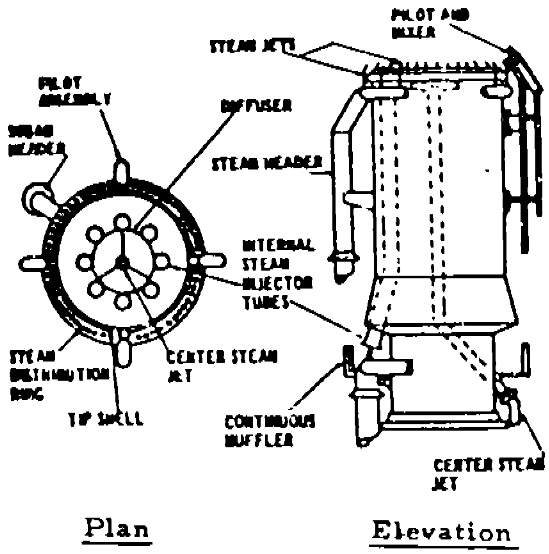


Fig. 3-4 - Detail of Internal Steam Injection System from John Zink Company

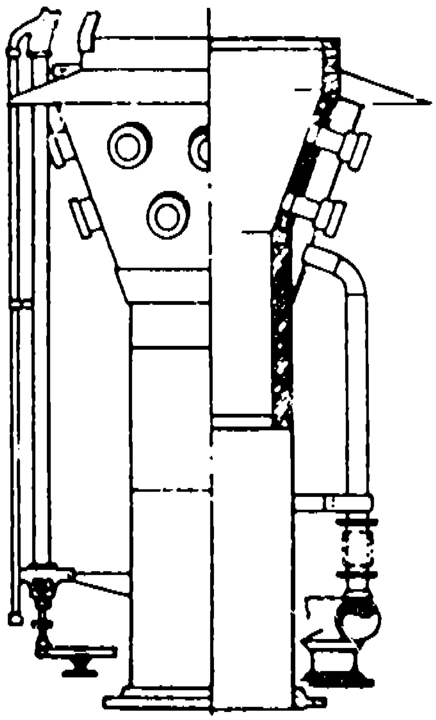


Fig. 3-5 - Coanda-Type Flare Tip from Flargas Engineering, Ltd.

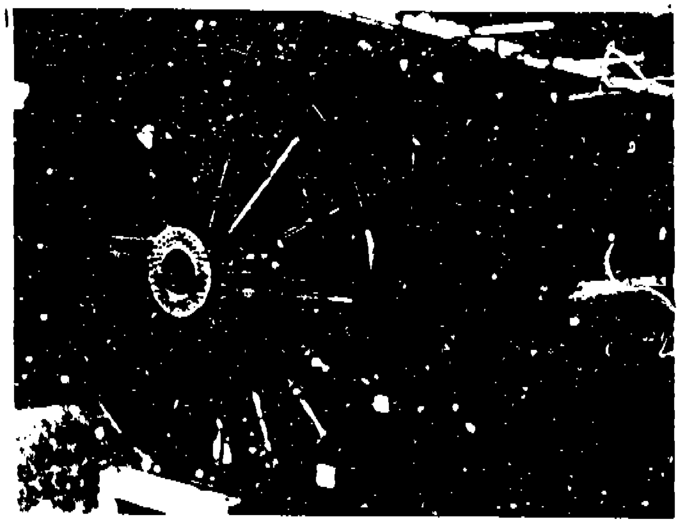


Fig. 3-6 - Jet Mix Vortex Flare Tip with Steam Assist (from National AirOil)

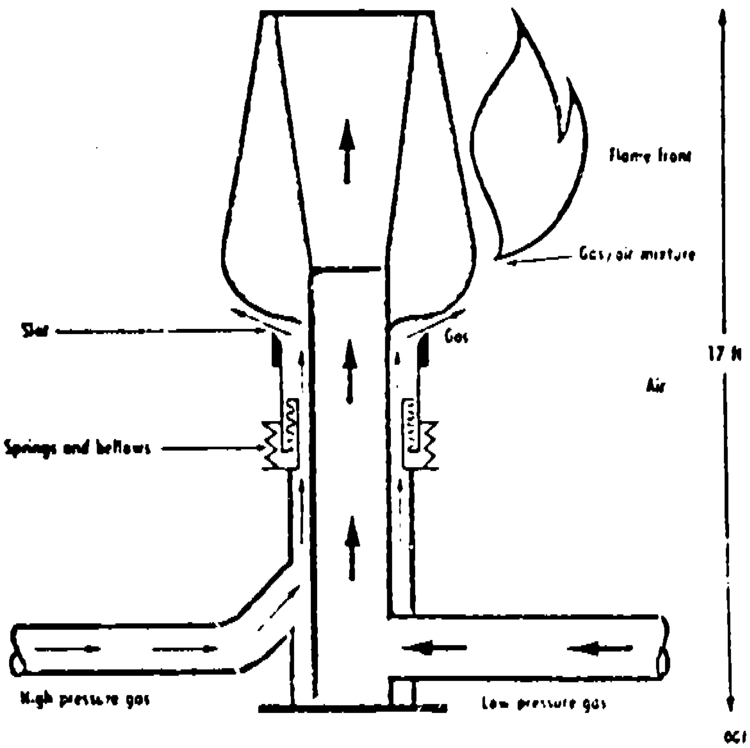
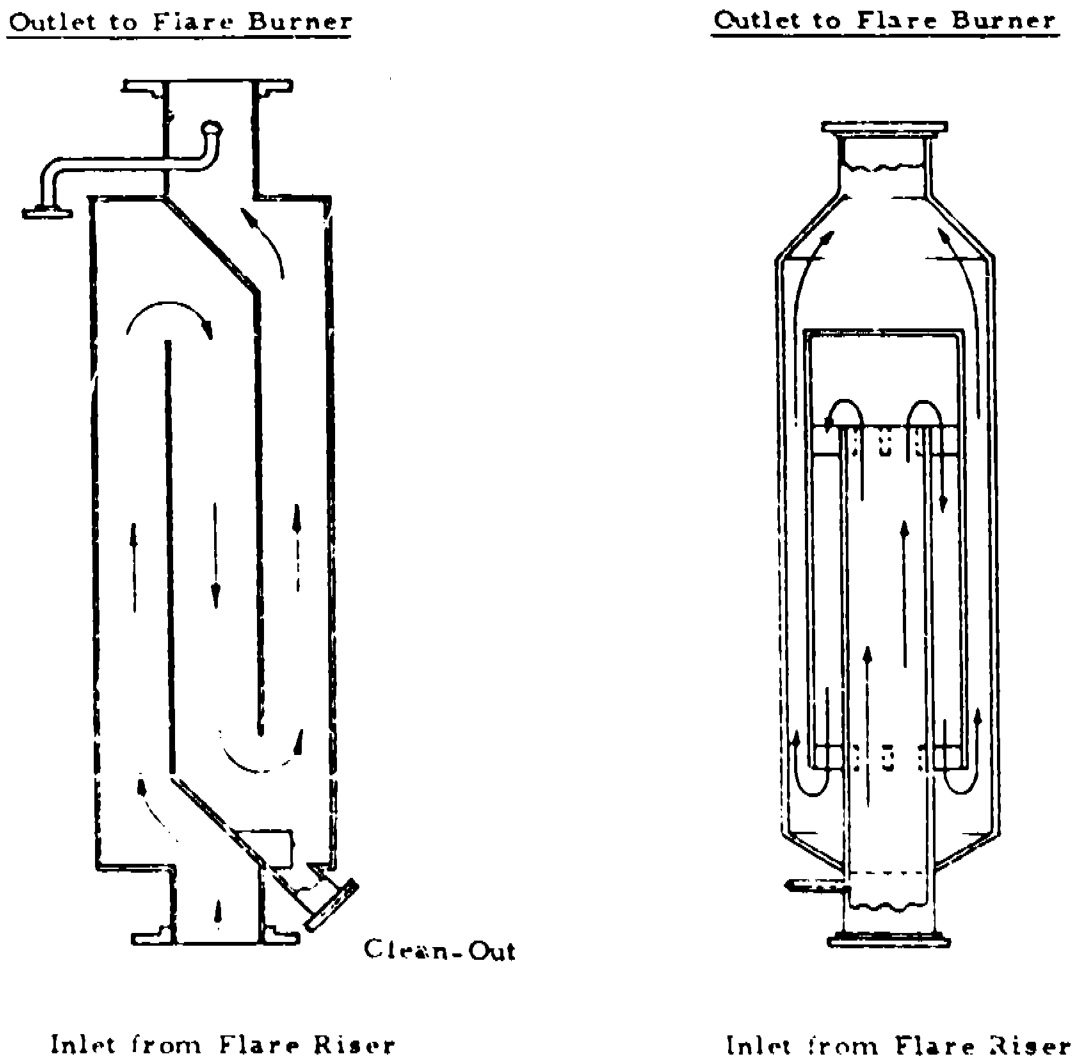


