After the closure of each stage, the piping downstream of the staging valve may be purged. An inert gas may be used to purge the line of any combustible gases.

B.7 Operations

A staging system is required to operate automatically without human intervention. After commissioning, no "operations" procedure is required (other than that described in B.8 and B.9), but the system supplier's advice should be followed.

B.8 Maintenance

Much of the staging-system equipment is in a position where local conditions allow maintenance, provided that access and isolation are permitted. There is nothing about the use of any such equipment that is specific to flare systems and, thus, the recommendations of the manufacturers of all equipment in the system should provide good guidance.

Maintenance items for a multi-burner staged flare system are primarily those associated with the staging system. A clear understanding of the automated sequence is necessary to enable an operator to recognize (diagnose) operational misbehavior. Refer to A.11.5 for a list of maintenance items.

B.9 Troubleshooting

Troubleshooting of multi-burner staged flare systems most often involves troubleshooting the staging system. Refer to A.11.6 for this troubleshooting guide.

Annex C
(informative)

Enclosed-flame Flares

C.1 Purpose

There are circumstances when it is desirable that all or part of a flare load be disposed of in a way that causes the minimum of disturbance to the immediate locality including:

a) to eliminate or reduce radiant heat to nearby equipment or work areas,

b) to reduce noise in the immediate vicinity,

c) to make the flare flame less obvious for community relations,

d) to potentially achieve improved emissions.

C.2 General Description

C.2.1 Overview

Enclosed-flame flares burn the flare gas from a burner or burners placed as near to the ground as is practicable to ensure good operation. The resulting flames are hidden from sight by a surrounding wall or chamber. The top of the chamber is open to the atmosphere and allowance is made in the bottom of the chamber to permit the ingress of combustion air. It is common for the chamber to be surrounded by a wind fence to reduce the effect of crosswinds on the combustion process and to prevent unauthorized access.

An enclosed-flame flare system has a number of key components, including:

— a combustion chamber,

— burners,

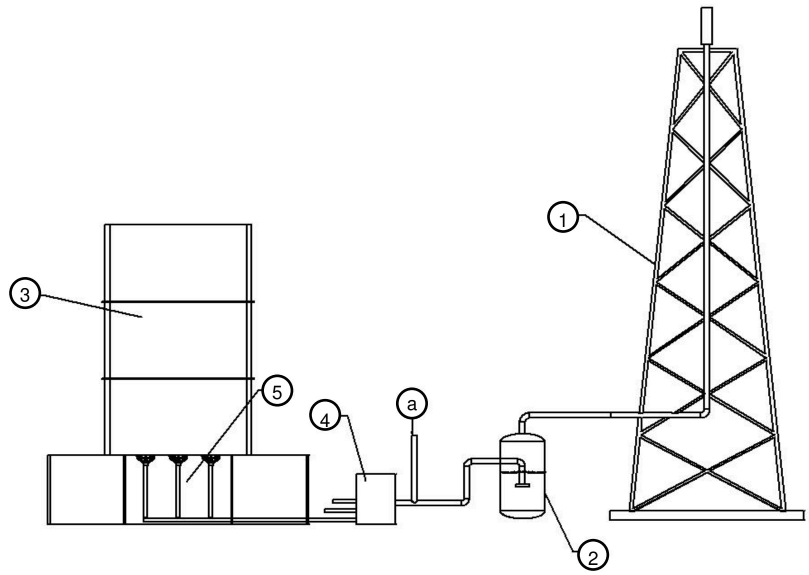
— piping systems,

— a wind fence,

— operational and safety controls.

An enclosed-flame flare is more complex than simply installing a pipe flare inside a combustion chamber. This flare design requires an engineered combustion process, with considerations for airflow into the combustion chamber and flue gas flow from the chamber. Burner designs have been specially developed to meet the combustion requirements of enclosed-flame flares.

Enclosed-flame flares are typically rated for normally occurring flare-relief conditions. For selected applications, an enclosed-flame flare is the first stage of a flare system that includes another flare for the combustion of larger, emergency flare-relief flows. See Figure C.1.



Key

1 elevated flare
2 liquid seal
3 enclosed flare
4 staging-control system
5 burner

[a] Relief gas from plant.

