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Revision Memo

12/99 Highlights of this revision are:

Page 14	Eq. (9) , corrected formula to include denominator inside the square root sign.
Page 54	Clarified how the flammability limits expand at higher pressures. Also clarified how to apply the multiplier in the table to estimate the UFL.
Page 57	Corrected typographical error of UFL of H_2/N_2 mixture in Calculation 8 and in Summary.
Page 59	Corrected formula for propane (C_2H_6) in the propane/ CO_2 mixture curve.



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SCOPE

This section presents the criteria for selecting, designing and spacing elevated, burning-pit and multijet flares. The design of safety valve and flare headers is covered in [Section XV-C](#), and associated blowdown drums, water disengaging drums etc., are covered in [Section XV-D](#).

REFERENCES

DESIGN PRACTICES

Section VIII	Fired Heaters
Section XIV	Fluid Flow
Section XVI	Noise Control

INTERNATIONAL PRACTICES

IP 2-1-1,	Plant Noise Design Criteria
IP 3-2-1,	Sewer Systems
IP 3-9-1,	Winterizing and Protection Against Ambient Temperatures
IP 4-2-1,	Auxiliary Structures for Operation and Maintenance

OTHER LITERATURE

1. API RP 521, *Guide for Pressure Relief and Depressuring Systems*, (3rd Edition, 1990).
2. *Predicting Radiant Heating from Flares*, ER&E Report No. EE.15ER.71.
3. *New Seal Drum Sparger Can Eliminate Flare Pulsing*, ER&E Report No. EE.57E.73.
4. *A Survey of Flaring Experience in Exxon Refineries and Chemical Plants*, ER&E Report No. EE.45E.77.
5. *Safe Flaring of Concentrated Hydrogen Sulphide Streams*, ER&E Report No. EE.49E.84.
6. *Flare Pilot Ignition and Verification*, ER&E Report No. EE.47E.88.
7. *Use of Dynamic Simulation for Estimating Flare Loads From Process Equipment*, ER&E Report No. EE.71E.97.

BACKGROUND

The flare is a key component of the closed emergency release system in a refinery or chemical plant.

Emergency releases originating from pressure relief valves, vapor blowdowns, process stream diversion, etc., and equipment drainage, which cannot be discharged directly to the atmosphere for reasons of safety or pollution control, are routed through closed systems to a blowdown drum where liquids and vapors are separated. Other emergency vapor streams are vented from disengaging drums handling contaminated effluent cooling water, process water drawoffs, etc.

The flare provides a means of safe disposal of the vapor streams from these facilities, by burning them under controlled conditions such that adjacent equipment or personnel are not exposed to hazard, and at the same time meeting pollution control and public relations requirements.

FLARE TYPES AND APPLICATION

Three types of flare are available: the elevated flare, the ground flare, and the burning-pit flare. Although the three basic designs differ considerably in required capital and operating costs, selection is based primarily on pollution/public relations considerations; i.e., smoke, luminosity, air pollution, noise and spacing factors. [Table 1](#) summarizes the advantages and disadvantages of the various types of flare.

ELEVATED FLARES

The elevated flare is by far the most commonly used type of flare used in refineries and chemical plants. The elevated flare, by the use of steam injection and effective tip design, can be made smokeless and of reasonably low luminosity up to about 20% of maximum flaring load. Steam injection introduces a source of noise, and a compromise between smoke elimination and noise is usually necessary. If adequately elevated, this type of flare has the best dispersion characteristics for malodorous and toxic combustion products, but visual and noise pollution can present public relations problems. Capital costs are relatively high, and an appreciable plant area may be rendered unavailable for plant equipment, because of radiant heat considerations.

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FLARE TYPES AND APPLICATION (Cont)

Despite some of its disadvantages, the elevated flare is the general choice either for total flare loads, or for handling over-capacity releases in conjunction with a multijet ground flare. For most applications, the elevated type is the only acceptable means of flaring "dirty gases," i.e., gases high in unsaturates or hydrogen sulfide, or which have highly toxic combustion products.

Three types of stack for elevated flares are used:

Guyed Stack - This type is usually the least expensive to build but in some cases the guy wires result in restrictions on the use of adjacent land, in addition to normal spacing restrictions.

Derrick Type Stack - This type of unit is well-suited for tall structures subject to strong winds. However, derrick type stacks are the most expensive to erect and maintain.

Self-Supporting Stack - This type of unit is designed so that the flare riser pipe has no lateral structural support. For short flares, this type is the least expensive to erect and maintain.

GROUND FLARES

Various designs of ground flare are available. The type, which has been used almost exclusively, is the multijet flare.

Smokeless operation can generally be achieved, with essentially no noise or luminosity problems, provided that the design gas rate to the flare is not exceeded. However, since the flame is near ground level, dispersion of stack releases is poor and this may result in severe air pollution or hazard if the combustion products are toxic or in the event of flame-out. Capital and operating cost and maintenance requirements are high.

The multijet flare is suitable for "clean burning" gases (i.e., where toxic or malodorous concentrations are unlikely to be released through incomplete combustion or as combustion products) when noise and visual pollution factors are critical. It should not be used in locations upwind of adjacent residential areas. Generally, it is not practical to install multijet flares large enough to burn the maximum release load, and the usual arrangement is a combination with an elevated over-capacity flare.

Other proprietary designs of ground flare suitable for refinery application are available. In some of these cases, noise is appreciable, in comparison with the multijet type, but their compact size, low space requirement, simplicity, and hence low cost, may give an overall advantage.

BURNING-PIT FLARES

The burning pit is of simple construction, with low capital and operating costs, and it can handle liquid as well as vapor hydrocarbons. Its use is usually limited by spacing requirements and smoke formation, and it is applied only in remote locations where there are essentially no pollution restrictions.

BASIC DESIGN CONSIDERATIONS

FLARE SPACING, LOCATION AND HEIGHT

Spacing, location and height of flares are determined by consideration of the following factors:

Radiant Heat - Acceptable levels of radiant heat density for equipment and in areas where personnel may be present.

Burning Liquid Fall-out - The possibility of burning liquid fall-out from an elevated flare, if liquid hydrocarbons should be entrained into it.

Pollution Limitations (i.e., smoke formation, malodorous or toxic combustion products, noise) - May be based on statutory and/or public relations requirements.

FLARE CAPACITY AND SIZING

Flare systems are designed to handle the largest vapor release from pressure relief valves, vapor blowdowns and other emergency systems, which results from the design contingency. Normally the largest single contingency basis is used, as discussed in [Sections XV-C](#) and [XV-D](#).

Flare sizing is covered in detail under Design Procedure in this section, and sizing of the overall flare system, including pressure relief valve and flare headers, blowdown drums and seal drums, is covered in [Section XV-C](#).

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BASIC DESIGN CONSIDERATIONS (Cont)

FLASHBACK SEALS

As described in [Section XV-B](#), flare systems are subject to potential flashback and internal explosion since flammable vapor/air mixtures may be formed in the stack or inlet piping by the entry of air, and the pilot constitutes a continuous ignition source. Flares are therefore always provided with flashback protection, which prevents a flame front from traveling back to the upstream piping and equipment. Design details are described later in this section.

DESIGN PROCEDURE

S ELEVATED FLARES

Sizing of Elevated Flares - Sizing of flare systems is a function of maximum allowable back pressure on pressure relief valves and other sources of release into the emergency systems.