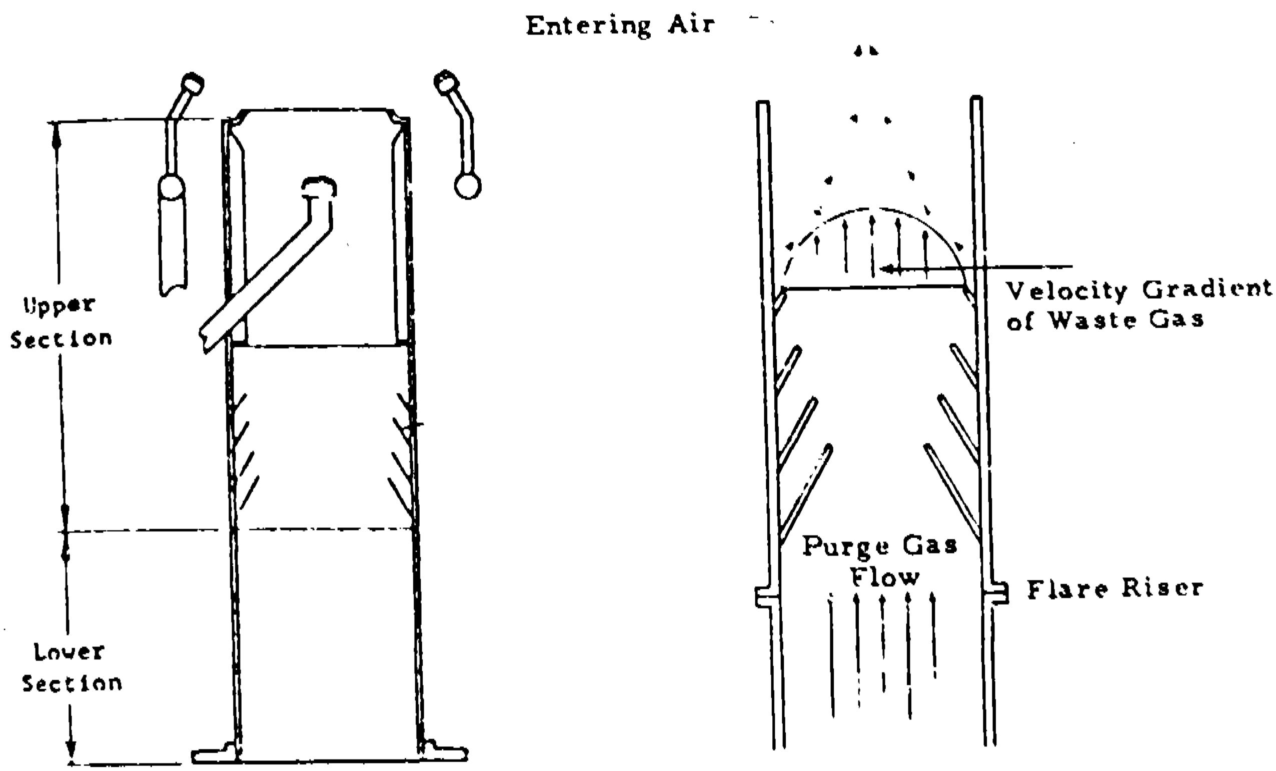
Fig. 3-7 - The Indair Flare Tip (from Oil and Gas Journal)



National AirOil NDS Double Seal
(Patent applied for)

John Zink Molecular Seal
(U.S. 3,055,417)

Fig. 3-8 - Air Reentry Seals



Flare Burner with Seal Baffles

Velocity Profiles

Fig. 3-9 - National AirOil Fluidic Seal

3.1.3 Pilot and Ignition System

The ignition mechanism for a flare installation usually consists of the pilot burners and the pilot burner igniters. The pilot burners serve to ignite the outflowing gases and to keep the gas burning. These pilots must provide a stable flame to ignite the flare gases, and in many cases, to keep them burning. To accomplish this more than one and usually three or four pilot burners are always used. The pilot burners are also sometimes provided with separate wind shields as shown in Fig. 3-10.

A separate system must be provided for the ignition of the pilot burner as safeguard against flare failure. The usual method used is to ignite a gas/air mixture in an ignition chamber by a spark. The flame front travels through an igniter tube to the pilot burner at the top of the flare. This system permits the igniter to be set up at a safe distance from the flare, up to 100 feet, and still ignite the pilots satisfactorily. Figure 3-11 shows one arrangement of the ignition system. The whole device is mounted on an ignition panel and set up in an accessible spot on the ground. The ignition panel must be explosion proof, have an unlimited life, and be insensitive to all weather conditions. On elevated flares, the pilot flame is usually not visible and an alarm system to indicate pilot flame failure is desirable. This is usually done by a thermocouple in the pilot burner flame. In the event of flame failure, the temperature drops and an alarm sounds.

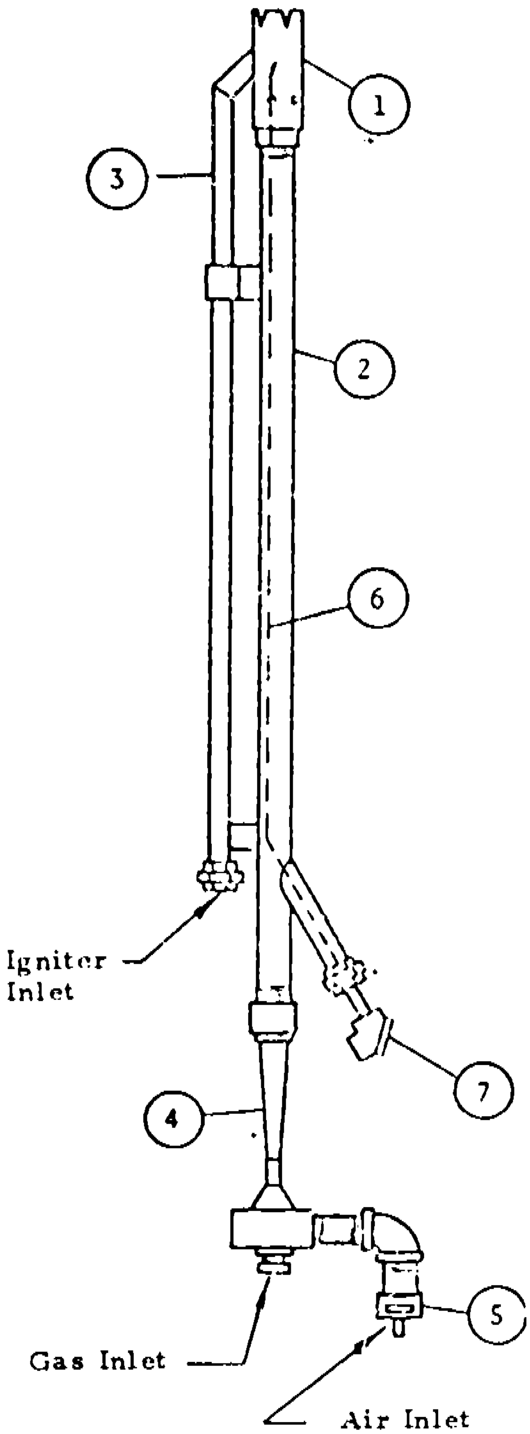
3.1.4 The Stack and Its Support

Figure 3-12 shows the methods used to support the complete flare tower. These towers must be provided with a climbing ladder with a cage and landing on top for repair and maintenance purposes. These towers for refineries can range from 200 to 400 feet high. Flare towers with a proportion of length-to-diameter ratio less than 30 are usually constructed as self-supporting stacks; towers with a proportion L/D < 100 are supported with a set of guys, and when the proportion is L/D > 100, the towers are made with two or more sets of guys (Ref. 2). Self-supporting stacks are usually not built over 50 feet high because of the large and expensive foundation required (Ref. [illegible]).

The guys need a large area for high stacks, that is why it is often preferred to build steel supports to which the stack is fastened. These are usually steel framework with a square cross section widened at the base. A triangular cross section adopted from the modern television antennas, is more economical and has been used in several refineries (Ref. 8). The flare stack will expand because of the hot gas flow, and the supporting structure must be able to accommodate this expansion.

3.1.5 Water Seals, Flame Arrestors and Knockout Drums

Water seals and flame arrestors are used to prevent a flame front from entering the flare system. Flame arrestors have a tendency to plug and obstruct flow and are not capable of stopping a flame front in mixtures of air with hydrogen, acetylene, ethylene oxide and carbon disulfide; thus they are of little value (Ref. 1).



1. Shielded Pilot Nozzle
2. 2 in. Pilot Tube
3. 1 in. Igniter Tube
4. Inspirator
5. Air Adjuster
6. Thermocouple
7. Explosion-Proof-Weather-Proof Junction Box

Fig. 3-10 - Flare Pilot Burner System

Description

(1)	Mounting Plate - 18 x 36 in.
(2)	Air Control Valve (1/2 in.)
(3)	Gas Control Valve (1/2 in.)
(4)	Gas Pressure Gage
(5)	Air Pressure Gage
(6)	Spark Sight Port
(7)	Spark Plug
(8)	Explosionproof Button (Push)
(9)	Transformer in Explosion-Proof-Weather-Proof Housing
(10)	Three-Way Valves

NOTE: Quantity of Item 10 will vary with number of pilots on flare.