Figure C.1—Typical Enclosed Flare Staged to Elevated Flare

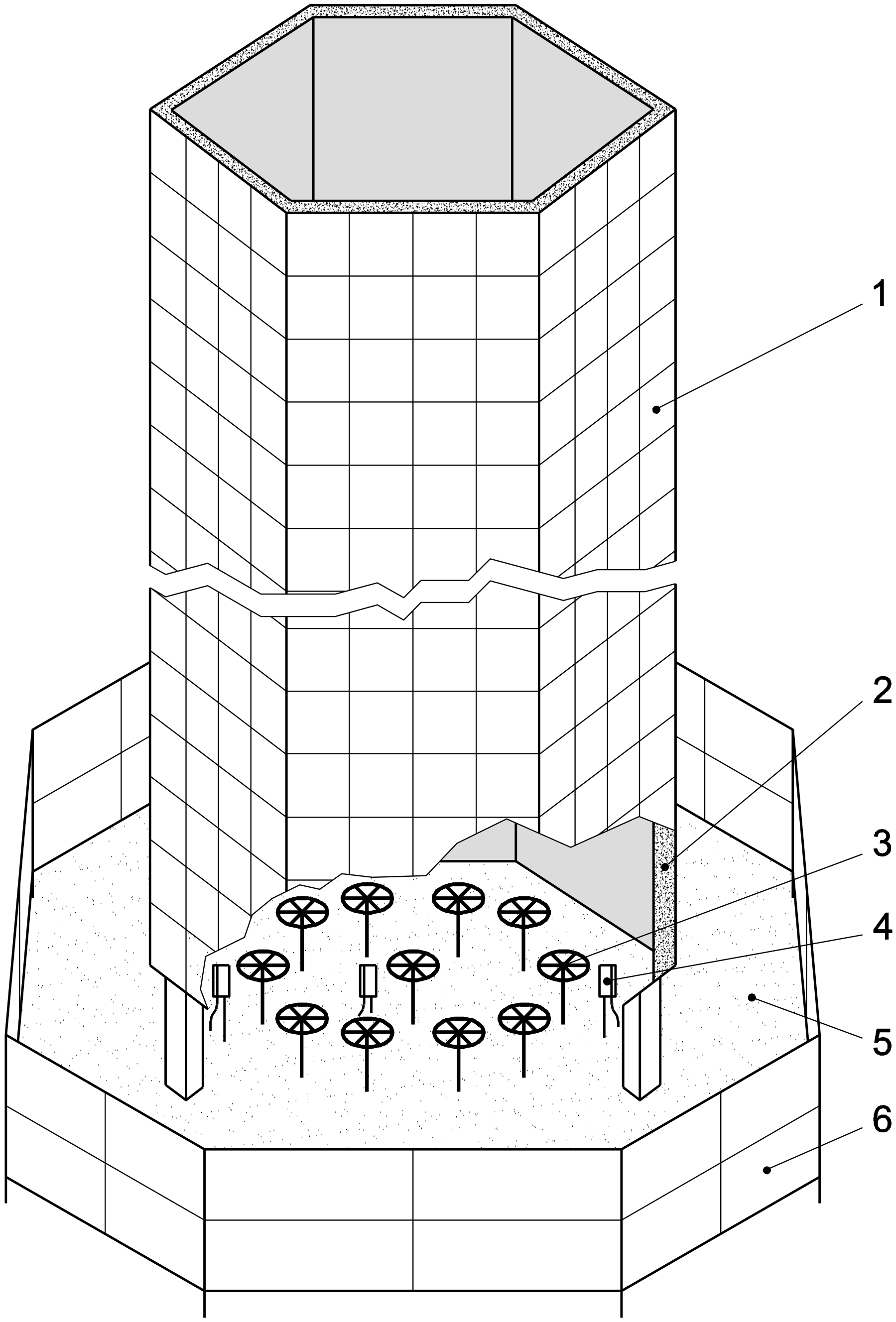
C.2.2 Combustion Chamber Size and Shape

Since the combustion chamber encloses the flare flame, it is necessary that consideration be given to the size of the flame. The flame size is a function of the burner design, the air-side pressure drop, and the burner gas pressure. Increasing draft and relief fuel pressure helps reduce flame size.

Combustion chamber design typically results in a volumetric heat release of about 310 kW/m^3 (30,000 $Btu/h/ft^3$). The design volumetric heat release is a function of the burner size and design, combustion chamber geometry, relief gas composition, and other factors. The largest enclosed-flame flares now operating are rated at capacities above 120,000 kg/h (270,000 lb/h). The smallest enclosed-flame flares are rated at only a few hundred pounds per hour of relief gas flow.

NOTE Other considerations include open surface heat release for an enclosed flare, getting air into the center of the enclosed flare on larger sizes, and the amount of air that should be entrained as part of the combustion process, i.e. excess air.