Flare stack sizing and pressure drop is included with considerations of pressure drop through the pressure relief valve headers, blowdown drums, flare headers, seal drum, etc., as described in [Section XV-C](#). Elevated flare tips incorporating various steam injection nozzle configurations (see **Elevated Flare Tip Types and Steam Injection** below) are normally sized for a velocity of 400 ft/s (120 m/s) at maximum flow, as limited by excessive noise and the ability of manufacturers to design tips which will ensure flame stability. This velocity is based on the inclusion of steam flow if injected internally, but the steam is not included if added through jets external to the main tip. Flared gas streams containing hydrogen can generally be flared at higher exit velocities. In these cases flare tip manufacturers should be consulted on higher velocity limitations.

A summary of suitable types of elevated flare tips is provided by [Table 2](#), along with details shown by [Figures 1A-1D](#).

Pressure drops for proprietary tips are obtainable from manufacturers' charts such as [Figure 2](#). Available pressure drop may in some cases dictate acceptance of a lower maximum velocity, but at least 250 ft/s (75 m/s) is recommended to insure good dispersion. Flare tips consisting of a simple open-ended pipe with a single pilot are subject to flame lift-off and noise problems at high velocities, and should therefore be designed for a maximum velocity of 160 ft/s (50 m/s).

Elevated Flare Location, Spacing and Height - Location, spacing and height of elevated flares are a function of permissible radiant heat densities, possible burning liquid fall-out, and pollution considerations. Design requirements are as follows:

1. Flares should be at least as high as any platform or building within 500 ft (150 m) horizontally, and in no case less than 50 ft (15 m) high.
2. Any source of ignitable hydrocarbons, such as separators or floating roof tanks, should be at least 200 ft (60 m) from the base of the flare stack, assuming the potential for liquid fall-out from the flare is minimal. Burning liquid fall-out from a flare can present extremely hazardous situations should ignitable hydrocarbons lie within the fall-out area. New facilities should be designed per this section and [Section XV-D](#) to minimize the potential for burning liquid fall-out.

For existing facilities that have a history of burning liquid fall-out or that are known to have design deficiencies (e.g., undersized blowdown drum, low points in the flare header where liquid can accumulate, long distances between the blowdown or seal drum to the flare, etc.) which will increase the probability of liquid entrainment to the flare, modifications should be made to reduce the potential for and/or reduce the impact of burning liquid fall-out. Until such modifications can be made, no new sources of ignitable hydrocarbons should be located close to the flare. In such situations, the 200 ft (60 m) spacing mentioned above may be inadequate. Drift distances of burning liquid droplets from an inadequately designed flare system can be considerably greater than 200 ft (60 m).

3. Flares should be located to limit the maximum ground level heat density to 500 Btu/hr/ft² (1.6 kW/m²) at any property line. The minimum distance from the base of the flare stack to the property line should be 200 ft (60 m).
4. Flare elevation and spacing must be such that permissible radiant heat densities for personnel at grade and on elevated structural platforms are not exceeded under conditions of maximum heat release. The appropriate calculation procedures and personnel exposure criteria are described in [Appendix A](#). In some special cases, flare elevation and spacing may be governed by radiant heat exposure of certain vulnerable items of equipment, rather than personnel.
5. Flare location and height must be such as to meet all applicable regulatory standards of noise level (refer to *Environmental Control*, [Section IV](#)) and atmospheric pollution by combustion products.

Elevated Flare Tip Types and Steam Injection - A simple open tip with no steam injection is used when there are no limitations on smoke emission and luminosity.

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DESIGN PROCEDURE (Cont)

Flare tips incorporating steam injection are used where smoke emission and luminosity must be minimized. Generally, tip selection and steam injection capacity are designed to give smokeless operation at flare gas rates up to about 20% of design, since this will cover a large proportion of releases in a typical plant. The economics of providing continuously available reserve steam capacity for higher loads is prohibitive unless special pollution regulations apply. The required steam to hydrocarbon ratio for smokeless operation is a complex function of gas composition, hydrogen to carbon ratio, degree of saturation, tip pressure drop, tip diameter steam pressure, and flare exit velocity.

Nominal steam rates at 200 ft/s (60 m/s) exit velocity for a typical proprietary flare tip are shown in **Figure 3** for guidance. Significantly higher or lower steam ratios may be required for different tip designs and gas composition. Therefore, definitive steam ratios should be obtained on a case by case basis from flare tip vendors. In some cases steam control consists of a flow ratio controller with adjustable ratio set point, related to flare gas flow. The ratio adjustment, located in the control house, provides for the higher steam ratios necessary at low flaring rates. More recently successful applications of infrared smoke control have been used - see under **REDUCING FLARE PULSING AND NOISE** later in this section. Manual smoke control is also possible using TV monitors in the operating control room.

Flare gas measurement is covered below under **FLARE GAS METERING**. If necessary, continuously vented surplus low-pressure steam may be used for smoke control at low flaring rates, with high-pressure steam cutting in through the flow ratio controller for larger releases.

Injection of steam introduces an additional source of noise, and an effective flare tip is one which achieves a good balance of smoke and luminosity reduction without exceeding acceptable noise levels. Low-frequency noise is encountered at relatively high steam to hydrocarbon ratios.

A flare performance chart, if available for the hydrocarbon being flared, may provide additional guidelines for flare tip design. **Figure 4** shows a provisional performance chart for propane, based on experimental data, which defines the design envelope of exit velocities and steam ratios necessary to avoid smoke formation, excessive noise, flame boilover (flame-lick) and flame lift-off.

Various designs of flare tip incorporating features such as central steam injection, an annular ring of steam nozzles, internal air-inspiring steam nozzles, windshields, etc., are available from a number of vendors. Details of suitable types from which selection may be made are given in **Table 2**, along with typical design details provided by **Figures 1A-1D**.

Other flare tip details:

1. Incoloy 800 and Type 310 Stainless Steel are the recommended materials for flare tips. It should be noted that Alloy 800 should be used rather than Alloy 800H. The former grade has superior high temperature ductility properties.
2. Length of flare tip is normally 10 ft (3 m).
3. A maintenance platform should be provided at the bottom of the flare tip (at the flange), with access by means of a caged ladder with intermediate platforms, in accordance with **IP 4-2-1**. Access onto the ladder should be permitted only when the flare is out of service.

Elevated Flare Pilots and Igniters - Proprietary flare tips are normally provided with the manufacturer's recommended igniter and pilot system. Typically, one to four pilots are used depending on flare tip type and diameter. The forced air supply type of igniter system described below under **FLARE PILOTS AND IGNITERS** is preferred. It is recommended that controls be located at a distance from the base of the flare such that pilot ignition can be readily observed, subject to a minimum of 25 ft (7.5 m). Since pilot nozzles are small, strainers are needed to prevent plugging.

S MULTIJET FLARES

Capacity of Multijet Flares - In most cases, the economics of providing a multijet flare sized to handle the entire release from the largest design contingency are prohibitive, because of the low frequency of such major releases. Instead, it is designed to handle a proportion of the maximum flow, typically 20%, so that releases up to this level will be relatively smokeless and non-luminous. To further reduce smoking, steam injection at rates of 0.3 lb steam/lb gas (0.3 kg steam/kg gas) may be provided. This will cover a large proportion of releases in a typical plant, but variations on this sizing basis may be dictated by considerations of the number and type of upstream process units, type and probability of major release contingencies, atmospheric pollution restrictions, and cost of the flare facilities.

An over-capacity line to an elevated flare is provided to handle the excess flow when the flaring rate exceeds the capacity of the multijet flare. The over-capacity flare is normally not provided with steam injection, and smoke formation is accepted during the infrequent occasions when it discharges. The over-capacity line and flare is normally designed to handle the entire maximum flow so that it can spare the multijet flare when the latter is shut down for maintenance.