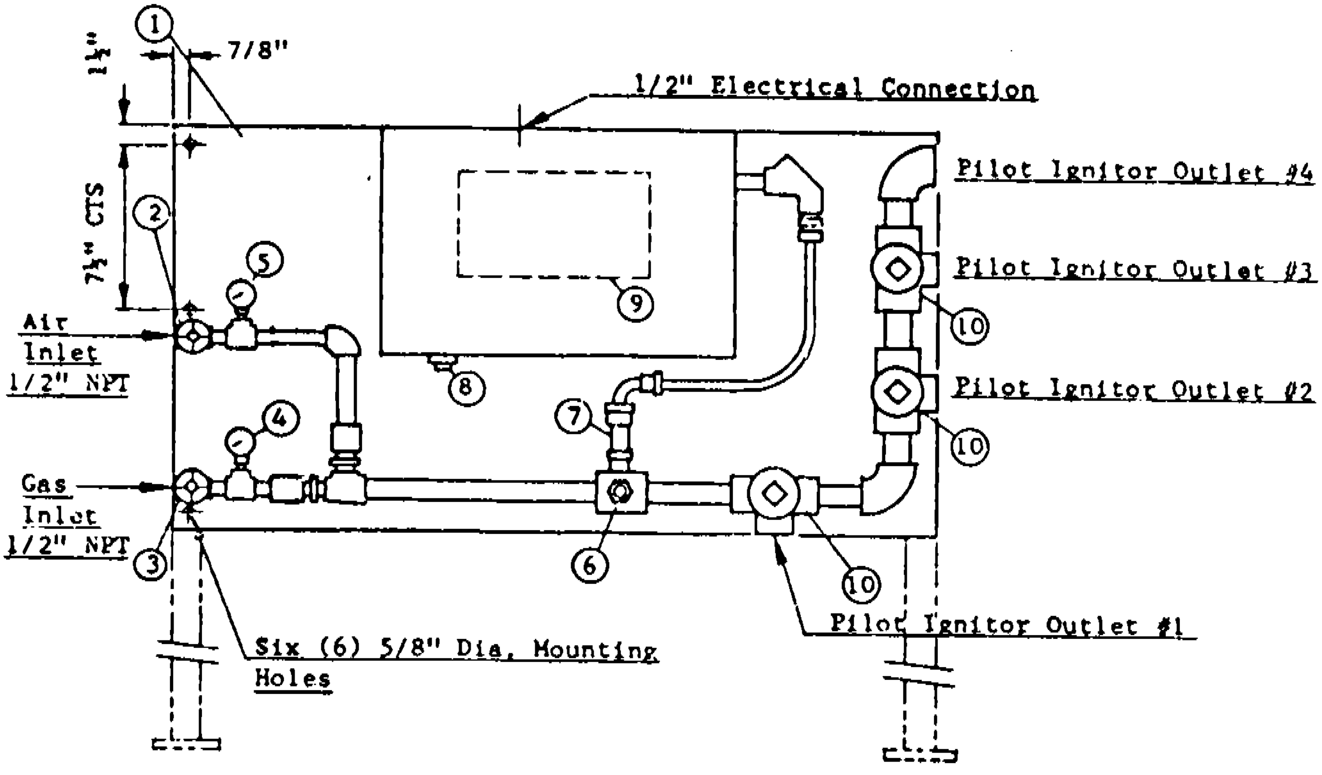


Fig. 3-11 - Flare Ignition System from National Air Oil

Table 6-1

METHODS FOR SO_2 (From Ref. 15)

Method	Principle	Instrumentation	Applicability	Limitations
Hydrogen Peroxide Titration Method (EPA method 3)	$SO_2 + H_2O_2 \rightarrow H_2SO_4$ Titration with base or B[illegible]	Laboratory Equipment: Absorber and titration units	Range: 0.01 to 100 ppm	Requires reagent additions.
Hydrogen Peroxide Conductometric Method	$SO_2 + H_2O_2 \rightarrow H_2SO_4$ Measure Conductivity	Monitors: Leeds & Northrup, AEROSCAN; Westhoff U3S ULTRAGAS ANALYZER; Instruments Development, IDC 902-1; Scientific Instruments, SI-67	Range: 0.01 to 5 ppm	Interferences by salt aerosols and acidic and basic gases which may be eliminated by filters.
Electrolytic (Boulometric) Method	$SO_2 + Br_2 + H_2O \rightarrow 2HBr + H_2SO_4$ $SO + I_2 + H_2O \rightarrow 2HI + H_2SO_4$ Br_2 and I_2 generated electrolytically	Monitors: Consolidated, TITRILOG; Beckman Instruments, Model 906; Barton 286 SULFUR TITRATOR; Phillips Instruments, Model PW 700; Atlas Electric Devices, Model 1200	Range: 0.01 to 5 ppm Monitors simple to operate and reliable for unattended service.	Interference by oxidizing materials, aldehydes, olefins, and hydrogen sulfide. Some interference can be alienated by filters.
WEST-GAEKE Colorimetric Method ASTM D 2914	Formation of dyestuff by reaction with bleached pararosaniline	Laboratory Equipment: Spectrophotometer Monitors: Atlas Electric Devices, Model 1500; Technicon Corp., AUTO ANALYZER	Range: 0.01 to 5 ppm Most nearly specific method for SO_2	Procedure cumbersome. Continuous analyzer needs close attention.
Electrochemical Sensor	Oxidation in a membrane-covered cell	Monitors: Dynasciences, SS-330; Envirometrics NS-200; Theta Sensors LS-800-AS	Range: 0 to 5000 ppm Simple to operate	NO and NO_2 interfere slightly.

the medium of interest, to a remote retroreflector. Again readings are obtained while the laser is both tuned to and detuned from an absorption line of the specie of interest, which leads to a direct measurement of the pollutant concentration.

Comparison of DAS and direct absorption methods show that DAS provides ranging capability by time-of-flight measurement, spatial resolution and three-dimensional, single ended measurement capability. The direct absorption method is simpler in that many of the low-power laser and broad-band sources presently available can be used (Ref. 92).

A common limitation inherent in all the absorption techniques is a practical limit on the detection sensitivity caused by atmospheric turbulence. Turbulent transfer of heat from the earth to the atmosphere causes localized variations in the index of refraction of air. Collimated light passed through the atmosphere is subject to distortion by the attendant focusing-defocusing effect (Ref. 93). Beam spreading, destructive interference within the beam cross section, and beam deflection can result. In remote measurements turbulence can cause the beam to overfill the receiver and can cause the energy received to vary as a function of time. One way to avoid these problems is to complete a measurement in less than a millisecond (Ref. 94). An alternative is signal-averaging over an appropriate time interval.

Long path techniques have many challenges to offer researchers over the next few years. Among the more important are the development of tunable sources and methods of tuning, the measurement of absorption coefficients with sources actually used in the remote-sensing system, and the thorough evaluation of systems to establish their sensitivity and accuracy under real measurement conditions. Once these challenges are met, the remote sensing of air pollutants should become a useful tool (Ref. 92).

SECTION VII

FLARE LOADINGS AND EMISSIONS FOR VARIOUS INDUSTRIES

To determine the impact of flaring on industrial emissions it was necessary to develop data on the quantity and composition of material being flared in order to estimate emissions. During this study of flare systems we have found almost no published data on the amount of flaring for a particular process. In talking to flare manufacturers and users, we have also found that usually users do not keep detailed data on what or how much they are flaring. However, it was generally agreed that the individual plant production people have a fairly good idea of the quantity and quality of gases being flared. It was decided that the best way to obtain this type of information on an industry-wide basis was through a questionnaire survey of a number of different users in each of the major industries that utilize flares. From the results of the survey, estimates were made of total flaring rates of various industries and also of the impact of flaring on total emissions. This section discusses the results of this survey including the calculation of flare loadings and emissions.

7.1 Questionnaire Format and Circulation

The primary purpose of the questionnaire was to determine the quantity and composition of waste streams now being flared. In addition general information on the type and operation of the flare unit was also sought. A copy of the questionnaire, together with the cover letter, is included in this section.

The questionnaire was submitted for approval to the Office of Management and Budget (OMB) in April 1974. After some modifications of the questionnaire, final approval was received from OMB in September 1974.

The flare survey was circulated to the following industries: petroleum refining, chemical manufacturing and iron and steel making. Except for petroleum and gas production, these three industries are the main users of flares. The actual circulation was done by the industry's trade association: The American Petroleum Institute (API) for petroleum refining, the Manufacturing Chemists Association (MCA) for chemical manufacturers and the American Iron & Steel Institute (AISI) for iron and steel making. Working through the trade associations not only made distribution of the survey simpler, since their mailing lists were used, but also helped the response. Response was excellent from all three industry groups with about 75% of the surveys being returned.

7.2 Refinery Questionnaire Results

Through cooperation of the American Petroleum Institute (API), a task force consisting of 10 representatives of the petroleum industry was

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HUNTSVILLE RESEARCH & ENGINEERING CENTER • P. O. BOX 1103 • HUNTSVILLE, ALABAMA • 35807

USER SURVEY – EPA FLARE SYSTEMS STUDY
Contract EPA 68-02-1331

We are currently engaged in an Environmental Protection Agency (EPA) sponsored engineering study of flare systems for control of gaseous emissions from stationary sources. The objective of this study is to evaluate the potential of flaring for hazardous emission control. Our final report, which will be publicly available, will include an evaluation of present flaring practice and design methods, general cost data, and data on any air pollution problem that flares themselves may cause. The EPA plans to use this report as a guide for potential utilization of flares and as a basis for future research and development programs in flare technology. We are obtaining our information from the literature by contacting flare manufacturers and from this user survey we are circulating.

We believe that industrial users of flare equipment comprise an important source of information for this study. Of particular interest is determining what waste streams are now being flared and the amount of flaring that is occurring. We ask that you participate in this survey by supplying the information requested on the enclosed questionnaire. Your participation will be valuable even if you can only supply part of the information requested. The information you supply will be held confidential by LMSC through the report writing stage, then destroyed. Some of it may appear in tabular or statistical form in our report but without identifying your company.