The combustion chamber can be configured in several shapes, including vertical cylindrical, rectangular, and multi-sided. The choice of shape includes a number of process, safety, structural, and economic considerations. Site fabrication and economic factors are often paramount in the selection of the shape of an enclosed-flame flare. The top of the combustion chamber is open for flue gas discharge. None of the combustion chamber shapes has an inherent advantage in the mitigation of combustion noise. See Figure C.2.



Key

1 combustion chamber
2 refractory lining
3 flare gas burners
4 pilots
5 crushed rocks/gravel
6 wind fence

Figure C.2—Enclosed-flame Flare

C.2.3 Mechanical Considerations

The shape and size of the combustion chamber impacts the degree to which the flare can be pre-assembled to meet field-erection requirements. The external shell of the combustion chamber is typically fabricated of carbon steel. Internal surfaces can be coated or painted to mitigate dew point corrosion as required by the enclosed-flame flare design and operating conditions. Any coating material should be compatible with the design metal temperatures for the flare and its refractory lining. Special consideration should be given to selection and application of protective coating systems since metal temperatures can exceed temperature limitations of standard protective coating systems [typically 205 °C (400 °F)].

Ladders and service platforms, for access to enclosed-flame flare instruments and for stack emissions sampling, can impact the structural design of the combustion chamber.

The internal floor is usually made of compacted earth or gravel. No paved area is used, unless protected from flame radiation.

C.2.4 Burners

Burners and burner-control systems for enclosed-flame flares are engineered for specified gas flow rates, pressures, and compositions. Burners can be natural draft (unassisted), steam-assisted, air-assisted, or use the relief gas pressure (pressure-assisted) to produce smokeless burning and to assist in control of the flame profile. Burners may have to be fuel gas enriched to achieve desirable combustion efficiency for low-heating-value and hard-to-combust relief gases.

Burners typically combust a variety of gas compositions and at a variety of flow rates. Staged and unstaged burner systems necessitate different design considerations. With a staged burner system, typically the first stage turns down to purge flow rates. This burner staging provides control of the gas discharge pressure to ensure proper mixing of fuel and air and thus control of the flame profile. Typically a large gas flow rate at a low-pressure discharge produces a soft, large flame, unless supplemented by energy from the combustion airflow or assist media. Such flames can be difficult to contain in the combustion chamber and have a propensity to produce smoke or visible flame from the combustion chamber.

All enclosed-flame flares, except the very smallest in size, use multiple burners. For larger-capacity enclosed-flame flares, the multiple burners typically operate in staged systems as is described in Section 6.

The design of burners for enclosed-flame flares is proprietary to the manufacturer.

Airflow design into the combustion chamber establishes the distribution and velocity with which the air mixes with the fuel discharge. A pilot flame initially ignites these fuel-air mixtures. Once a main-burner flame is established, the burner should be stable and maintain continuous flame ignition on its own. It should never be necessary for the flame stability of a main burner to rely on the pilot flame. Burner-flame stability is produced by the flare manufacturer's proprietary means. Mechanisms include mechanical elements of the burner design in conjunction with air and gas flow dynamics.

C.2.5 Burner Piping

It can be necessary to protect piping that is internal or external to the combustion chamber, but within the wind fence, from radiant heat loads by radiation protection. When there is a possibility of condensation and liquid drainage into the combustion chamber resulting in flame impingement on internal piping, the piping should be engineered for high-temperature exposure. Piping is typically covered with loose gravel or metallic shielding. The covered piping should be suitably protected from environmental effects and corrosion.

If liquid carryover and/or gas condensation can occur, the piping design should accommodate liquid removal (e.g. sloping piping to knockout drum).

C.2.6 Pilots

Pilot fuel and supply systems should be clean and reliable. The typical pilot is a fixed-firing-rate, pre-mix burner. The pilot gas orifice is generally quite small. Potential plugging of this orifice should be mitigated by good piping design and by the use of a strainer located immediately upstream of the pilot gas orifice.

Pilots for enclosed-flame flares can be engineered to facilitate inspection and maintenance while the flare remains in service. This is accomplished by locating key components external to the wind fence and/or by making the pilot assemblies easily removable from outside the wind fence.

Many of the pilot and pilot-ignition details covered in A.3 and A.4 are applicable to enclosed-flame flares.

