A review of the usefulness of gas flares in air pollution control

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Keywords *Natural gas extraction, Petroleum extraction, Air pollution, Mineral extraction equipment, Environmental and safety engineering*

Abstract *Various impacts of direct venting of natural gas into the environment, both in the upstream and downstream petroleum operations, often compel the chemical engineer to specify air pollution control equipment for installation on new and existing platforms/facilities. Flares, a special class of such equipment, are considered in this paper. The major types of flares used in the oil industry are reviewed and the principles guiding their operation and performance discussed. Information which would aid the choice of flare system for new applications is also discussed.*

Gas flares and their applications

Flaring is a common method of disposal of flammable waste gases in the upstream oil, gas, downstream refining, and chemical processing industries. A flare is an open-air flame, usually at the tip of a long stack. The flame is usually exposed to the weather elements, particularly winds. It is commonly located far away from personnel and other structures in order to prevent damage. For air pollution regulatory purposes, it is classified as a stationary combustion source (Ritter *et al.*, 2002).

With the development of crude oil extraction industry in the last decades of the nineteenth century, large amounts of associated gas, considered more often as a nuisance rather than assets, were produced (IGU, 2000). Solving the problem of this "nuisance" while ensuring safe operation and to minimize undesirable venting, led to the introduction of flaring. Flaring found use in landfill management where the methane (CH_4) produced by microorganisms within the landfill under anaerobic conditions (Environmental Protection Agency, 1997) needed to be safely eliminated when not being recovered for use (Environmental Protection Agency, 1992). Other key applications of flares include rocket testing and recovery, steel production, and use in petrochemical feedstock.

Gas flares are the choice disposal option for handling waste hydrocarbon gases because of their ability to burn efficiently (Strosher, 1996). In a flare, complete combustion must occur within the available short residence time. Flame temperature is the primary variable in that combustion process (Roe *et al.*, 1998).

A typical flare system (Figure 1) consists of the flare stack/boom and pipes that collect the gases to be flared. The flare tip at the end of the stack/boom is designed such as to promote the ingress of air into the flare for improved efficiency. Seals installed in the stack prevent flashback of the flame. At the base of the stack is knock-out drum to prevent liquid carryover into flare. Other flare ancillaries are the auto igniter, the wind deflector which acts as a guard to prevent flame blowout, the inlet baffle which prevents liquid accumulation, steam which prevents smoke formation. Usually the target heating value of the waste gas to be flared is 11 MJ/scm (300 Btu/scf). According

Management of Environmental Quality: An International Journal
Vol. 15 No. 6, 2004
pp. 574-583