We would appreciate your completing a separate copy of Sections II-IV for each flare unit. We can supply additional copies if needed. If you have any questions, please call us at (205) 837-1800 and ask for M. G. Klett, J. B. Galeski or S. V. Bourgeois. Please return this questionnaire to Lockheed Missiles & Space Company, P. O. Box 1103, Huntsville, Alabama 35807, Attention: M. G. Klett.

Your cooperation in participating in this survey will be greatly appreciated.

Sincerely yours,

S. V. Bourgeois

S. V. Bourgeois
Project Manager

Enclosure: (1) Survey Questionnaire

O. M. B. No. 158-S74008
Appr. Exp: 30 April 1975

SURVEY OF USERS OF INDUSTRIAL FLARE SYSTEMS
Contract EPA 68-02-1331

Date ______________________

Section I - Plant Identification

1. Name and Location:

   a. Name of Company: ______________________
   b. Plant/Division: ______________________
   c. No., Street: ______________________
   d. City: ______________ State: __________ Zip: __________

2. Person to contact regarding information contained in this report:

   a. Name: ______________________
   b. Department/Division ______________________
   c. Telephone: (Area Code) ______________________

3. Principal product(s) of this plant: ______________________

   ____

4. How many flare systems (individual stack/burners) do you have at this location? ______________
   (If two or more, please complete Sections II to IV for each system. Additional blanks are enclosed.)

Section II - General Information

1. Flare identification (if more than one at location): ______________
2. Name of process(es) generating waste gas stream: ______________
3. Capacity of process(es) (lb/hr, b/d, etc.): ______________
4. Is the flare operated principally to control (check applicable items):

   a. Intermittent flow of excess waste gas ______________
   b. Continuous flow of waste gas ______________
   c. Odor nuisance ______________
   d. Toxic nuisance ______________

e. Emergency or abnormal process venting ______________

f. Other (please specify) ______________

5. Description of waste stream fed to flare (Engineering Estimate Permissible):

a. Waste stream(s) being flared: ______________

b. Average composition of waste stream being flared: ______________

____

c. Average load to flare for each combustible constituent(s) (for intermittent flares average load over a year): ______________

______________ lb/hr.

d. Number of major dumps to flare in previous year: ______________

____

e. Amount of gas flared/dump ______________ lb or scf

f. Heating value of waste stream: ______________ Btu/scf

6. Is the waste stream pretreated prior to flaring? ______________

If yes, please specify: ______________

Section III - Flare Information

1. What is the type of flare (check one)?

a. Elevated ______________ Height (ft) ______________

b. Ground Level ______________

c. Burning Pit ______________

d. Other (Please specify) ______________

2. Flare Capacity (lb/hr) ______________

3. Flare Diameter (inches) ______________

4. Does the flare have the following auxiliaries (check applicable items)

a. Knockout Drums ______________

b. Water Seals ______________

c. Flame Arrestor ______________

d. Purging ______________ Type of Purge Gas ______________

Purge Rate ______________ lb/hr.

e. Stack Seal ____________

f. Smokeless Burning ________ Water ________ Stream ________

g. Automatic Control of Smokeless Burning ________________

5. Do you monitor flare emissions? ________ If yes, please specify how:

____

Are these data available to us? ________________

6. What problems have you had in keeping the system operable?

7. Name of manufacturer of flare: ________________

Did the same company design and install the system? ________

If not, name of company(s) which did: ________________

____

Date of Installation: ________________

Section IV - Follow-Up

Would you be willing to discuss in more detail system performance, data, and design features through a telephone call or visit to your plant by one of our representatives? ____________

If you have any questions, please call one of the people listed on the cover letter at (205) 837-1800. Please return this questionnaire to Lockheed Missiles & Space Company, P.O. Box 1103, Huntsville, Alabama 35807, Attention: M.G. Klett. Thank you again for your cooperation.

assembled in order to develop the information that was required. The task force knew of no actual measurements of quantity and quality data for flares. However, they agreed that personnel at many refineries could make reasonable engineering estimates of these data. It was decided to obtain this information by means of the survey from a relatively small number of representative refineries. The sample included 18 refineries, three each from six different geographical locations, operated by 11 different oil companies. The questionnaire was circulated to the refineries through the API.

Replies were received from 17 of the 18 refineries contacted. All replies have reiterated that the quantity and quality data were from engineering estimates since these data were not measured. Five of the refineries that replied, supplied information on the number of flares and design specifications but felt they could not make even engineering estimates on the quantity and quality of material being flared.

For the remaining 12 refineries that supplied estimates on quantity and quality, 11 estimates were reasonably consistent. However, one estimate was so large, an-order-of-magnitude greater than the previous largest estimate, that it was not used for estimating flare loading but is included in the tabulated data for completeness (Refinery 12).

The refineries contacted had previously been selected for study in a joint API-EPA refinery modeling program because it was felt that they formed a representative sample of the total United States petroleum industry. The 11 refineries on which flare data are reported include at least one from each geographical location. These refineries represent 4% of the total number of refineries in the United States. However, their throughput totaled 14% of the total United States throughput for the 1973-74 time period. While our sample included refineries of varying size ranges, refineries greater than 100,000 bbl/cd predominated.

Table 7-1 shows a summary of the reduced data for the 11 refineries. This table includes the number of flares, the sum of the flare loads for each refinery broken down by composition, the percent of the refinery throughput that is sent to the flare and the heat loss for each refinery computed from the heating value of the streams sent to each flare. Most of the quantity data were given for both 1973 and 1974. The numbers reported in the summary table are the two year average value. Normally flare loading is very intermittent with flare occurrences happening on the order of 8 to 10 times a year. The reported flare loadings are the two year averaged loadings reduced to a calendar day basis.

The amount of gas flared from each refinery ranged from 0.04 to 0.60% of the refinery's crude runs with an average of 0.19% for the 11 refineries. Applying this percentage to the total crude processed in the United States of 12,281,000 bbl/cd would indicate an amount of flaring from refineries for 1973 and 1974 of 7.2×10^6 pounds per calendar day or about 24,000 bbl/cd.

Table [illegible]

SUMMARY OF REFINERY FLARE DATA

Refinery Number	No. of Flares	Design Capacity (Mlb/hr)	C_1 (lb/d)	C_2 (lb/d)	C_3 (lb/d)	C_4 (lb/d)	C_{5+} (lb/d)	Aromatics (lb/d)	Olefins (lb/d)	Paraffins (lb/d)	Total Hydrocarbon (lb/d)	H_2 (lb/d)	H_2S (lb/d)	NH_3 (lb/d)	Other (lb/d)	Total (lb/d)	Refinery Throughput (bbl/d)	% to Flare	Heat Loss (Btu/d x 10^6)
1	3	333	—	[illegible]	[illegible]	664	—	—	—	1,514	1,514	—	2,640	—	23,760	27,914	54,437	0.170	49
2	2	240	135,425	39,836	35,400	23,617	30,458	—	25,179	238,367	[illegible]	5,233	2,398	—	—	274,707	167,658	0.554	6,060
3	4	3,305	2,124	4,691	18,799	27,987	36,709	10,536	27,043	52,481	90,510	1,456	32	2	—	91,800	213,000	0.143	1,896
4	2	1,407	15,488	4,576	4,575	3,930	2,874	—	3,543	28,334	31,677	343	260	—	—	32,300	73,700	0.145	702
5	5	385	2,090	4,926	339	531	477	—	2,411	6,952	8,363	181	8,278	244	1,844	18,910	106,064	0.059	250
6	7	2,319	3,326	9,683	4,737	4,286	2,021	359	5,282	22,412	[illegible]	363	872	—	8	29,896	255,000	0.039	653
7	4	640	3,404	3,384	13,788	16,721	1,807	—	[illegible]	35,198	34,199	577	436	—	—	40,112	239,400	0.056	835
8	8	2,600	17,047	21,309	128,139	12,359	20,457	—	[illegible]	[illegible]	[illegible]	852	4,850	—	28,556	233,549	369,500	0.210	4,177
9	[illegible]	1,600	42,946	36,602	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	3,254	2,766	—	6,630	205,132	112,652	0.604	4,243
10	[illegible]	3,051	15,922	27,332	12,584	4,999	6,206		8,181	[illegible]	62,043	3,181	4,396	—	—	69,620	162,908	0.142	1,541
11	2	684	20,084	10,038	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	0.149	1,910
Total	45	[illegible]	258,260	158,852	350,128	126,529	122,044	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	246	[illegible]	1,106,644	[illegible]	[illegible]	22,316
12	8	18,701	215,928	167,131	1,244,011	864,345	80,223	—	—	2,569,638	2,569,638	—	—	—	—	2,569,638	306,590	[illegible]	52,446

The heat loss that flaring represents was calculated for each refinery and averaged nearly 20,000 Btu/lb. This would indicate a total heat loss from refinery flaring in the United States of 1.4×10^{11} Btu/cd. This represents about 0.6% of the total gas sold for industrial use in the United States for 1973 and 1974 (Ref. 95).

Figure 7-1 is a plot of the crude run versus flare loading for each refinery. The solid curve represents the simple average flare loading for these 11 refineries. While the flare loading generally increased with refinery throughput, the scatter of the data indicates that there are other parameters involved in flare loading other than refinery throughput. However, the average flare loading of these 11 representative refineries is probably a good indication of the average flare loading of the petroleum industry.