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DESIGN PROCEDURE (Cont)

Spacing of Multijet Flares - Recommended minimum spacings for heat releases between 300 x 106 and 1 x 10⁹ Btu/hr (90-300 MW) are given below. For heat releases outside this range, a special study must be made.

1. Clearance from property lines: 200 ft (60 m).
2. Clearance from structures higher than the flare stack: 200 ft (60 m). In addition, no structure where personnel access may be required while the multijet flare is in operation shall exceed in height a projected diagonal line from the base of the flare stack to the top of the stack wall diametrically opposite.
3. Clearance from structures lower than the flare stack: 150 ft (45 m).
4. Clearance from refinery roads and pipe bands: 75 ft (22.5 m).
5. Clearance from the elevated over-capacity flare must comply with radiant heat spacing requirements for elevated flares, considering personnel exposure when maintenance work is being performed on the multijet flare and the over-capacity flare is taking full design load. Clearance should be sufficient to allow personnel to evacuate promptly to a safe location. This clearance should not, however, be less than 100 ft (30 m).

S STACK DESIGN AND DIMENSIONS FOR MULTIJET FLARES (SEE FIGURE 6)

Dimensions - The inside diameter of the stack is based on the rate of heat release at design capacity, in accordance with the following equation:

$$D = 0.83 \sqrt{Q} \quad (\text{Customary}) \quad \text{Eq. (1)}$$

$$D = 0.47 \sqrt{Q} \quad (\text{Metric}) \quad \text{Eq. (1)M}$$

where: D = Stack inside diameter, ft (m)

Q = Heat release at design flaring rate, millions Btu/hr (MW) (Based on lower heating value)

For stack diameters up to 25 ft (7.5 m) the stack height is normally 50 ft (15 m) above grade. The bottom of the stack is elevated to allow air for combustion to enter. The minimum clearance between the bottom of the stack and grade is either 6 ft (1.8 m) or 0.3 D, whichever is greater.

Insulation - The steel shell of the stack is lined for its entire length with monolithic type castable refractory.

Windbreaker - A windbreaker is necessary to prevent the wind from extinguishing the flames. It serves also to hide the flames. Since a solid wall produces undesirable eddies, a louvered type is used.

The windbreaker is octagonal and is placed 8 ft (2.4 m) from the stack. The height should be at least 2 ft (0.6 m) more than the stack clearance. The slats should be at least 9 in. (225 mm) wide and overlap by at least 2 in. (50 mm). They should slope 45° to direct the flow of air downward on the inside of the enclosure. Four access doors are provided in the windbreaker, equally spaced around the periphery.

The area below the stack and windbreaker is paved with concrete, surrounded by a 8 in. (200 mm) curb, and graded to a central drain point from which a drain line is routed to a manhole in a vented section of the oily water sewer. The water inlet should be sealed and the manhole should be located at least 50 ft (15 m) from the windbreaker.

Burner Design and Back Pressure for Multijet Flares - The "burner" consists of a large number of small burner jets, arranged in a grid pattern inside the stack, near the bottom. To increase the rangeability of the burners, a two-stage piping system is provided, such that one set of burners handles low flows and the second set cuts in as the gas flow rate increases.

1. **Staging Design** - A single-stage multijet burner has a turndown ratio (maximum smokeless flaring rate/minimum flaring rate) of about 10:1. A two-stage burner therefore has a maximum turndown ratio of 100:1. In an actual two-stage design, the first stage is designed to handle about 20% of the design load of the multijet flare. Although this reduces the overall turndown ratio to about 50:1, it permits a large overlap between the maximum burning rate of the first stage and the minimum burning rate of the second. The overlap is desirable for smooth operation. The first stage burner grid should extend full width with the tube ends near the pilot to more readily promote ignition at very low flaring rates.

A simple sequential water seal system with two seal drums is used to control the distribution of flare gas to the two stages and to provide flashback protection, as illustrated in **Figure 5**. The seal in the over-capacity line is designed to start releasing when the pressure in the second stage burner header reaches a value corresponding to maximum design flow to the multijet flare. Design of the seal drums, loop seals, disposal of effluent seal water, etc., follows the procedure described below for elevated flares under **FLASHBACK PROTECTION FOR FLARE SYSTEMS**, with the following exceptions:

- a. Vapor inlet dipleg submergence is selected to control progressive operation of the stages. Typical values are indicated in **Figure 5**.

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- b. The second stage seal drums should be vertical, to minimize its size, provided that the required slope up to the burners can be achieved.

A butterfly valve in the line to the first stage seal drum limits the maximum flow to the first stage burner. The valve is set by observing the burners while flaring at design capacity. Once adjusted, the valve should be locked in position.

Pressure indicators are specified to aid in making adjustments and in evaluating burner performance. Water manometers may be used in this service, but must be shut-off when not in use.

2. **Piping to Burners** - First and second stage piping and headers, as well as the burner lines themselves, are sized to minimize pressure drop and velocity effects. Thus, maldistribution of flow to the burners will be minimized. The burner lines are fabricated from standard 4 in. (100 mm) pipe, and are arranged in a split grid layout with distribution headers and split feed lines on opposite sides, for both first and second stage burners.

First and second stage headers must be sloped so that any condensate will drain back to the seal drums. However, the burner lines must be accurately installed in a horizontal plane.

3. **Size, Spacing and Number of Burner Jets** - The jet nozzles are 15 in. (380 mm) lengths of 1 in. (25 mm) stainless steel pipe. They discharge vertically from the horizontal burner lines, which run across the bottom of the stack. The jet nozzles are not insulated.

The number of jets is based on gas velocity. For 1 in. (25 mm) standard pipe, the recommended maximum velocity permits a flow rate of 2550 SCFH. (72.2 Sm³/h) of gas per jet. Expressed as an equation:

$$N = 16.4 V \text{ (SCF/day)} \quad \text{(Customary)} \quad \text{Eq. (2)}$$

$$N = 0.0139 V \text{ (Sm}^3\text{/h)} \quad \text{(Metric)} \quad \text{Eq. (2)M}$$

where: N = Number of jets (N should be rounded off upward to a whole number)

V = Flare design capacity, millions SCF/day (Sm³/h)

The jets are laid out on an approximately square pitch, with spacings in both directions varying between roughly 18 and 24 in. (450 and 600 mm)*. A first approximation of the required spacing is obtained from **Eq. (3)**:

$$P_1 = P_2 = 10 \frac{D}{\sqrt{N}} \quad \text{(Customary)} \quad \text{Eq. (3)}$$

$$P_1 = P_2 = 833 \frac{D}{\sqrt{N}} \quad \text{(Metric)} \quad \text{Eq. (3)M}$$

where: P₁ = Center-to-center spacing of adjacent burner lines, in. (mm)

P₂ = Center-to-center spacing of jets along a burner line, in. (mm)

D = Inside diameter of stack [from **Eq. (1)**], ft (m)

This equation is based on a negligible wall effect. The design values of P₁ and P₂ must be determined from a scale drawing, which is made to allow the required number of jets to be installed in the available area. This area is restricted by the limitation that no jet should be placed closer than 12 in. (300 mm) from the inside wall of the stack. The spacing is also affected by air flow considerations (see below), which may require the layout to be modified.

4. **Air Flow** - The capacity of a multijet flare to induce air flow must be calculated, to make sure that it is adequate to meet the maximum air flow requirement for smokeless combustion. [W_a of **Eq. (4)** must ≥ W_r of **Eq. (5)**.]

