

<b>KLM Technology Group</b>  Practical Engineering Guidelines for Processing Plant Solutions	  <b>SOLUTIONS, STANDARDS AND SOFTWARE</b>  <a href="http://www.klmtechgroup.com">www.klmtechgroup.com</a>	Page : 1 of 124
		Rev: 03  Rev 01 July 2007 Rev 02 May 2014 Rev 03 Jan 2015
KLM Technology Group 03 12 Block Aronia Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru, Malaysia	<b>Kolmetz Handbook          Of Process Equipment Design</b>  <b>FLARE SYSTEMS          SAFETY, SELECTION AND SIZING</b>  <b>(ENGINEERINGDESIGNGUIDELINE)</b>	Co Author  Rev 01 A L Ling Rev 02 Yulis Sutaningsih Rev 03 Riska Ristiyanti  Author / Editor: Karl Kolmetz

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## INTRODUCTION

### Scope

The flare is a last line of defence in the safe emergency release system in a refinery or chemical plant. It is used to dispose of purged and wasted products from refineries, unrecoverable gases emerging with oil from oil wells, vented gases from blast furnaces, unused gases from coke ovens, and gaseous water from chemical industries. Flares are also used for burning waste gases from sewage digesters process, coal gasification, rocket engine testing, nuclear power plants with sodium, water heat exchangers, heavy water plants, and ammonia fertilizer plants.

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

The chemical process used for flaring is a high temperature oxidation reaction to burn combustible components, mostly hydrocarbons, or waste gases from industrial operations. In combustion, the gaseous hydrocarbon (natural gas, propane, ethylene, propylene, butadiene, butane and etc) reacts with atmospheric oxygen to form carbon dioxide (CO<sub>2</sub>) and water. Several by-products formed will be carbon monoxide, hydrogen and others dependent upon what is being burned. Efficiency of hydrocarbon conversion is generally over 98%.

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## Flare Types

In industrial plants the most common utilized flare systems are elevated flares and ground flares. Selection of the type of flare is influenced by several factors, such as availability of space; the characteristics of the flare gas (composition, quantity and pressure); economics; investment and operating costs; public relations and regulation.

### 1) Elevated Flare

Elevated flare (refer Figure 1) is the most commonly used type in refineries and chemical plants. They have larger capacities than ground flares. The waste gas stream is fed through a stack from 32ft to over 320 ft tall and is combusted at the tip of the stack.

The elevated flare, can be steam assisted, air assisted or non-assisted. The elevated flare can utilize steam injection / air injection to made smokeless burning and with low luminosity up to about 20%+ of maximum flaring load. The disadvantage of steam injection / air injection is it introduces a source of noise and may cause noise pollution.