1477-7835
DOI 10.1108/14777830410560674

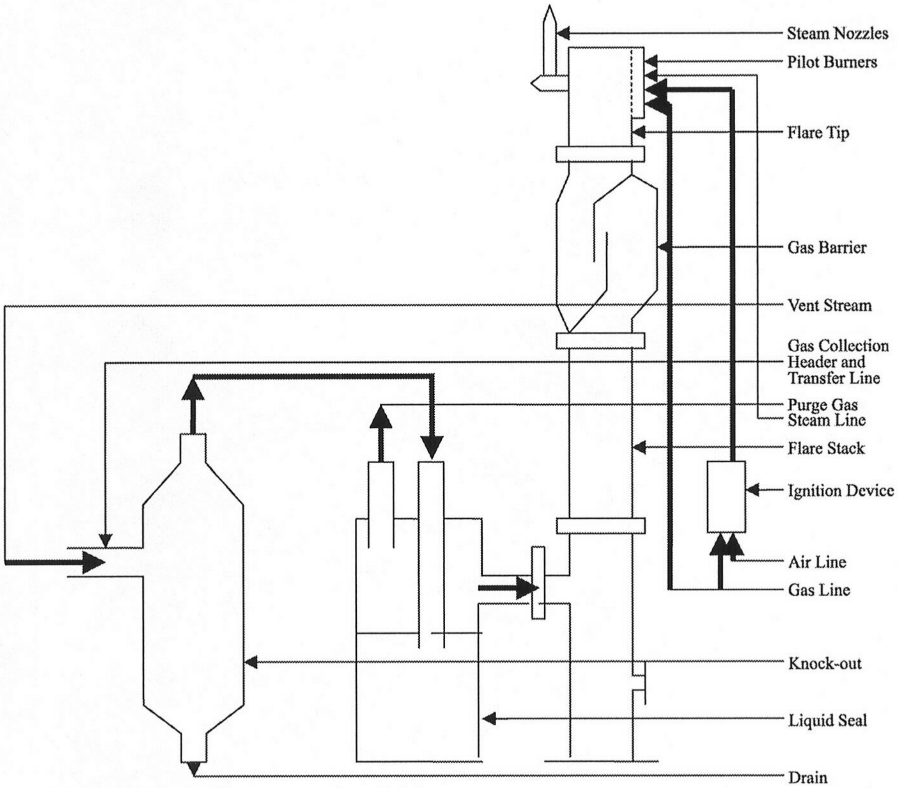

Figure 1.
Schematic diagram of a typical flare system

to the Environmental Protection Agency (1995), if the waste gas does not meet this minimum heating value, auxiliary fuel must be introduced in sufficient quantity to make up the difference. It has even been proposed that a gas recovery system be installed in the blow down to the flare for energy saving purposes (Alcazar and Amillo, 1984).

Flares classification

Flares are categorized either by geometry or by the method of achieving mixing at the flare tip. Factors influencing the type of flares to be used include the composition and volume of gas to be handled, the availability of land on which it is to be sited and the soil type involved.

Classification by geometry

Flares may be elevated and or located near the ground. The handing capacity for ground flares varies up to 50, 000 kg/hr and about 1 million kg/hr or more for elevated flares (Environmental Protection Agency, 1991).

Elevated flares. Elevated flares are flares raised above grade. Depending on their heights, they can be self-supported, i.e. free standing (Figure 2), guyed (Figure 3) or structurally supported (Figure 4). Free-standing flares provide ideal structural support

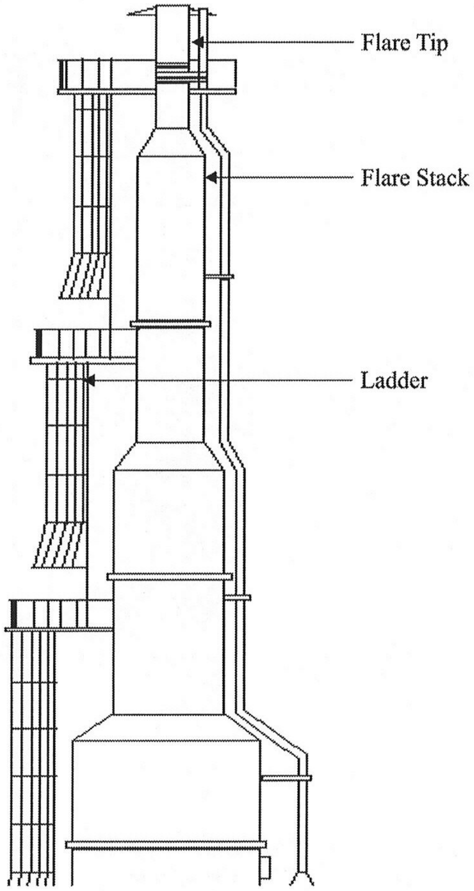

Figure 2.
Self-supported elevated flare

but they can only support lower heights (around 30-100 feet (9-30 m)). For over 300 feet (91 m), guy towers are used while derrick tower flares are used for flares above 200 feet (61 m). Derrick-supported flares can be built as high as required since the system load is spread over the derrick structure. This design provides for differential expansion between the stack, piping, and derrick. For guy-supported flare, a considerable amount of land is required since the guy wires are widely spread apart. A rule of thumb for space required to erect a guy-supported flare is a circle on the ground with a radius equal to the height of the flare stack. Derrick-supported flares are the most expensive design for a given flare height while the guy-supported flare is the simplest of all the support methods.

Elevated flares have the advantage of preventing potential dangerous conditions at ground level in addition to its ability at dispersing combustion products emanating from it above working areas for noise, heat, smoke, and objectionable odours.