- a. **Air Flow Capacity** - The primary air flow rate which will be induced around each jet may be estimated from **Eq. (4)**:

$$W_a = \frac{5.7A_j \sqrt{H_1 \left(1 - \frac{520}{T_s}\right)}}{\sqrt{1 + 10.9 \left(\frac{A_o}{A_B}\right)^2 + 0.138 \left(1 - \frac{A_o}{A_S}\right)^2}} \quad \text{(Customary)} \quad \text{Eq. (4)}$$

*In the case of a low heating value flare gas (less than about 1000 Btu/SCF (37 MJ/m³) HHV @ std. condition) which requires relatively little air, this spacing may be as low as a minimum of 15 in. (380 mm).

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or

$$W_a = \frac{2.02 \times 10^{-6} A_j \sqrt{H_1 \left(1 - \frac{289}{T_S}\right)}}{\sqrt{1 + 10.9 \left(\frac{A_o}{A_B}\right)^2 + 0.138 \left(1 - \frac{A_o}{A_S}\right)^2}} \quad (\text{Metric}) \quad \text{Eq. (4)M}$$

- where:** W_a = Available primary air flow per jet, lb/hr (kg/s)
- A_j = Net free flow area per jet, in.² (mm²) = $P_2 (P_1 - d)$
- d = Outside diameter of burner line (including insulation), in. (mm)
- H_1 = Net stack height, ft (m)
- T_S = Average stack gas temperature, °R (°K). This temperature depends on the heating value of the flare gas and the percent excess air. Assume that $T_S = 2800^\circ\text{F}$ (1538°C) = 3260°R (1811°K). This should be close enough, since **Eq. (4)** is relatively insensitive to changes in T_S .
- A_o = Total free flow area for primary air, ft² = $\frac{N A_j}{144} \left(\text{m}^2 = \frac{N A_j}{10^6} \right)$
- A_B = Peripheral area between bottom of stack and grade, ft² (m²)
- A_S = Total inside cross-sectional area of stack, ft² (m²)

Note: **Eq. (4)** has a partially theoretical origin, based on the pressure drops through the three successive major restrictions to air flow through the flare, i.e., the cylindrical area under the stack, the burner grid, and the stack itself. However, the constants have been determined from actual performance data on two flares, of 6 ft (1.8 m) and 30 ft (9.2 m) diameter.

- b. **Air Flow Requirement** - The primary air flow rate per jet necessary for smokeless combustion depends on the molecular weight and degree of unsaturation of the flare gas. Experience indicates that it varies linearly with percent unsaturates, from a minimum of 20% excess air for a flare gas containing 0% unsaturates to 35% excess air for a gas containing 67 mol% unsaturates. Based on this relationship and a design gas flow rate of 2550 SCFH (72.2 m³/h) per jet, the required primary air flow rate can be calculated directly from the gas composition or approximated conservatively from **Eq. (5)**:

$$W_r = 120 M + 56 y_u + 22 M y_u + 300 \quad (\text{Customary}) \quad \text{Eq. (5)}$$

or

$$W_r = 1.26 \times 10^{-4} [120 M + 56 y_u + 22 M y_u + 300] \quad (\text{Metric}) \quad \text{Eq. (5)M}$$

- where:** W_r = Required primary air flow rate, lb/hr (kg/s) per jet, for a gas flow rate of 2550 SCFH (72.2 m³/h) per jet
- M = Molecular weight of flared gas
- y_u = Mole fraction unsaturates in flared gas

If $W_r > W_a$, it will be necessary to modify the burner layout in order to provide more air flow area per jet. If necessary, the stack diameter must be increased. (Another possibility is reducing the piping diameter, if pressure drop is not limiting.)

The value of W_r calculated from the gas composition or from **Eq. (5)** should be considered to be a minimum requirement. A multijet flare should be designed with a calculated air capacity W_a as high as possible, as limited by practical considerations of geometry and economics.

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- c. **Stack Gas Temperature** - The average stack gas temperature, T_S , which is required in [Eq. \(4\)](#) for calculation of W_a has to be estimated. [An assumed value of 2800°F (1538°C) is recommended.] It can be checked as follows:
 - i. Calculate the percent excess air which corresponds to the value of W_a calculated per [Eq. \(4\)](#).
 - ii. Find the chart ([Figure 7, 8, 9](#) or [10](#) of [Section VIII-M, Combustion Design Data](#)) which most nearly corresponds to the heating value of the flare gas.
 - iii. The intersection of the curve for the percent excess air in question with the abscissa (heat available = 0) is the stack temperature, T_S .
 - iv. If this value of T_S differs from the assumed value by 300°F (149°C) or less, the change in W_a will be less than 1%.
5. **Flameholder** - Flameholders are necessary to prevent the flame from "riding" up to the top of the stack. They provide a surface at which burning can take place and also promote better mixing of air and gas by the additional turbulence which they cause above the jets. Construction is simply a solid, 1 in. (25 mm) diameter rod of refractory material (silicon carbide) supported horizontally above each burner line. The bottom of the rod should be 1/2 in. (13 mm) above the tips of the jets. Typical flameholder support details are shown in [Figure 6A](#).
6. **Critical Burner Dimensions** - The position of the flameholders and burner lines relative to the bottom of the stack is critical for efficient operation. For example, the multijet flare has a turndown ratio of 10:1 when the flameholder centerline is 5 in. (125 mm) below the bottom of the stack but only 2:1 when it is 6 in. (150 mm) above the bottom of the stack. Critical dimensions are shown in [Figure 6A](#).
7. **Burner Insulation** - The burner lines should be insulated with a 1 in. (25 mm) layer of castable insulation.
8. **Pilots and Igniters** - Duplicate continuous gas pilots are required at each side of the flare, corresponding to the split burner grid layout. Selection of pilot and igniter systems follows the guidelines described below under **FLARE PILOTS AND IGNITERS**, and the controls should be located 50 to 100 ft (15 to 30 m) from the windbreaker.
 Because of the potential hazard of release of unignited hydrocarbons at ground level, a flame detection system, e.g., scanner, flame rod, TI / TLA, with alarm in the control house is included for each pilot.
 If an ultra violet detector is used, the flame scanner must be located so that interference of ultra violet rays from the main flame or other sources do not cause false readings. Mount ultra violet detectors looking straight down through the pilots toward the ground. Provide strainers in each gas or oil line to pilots.
9. **Steam Injection** - While the multijet flare will achieve a significant reduction in the smoke produced, it does not provide true smokeless combustion over its full operating range. This is particularly true with the heavier (C4+) and unsaturated gases. Steam injection at a rate of about 0.3 lb steam per lb of gas (0.3 kg of steam/kg of gas) will provide an additional reduction in smoke for most gases. Steam should be injected into the flare gas either upstream or downstream of the burner nozzles, according to the burner design.
10. **Materials** - In selection of materials for burner grid, stack lining, and piping inside the windbreaker, temperature rise due to heat radiation from the flame should be evaluated. A flare tip refractory lining should be provided, as shown in [Figure 6A](#).

S BURNING-PIT FLARES

Burning-pit flares can handle flammable liquids or gases or mixtures of the two. A typical design is shown in [Figure 7](#). A circular pit is illustrated, but any convenient shape may be used.

The burning pit is simply a shallow earth-or concrete-surfaced pool area enclosed by a dike, with a liquid/vapor inlet pipe through the wall, and provided with pilots and igniters. While the design basis below is adequate for handling emergency releases, a more conservative approach is recommended for continuous flaring services, incorporating up to twice the calculated pit area.