Flame scanners may be used as the flames are enclosed in the combustion chamber. Pilots for burners in enclosed-flame flares are typically more protected from the weather than those of open-air elevated flares. With a properly designed enclosed-flame flare and with an effective wind fence design, the airflow across the pilot and burner is unidirectional, whereas open-air elevated-flare pilots are affected by wind from varying directions.

C.2.7 Air and Flue Gas Flows

An enclosed-flame flare design provides for the airflow into the combustion chamber and for the flow of hot flue gases out of the combustion chamber. The heat produced in the combustion process is absorbed by large quantities of excess air so that the resulting flue gas temperature is low enough to allow the use of common refractory materials. The airflow into the combustion chamber can be by natural draft or forced draft. Natural draft is most often employed on large-size enclosed-flame flares. The natural draft level produced at any flaring rate is a function of:

— the heat release and resulting flue-draft gas temperatures,

— the airflow dynamics into the combustion chamber,

— frictional and combustion pressure losses as the flame propagates,

— the flow throughout the combustion chamber,

— the pressure loss of the flue gases exiting the combustion chamber,

— the combustion chamber dimensions and

— air fuel ratio controls (if equipped).

These factors can be engineered for the performance of the enclosed-flame flare from minimum flow rates to maximum flow rates. The maximum operating temperature of the combustion chamber is set by such engineering. For natural-draft enclosed-flame flares (without air control) at gas flow rates less than maximum, the combustion chamber temperature is lower and its operating excess air is higher. Even with cooler flue gas exit temperatures and higher overall excess-air levels, high combustion efficiencies are achieved from the flames alone, as is the case for most open-air elevated flares.

The enclosed-flame flare may achieve higher combustion and destruction efficiencies with the flare flame contained in the combustion chamber. Dampers or other means may be used to control the natural-draft airflow into the combustion chamber. Control of the airflow can allow for control of the combustion chamber operating temperature over variations of relief gas flow rate and composition. Controlled combustion temperature may achieve higher hydrocarbon destruction efficiencies.

Forced-draft air movement may be used for multiple purposes in enclosed-flame flares.

a) Some air-assisted designs use forced air to supplement the flame energies to produce smokeless flames of reduced flame volume.

b) Designs for 100 % forced-draft air volumes are controllable and thereby control the enclosed-flame flare combustion chamber temperature.

Excessive use of forced draft can contribute to enclosed-flame flare noise, resonance, and vibration. The use of a forced-draft fan and its driver impacts the reliability and availability of the overall system and should be evaluated.

Flue gas flows from the enclosed flare occur at the temperature of the combustion chamber for the given operating conditions. Typically, the temperature factor dominates for the dispersion of combustion products. If the flame volume is contained within the combustion chamber, there is very little, if any, measurable thermal radiation from the plume. However, the hot plume from the flare can impinge upon structures and components that are close by and above the elevation of the combustion chamber discharge. Design considerations for local structures include distance, height, dispersion, and exposure for personnel. This is done on a case-by-case basis.

C.2.8 Wind Fences

Enclosed-flame natural-draft flares use wind fences or other designs to mitigate the potential of the wind to upset air and flue gas flows. Uniform airflow to all sides of all burners is important in achieving controlled combustion. Wind fences surround the burner air inlets and are designed to allow distribution of the airflow to the burners. Without a wind fence, the wind can upset the natural draft of the combustion chamber. This can result in flames exiting the base of an enclosed flare. Without a wind fence, the wind can flow in the upwind burner openings and out of the downwind ones. It is necessary that wind fence design consider the enclosed-flame flare operating draft levels; care should be taken not restrict airflow outside the intended design to the burner openings. See Figure C.3.

Wind fence designs acoustically dampen the noise. See C.3.2.

Wind fences also offer safety protection for personnel from the radiation of the flare flames and from the external surfaces of the combustion chamber. The inside surface of the wind fence and all components of the enclosed-flame flare inside the wind fence should be engineered for the temperatures that are experienced from the thermal radiation of the flames visible there. Personnel access inside the wind fence of an operating enclosed-flame flare should be restricted.

The wind fence also isolates the air intake for the enclosed-flame flare from the adjacent ground-level environment. Elevating the air intake can mitigate the possible ignition of combustible ground-level hydrocarbon vapor clouds. This is an important factor where the enclosed-flame flare is located in close proximity to hydrocarbon storage or processing equipment.