Ground flares. The stack is horizontally positioned in this flare type. Usually, it is composed of multiple gas burner heads at ground level in a stack-like enclosure that is usually refractory-lined. This shell/enclosure reduces noise, luminosity, and heat

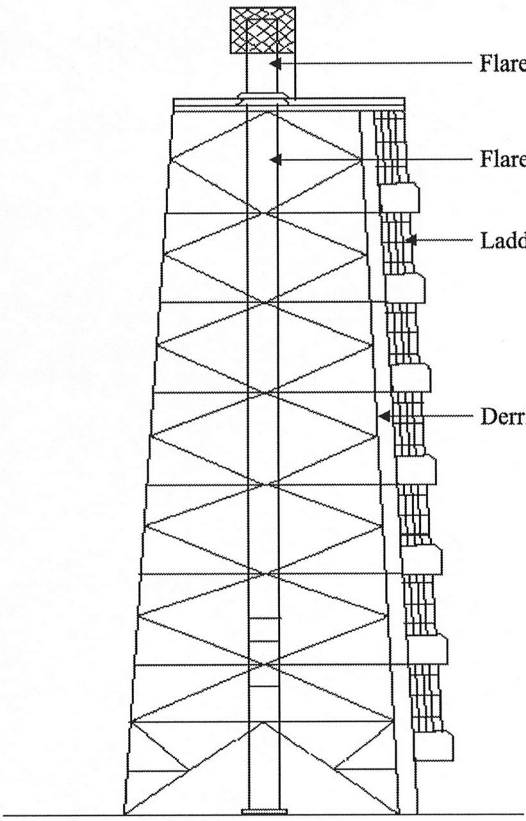

Figure 3.
Derrick-supported elevated flare

radiation and provides wind protection. The height (above grade) must be adequate for creating enough draft to supply sufficient air for smokeless combustion and for dispersion of the thermal plume.

These flares are always at ground level. Generally, they have a lower capacity than elevated flares and are used to burn continuous, constant flow vent streams, although reliable and efficient operation can be attained over a wide range of design capacity. Stable combustion can be obtained with lower Btu content vent gases than is possible with elevated flare designs. Kalcevic (1980) reported their applications for vent gas of Btu as low as 50 to 60 Btu/scf (1.8-2.2 MJ/m^3). Many facilities adopt them for landfills gas destruction (Environmental Protection Agency, 1995). Although Ito and Sawada (1976) pointed out that they could cost three to four times as much as elevated flares, it was discovered that they could aid safety more. Therefore their use should be more widespread.

Classification by method of mixing enhancement

At times, mixing enhancement may be required to achieve complete combustion and hence improved gas flare efficiency. Classification based on this method gives four classes which are steam assisted, air assisted, pressure assisted, and non-assisted.

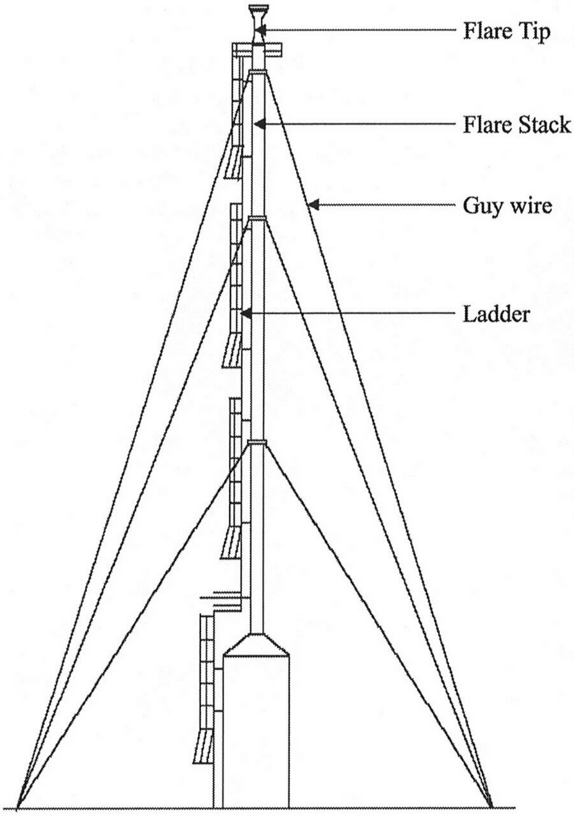

Figure 4.
Guy-supported elevated flare

Steam assisted flares. These types of flares are predominantly found in refineries and chemical plants. They are single burner tips elevated above ground level for safety reasons, which burn the vented gas. Steam is injected into the combustion zone to enhance adequate air supply and good mixing to promote turbulence for mixing and induce air into the flame. The essence of this steam is to give the flares a smokeless characteristic. When steam is injected, it is believed that it (H_2O) rapidly breaks down in the flame zone to H and OH species. The OH species then combine with the C_2H_2 (produced from the hydrocarbon gas and which gives it the smoking property) thereby eliminating it.