If adequately elevated, this type of flare has the best dispersion characteristics for malodorous and toxic combustion products. 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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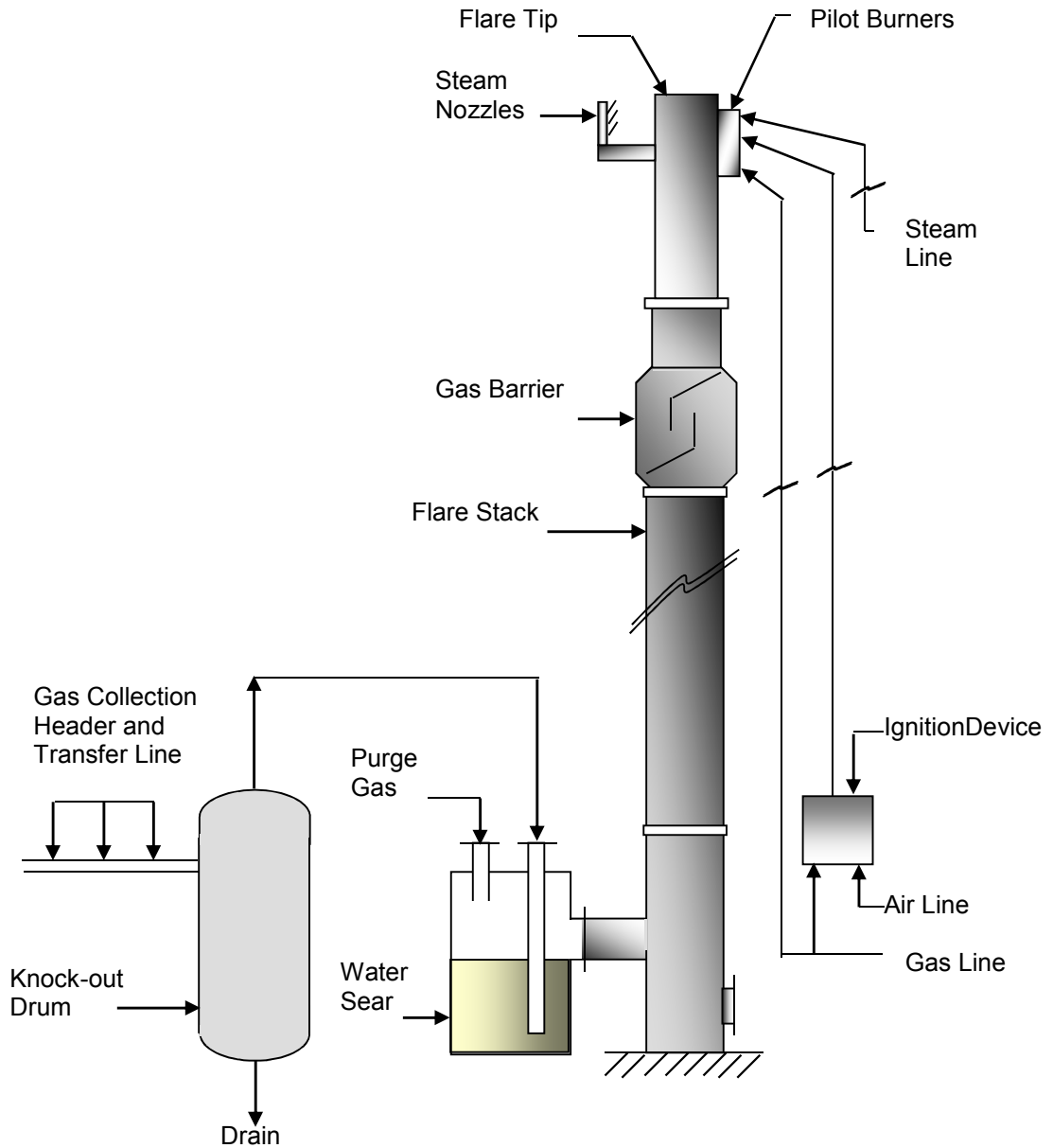


Figure 1: Steam Assisted Elevated Flare System

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## II) Ground Flare

A ground flare is where the combustion takes place at ground level. It varies in complexity, and may consist either of conventional flare burners discharging horizontally with no enclosure or of multiple burners in refractory-lined steel enclosures. The type, which has been used almost exclusively, is the multijet flare (enclosed type).

Compare to elevated flare, ground flare can achieved smokeless operation as well, but with essentially no noise or luminosity problems, provided that the design gas rate to the flare is not exceeded. However, it have poor dispersion of combustion product because its stack is near to ground, this may result in severe air pollution or hazard if the combustion products are toxic or in the event of flame-out. Capital, operating and maintenance requirements cost are higher.

Because of poor dispersion, multijet flare is suitable for "clean burning" gases when noise and visual pollution factors are critical. Generally, it is not practical to install multijet flares large enough to burn the maximum release load, because the usual arrangement of multi jet flare system is a combination with an elevated over-capacity flare.