Ninety percent by weight of the total load to flares consisted of hydrocarbons. Hydrogen made up 1.6% of the load and hydrogen sulfide 2.6% with the remainder consisting of mainly water vapor and nitrogen. Much of the hydrogen sulfide flared was of low concentration in hydrocarbon streams. However, there were flares mainly in sulfur recovery units where streams containing hydrogen sulfide concentration of up to 50% were flared.

7.3 Impact of Flares on Refinery Emissions

In order to determine the impact of flares on refinery emissions not only data on the quantity and quality of gases being flared are necessary but also information is needed on the efficiency of flares as combustion devices and the nature and amount of flare emissions. However flare systems - especially elevated flares - present very difficult sampling problems. As a result, very little emission data are available from flares.

The only known published report of a field test on a flare unit was by Sussman et al. (Ref. 31). He reported the results of the test for a steam inspirated type of elevated flare in the form of volume ratios:

CO_2:	Hydrocarbon	2100:1
CO_2:	CO	243:1

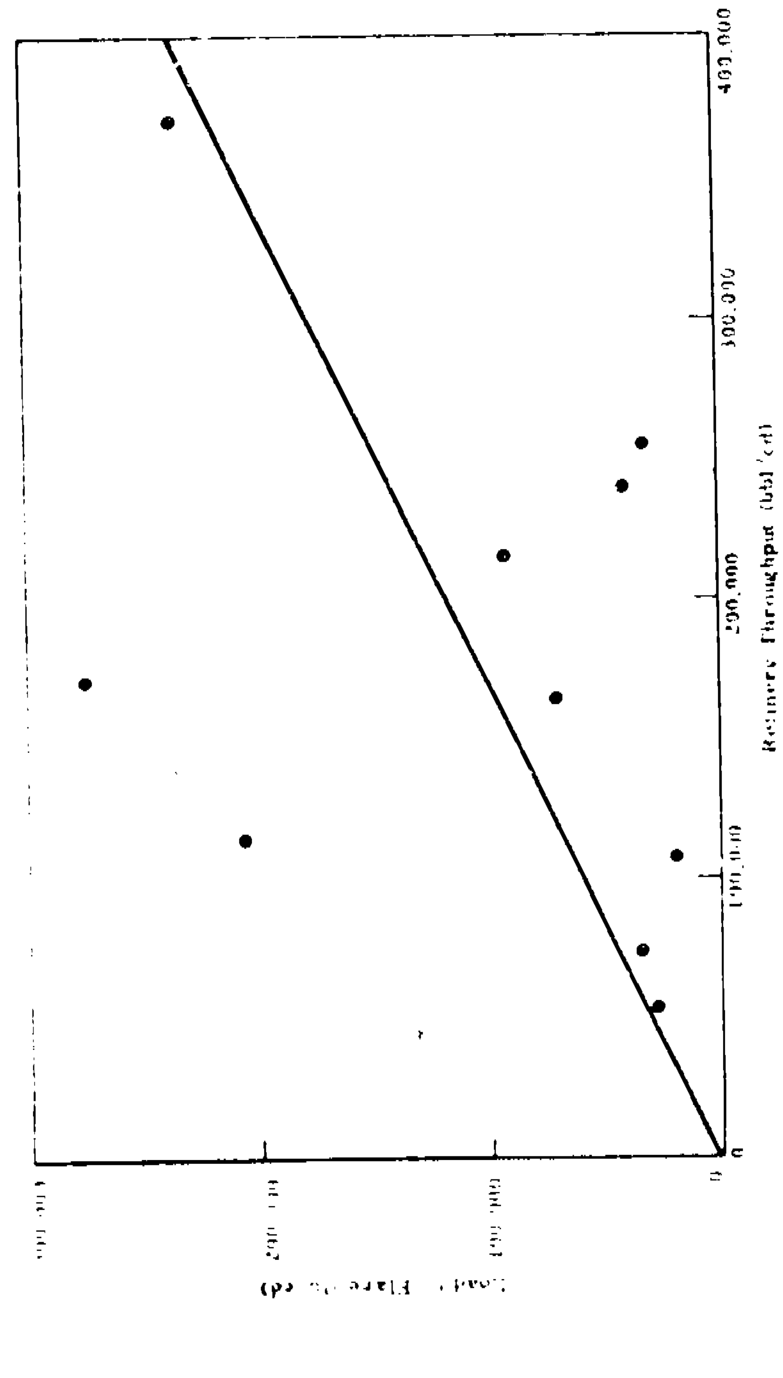

Fig. 7-1 - Crude Run vs Flare Loading

Calculations based on these data were made using the estimated quantity and quality data of the previous section in order to obtain an estimate of the total emissions of carbon monoxide and hydrocarbons caused by flaring. The calculations assumed a gas with three carbon atoms and a molecular weight of 42, the average molecular weight of the refinery gas being flared.

NO_x emissions were estimated from the data of Chase and George (Ref. 96) and SO_2 emissions were calculated from the total amount of sulfur being flared. Table 7-2 shows the calculated total emissions of hydrocarbon, carbon monoxide, nitrogen oxide and sulfur dioxide from refinery flares. Table 7-2 also shows the percent of the total refinery emission from each gas due to flaring. The total refinery emissions were estimated from refinery emission factors (Ref. 58) and base on average refinery runs for 1973 and 1974.

Table 7-2

TOTAL ESTIMATED EMISSIONS FROM REFINERY FLARES

Gas	Emissions (10^6 lb/yr)	Percent of Total Refinery Emissions
HC	3.4	0.2
CO	6.5	0.1
NO_x	17.1	0.5
SO_2	137.3	0.9

These numbers, based on engineering estimates of quantity and quality and a minimum of field testing, should be considered tentative. However, they do indicate that the average yearly emission from flares constitutes just a small fraction, less than 1%, of the average yearly refinery emissions. Total flare emissions over a year's time therefore probably only have a small impact on total refinery emissions. However, because of the intermittent nature of flaring, the majority of flare emissions are concentrated into just a few minutes of actual flaring. During this time four or five times the normal refinery emissions are released into the atmosphere. While design modifications for flares to suppress smoke formation has been largely successful, very little if any work has been done to suppress emissions resulting from unburned hydrocarbons and partial oxidation products.

7.4 Iron and Steel Mills Questionnaire Results

Through the cooperation of the American Iron and Steel Institute (AISI), the survey was distributed by the AISI to the major manufacturers of iron and steel in the United States. There are two types of gases that are flared in iron and steel mills, excess blast furnace gas and excess coke oven gas. Flaring is only done on an intermittent basis, usually to control line pressure, and generally the gases are scrubbed before flaring.

Ninety-nine percent by weight of the combustible blast furnace gas consisted of carbon monoxide. The remaining one percent consisted mainly of hydrogen and methane. Hydrocarbons made up 73% by weight of the coke oven gas, carbon monoxide 17%, hydrogen 9% and hydrogen sulfide 1%.

Replies were received for 61 blast furnace gas flares and 30 coke oven gas flares. Several of the replies received supplied information on the capacity and design specifications of the flares but felt that they could not make engineering estimates on the quantity and quality of material being flared. Quantity and quality data were given for 35 blast furnace gas flares and 20 coke oven gas flares. The replies represent 38% of the raw steel production capacity in the United States.

Table 7-3 shows a summary of the reduced data for the blast furnace flares and Table 7-4 for the coke oven flares. The table includes the number of flares, the sum of the flare loads broken down by composition and the heat loss associated with this flaring. The reported flare loadings are averaged yearly loadings reduced to a calendar day basis.

The weight of combustible gas flared from blast furnaces averaged 6.6% of the furnace's capacity. Applying this percentage to the total 1974 United States' capacity of 145.5×10^6 tons would indicate an amount of flaring from blast furnaces in 1974 of 5.3×10^7 pounds of combustible gases per calendar day. The heat loss that this flaring represented amounted to 2.5×10^{11} Btu/cd.

The amount of combustible gas flared from coke ovens averaged 0.4% of the ovens' capacities. Applying this percentage to the total iron and steel industry's coke capacity of 55×10^6 tons would indicate the amount of flaring from coke ovens in 1974 of 1.1×10^6 lb/cd. The heat loss that this flaring represented amounted to 1.9×10^{10} Btu/cd.

While the lost heating value of blast furnace gas that is flared is comparable to the heating value of the gas flared from refineries, the iron and steel industry has little alternative but to flare the excess gas. Blast furnace gas typically consists of 25% CO and the remaining inert gases. Therefore, the heating value of the gas is low, around 90 Btu/ft^3, making it uneconomic to recover any that cannot be used immediately.

In addition to blast furnace gas and coke oven gas flares there were a few other flares reported from the iron and steel industry on miscellaneous processes including sulfur plants and an annealing plant. Table 7-5 gives a summary of the reduced data for these plants.

7.5 Impact of Flares on Iron and Steel Mill Emissions

While there have been no published report of field tests on blast furnace gas flares, the data of Sussman et al. (Ref. 31) for a refinery flare indicates greater than 99% complete combustion of hydrocarbons. Assuming a 99% efficiency for blast furnace flares, the emissions of CO from these flares in 1974 was 1.9×10^8 lb which is equal to about 1% of CO emmissions from industrial processes.