Burning Pit Flare Sizing - The burning-pit area is sized to provide sufficient surface to vaporize and burn liquid at a rate equal to the maximum incoming liquid rate. The calculation procedure is as follows:

1. Determine the linear regression rate of the liquid surface (i.e., the rate at which the liquid level would fall as a result of vaporization by radiant heat from the burning vapor above it, assuming no addition of incoming liquid):

$$R = 0.003 \frac{LHV}{H_v} \quad (\text{Customary}) \quad \text{Eq. (6)}$$

$$R = 0.00127 \frac{LHV}{H_v} \quad (\text{Metric}) \quad \text{Eq. (6)M}$$

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2. Determine the pit area necessary to vaporize and burn liquid at a rate equal to the liquid input rate:

$$A = \frac{0.2m}{R\rho_L}; \quad (\text{Customary}) \quad \text{Eq. (7)}$$

$$A = \frac{1001m}{R\rho_L} \quad (\text{Metric}) \quad \text{Eq. (7)M}$$

where: LHV = Lower Heating Value of incoming vapor and vaporized liquid, Btu/lb (kW/kg).

A = Pit area required to vaporize and burn liquid, ft² (m²).

m = Rate of vaporization and burning of liquid, lb/hr (kg/s) (selected as equal to the rate of flashed liquid entering the pit).

R = Linear regression rate of liquid surface, in./min (mm/s).

ρ_L = Liquid density, lb/ft³ (kg/m³).

H_v = Liquid latent heat of vaporization, Btu/lb (kJ/kg).

3. The dike wall height above the water level is selected to provide holdup capacity for the largest liquid release resulting from a single contingency during 30 minutes, plus 18 in. (450 mm) freeboard. The liquid rate is based on the actual flashed liquid entering the pit, assuming no burning or further vaporization in the pit. The height of the dike wall above the water level should not, however, be less than 4 ft (1.2 m).

Spacing of Burning Pit Flares - Spacing is based upon radiant heat considerations at maximum heat release, using a simplified calculation procedure, as follows:

$$D = \sqrt{\frac{FQ}{4\pi K}} \quad \text{Eq. (8)}$$

where: D = Distance from flame to point under consideration, ft (m).

Q = Total heat released by liquid and vapor, Btu/hr (kW).

K = Radiant heat density, Btu/hr ft² (kW/m²).

F = Fraction of heat radiated. Refer to **Appendix A** for appropriate values of F.

The center of the flame is assumed to be 1-1/2 pool diameters from the center of the pool at a 45° elevation, in the direction of the point where radiant heat density is being considered. This assumption is used to allow for flame deflection by wind.

Permissible radiant heat densities for personnel are described in **Appendix A** and later in this section. In some special cases, spacing may be governed by radiant heat exposure of certain vulnerable items of equipment, rather than personnel. Radiant heat density at the property line must not exceed 500 Btu/hr ft² (1.6 kW/m²).

In addition, the following minimum spacings apply to burning pit flares:

- 500 ft (150 m) from property lines, roadways, or any process or storage facilities.
- 200 ft (60 m) from any source of ignitable hydrocarbons, such as separators or floating roof tanks.

Valves in the inlet, seal water and pilot gas lines should be located according to permissible radiant heat densities for personnel, as defined in **Appendix A**, consistent with being able to carry out emergency actions. Piping to the burning pit should be suitably protected against flame impingement (e.g., by installation below grade).

Inlet Piping and Flashback Protection - In non-freezing climates, for services where incoming liquid or vapor hydrocarbon temperatures do not fall below 32°F (0°C), flashback protection is provided by submerging the inlet below a layer of water in the bottom of the pit. The top of the inlet distributor is 4 in. (100 mm) below the water level, and the bottom of the distributor is 6 in. (150 mm) above the bottom of the pit. A continuous flow of at least 20 gpm (1.3 dm³/s) of makeup water into the pit is provided, with the level maintained by an overflow seal discharging to the oily water sewer. Higher water rates may be required on account of ground seepage or evaporation during maximum release conditions.

For services where ambient or inlet temperatures may fall below 32°F (0°C), flashback protection is provided by a special seal drum or loop seal in the inlet line. This equipment is designed specifically for the particular liquid and vapor materials being flared. In these cases a 6 in. (150 mm) minimum water layer is included in the bottom of the pit to prevent oil seepage into the ground, and the hydrocarbon inlet distributor is mounted 6 in. (150 mm) above the water surface.

Details of the inlet distributor are shown in **Figure 7**.

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Pilots and Igniters - Two gas-fired pilots with igniters are installed adjacent to the inlet distributor. As described below under **FLARE PILOTS AND IGNITERS**, the igniter assembly and pilot gas valves must be located remote from the flare for protection of personnel and equipment. This restricts igniter selection to the forced air supply type. Location of these components should be such that the calculated radiant heat density at maximum load does not exceed permissible levels for personnel exposure. Because of the potential hazard of release of unignited hydrocarbons at ground level, a flame scanner (suitably shielded and air-cooled and connected to an alarm in the control house) is provided for each pilot.

S FLARE PILOTS AND IGNITERS - ALL FLARES

All flares must be provided with continuous pilots to ensure combustion of any releases discharged to them, and to prevent flame-out. Various designs of pilot burner are available, and proprietary tips for elevated flares are normally provided complete with pilots.

In addition, an ignition system is required for igniting the pilots when a flare is commissioned. Various proprietary flame front igniters are available, which function by the application of an electrical spark to a gas/air mixture in an ignition chamber, and allowing the resulting flame front to travel through an igniter tube which terminates with an open end adjacent to the pilot burner tip. In some designs, to improve the reliability of achieving ignition, the igniter tube ignites a raw gas on-off pilot burner provided with a special wide-angle tip, which in turn ignites the continuous pilot.

Air to the ignition chamber may be inspirated through a gas-operated venturi, which is designed to provide the correct gas/air mixture, but this type does not function reliably when horizontal igniter tube runs exceed 20 to 30 ft (6 to 9 m). The ignition chamber and igniter tube venturi must therefore be placed close to the flare, i.e., at the base of an elevated flare or adjacent to the windbreaker of a multijet flare. Remote operation of the ignition controls may however be achieved by locating the spark ignition pushbutton and the igniter gas and pilot gas valves at any required distance from the flare. The inspiring system is not, however, acceptable for burning-pit flares since, even with remote control, the ignition chamber and venturis, etc. would be subject to damage by overheating.

An alternative design uses a compressed air supply (from the instrument air header) for the ignition chamber, the gas/air mixture being controlled by restriction orifices. The flame front passes through an igniter tube as for the inspiring type, but there are no limitations on horizontal distance from the flare, and the igniter assembly may therefore be located remotely.

The forced air supply type of igniter system is preferred for all flare applications.

When pilot and igniter systems for flares are being selected available proprietary systems may be considered but the choice should be based upon proven satisfactory operating experience. The John Zink Flame Front Generator, which uses an instrument air supply to the ignition chamber, is typical of the igniter systems most frequently applied during recent years. It is illustrated in **Figure 8**.

Flares, which depend only on PHA and PLA alarms in the pilot gas supply to indicate the pilots are lit, should be Priority 1 alarms which have dedicated alarms in the control room. For flares using thermocouples to verify pilot flame, such as used on a H₂S flare, the use of PHA and PLA instrumentation in the pilot fuel gas supply is not required. However, the thermocouples should be equipped with Priority 2 alarms.

Reliability of flare pilots has been a problem at some installations when using a 45 scfh fuel supply. Plugging of the in-line strainers has occurred and it is recommended that such in-line strainers be removed prior to pilot installation. For these problem installations, the strainers were not accessible without a flare shut down and the strainer mesh was too fine for the service. Filtering of the fuel should be done at grade and cartridge filters have been used to provide adequate protection. Testing of the pilots prior to installation is strongly recommended since the primary air setting may not be valid if site location is different from factory location. Pilot tip temperature must be above the ignition temperature of the fuel and testing will confirm that the desired tip temperature of 1500°F (816°C) is achieved. Use of 80 scfh pilots appears to be adequate to ensure flame stability, and is recommended.