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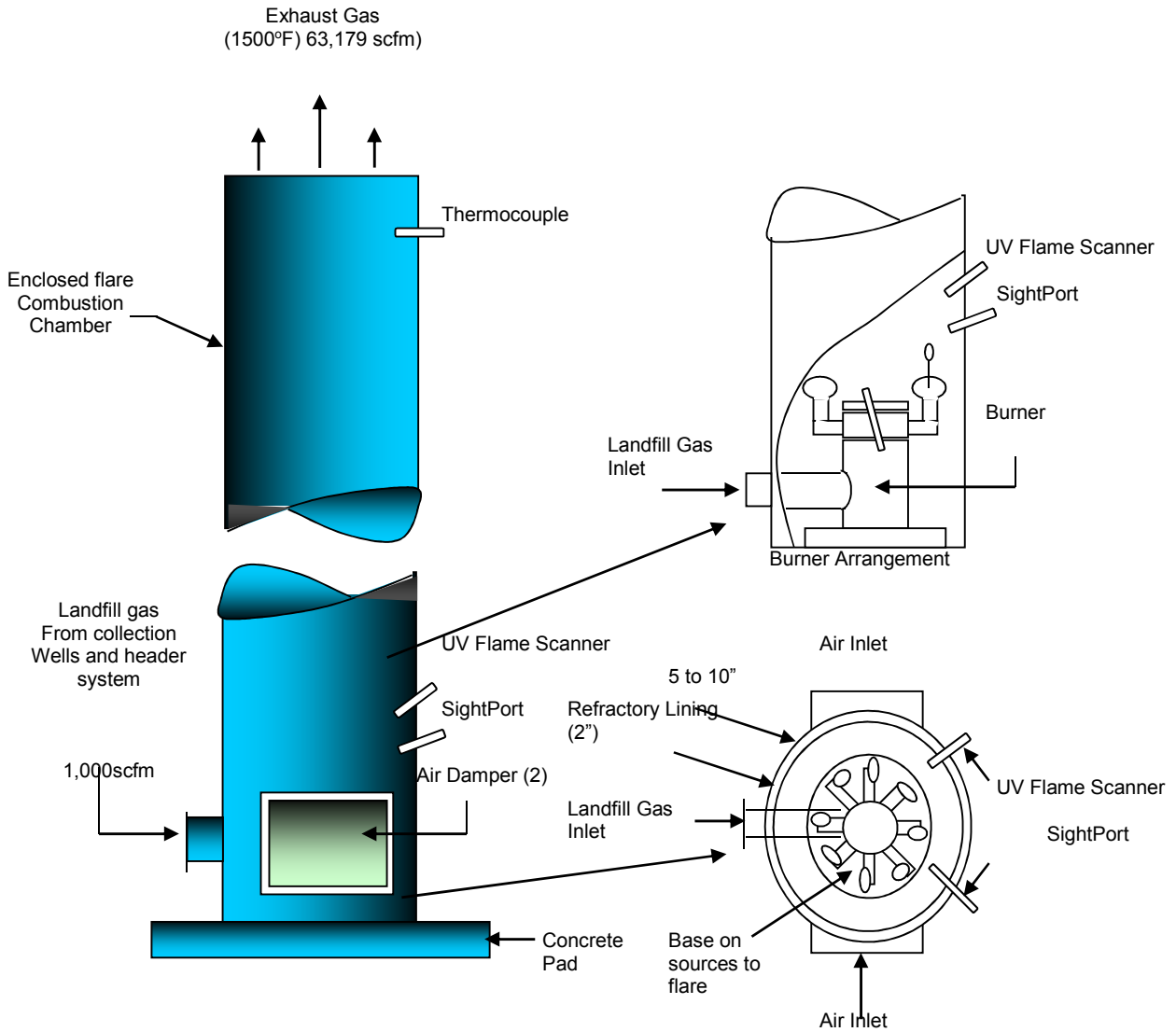


Figure 2: Typical Enclosed Ground Flare

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## Flare System

Typical flare system consists of :

- i) Gas collection header and piping for collecting gases from processing units,
- ii) A knockout drum to remove and store condensable and entrained liquids,
- iii) A proprietary seal, water seal, or purge gas supply to prevent flash-back
- iv) A single or multiple burner unit and a flare stack,
- v) Gas pilots and an igniter to ignite the mixture of waste gas and air and
- vi) A provision for external momentum force (steam injection or forced air) for smokeless flaring.

Flare System is represented in Figure 3 .