Table 7-3
SUMMARY OF BLAST FURNACE FLARE DATA

No	Process Capacity (tons/day)	No. of Flares	CO (lb/cd)	H_2 (lb/cd)	CH_4 (lb/cd)	N_2 and CO_2 (lb/cd)	Total Combust. (lb/cd)	Heat Loss (Btu/cd x 10^6)	Height (ft)
1	6,700	3	333,000	1,800	–	1,048,000	335,000	1,600	160
2	2,200	1	3,000	–	–	9,000	3,000	700	109
3	2,800	1	936,000	4,800	–	2,082,000	941,000	4,200	130
4	3,600	1	864,000	2,400	–	3,975,000	866,000	3,800	201
5	900	1	197,000	1,100	–	275,000	198,000	800	112
6	4,300	1	16,000	–	–	43,000	16,000	100	140
7	2,500	1	459,000	7,300	–	1,638,000	466,000	2,300	109
8	6,900	1	1,386,000	20,400	–	4,585,000	1,306,000	6,400	200
9	500	1	92,000	1,500	–	321,000	93,000	500	160
10	5,200	2	3,229,000	50,100	–	11,295,000	3,279,000	17,100	150
11	2,600	1	2,228,000	12,300	4,700	5,757,000	2,244,000	9,500	111
12	2,500	1	240,000	600	–	656,000	241,000	900	125
13	2,000	1	348,000	3,300	–	1,164,000	351,000	1,500	167
14	3,900	1	254,000	2,000	–	867,000	256,000	1,100	200
15	3,200	1	207,000	1,600	–	708,000	209,000	900	200
16	7,600	1	171,000	–	–	121,000	171,000	700	240
17	16,000	4	164,000	500	–	493,000	165,000	700	140
18	3,400	2	232,000	2,200	–	712,000	232,000	1,100	89
19	11,700	1	701,000	7,200	12,000	2,280,000	691,000	3,200	113
20	5,500	1	179,000	1,400	500	662,000	181,000	900	198
21	2,700	1	217,000	100	–	781,000	217,000	1,000	155
22	5,900	1	392,000	–	–	214,000	392,000	1,600	230
23	800	1	177,000	500	–	517,000	177,000	800	160
24	4,000	1	246,000	2,000	–	712,000	248,000	1,000	150
25	6,000	3	189,000	1,500	–	720,000	190,000	1,000	137
26	6,600	1	753,000	2,000	–	2,138,000	755,000	3,200	150
27	5,800	2	556,000	1,400	–	1,578,000	557,000	2,600	125
28	13,000	4	1,639,000	12,900	22,400	6,439,000	1,674,000	8,900	200
29	2,600	1	674,000	5,900	–	2,565,000	680,000	3,200	139
30	600	1	65,000	500	–	247,000	66,000	300	110
31	3,500	1	914,000	8,500	–	3,393,000	922,000	4,300	202
32	1,200	1	883,000	7,100	–	2,845,000	890,000	4,000	100
33	1,100	1	34,000	9,600	–	48,000	43,000	600	230
34	2,500	1	248,000	900	–	713,000	249,000	1,100	150
35	2,500	1	1,107,000	18,100	–	3,533,000	1,125,000	5,200	160
Total	152,800	48	20,233,000	191,300	39,600	66,034,000	20,431,000	96,800	154 (Average

Table 7-4

SUMMARY OF COKE OVEN FLARE DATA

No.	Process Capacity (ton/day)	Hydrocarbon (lb/cd)	H_2 (lb/cd)	CO (lb/cd)	H_2S (lb/cd)	N_2, CO_2 H_2O (lb/cd)	Total Combust. (lb/cd)	Heat Loss (Btu/cd x 10^6)	Height (ft)
1	500	62,500	1,800	18,700	850	377,000	84,500	1,080	36
2	450	2,000	300	600	—	600	2,900	60	100
3	2,170	900	100	100	—	200	1,100	10	115
4	1,340	900	100	300	—	400	1,300	30	100
5	3,940	5,300	1,500	2,700	—	1,600	9,600	240	135
6	2,010	21,300	1,500	1,400	170	4,600	24,500	280	121
7	410	10,400	2,000	2,800	210	4,000	15,200	360	80
8	2,340	5,200	1,200	1,700	—	1,100	8,100	170	100
9	2,830	70,700	11,100	7,500	—	36,800	89,300	1,780	100
10	1,910	3,100	500	700	—	1,400	4,300	110	—
11	260	5,500	1,100	1,500	—	2,100	8,000	190	80
12	510	600	100	100	—	100	800	10	100
13	1,570	800	100	200	—	100	1,100	20	100
14	4,750	1,100	200	400	—	700	1,700	20	100
15	2,480	8,300	300	4,500	270	3,900	13,400	290	110
16	3,800	6,500	1,200	3,500	210	3,000	11,400	250	151
17	3,500	700	100	300	—	400	1,100	30	150
18	1,000	12,000	1,600	1,800	—	—	15,400	250	225
19	5,070	1,700	300	600	—	1,100	2,600	70	125
20	2,510	6,600	1,200	2,100	200	4,400	10,100	230	104
Total	43,350	226,100	26,300	51,500	1,910	443,500	306,400	5,480	112*

*Averag

Table 7-5

SUMMARY OF FLARE DATA FROM MISCELLANEOUS IRON AND STEEL PROCESSES

No.	Process	Capacity (ton/day)	Hydro-carbon (lb/d)	H_2 (lb/d)	CO (lb/d)	H_2S (lb/d)	Inert (lb/d)	Total Combust.	Heat Loss (Btu/d x 10^6)	Height (ft)
1	Sulfur Plant	15	1,200	—	—	36,100	20,520	37,750	328	150
2	Desulfurization	94	—	HCN 2,550	1,120	16,847	9,630	20,500	240	206
3	Anneal Atmos. Gas	3,000	2	6	66		710	74	1	8
4	NH_3 Destruction	87	—	NO_x 29	NH_3 29	SO_2 2,470	171,370	29	—	100

For coke oven flares, calculations were made for emissions of HC CO, NO_x and SO_2 in the same manner as the refinery flares. Table 7-6 shows the results of these calculations along with the percent of the total emission from coking from each gas due to flaring. The total coke plant emissions were estimated from emission factors (Ref. 58) and based on 1974 coke production.

Table 7-6

TOTAL ESTIMATED EMISSIONS FROM COKE OVEN GAS FLARES

Gas	Emissions (10^6 lb/yr)	Percent of Total Coke Plant Emissions
HC	0.4	0.2
CO	1.5	2.1
NO_x	0.7	5.8
SO_2	4.8	0.9

These results, based on engineering estimates and a minimum of field testing, are tentative. However, as with refinery flares, they indicate that the emissions from coke oven flares constitute a small portion of the average yearly emissions from coke plants.

7.6 Manufacturing Chemists Questionnaire Results

Through the cooperation of the Manufacturing Chemist Association (MCA), the survey was distributed by the MCA to members likely to make use of flare systems. Replies were received for 75 different flare units. However, many of the questionnaires did not give information on the quantity and quality of gases being flared. Forty replies were received covering the manufacture of 15 different chemicals which gave data on the quantity and composition of gases being flared.

Table 7-7 shows a summary of the reduced data for these chemical process flares. The table includes the identification of the process, the capacity of the process, the sum of the flare loads broken down by composition and the heat loss associated with this flaring. The reported flare loadings are averaged yearly loadings reduced to a calender day basis.

Most of the different chemicals for which flare loading data were reported included data from only one or two plants. Because of the scatter of the flare loading data from plant to plant, meaningful estimates of industry flaring loads can only be made by averaging the loadings for a number of individual plants. The only chemical in which flare loading data were available from a number of different plants was ethylene. However, the other data give a rough idea of the magnitude of flare loadings for these processes.

Table 7-7

SUMMARY OF CHEMICAL PROCESS INDUSTRIES FLARE DATA

Process	Capacity (lb/yr)	Hydrocarbon (lb/cd)	CO (lb/cd)	H_2 (lb/cd)	N_2, H_2O, CO_2 (lb/cd)	Other (lb/cd)	Total Combust. (lb/cd)	Heat Loss (Btu/cd × 10^6)
Olefins								
Ethylene	964 MM	10,100					10,000	195
Ethylene	630 MM	44,650	1,100	1,670	2,580		47,420	660
Ethylene	500 MM	17,400			700	1300-H_2S	18,700	350
Ethylene	750 MM	10,100					10,100	155
Ethylene	830 MM	26,300		600			26,900	562
Ethylene	775 MM	48,000					48,000	960
Acetylene	325 MM	1,700					1,726	33
Aromatics	750 MM	7,900					7,900	157
Petrochemicals	2,000 MM	96,000					96,000	2,600
Petrochemicals	660 MM	300					300	5
Polypropylene	260 MM	55,200			20,000		55,200	[illegible]
Polyproplylene	110 MM	2,500					2,500	37
Butyl Rubber	200 MM	36,000					36,000	650
Acetic Acid	110 MM	8,700					8,700	152
Acetic Acid	110 MM	7,900	19,800	39,600	11,900		67,200	455
Acetic Anhydride	160 MM	6,900	8,700		3,600		15,600	
Acetic Anhydride	140 MM	70,000	30,400	300	16,200		100,700	1 080
Adipic Acid	380 MM					9600-NO_x		
Acrylonitrile	365 MM					16-HCN	16	1
Acrylonitrile	350 MM					276-HCN	276	3
Ammonia	550 MM	40,600		13,500			54,100	1,680
Ammonia	660 MM					192-NH_3	192	1
Ammonia	800 MM					4800-NH_2	4,800	43
Alcohols	215 MM	16,300					16,300	335
Carbon Black	244 MM	3,600	30,300	2,900	430,000	650-H_2S	37,500	421
Phosphorus	9 MM	19	10,300	37	236		10,400	46
C_2S and S Recovery	73 MM	360				84-C_2S	444	9
Na H S	37 MM					10-C_2S	10	1
Aldicarb	53 MM	3,100				528-HCN	3,600	27
CO For Phosgene	70 MM	1,440					1,440	2
Oil Additive	342 MM	10,900					10,900	216
Storage and Loading								
Ethylene Loading	10^5 lb/hr	12,000					12,000	243
Ethylene Storage	263 M	2					2	
Buladine Storage	536 M	1,000					1,100	21
Ammonia Storage	40 MM					950-NH_3	950	9
HCN Storage	200 M					480-HCN	480	2
Tank Car Loading		1,080			120		1,080	9
Azodrin	12 MM	96					95	1
Nudrin	6 MM	15			7-H_2C	10-HCN	32	1
Nudrin	6 MM				18	6-HCN	6	1