Gas pilots must be provided with a reliable source of gas, which will remain available under any single contingency such as power or air failure. Pilots should be designed for the anticipated gas composition, which should be reasonably constant.

An alternative means of igniting flare gas is to use direct electronic ignition, instead of continuous pilots. This has been attempted over the years but was hampered by a variety of problems. These were corrosion, erosion, melt-down, and carbon build-up problems associated with the electrodes. Successful flare ignition is highly dependent on the position of the electrodes. There could be flaring conditions where the arc would not ignite the discharging gas because the flare gas/air mixture at the electrodes was either over-rich or too lean. Before specifying an electronic ignitor, a thorough investigation should be conducted to determine the reliability of such devices.

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S FLASHBACK PROTECTION FOR FLARE SYSTEMS

All flares must be provided with flashback protection to prevent a flame front from traveling back to the upstream piping and equipment. A number of different flashback seal designs are available, of which the seal drum is used in nearly all applications. Details are as follows:

Seal Drum - A typical flare seal drum for an elevated flare stack is illustrated in **Figure 9A** (**Figure 9B** - Metric). (Seal arrangements for multijet flares and burning pits were covered earlier in the section.) With a continuous flow of water to the seal drum, loss of level downstream of the baffle is not possible. Condensed hydrocarbon may accumulate downstream of the baffle and skimming connections should be provided. The need for a LHA and LLA in the drum is not needed because the level downstream of the baffle is determined by the height of the seal leg.

A baffle maintains the normal water level, and the vapor inlet is submerged 3 to 4 in. (75 to 100 mm). Drum dimensions are designed such that a 10 ft (3 m) slug of water is pressured back into the vertical inlet piping in the event of flashback, thus preventing the explosion from propagating further upstream.

The inlet piping or diplegs should have sufficient wall thickness to withstand an internal explosion and should be good for 50 psig (345 kPa), or consistent with the drum internal design pressure.

The vapor space is sized to avoid water entrainment into the flare gas. The vapor residence time in the drum should allow larger liquid droplets to fall to the liquid surface. The method used follows API 521. The vapor space velocity as measured through the vertical cross-sectional area above the baffle level (see **Figure 9**) determines the residence time. The liquid "dropout velocity" is determined as follows:

$$U_c = 1.15 \sqrt{\frac{g D (\rho_L - \rho_v)}{\rho_v C}} \quad \text{Eq. (9)}$$

- where:**
- U_c = Dropout liquid velocity, ft/sec (m/s).
 - ρ_L = Liquid density, lb/ft³ (kg/m³) at operating conditions (water).
 - ρ_v = Vapor density, lb/ft³ (kg/m³) at operating conditions.
 - D = Liquid particle diameter, ft (m).
 - g = Acceleration due to gravity 32 ft/s² (9.8 m/s²).
 - C = Drag coefficient (see figure in **Section XV-D** for drag coefficient).

The droplet size should be selected as follows for normal contingencies:

- 600 microns for new/existing facilities.
- The vapor velocity should be limited to 25 ft/s (7.6 m/s) or less in all cases.
- The depth of the vapor space should be no less than 20% of the drum diameter or 12 in. (300 mm), whichever is greater.

For remote contingencies:

- The droplet size may increase to 1000 microns for all cases.
- The vapor velocity should be limited to 25 ft/s (7.6 m/s) or less in all cases.

The former seal drum designs included a serrated edge at the base of the dipleg (see Detail A, **Figure 9**). Intermittent bubbling through the seal dipleg sometimes causes problems of flame pulsation, low frequency noise and/or smoke pollution. The alternative is to design using successive diplegs as shown in **Figure 5** plus the non-pulsing sparger shown in **Figure 12** and discussed in subsequent paragraphs.

Seal water should be taken from a reliable source (firemain water may be permissible, per **Section XV-I**). Salt water should not be used where flare gas components would cause deposition of solids. Winterizing should be provided if required by **IP 3-9-1**. At some locations, which experience extremely cold weather, e.g., Strathcona, a recirculation glycol system is used.

The vertical downflow section of the water outlet line from the drum is sized for a maximum velocity of 0.4 ft/s (0.12 m/s), to allow entrained gases to disengage. The seal loop should be sized for the design water flow. 20 gpm (1.3 dm³/s) has been used as a guideline in the past. The make-up water rate must be sufficient to compensate for drum purge and evaporation. The maximum make-up rate assumes that the drum is empty after a blow and should be high enough to reestablish the seal within a reasonable time after each flaring incident. However, the seal must be reestablished before the ingress of air reaches the seal drum. Air ingress occurs as the system cools down after a pressure release. Where higher water rates are considered necessary then facilities for manually increasing the make up should be provided. The seal depth is equivalent to 175% of the maximum drum operating pressure, subject to a minimum of 10 ft (3 m). A seal depth of 110% of the maximum operating pressure is permitted when applying the "1.5 times design pressure" rule to remote contingencies. (See **Section XV-C**.)

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The drum is normally gunite-lined for corrosion control and must be designed to meet all the following combinations of extreme temperature and pressure requirements:

1. A design pressure of 50 psig (345 kPa) at the highest possible operating temperature of the entering vapors resulting from a single contingency. For those hydrocarbons typically encountered in refinery operations, this design pressure should adequately protect the drum against an internal explosion. This design pressure must also be applied to the flare stack and the water outlet seal loop. However, for those locations which may flare streams containing more than 75% by volume ethylene, a design pressure of 150 psig (1035 kPa) should be used.
2. A design pressure of 50 psig (345 kPa) at the lowest possible operating temperature of the entering vapors resulting from a single contingency.

Credit may be taken for heat transfer to the atmosphere from the flare header upstream of the seal drum when determining the lowest and highest temperatures of the entering vapors.

A flare seal drum may also serve as a sour water disengaging drum, if economically advantageous. In such cases, special care is needed to insure the drum is adequately sized to simultaneously meet all design features required for both functions. Also a separate source of makeup water must still be provided to ensure continuity of the seal.

Disposal of the effluent water is discussed under **Disposal of Seal Water** below.

The drum is provided with steam injection if required for winterizing or cold releases, per **Figure 9**. If winterizing is called for by **IP 3-9-1**, then the steam should be temperature-controlled to maintain the seal water temperature at 40 to 50°F (4 to 10°C).

Oil skimming connections should be provided to remove accumulated oil, carried over from the blowdown drum, to the seal drum. Details are shown in **Figure 9**.

The seal drum should be located a minimum practical distance from the flare.

Gas Purge - Although not normally recommended as an alternative to a water seal, a continuous hydrocarbon gas purge may be used to provide protection against internal burning or flashback explosion which might result from air backing down from the flare tip at zero or low flaring rates. Application of this method is limited to cases where a continuous low-cost gas supply is available, where there are no public relations or atmospheric pollution objections to continuous flaring, and where problems that would be associated with a water seal (e.g., freezing up by cold vapors) can thereby be avoided.

The purge gas must be non-fouling and the source must be reliable and assured during any single contingency such as power or air failure. Purge rate (controlled by restriction orifice) must be calculated in accordance with the procedure described for purging atmospheric vent stacks in **Section XV-B**.