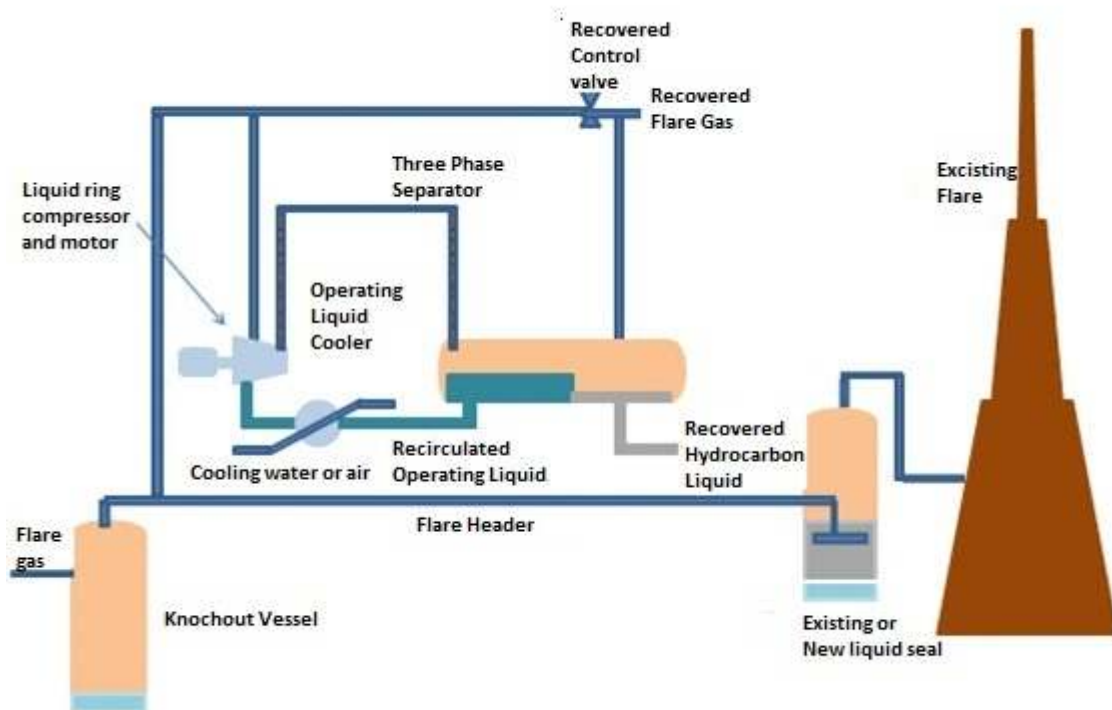


Figure 3 : Simplified representation of a flare gas recovery unit integrated with an existing flare system.

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## Design Factors

Is very important for the flare designer to understand several factors which can affect his flaring system design, the major factors influencing flare system design are:

- |  |   |                                    |
|--|---|------------------------------------|
| <ul style="list-style-type: none"> <li>➤ Flow rate;</li> <li>➤ Gas composition;</li> <li>➤ Gas temperature;</li> <li>➤ Gas pressure available;</li> <li>➤ Utility costs and availability;</li> </ul> | } | Depends on the gas stream released |
| <ul style="list-style-type: none"> <li>➤ Safety requirements;</li> <li>➤ Environmental requirements;</li> <li>➤ Social requirements.</li> </ul>  | } | Related to regulatory mandates     |

### I) Flow Rate

How flow rate will affect the design of flare system? Normally the designer of the flare system will follow exactly the flow data provided, therefore overstated of the flows will lead to oversized of flare equipment which lead to more expensive capital and operating costs and can lead to short service life as well. Understated the flow can result in a design of an unsafe system.

Flow rate obviously affects the mechanical size of flare equipment, increased flow will results increase of thermal radiation from an elevated flare flame, which have direct impact on the height and location of a flare stack.

### II) Gas composition

The combustion gas products are depend on the feed gas composition, by studying the feed gas composition the potential combustion product can be determined and burning characteristic can be identified. It enables the design company to shown the weight ratio of hydrogen to carbon in gas which indicates the smoking tendency of the gas. Some gas, such as hydrogen sulfide will need special design for metallurgies, therefore detail of the feed gas compositions to design the flare system is very important and should be determined accurately.

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### III) Gas Temperature

Gas temperature has direct impact on thermal expansion, gas volume and metallurgical requirements for pipe & vessels. Beside this the more important impact of gas temperature to flare design is the potential of substance / components of the gas to condense, because condensation or two-phase flow will cause a greater smoking tendency and/or the possibility of a burning liquid rain. This can be solved by adding a liquid removal equipment such as a knockout drum.

### IV) Gas Pressure Available

The gas pressure available for the flare is determined by hydraulic analysis of the complete pressure relief system from the pressure relieving devices to the flare burner. This parameter is a factor for smokeless burning design of flare. Some flare design companies have proved that smokeless burning can be enhanced by converting as much of the gas pressure available as possible into gas momentum. With the higher pressure drop across the flare burner it can reduce the gas volume, which can lead to a smaller flare header size & reduced cost and finally allows a reduction in purge gas requirements.