High steam requirement together with the need for generating steam in boilers as well as piping maintenance are a major drawback of these flares.

Air assisted flares. They are built with a spider-shaped burner (with many small gas orifices) located inside but near the top of a steel cylinder which is about 0.50 m or more in diameter. Combustion air is provided by a fan in the bottom of the cylinder and varying the fan speed will vary the quantity of combustion air made available. The purpose is to allow forced air in to provide the combustion air and the mixing required for smokeless operation. Where steam is not readily available, this type of flare becomes highly attractive. However, they are not usually recommended for large flares for economic reasons (Environmental Protection Agency, 1990).

Pressure assisted flares. Vent stream pressure is used to promote mixing at the burner tip in this type of flare. They can be used for flares that could have required steam or air if vent stream is in sufficiently large quantities. Availability of staged multiple burner heads which operate based on the quantity of gas being handled makes them peculiar. Generally, they have the burner arrangement at ground level, and consequently must be located in a remote area of the plant where plenty of space is available.

Non assisted flares. Flares which require no assistance of any auxiliary provision for enhancing the mixing of air into their flame are referred to as non-assisted. Usually, they are limited in use and are applicable only in gas streams that have a low heat content and a low carbon/hydrogen ratio and that burn readily without smoke production.

The nature of gas available for disposal dictates the type of flare to be installed for operation. Wu (1983) gave the principal items to be checked while considering a particular flare. These include flare header and the flare-stack exit speed, height of the flare stack and the adequacy of knockout drums.

Performance of gas flares

The primary measure of flare performance is combustion efficiency (Romano, 1983). It is determined as the percentage of flare emissions that are completely oxidized to CO_2 and mathematically defined as:

$$\%CE = \frac{CO_2}{CO_2 + CO + THC} * 100 \tag{1}$$

where:

CO_2 = parts per million by volume of carbon dioxide;

CO = parts per million by volume of carbon monoxide; and

THC = parts per million by volume of total hydrocarbon as methane.

The combustion efficiency can be measured thus: emission from the flare is extracted by a sampling probe and analyzed using continuous emissions monitors for the compositions from which individual concentrations of CO_2, CO, and THC are determined. Other methods have been adopted for measuring the flare composition such as the use of Fourier Transform Infra Red (FTIR) analyzers.

Factors affecting flare performance include:

- *Vent gas flammability.* Flammability limits, defined as the stoichiometric composition limits (maximum and minimum) of an oxygen-fuel mixture that will burn indefinitely at given conditions of temperature and pressure without further ignition, influences the ignition stability and flame extinction.
- *Vent gas auto ignition temperature.* Auto ignition temperature of a material is the lowest temperature at which the material will ignite without an external source of ignition. For effective performance of flare, this must be low.

- *Vent gas heating value.* Total heating value of a fuel is the heat evolved in its complete combustion under constant pressure at a temperature of 298° K when all the water initially present as liquid in the fuel and that present in the combustion products are condensed to the liquid state. The heating value affects flame stability, emissions, and flame structure. A lower heating value produces a cooler flame that does not favour combustion kinetics and can more easily be extinguished thus lowering the efficiency of the flares.
- *Vent gas density.* The density of the vent stream is another factor affecting the structure and stability of the flame, through the effect on buoyancy and mixing thus affecting the performance of the flares. By design, the velocity in many flares is very low; therefore, most of the flame structure is developed through buoyant forces because of combustion. Lighter gases tend to burn better thus allowing higher efficiency. In addition to burner tip design, the density also directly affects the minimum purge gas required to prevent flashback, with lighter gases requiring more purge.
- *Flame zone mixing.* Mixing of the fuel with the oxidant is one of the processes which allow enough oxidant to have access to the fuel thus aiding the desired complete combustion. Poor mixing at the flare tip is the primary cause of flare smoking when burning a given material. Streams with high carbon-to-hydrogen mole ratio (greater than 0.35) have a greater tendency to smoke and require better mixing for smokeless flaring. For efficient performance of gas flares, efforts should be made to see that mixing is in required level.