Dry Seals - Various proprietary dry seals are available, such as the John Zink Molecular Dry Seal (illustrated in **Figure 10**) and the National Air-Oil Fluidic Seal (shown in **Figure 11**). They may be used in conjunction with a gas purge system when the purge gas is lighter than air. The molecular dry seal functions by trapping a volume of the light gas in the internal inverted compartment, thus preventing air from displacing light gas in the flare stack by buoyancy effects. The fluidic dry seal utilizes the kinetic properties of the gases to prevent movement of air down the flare. The continuous purge flow requirements for these dry seals may be 30-60% of the open stack purge rates as determined from **Figure 1** of **Section XV-B**. The vendor should be contacted to determine their specific recommendation for each proposed installation. This reduced purge requirement is the only incentive for installing a dry seal.

In the case of heavier-than-air purge gas, there is no buoyancy mechanism causing air entry into the stack, and there is thus no incentive to include a dry seal.

Unlike a water seal, a dry seal cannot prevent a flashback from traveling upstream if a combustible mixture has been formed by the entry of air into the pressure relief valve or flare headers. It only protects against internal burning flashback, which might result from air backing down from the flare tip at zero or low flaring rates. Dry seals are therefore not normally specified for new designs.

The location of the John Zink Molecular Seal recommended by the manufacturer is approximately 11 ft (3.6 m) below the top of the flare.

The NAO Fluidic Seal is located as close to the top of the tip as possible to eliminate the need for internal refractory.

Disposal of Seal Water - Effluent water from water seals must be routed to safe means of disposal, considering possible hazards arising from liquid or vapor hydrocarbons or toxic materials that may be entrained or dissolved in the water. The separation of liquid hydrocarbons (formed by condensation in flare lines) in flare seal drums is discussed in **Section XV-D**.

Seal water should be discharged as follows:

1. If H₂S is never present in the flare gas, seal water effluent should be routed through an open funnel (to permit checking of seal water flow) to a manhole in a vented section of the oily water sewer. The water inlet to the manhole must be sealed.

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2. If H₂S in any concentration is intermittently present in the flare gas, seal water effluent should be routed through a closed connection (incorporating a sight glass for checking flow) to a manhole in a vented section of the oily water sewer. The water inlet to the manhole must be sealed. In addition, the seal drum should include a baffle (Detail B in **Figure 9**) to preferentially route the makeup water to the sewer, while confining H₂S-saturated water to the drum.
However, pollution considerations may make the routing of seal water to the sewer unacceptable, in which case disposal must follow method (3) below.
3. If H₂S is continuously present in the flare gas (see definition of "continuous" under **FLARING OF H₂S STREAMS**, below), or if the flare seal drum also functions as a sour water disengaging drum, then the effluent seal water must be routed to a sour water stripper, desalter, or other safe means of disposal. Withdrawal from the drum is by pump in place of the normal loop seal arrangement. Two pumps are provided: one motor driven for normal use, and the other having a steam turbine drive for high level cut-in. Seal drum level is controlled by LIC with high and low alarm lights plus an independent high level alarm.
4. Disposal of effluent water from multijet ground flare seal drums should comply with paragraphs (1), (2), and (3) above, except that:
 - In (1), closed piping with a sight glass should be used rather than an open funnel.
 - In (1) and (2), the manhole receiving effluent seal water should be located at least 50 ft (15 m) from the windbreaker.

Flame Arresters - Flame arresters are not permitted as a means of flashback protection in flare systems.

REDUCING FLARE PULSING AND NOISE

A major cause of pulsing in flare systems is flow surging in the water seal drum. This can be eliminated by providing a gas distributor in the seal drum.

One of several reasons why it is important to eliminate pulsing is to reduce flare noise. Combustion flare noise has been shown to increase as the steam rate increases. Since the amount of steam required to suppress smoke in a flare is set by the flaring rate, flow surges will require a higher steam rate than for a steady flow. A past test at one of the Baton Rouge flares showed that through the elimination of seal drum pulsing, steam rates could be reduced by one third at about 20% of the flare capacity.

At much higher steam rates than required to suppress smoke, flares occasionally exhibit another type of noise problem, a low frequency rumble that can be sensed in the surrounding community as vibrations. The over steaming of the flare produces pockets of uncombusted gases which then ignite sporadically. By reducing the steam requirement of a flare through eliminating flow surges, there is a greater operating margin between smokeless flaring and high steam rate associated rumble.

The likelihood of over steaming a flare and causing noise problems can be reduced by providing automatic smoke control. Since neither the gas rate nor the gas composition to a flare is rarely constant, the required steam addition rate to a flare for optimum smoke control requires frequent adjustment. With manual addition of steam there will be occasions when a flare is receiving significantly more steam than is required for smoke suppression and low frequency rumbling noise may result. This is particularly likely at night when visual smoke control is difficult.

Infrared techniques which rely on measuring radiation being emitted from soot particles and carbon monoxide emissions have been used at several Exxon locations. Experience varies from extremely poor in the case of Baytown Olefins Plant to very good at Baton Rouge Refinery. It would seem that the key to a successful automatic infrared smoke control system is to use a sensor which measures radiation in the 2.0-2.5 μ wavelength range. Raytek detectors are examples of such devices which sense radiation over this range and have been used successfully at several Exxon locations.

Other advantages of eliminating pulsing are reduced steam costs, more accurate flow measurements possible with a steady flow, and reduced incidence of blowing and seal liquid. Also, the size of the seal drum can sometimes be reduced.

Flow surges in the seal drum are generated by the cyclic formation of large bubbles as the flare gas is discharged into the drum. These pulsations can be virtually eliminated by the use of a horizontal sparger incorporating many small diameter holes arranged specifically to allow the open area to increase as flow increases. These holes must be spaced sufficiently far apart to avoid interference between bubbles.

The specific design of the non-pulsing sparger distributor is shown in **Figure 12**. The hole arrangement was determined experimentally. Hole density is low at the top of the pipe and is increased lower on the pipe. The maximum open area density of about 10% assures reasonable bubble formation. The average velocity out of the top row of holes starts at about 130 ft (40 m/s) and increases as the pressure rises and total flow increases. Total areas of holes plus bottom slot should be equal to at least two times the cross sectional area of the inlet pipe.

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S FLARING OF H₂S STREAMS

Continuous releases of concentrated H₂S streams must be segregated in a separate flare system to limit the extent of fouling and plugging problems. Releases of H₂S such as diversion of Amine Regeneration Unit sour gas product to flare during shutdown or upset of a downstream sulfur recovery unit are considered to be "continuous," but safety valve releases are not included in this category. Concentrated H₂S pressure relief valve releases should be tied into the regular flare system rather than a segregated flare system for continuous releases, since the segregated H₂S flaring system has a higher probability of fouling. Due to the nature of H₂S one should plan on frequent inspection and flushing of H₂S flares to remove scale and corrosion products.

Preferably, the H₂S flare system should consist of a segregated header and separate line routed up the side of a conventional elevated flare stack, sharing the same structure, but having separate pilots and igniters. However, the H₂S header may be tied into the regular flare seal drum if there are special mechanical design problems associated with the separate stack, e.g., in the case of a flare, which is to be dismantled for overhaul. Flare elevation must be sufficient to meet atmospheric pollution and ground level concentration requirements for the sulfur dioxide produced.

