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KLM Technology Group Unit 23-04 Menara Landmark 12 Jalan Ngee Heng 80000 Johor Bahru, Malaysia	<b>FLARE SELECTION AND SIZING          (ENGINEERING DESIGN GUIDELINE)</b>	July 2007
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## INTRODUCTION

### Scope

This design guideline covers the sizing and selection methods of a flare system used in the typical process industries. It helps engineers understand the basic design of different types of flare systems and gain their knowledge in selection and sizing.

The selection section contains the explanation for the suitability of types of flare system used in processing industries, which are based on the environmental regulations, location, and process materials involved.

All the important parameters used in this guideline are well explained in the definition section which helps the reader understand the meaning of the parameters and the terms used.

The theory section includes sizing theory and formulations for the flare systems design. It includes explanation of using the Simple Approach and the Brzustowski's and Sommer's Approach methods for determination of the flare stack dimensions and others important parameters.

In the application section, three cases examples are included by guiding the reader step by step to do flare sizing by using Simple Approach or Brzustowski's and Sommer's Approach methods.

In the end of this guideline, example specification data sheets for the flare system are included which is created based on an industrial example. Calculation spreadsheet is included as well and to aid user more understand and to apply the theory for calculations.

### Flare

The flare is a last line of defense in the safe emergency release system in a refinery or chemical plant. It uses 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.

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The flare provides a means of safe disposal of the vapor streams from its facilities, by burning them under controlled conditions such that 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%.

### Flare Type

In industrial, 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. 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. Elevated 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 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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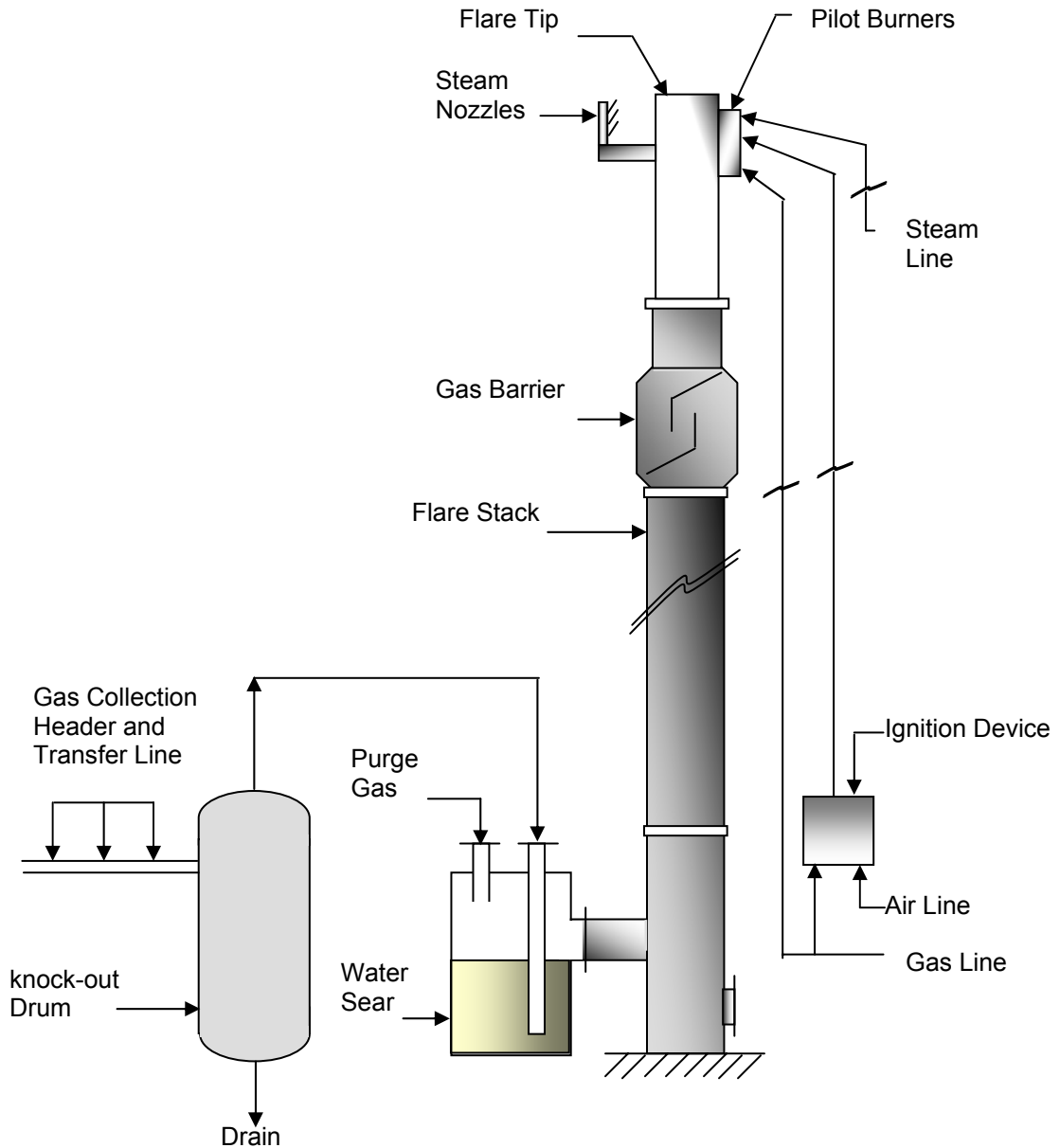