### V) Utility Costs and Availability

To achieve smokeless operation, it is necessary to add an assist medium to increase the overall momentum to the smokeless burning level. The common medium is steam which is injected into nozzles of the flare system. In order to achieve this objective, local energy costs, availability and reliability must be taken into account in selecting the smoke-suppression medium.

Other utilities are needed to be in place are purge gas and pilots. The quantity required is depending on the size of the flare system. The purge gas requirement can be influenced by the composition of the purge gas and/or the composition of the waste gas. Pilot gas consumption will also be influenced by the combustion characteristics of the waste gases.

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## VI) Environmental Requirements

The primary environmental requirement is the need for smokeless burning to protect the environment from pollution, it may be necessary to inject an assist medium such as steam in order to achieve smokeless burning. Unfortunately the injection of the steam and the turbulence created by the mixing of steam to solve the smoke burning problem causes the emission of sound. The sound level at inside and outside the plant boundary is often limited by regulation.

## VII) Safety Requirements

The main safety concern for the flaring system is thermal radiation issues. The allowable radiation from the flare flame to a given point is frequently specified based on the owner's safety practices by following the safety regulation. Special consideration should be given to radiation limits for flares located close to the plant boundary.

## VIII) Social Requirements

Although the plant operation has complied with the environmental regulation, sometime the outcome resulting flare system may not meet the expectations of the plant's neighbors. Example: A smokeless flame may meet the regulatory requirements, but the neighbors may complaint due to light and noise from flare system.

## Design Consideration

When designing the flare system, several important parameters have to be consider, there are flare head design, flare exit velocity, VOC (Volatile Organic Compounds) heating value, and whether the flame is assisted by steam or air.

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The design should be based on consideration bellow as well,

1. Flare Spacing, Location, and Height

- Radiant heat
- Burning liquid fall out
- Pollution limitations

2. Flare Capacity and Sizing

- Flare design capacity is design to handle largest vapor release from pressure relief valve, vapor blow down and other emergency system

3. Flashback Seals- flashback protection, which prevents a flame front from travelling back to the upstream piping and equipment. 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.

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## Flare Safety

### Flare Stack Accidents and Incidents

The most frequent causes of flare accidents are:

1. Internal explosion
2. Liquid carryover
3. System obstructions
4. Faulty maintenance procedures
5. Ignition loss

Incidents categories:

- Flame out – Operation 18.6%
- Flame out – Unknown 15.9%
- Flame out – Weather 15.0%
- Flame out – Instrumentation 6.2%
- Flame out – Mechanical 5.3%
- Flame out – Steam 5.3%
- Flame out – Fuel 4.4%
- Flame out – Pilot plugged 0.9%
- Surrounding are fire 4.5%
- Flare pluggage 3.6%
- Material Issues 3.6%
- Flare damage 2.7%
- Flashback – Operations 2.7%
- Flame in muffler 2.7%
- Instrument failure – Operations 1.8%
- Internal burning – coke 1.8%
- Noise 1.8%
- Flare tip crack – Mechanical 0.9%
- Liquid out of flare 0.9%
- Smoke 0.9%

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## Stack Explosions

Most of incidents in flare stack is flame out or stack explosions. There are many problem that may cause a stack explosion.

- 1) The stack was supposed to be purged with inert gas. However, the flow was not measured and had been cut back almost to zero to save nitrogen. Air leaked in through the large bolted joint between unmachined surfaces. The flare had not been lit for some time. Shortly after it was relit, the explosion occurred the next time some gas was put to stack. The mixture of gas and air moved up the stack until it was ignited by the pilot flame.

To prevent similar incidents from happening again:

1. Stack should be welded. They should not contain bolted joints between unmachined surfaces.
2. There should be a continuous flow of gas up every stack to prevent air diffusing down and to sweep away small leaks of air into the stack. The continuous flow of gas does not have to be nitrogen a waste gas stream is effective. But if gas is not being flared continuously, it is usual to keep nitrogen flowing at a linear velocity of 0.03 - 0.06 m/s. The flow gas should be measured. A higher rate is required if hydrogen or hot condensable gases are being flared. If possible, hydrogen should be discharged through a separate vent stack and not mixed with other gases in a flare stack.
3. The atmosphere inside every stack should be monitored regularly for oxygen content. Large stack should be fitted with oxygen analyzers that alarm at 5% (2% if hydrogen is present). Small stacks should be checked with a portable analyzer.