Incomplete or no combustion of flared hydrogen sulfide can lead to extremely dangerous situations because of the relatively low lethal concentration of hydrogen sulfide. Concentrated streams of hydrogen sulfide can be flared safely provided the following features are incorporated into the flare design (these features equally apply to those locations where a dedicated H₂S flare is not available and concentrated H₂S streams are handled via the regular hydrocarbon flare):

- It is absolutely essential that flare pilots be lit at all times. The flare pilots should be provided with a reliable source of fuel gas, a reliable forced air type igniter system and a means of automatic pilot flame verification such as thermocouples situated inside a thermowell which is located at the base of the pilot flame. Auto relight based on pilot verification is to be considered where manning may limit operator attention. The fuel gas used for the pilots should be clean and free of any appreciable quantities of condensables and should be provided with a pressure controller and high and low pressure alarms. Refer to **Figure 8** for a typical pilot gas / igniter system design. If appreciable quantities of condensables in the fuel gas are likely, then a knock-out drum with a high level alarm should be provided. Piping should be self-draining back to the drum. At least three pilots should be provided where possible. For very small flares [less than 8 in. (200 mm) diameter], at least two pilot and igniter assemblies should be provided. For large flares [greater than 42 in. (1067 mm) diameter], at least 4 pilots should be provided. Each pilot burner should be rated for a minimum heat release of 80000 Btu/hr (23.4 kW). Individual pilot gas lines to the flare tip with isolation capability at grade should be provided to enable isolation of a burnt out pilot. A burnt out pilot may tend to preferentially take gas from the undamaged pilots, which could ultimately lead to their extinguishment.
- The combustion characteristics of the flared gas must be high enough to ensure flame stability. Typical refinery H₂S streams containing H₂S, CO₂ and water vapor are flammable without assist gas if the UFL is 30 vol. % or higher. If UFL is below 30 vol. %, it is recommended that assist fuel gas be added until the UFL is increased to 30 vol. % or the heating value increased to 500 Btu/SCF (5.2 kJ/Sm³). Hydrogen rich streams will increase the UFL and paraffin hydrocarbon streams will increase the heating value. Supplemental fuel gas, when required, should be automatically introduced (at the upstream end of the flare header for mixing and purging) via ratio control of the fuel gas stream to the measured flare header acid gas rate. Ratio control of fuel gas/acid gas should be a safety critical instrument.
- To avoid flame "blow off," acid gas flare exit velocity, including any supplemental fuel gas, should be limited to 150 ft/sec (45 m/s).
- Steam should not be added to acid gas while flaring because of the quenching effect it will have on the flame temperature. This can result in incomplete or no combustion. Hydrogen sulfide burns smokelessly as will any supplemental fuel gas (unless the fuel gas contains a very high level of unsaturated compounds). Thus, steam addition for smokeless flaring is normally not required.
- The flare stack should be high enough that dangerous concentrations of uncombusted hydrogen sulfide are unlikely to accumulate at grade should the flare become extinguished or flaring efficiency drop off. For a given set of conditions, there will be a certain wind velocity and downwind distance from the stack that produce the highest ground level concentration, referred to as the critical ground level concentration. As a design guideline, the flare elevation should be such that the critical ground level concentration of hydrogen sulfide does not exceed 10 vppm over a one hour averaging time assuming none of the hydrogen sulfide entering the flare is converted to sulfur dioxide. In addition to meeting the critical ground level concentration criterion, the stack should be high enough that radiant heat levels at grade do not exceed 3,000 Btu/hr ft² (9.45 kW/m²) at maximum release rate.
- Mechanical reliability of the flare tip assembly should be maximized by providing features such as wind shields to protect the outside of the flare tip against damage from flamelick and internal refractory lining to protect against burning inside the flare tip at low flaring rates.

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- A potential problem with flaring acid gas is the deposition of ammonium bisulfide ($\text{NH}_3 + \text{H}_2\text{S}$) and ammonium bicarbonate ($\text{NH}_3 + \text{CO}_2 + \text{H}_2\text{O}$) in the flare header and even at the base of the flare stack. The potential for such deposits depends on the temperature of the gas and the partial pressures of NH_3 , H_2S , CO_2 and H_2O . Refer to **Figures 13** and **14** for plots of ammonium bisulfide and ammonium bicarbonate deposition temperatures versus partial pressure. Any lines, including the flare header and flare stack, which are susceptible to the formation of such deposits should be heat traced and insulated to maintain stream temperatures at least 25°F (14°C) higher than the deposition temperature. As a minimum, the line temperature should be maintained above 120°F (49°C). An alternative to heat tracing and insulating the flare stack would be to provide water wash connections into the flare stack approximately 30 ft (9 m) above the acid gas header inlet. If protection of the stack via water wash is provided, it is imperative that routine washing be carried out.

Flashback protection is required for H_2S flaring systems, either by water seal or continuous gas purge, as described above under **FLASHBACK PROTECTION FOR FLARE SYSTEMS**. If a water seal is used, special requirements apply to the disposal of the effluent seal water. In the case of an H_2S flaring system handling a flow of H_2S which is uninterrupted throughout the period that a plant is in operation, and which stops only when the producing plant is shutdown, then flashback protection is not required. However, steam or inert gas connections are required to permit purging the flare line during start-up, shutdown and plant upsets.

SPARE FLARE CAPACITY CONSIDERATIONS

Flare capacity must always be available for emergency releases that may occur from the upstream plant facilities which are in operation. Flaring rates corresponding to the design contingency basis of the facilities should be assumed. Thus, when a flare is taken out of service for maintenance, either spare capacity must be available in other flares connected to the same system, or the necessary upstream process units must be shutdown. The justification of spare flare capacity is therefore considered on the basis of an economic evaluation of the debits associated with plant downtime.

As a means of providing spare flare capacity without rendering additional plot area unavailable for plant equipment, a double elevated flare arrangement is permissible. This consists of two flare stacks in a common supporting structure, each sized for the full design flow. Either stack can be dismantled and removed for maintenance while the other is in service. Appropriate platforms and radiation shielding are installed to provide safe working conditions for personnel during the dismantling and reassembly stages, but the mechanical design should be such that this work can be carried out without requiring access above an elevation of 50 ft (15 m).

FLARE GAS METERING

Metering flare gas is important for loss accounting and for control of steam injection. A special requirement for flare gas meters is low-pressure drop and the ability to continue functioning in fouling conditions. The flare gas metering methods listed below have been used with varying degrees of success, or are under test or development. In view of the new techniques and developments in this field, reference should be made to the Control Systems Development Section of Exxon Engineering Technology Department for advice on selection of flow meters for flare gas service.

Venturi Meter - Limited experience of this flow meter in flare gas service has been obtained. Its advantage is that it has a permanent head loss of only 5% of the measured pressure differential. This is the lowest AP of all orifice meter designs. Flow ratios as high as 1:10 (e.g., 1.0 to 10 lb/s) can be measured within + 2% of actual flow. Venturi meters are available in different materials and diameters up to 60 in. (1500 mm) from B.I.F. Industries, Providence, Rhode Island.

Anemotherm - The Anemotherm, a hot wire anemometer, has been extensively applied to flare gas measurement and has been successfully used after modifications to reduce probe fouling. A technique used to reduce fouling is the installation of a steam coil around the tip of the probe, to prevent gases from condensing on the probe. The unmodified Anemotherm is available from the Anemostat Corporation of America, Scranton, Pennsylvania.

Acoustic Flow Meter - Several Exxon locations now use the Panametrics ultrasonic flow meter. This meter was developed by Panametrics at Waltham, Massachusetts, USA in conjunction with Baytown Refinery. These meters use the differences in sound velocity to measure flow and density of the flared gases. A flow range from 0.02 to 30 ft/s (0.006 to 9 m/s) is possible with this meter.

S PROTECTION AGAINST LOW AMBIENT OR FLARE GAS TEMPERATURES

Flare systems must be protected against any possibility of partial or complete blockage by ice, hydrates, solidification, etc. The following design requirements should be included:

International Practices - The requirements of **IP 3-9-1** applying to pressure relieving systems, seal legs, bottom of flare stacks and seal drums, must be met.