Figure 1: Steam Assisted Elevated Flare System

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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 it 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 high.

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 multijet flare system is a combination with an elevated over-capacity flare.

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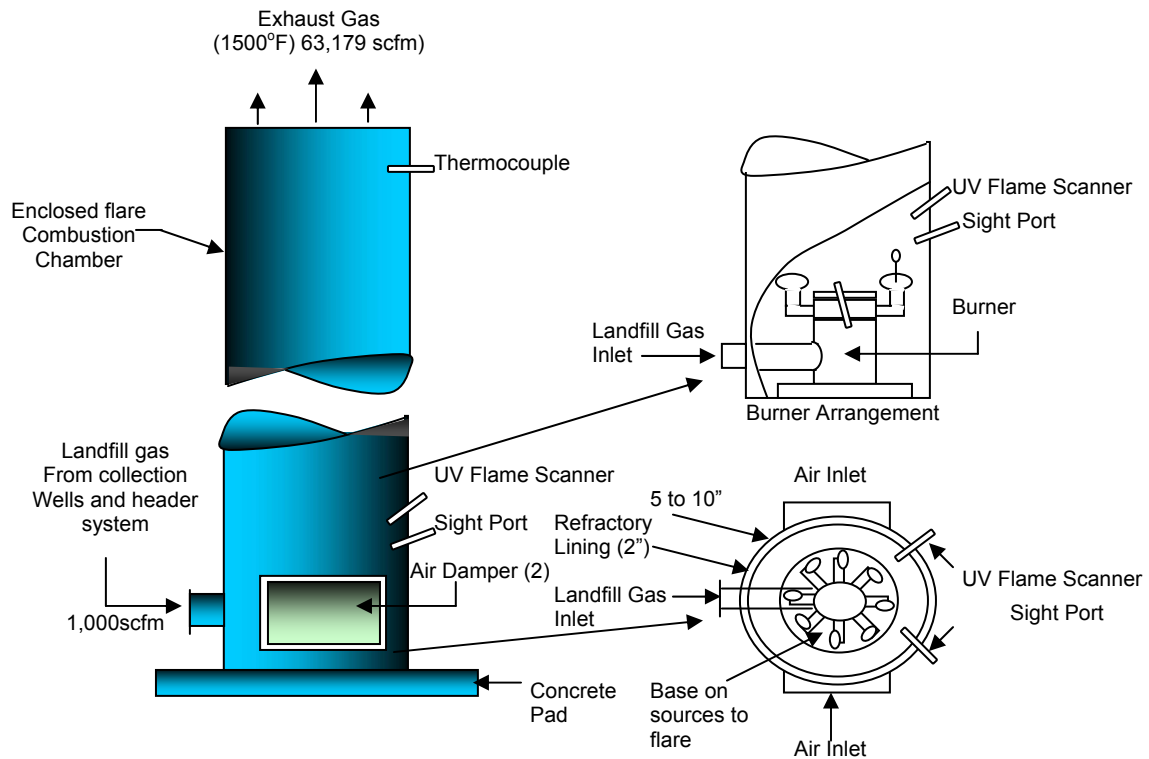


Figure 2: Typical Enclosed Ground Flare

## 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 ignitor 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.

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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:

- Flow rate;
  - Gas composition;
  - Gas temperature;
  - Gas pressure available;
  - Utility costs and availability;
  - Safety requirements;
  - Environmental requirements;
  - Social requirements.
- } Depends on the gas stream released
- } 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 as hydrogen sulfide it 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 solve by add a liquid removal equipment (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 pilot. 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 is 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 neighbours may complaint due to light and noise from flare system.