Previous work on flares by the Air and Waste Management Association (1992) showed that their efficiency could range between 98 and 99 percent. This was in line with earlier finding by Pohl *et al.* (1986) and the Environmental Protection Agency (1991) but a recent study by Blackwood (2000) indicated otherwise. It was found that if the heading value of gas flared is reduced, the efficiency might also be reduced, even to as low as 65 percent. High wind speeds and high stack velocities are identified as factors that could even bring lower efficiency (Johnson *et al.*, 1999; Majeski *et al.*, 1999; Poudenx and Kostiuk, 1999). Strosher (2000) also identified liquid hydrocarbon presence and condensates in flare as another factor that could lower the flare efficiency. Some steps expected to be taken to prevent this unfriendly situation were identified by Schwartz and Keller (1988) and Bussman *et al.* (1997), while observation of some guides provided by American Petroleum Institute (1969) could also assist greatly. If there is an oxygen deficiency and if the carbon particles are cooled to below their ignition temperature, smoking occurs (Environmental Protection Agency, 2003) and this is a sign of flares' low efficiency. Turbulence which can prevent smoke formation (Calcote, 1981) is one of the factors to control for higher efficiency accomplishment.

Lowering of efficiency should be avoided if the objective of total destruction of the gaseous waste is achieved. At lower flare temperatures or lower flare efficiencies, many dangerous chemicals could be present in the flare plume (Chambers, 2002) with adverse implications to health (Waldner *et al.*, 1991).

Important factors in the choice of a gas flare system

In addition to its contribution to environmental protection and prevention of environmental risks, the prime objective of the use of flares is safe, effective disposal of gases at an affordable cost. Thus the factors considered in making a choice of flare gas system must have these as focus.

The gas flow rate anticipated to be handled is one of the factors when considering a flare system for an operation. If it is overestimated, it will lead to the installation of oversized equipment which increases both capital and operating costs and can lead to shorter service life. An underestimation of gas flow rate may lead to the choice of an ineffective and unsafe system. Increased flow may result in an increase in thermal radiation from elevated flare flame and this may have direct impact on the location of flare stack. There can be maximum emergency flow rate during major plant upset (e.g. if total loss of electrical power or cooling water is experienced) and this must be taken care of when making a choice.

Gas composition which influences combustion characteristics of flared gas is another important factor in flare system choice. The presence of any non-hydrocarbon components such as hydrogen sulphide or inerts should be ascertained, as such might necessitate flare system with special metallurgies. A metallurgical requirement of flares also imposes a need for the perfect knowledge of gas temperature, as this will assist the choice of flare system that can withstand the anticipated heat. The potential for condensation or two-phase flow may also require the installation of additional liquid removal equipment in order to avoid a greater smoking tendency and/or the possibility of a "burning liquid rain".

The anticipated gas pressure is a factor that must also be taken seriously when considering a flares system for use in the petroleum and chemical industries. Smokeless burning can be enhanced by converting as much of the gas pressure available as possible into gas momentum. Also, higher pressure drop across the flare leads to reduction in the gas volume which may require a smaller flare header size and reduced cost.

In addition to the aforementioned factors are the utility costs and its availability. Smokeless burning requirements may require utilities in the form of steam, which is injected through one or more groups of nozzles. When fresh water availability becomes a constraint for this, large volume of low-pressure air furnished by a blower may be used as an alternative, but energy costs, availability and reliability must be ascertained. The need for purge and pilot gas, which are functions of compositions, should be considered. A combustion characteristic of the waste gas is another strong factor.

Before a flare system can be marked for selection, there must be provision for environmental requirements. The various regulations set by the regulatory agencies for parameters like thermal radiation, combustion efficiency, flue gaseous emissions, etc., must be considered. Finally, the facility neighbours must be considered with respect to their reactions towards smoke, light, and noise emanating from the flaring activity.

Conclusion

Gas flaring system has been looked into in an introductory manner with its main concepts discussed. It has been shown that flares are of utmost importance for safe disposal of waste gas in industries. Various factors that can assist in achieving the objectives of waste gas destruction were critically reviewed. Also, for proper choice of a particular flare system, the important factors were reviewed. Various factors required for smooth running of gas flare systems showed that there is a need for the gathering of accurate data, right from the design stage to the operational stage of the flares.

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