Data were received from six different ethylene plants representing 19% of the total U.S. ethylene capacity. The weight of the combustible gas flared by these plants averaged 1.3% of the capacity. Applying this percentage to the total U.S. 1974 capacity of 24 x 10^9 lb would indicate an amount of flaring from ethylene plants in 1974 of 8.7 x 10^5 lb/cd. The heat loss that this flaring represented amounted to 1.6 x 10^{10} Btu/cd.

7.7 Summary of Flare Loadings

From the survey results, flare loadings of combustible gases were calculated for four process industries: (1) petroleum refining; (2) ethylene production; (3) blast furnace operation; and (4) coke production. Table 7-8 summarizes the data for these industries.

Table 7-8

INDUSTRY FLARE LOADINGS AND HEAT LOSS

Industry	Industry Flare Loading (lb/cd)	Flare Loading as Percent of Capacity	Heat Loss (Btu/cd)
Petroleum Refining	7.2 x 10^6	0.19	1.4 x 10^{11}
Ethylene Production	8.7 x 10^5	1.3	1.6 x 10^{10}
Blast Furnace Operation	5.3 x 10^7	6.6	2.5 x 10^{11}
Coke Production	1.1 x 10^6	0.37	1.9 x 10^{10}

To estimate emissions from flares, information is needed on the efficiency of flares as combustion devices. Estimating emissions from very limited field test data on flares and using industry flare loadings from the survey results indicate that the average yearly emission from flares constitutes just a small fraction, less than 1%, of the average yearly industry emission. Total flare emissions over a year's time, therefore, probably only have a small impact on total emissions. However, because of the intermittent nature of flaring, most of flare emissions are concentrated into just a few minutes of actual flaring. During this time four or five times the normal industry emission are released into the atmosphere.

SECTION VIII

RECOMMENDED RESEARCH PROGRAM

8.1 Theoretical Analysis of Combustion Modifications Applicable to Flaring

8.1.1 Summary and Objectives

Because of the lack of present sampling capability and emissions data for elevated flares, other means of estimating gaseous emissions are required for evaluating proposed pollution control methods and regulations and for evaluating the applicability of current combustion technology to flare emission control. In particular, some means of calculating combustion efficiency and partial oxidation products is required.

The objective of this research is to extend previously developed technology to the analysis of flare systems. The theoretical model developed would be applied to evaluating combustion modifications applicable to flaring (Section 7.1.4) and to the evaluation of the applicability of flaring to the control of gaseous emissions (Section 7.3).

8.1.2 Background

Analysis of turbulent combustion depends on combining turbulent mixing models with kinetic data for elementary reaction steps. Combustion rates are limited by turbulent mixing rates and are typically several orders of magnitude lower than theoretical even for highly efficient gas turbine combustors. No simple analytical methods have been developed.

When analyzing turbulent mixing problems it is customary to use empirical correlations to describe the transport rates because of the lack of useful theoretical formulations. Unfortunately, empirical correlations have not been developed which are suitable for detailed analysis of subsonic reacting flows because of the dearth of experimental data.

Numerical analysis techniques have recently become available for the precise analysis of temperature, composition and velocity profiles in reacting flows. Figure 8-1 illustrates the application of such a model to the analysis of a hydrogen diffusion flame, comparing theoretical predictions (Ref. 97) against experimental measurements (Ref. 98). The jet diameter was 7.62 mm. Jet velocity was 590 ft/sec.

The recommended research program would involve the application of present analytical capability to the measurement of combustion efficiencies, partial oxidation products, and nitrogen oxides formed in a diffusion flame analogous to an elevated flare system. The program would consist of the following parts:

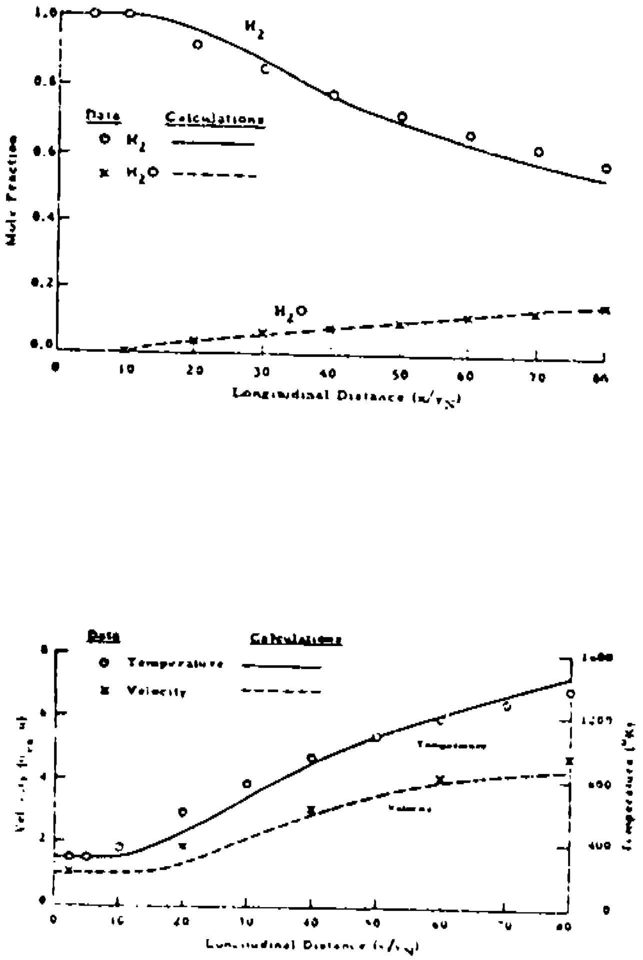

Fig. 8-1 - Comparison Between Measured and Calculated Centerline Distributions (Hydrogen Jet Exhausting into Air). Upper Figure: Species Distributions. Lower Figure: Temperature and Velocity Distributions (Ref. 97).

8.1.3 Validation of the Analytical Model

Sample cases would be run to check the validity of the selected analytical model for large diffusion flames. Data available in the literature would be summarized. Comparison would be made between predicted and experimentally measured flame properties for selected representative cases.

8.1.4 Evaluation of Flare Design Modifications

Representative cases would be run to evaluate the effect of combustion modifications applicable to flaring. Variables considered would include gas discharge velocity, burner diameter, flow distribution through multiple ports, effect of steam distribution and discharge velocity and substitution of air and oxygen for steam. Calculations would be made of emission rates of nitrogen oxides, partial oxidation products and soot or particulates. Combustion efficiencies would be calculated to estimate unburned hydrocarbons.

8.1.5 Priority

On a scale of A through E, the priority for research described in Sections 8.1.3 and 8.1.4 is A.

8.2 Evaluation of Remote Sampling Methods

8.2.1 Summary and Objectives

Elevated flare systems have eluded present sampling methods for reasons of remoteness and non-stoichiometric air-fuel dilution. Evaluation of remote sampling techniques for typical flare emissions is therefore needed.

8.2.2 Background

The problem of sampling elevated flare emissions is essentially one of accessibility. Flare stacks typically range from 200 to 400 feet in length with flames reaching 200 or 300 feet in emergency flaring. A summary of conventional sampling techniques and application to flare systems is presented in Section 6. Recently developed sampling methods which may be applicable rely on spectroscopic techniques and may include laser sources.

8.2.3 Summary of Remote Sampling Technology

Remote sampling methods and instrumentation would be summarized according to cost, performance and availability. For each instrument selected as applicable to flare emissions monitoring, instrument range, sensitivity and other operating characteristics such as drift and reproducibility would be included. Complete monitoring systems would be chosen based on suitable components and auxiliaries. Instrument manufacturers would be contacted for complete instrument specification and other available performance data based on previous applications.

8.2.4 Remote Sampling Field Studies

A remote sampling unit would be selected or assembled for components for field testing at selected locations. Emissions measured would include particulates, hydrocarbon classes, nitrogen and sulfur oxides and hydrocarbon oxide classes. Resolution of emission classes would be defined.

8.2.5 Priority

On a scale of A through E, the priority for research described in Sections 8.2.3 and 8.2.4 is C.

8.3 Application of Flaring to Control of Gaseous Emissions

8.3.1 Summary and Objectives

The objective of the following research program would be to evaluate the potential of flaring as a means of pollution control. Guidelines for determining the suitability of given waste streams for flaring would also be established.