## Design Consideration

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

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Beside that, the design should be base 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 traveling 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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## 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 oil wells 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 devices are 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.

**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.

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**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 nonreclosing 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 serves also 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

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

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- 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).

### Stack Support

Three type of stack support available, there is self supported, guy-wire supported and derrick supported. (Figure 3: Stack Support).

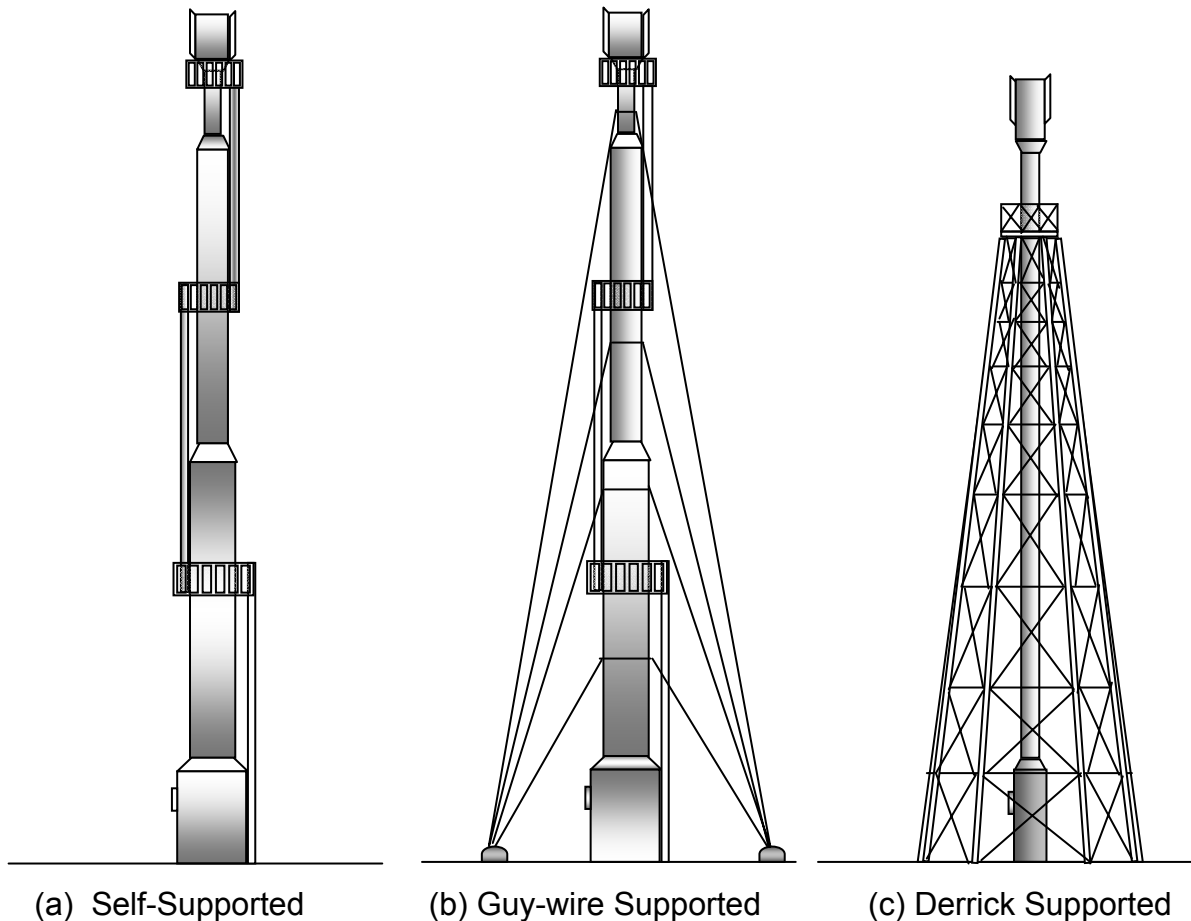


Figure 3: Common Type of Stack Support

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Self-supported stacks are normally use for flare system. However, it cost more expensive than other design, because it need greater material to ensure structural integrity over the anticipated condition. Normally the stack height for the self-supported design was range from 200 to 300ft.

Guy-wire supported is less expensive but it need the largest land are due to the guy wire radius requirements. The radius of guy-wire is equal to 1.5 of the overall stack height. Guyed stacks heights from 600 to 800 feet have been used.

Derrick supported only used when the stack is large (self-supported not practical) and available land area is limited (guy-wire supported not suitable). Advantage of derrick design it allow the flare stack and tip to be lowered to grade on movable trolleys for inspection and maintenance.

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