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- 2) Three explosions occurred in a flare stack fitted, near the tip, with a water seal, which was intended to act as a flame arrestor and prevent flames from passing down the stack. The problems started when, as a result of incorrect valve settings, hot air was added to the stack that was burning methane.

The methane/air mixture was in the explosive range, and as the gas was hot (300°C), the flashback speed from the flame was above the linear speed of the gas. An explosion occurred, which probably damaged the water seal, though no one realized this at the time. Steam was automatically injected to the stack, and the flow of the methane was tripped. This extinguished the flame.

When flow was restarted, a second explosion occurred and as the water seal was damaged, this one traveled right down the stack into the knock-out drum at the bottom. Flow was again restarted and this time the explosion was louder. The operating team then decided to shutdown the plant. One should not restart a plant after an explosion until we know why it occurred.

#### Blocked Stack

- 1) Vent stack became blocked by ice because cold vapor (at -100°C) and steam were passed up the stack together. The cold gas met the condensate running down the walls and caused it to freeze. A liquefied gas tank was overpressured, and a small split resulted. The stack was design to operate without steam. But the steam was then introduced to make sure that the cold gas dispersed and did not drift down to ground level.
- 2) On other occasions, blowdown lines or stack have become blocked in cold weather because benzene or cyclohexane, both of which have freezing points of 5°C, were discharged through them. Steam tracking of the lines or stack may be necessary.
- 3) Blowdown lines should never be designed with a dip in them, or liquid may accumulate in the dip and exert a back pressure. This has caused vessels to be overpressured.
- 4) A blowdown line that was not adequately supported sagged when exposed to fire and caused a vessel to be overpressured.
- 5) Water seals have frozen in cold weather. They should not be used except in locales where freezing cannot occur.

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- 6) Vent stacks are sometimes fitted with flame arrestors to prevent a flame on the end of the stack from traveling back down the stack. The arrestors are liable to choke unless regularly cleaned. They are also unnecessary, because unless the gas mixture in the stack is flammable, the flame cannot travel down the stack. If the gas mixture in the stack is flammable, then it may be ignited in some other way. Stack should therefore be swept by a continuous flow of gas to prevent a flammable mixture from forming.
- 7) Molecular seals have been choked by carbon from incompletely burned gas, and water seals could be choked in the same way. The relief valve on a liquid hydrogen tank discharge to atmosphere through a short stack. The escaping hydrogen caught fire. The fire service poured water down the stack, the water froze, and the tank was over pressured and split. The fire should have been extinguished by injecting nitrogen up the stack.

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## DEFINITION

**Back Pressure-** Back pressure is the sum of the superimposed and build-up back pressures. The pressure that exists at the outlet of a pressure relief device is as a result of the pressure in the discharge system.

**Gas Blower** - Device for blowing air to flare system.

**Blowdown** - The difference between the set pressure and the closing pressure of a pressure relief valve, expressed as a % of the set pressure of in pressure units.

**Closed Disposal System-** Disposal system which is capable of containing pressure that is different from atmospheric pressure.

**Flare System** – A system that safely disposing of waste gases through the use of combustion.

**Flare Stack-** Is an elevated vertical stack found on oilwells or oil rigs, and in refineries, chemical plants and landfills used for burning off unusable waste gas or flammable gas and liquids released by pressure relief valves during unplanned over-pressuring of plant equipment.

**Flame Arrestors-** A crimped ribbon aluminum or stainless steel flame cell to protect against rapid burn backs in low-pressure situations. These passive safety device guaranteed to prevent flame fronts from propagating back through lines, destroying facilities, and causing injuries.

**Flare Tips-** Structure at top of the flare play the role to keep an optimum burn and control over all flow rates, which results in a cleaner combustion. The design of the tip makes sure that the tip does not come into contacting with the flame making the tips reliable and long lasting.

**Ignitions system** – Is a system use to ignite the flare of flare systems. Normally this system designed to ignite the flare quickly the first time, maintain combustion and re-ignite rapidly to prevent industrial hazards and personal injury while protecting the environment.

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**Knockout Drum** – Is a drum installed near the flare base, and serves to recover liquid hydrocarbons, prevent liquid slugs, and remove large liquid particles from the gas streams released from relief system.