8.3.2 Background

The application of flaring for controlling gaseous emission promises to be a relatively inexpensive means of pollution control when compared to conventional methods such as incineration. Flaring has been applied to odor control in removal of trace quantities of $NH(CH_3)_2$. In this application, flaring was reportedly more effective than other methods of control (Ref. 3). Application of flaring to other streams and components requires experimental confirmation of effectiveness for reasons discussed previously, i.e., lack of suitable theoretical and experimental data for large turbulent diffusion flames.

A list of the types and magnitudes of emissions from petrochemical manufacturing is given in Table 8-1. Of these, emission control by flaring is most promising for those emissions which are themselves combustion intermediates: organic acids and anhydrides, esters, ethers and oxides. These constitute a large part of present petrochemical emissions.

8.3.3 Theoretical Analysis

Theoretical analysis of combustion products and efficiencies would be conducted for selected components and conventional flare systems. The modeling technique described in Section 8.1 or similar techniques would be used for the analysis. Maximum concentration limits and other operating conditions would be defined.

Table 8-1
EMISSIONS FROM PETROCHEMICAL MANUFACTURE, MM LBS (Ref. 15

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ar[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]e	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
xyl[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
vi[illegible] chloride	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] and Anhydrides					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
maleic anhydride	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ph[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
xylene base acids	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Alcohols					
butyl alcohols	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ethyl alcohol	2.6	[illegible]	[illegible]	[illegible]	[illegible]
isooctyl alcohol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
isopropyl alcohol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
methyl alcohol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	15.6	[illegible]	[illegible]	[illegible]	[illegible]

(Continued)

Table 8-1 (Concluded)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.6
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2.1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35.2
[illegible]	16?	[illegible]	[illegible]	1,???.6	3,0?0.9

8.3.4 Experimental Analysis

This study would define experimental techniques and sampling methods for evaluating industrial flaring as applied to pollution control. The main result of the study would be a user guid with recommendations for determining the suitability of a given waste stream for flaring.

A pilot-scale flare burner and combustion chamber would be constructed. Suitable sampling techniques would also be developed. Components selected from Table 8-1 and at least one component evaluated as part of the study outlined in Section 8.3.3 would be tested using the pilot flare burner.

For each component selected for testing, operating conditions would be varied to determine optimum conditions for pollution control. Effects of flame stability and turbulence level on the production of pollutants would be determined.

8.3.5 Priority

On a scale of A through E, the priority of research described in Section 8.3.3 is A. The priority of research described in Section 8.3.4 is B.

An experimental study almost identical to that described in Section 8.3.4 has been recommended as part of the Federal R&D Plan for Air Pollution Control by Combustion-Process Modification (Ref. 99):

The objective is to determine the effect of turbulence and fuel type on the production of pollutants is turbulent diffusion flames with gaseous fuels. A large burner is recommended for this study, especially if the level of effort is minimum. Turbulence scale and intensity should be the major variables considered. The effect of fuel type should also be investigated. Special instrumentation might have to be developed for solving problems related to the effect of "unmixedness" on the production of pollutants. Attention would be given to the part that flame stability plays in the production of pollutants. The rationale and incentive for this proposed research (R&D Opportunity: VIII-22) is that many industrial flames are of the turbulent-diffusion-flame type. The research would provide guidelines for the optimization of turbulent conditions in gaseous-fuel combustion systems to minimize pollutant emission and form a basis for studies of other fuels burned in like manner. The relative overall priority rated for this research is 2 on a scale of 1 through 5.

8.4 Economic Analysis of Waste Stream Recovery and Alternate Disposal Methods

8.4.1 Summary and Objectives

An inventory of waste streams currently being flared is being compiled by means of a questionaire as part of this Task Order. Waste streams burned in flares represent a potential loss of profit as well as a source of gaseous and particulate emissions. For these reasons, and in order to define a basis for pollution control purposes, the economic basis for flaring as opposed to stream recovery or alternate disposal methods is needed.

8.4.2 Background

There are numerous gaseous plant emissions which are disposed of by means of flaring which are not associated with outright emergencies. These include:

1. Low pressure vent gases (Ref. 100) from an absorber. These gases contain light hydrocarbons, methane, ethane and propane plus oil droplets. The heating value of these discharged gases will not vary appreciably.

2. Partial Condenser Vent Gases. These gases may contain water and oil droplets (Ref. 100).

3. Disposal of off-spec or excess product (Ref. 23). This disposal problem is most frequent during plant start up which may last for periods up to about one year.

4. Leakage of gas through safety valves and block valves. Valve leakage to flare during routine operation of a 550 million-pound-per-year ethylene unit has been estimated at 4,000 lb/hr (Ref.23).

5. Disposal of by-product streams which are produced in quantities too small or of insufficient purity for economical recovery (Ref. 23).

6. Venting of fuel and product storage tanks and loading platforms.

Gases which are sent to the flare system from the above sources are produced in quantities which can be estimated and for which storage for sale, recyling to process units or use as fuel in heaters and incinerators appear to be practical alternatives. For this reason guidelines need to be established to aid in determining these situations in which alternatives to flaring are reasonable. The following research program is recommended:

8.4.3 Identify Economic Considerations Now Used to Determine Whether a Given Flared Stream has Sufficient By-Product Value for Recovery

Representative processes would be chosen for evaluation from the process industries. By-product and waste streams would be listed for chosen processes. Stream composition and volume and recovery conditions (temperature and pressure) would be listed for each process stream along with recovery value, capital, operating and utilities costs for recovery and end use.

8.4.4 Identify Alternative Uses of Low Pressure Flammable Hydrocarbon Gases

Waste streams sent to the flare system are usually available at relatively low pressure. Suggested or potential uses for such streams would be identified and evaluated. One such suggested use which seems reasonable is the use of the waste stream for afterburner fuel gas (Ref. 100).

8.4.5 Evaluation of Alternative Disposal Methods

For the processes and waste streams selected for economic analysis in Section 7.4.3, alternative disposal methods such as incineration, adsorption, absorption, scrubbing and filtration would be identified. These will be evaluated for technical and economic feasibility.

8.4.6 Priority

On a scale of A through E, the priority of research described in Sections 8.4.3, 8.4.4 and 8.4.5 is D.

8.5 Emission Factors for Elevated Flare Systems

8.5.1 Summary and Objectives

The objective of the study would be to recommend the best available method for sampling and analysis of gaseous flare emissions and conduct field testing of elevated flare systems.

8.5.2 Background

Very little information on elevated flare emissions is available as has been discussed previously in several sections of this report. Furthermore, the validity of the fragmentary information available is unknown.

Based on our conversations with flare vendors and a major chemical manufacturing firm, two methods of sampling elevated flare emissions were identified, direct probe sampling and tracer-assisted probe sampling. Direct probe sampling involves inserting a probe into the exhaust plume beyond the flame boundary and is therefore stongly dependent on probe location. The use of a tracer aids the sampling technique by allowing a correction for dilution of the plume by ambient air.

These techniques are preliminary and many other improvements are foreseen. For example, the use of heavy and light tracers in conjunction may allow a further correction for buoyant and diffusion forces and a measurement of reliability; if the measured dilution of both tracers is the same, the air dilution factor can be calculated without consideration of the buoyancy factor.

In addition to air dilution problems, the direct sampling methods are complicated by accessibility to the plume, and other problems which typically arise in direct source sampling such as the requirement for rapid quenching of reaction products, condensation of liquid products in the probe and correction for the finite sampling and analysis times involved (Ref. 39). Of these, plume accessibility appears to be the most difficult obstacle; methods used have involved either a construction derrick or a long pole to support the sampling probe. Other methods considered have involved the use of helicopter borne sampling equipment. In general, these methods tend to be dangerous, cumbersome and expensive. Improvements envisioned in this area include the use of fixed supporting structures taller than the flare stack and at a safe distance from which boom lowering of the probe into the plume would be practical. For steady-state emissions over long periods of time, the problem of flare sampling is not significantly different from stack gas sampling using multiple receptor locations relatively close to ground level. Such receptor methods normally require a relatively isolated source and require a relatively large number of points for a statistically reliable estimate of the source strength. Such requirements are rarely met with flares.

8.5.3 Site Selection and Evaluation of Sampling Methods and Hardware

From a survey of sampling and analytical techniques now in use, a sampling system would be chosen which is best suited to the problem of monitoring source emissions from flares, and a program developed for the determination of emissions factors. Emissions considered would include hydrocarbons, NO_x, SO_x, particulates and partial oxidation products such as CO and aldehydes. The sampling and analysis technique would be suitable for emissions monitoring of sudden upsets as well as steady-state flow. The duration of plant upsets may be from a few minutes up to a maximum of about one hour (Ref. 10). During major upsets, discharge of several hundred thousand pounds per hour to the flare is common with resulting flame lengths of several hundred feet and combustion rates upwards of a billion Btu's per hour (Ref. 30). Testing sites would be selected from among industrial locations and experimental flare systems furnished by manufacturers of combustion equipment. At least one site would be chosen from the hydrocarbon process industries.

8.5.4 Field Testing of Elevated Flare Systems

Field testing would involve the measurement of emission factors at selected sites. Analysis of data would include an estimation of precision. Analysis of the emissions from the selected plant site(s) would include an inventory of flared streams and measured emissions on a day-to-day basis for a period of time long enough to give an indication of typical plant flaring practices.

8.5.5 Priority

On a scale of A through E, the priority for the research outlined in Sections 8.5.3 and 8.5.4 would be A.

SECTION IX
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