**Open Disposal System-** A disposal system that discharges directly from relief system to atmosphere without other devices.

**Overpressure-** Pressure value increase more than the set point pressure of the relieving device, expressed in percent.

**Pressure Relieving System-** An arrangement of a pressure-relieving device, piping and a means of disposal intended for the safe relief, conveyance, and disposal of fluids in a vapour, liquid, or gaseous phase. It can consist of only one pressure relief valve or rupture disk, either with or without discharge pipe, on a single vessel or line.

**Relief Valve** – A spring-loaded pressure relief valve is actuated by the static pressure upstream of the valve. The valve opens normally in proportion to the pressure increase over the opening pressure. A relief valve is used primarily with incompressible fluids.

**Rupture Disk Device-** A non reclosing differential pressure relief device actuated by inlet static pressure and designed to function by bursting the pressure containing rupture disk. A rupture disk device includes a rupture disk and a rupture disk holder.

**Support Structure** – Structure which is designed to withstand local wind conditions for flares. Three types are available: self-supported, Guy-wire supported and Derrick supported.

**Windbreaker** - A windbreaker is a structure used to prevent the wind from extinguishing the flames which are located at the flare tip. It also serves to hide the flames.

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## NOMENCLATURE

$A_t$	Flare tip area, ft <sup>2</sup>
$C$	Drag coefficient (Dimensionless)
$d_j$	Pipe/Tip inside diameter, ft
$D$	Particle diameter, in
$g$	Acceleration due to gravity, 32.2 ft/s <sup>2</sup>
$H$	Heat of combustion gases, Btu/lb
$h$	Distance, in feet
$k$	Ratio of specific heats ( $C_p/C_v$ )
$L_f$	Flame length, ft
Mach	Mach number at pipe outlet
$M_j$	Gas molecular weight
$m$	Mass flow rate, lb/s
$P$	Maximum header exit pressure, in lb/in <sup>2</sup> g
$P_j$	Pipe outlet pressure, in lb/in <sup>2</sup> (absolute)
$Q_f$	Heat release, Btu/hr
$q_f$	Heat intensity (Btu/hr/ft <sup>2</sup> )
$R$	Gas constant, 10.7 (British unit)
$R_f$	Distance from the midpoint flame (ft)
$T_j$	Absolute temperature, in °R
$U_d$	Maximum allowable vapor velocity for vertical vessel, ft/s
$U_\infty$	Design wind velocity
$V$	Volumetric flowrate, ft <sup>3</sup> /s
$W$	Gas flow rate, in lb/hr
$W_{stm}$	Mass flow rate of steam, lb/hr
$Z$	Compressibility factor, dimensionless

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## Greek letters

$\varepsilon$	Emissivity, (dimensionless)
$\rho$	Sealing liquid density, in lb/ft <sup>3</sup>
$\rho_L$	Density of liquid, lb/ft <sup>3</sup>
$\rho_V$	Density of vapor, lb/ft <sup>3</sup>

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## THEORY

### Elevated Flare Tips Sizing

The elevated flare tips normally are sized as below:

- i) Flare tip with steam assisted: steam injection nozzles are sized for a velocity of 400 ft/s (120 m/s) at maximum flow with considering the limitation of noise emission.
- ii) Velocity is sized at least 250 ft/s (75 m/s) to insure good dispersion. But the flare tips consisted with a simple open-ended pipe and a single pilot, this will subjected to flame lift-off and noise problems at high velocities, therefore it should be designed for a maximum velocity of 160 ft/s (50 m/s).
- iii) The flare height should be at least as high as any platform or building within 500 ft (150 m) horizontally, and in no case less than 50ft (15 m) high.
- iv) Any source of ignitable/ flammable hydrocarbons 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.
- v) To prevent probability of liquid entrainment to the flare, knockout drum should be included reduce the potential for and/or reduce the impact of burning liquid fall-out.
- vi) Drift distances of burning liquid droplets from an inadequately designed flare system can be considerably greater than 200 ft (60 m).
- vii) Flares should be located to limit the maximum ground level heat density to 500 Btu/hr/ft<sup>2</sup> (1.6 kW/m<sup>2</sup>) at any property line. The minimum distance from the base of the flare stack to the property line should be 200 ft (60 m).
- viii) 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. In some special cases,

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flare elevation and spacing may be governed by radiant heat exposure of certain vulnerable items of equipment, rather than personnel.

- ix) Flare location and height must be such as to meet all applicable regulatory standards of noise level

The diameter of the flare must be suitable to maintain a stable flame and prevent a blowout (when vapor velocities are greater than 20% of the sonic velocity).

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**Stack Support**

Three type of stack support available, there is self-supported, guy-wire supported and derrick supported. (Figure 4: Stack Support).

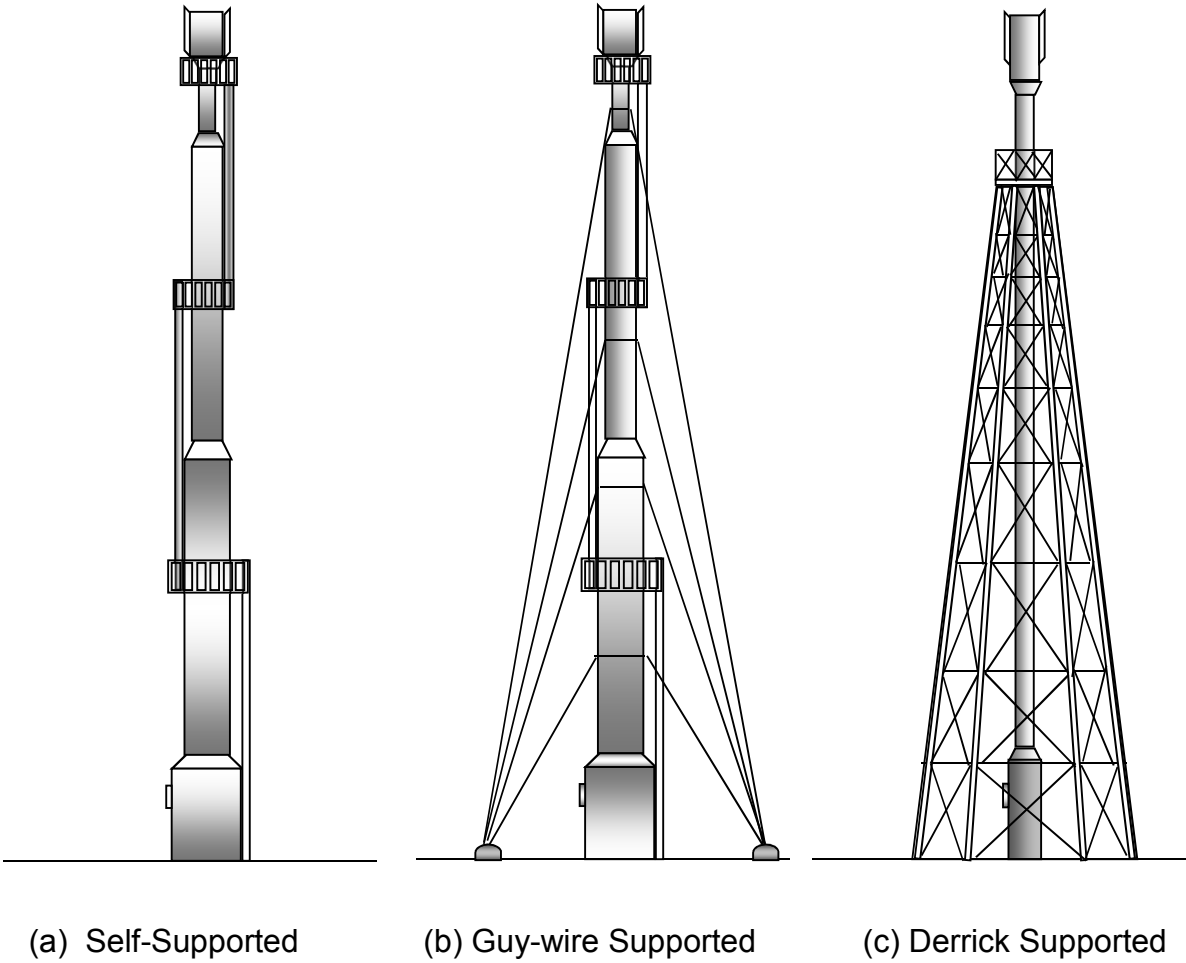


Figure 4: Common Type of Stack Support

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