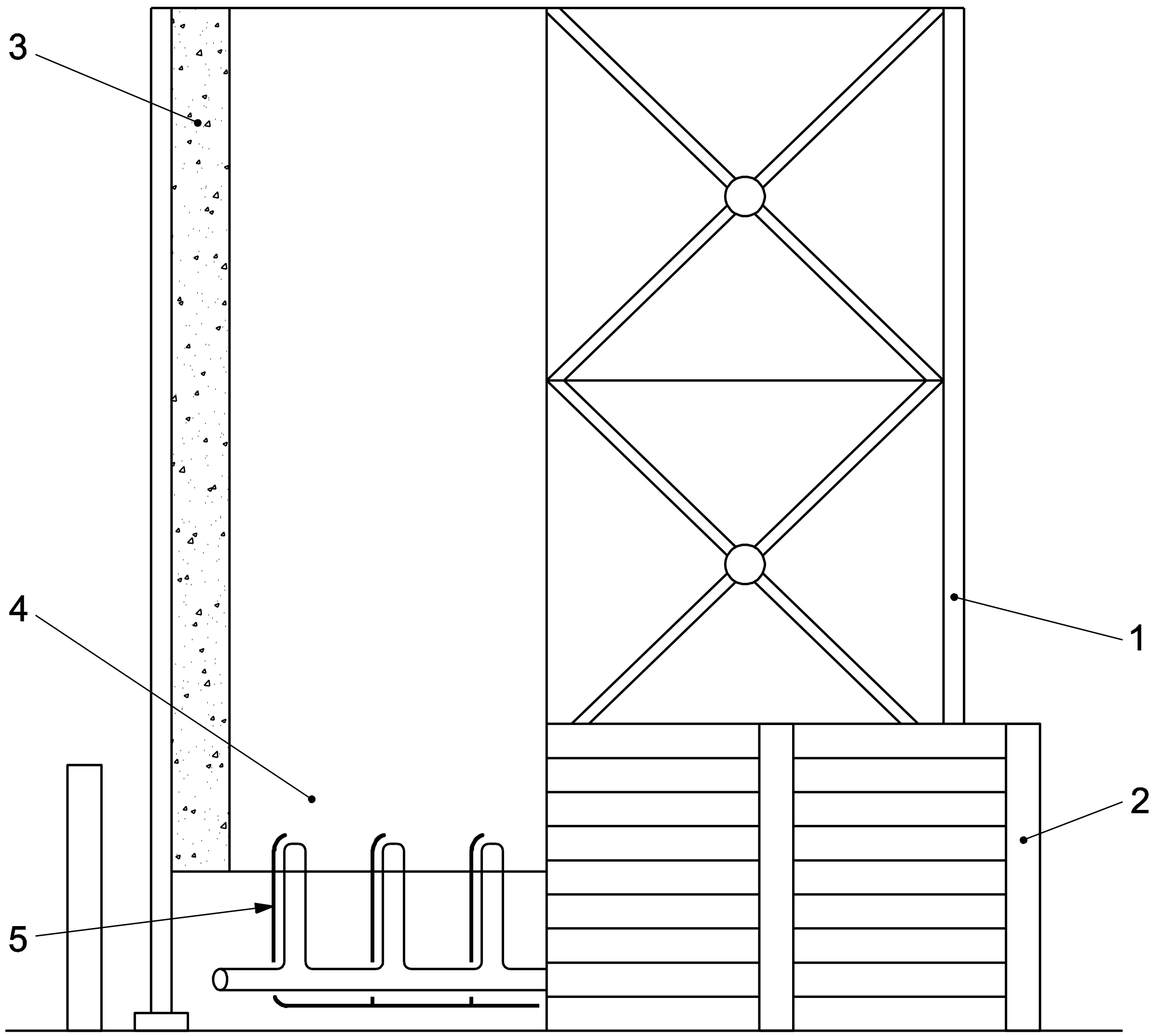
C.2.9 Operational and Safety Controls

Enclosed-flame flares require a number of operational and safety controls. As for any flare, the relief gas should never be ignited without the assurance that safe operating conditions exist. A prerequisite is that the flare system is purged and all flare safety systems are operational.

Some flare burners in a stage utilize pilots and pilot ignition systems. A flame front generator or direct electric ignition of the pilots is often employed. Flame-detection devices monitor pilot flames. It is necessary that automatic pilot re-ignition be incorporated into the system design. Operating pilots are necessary to allow flare burner staging.

A burner staging system, as is described for the burners above and in Annex B, is used on larger-capacity enclosed-flame flares.

The combustion chamber of an enclosed-flame flare can overheat if the gas heat release is too high and/or if the airflow is not sufficient. The gas heat release can be too high due to excessive gas flow or due to changes in gas composition. The airflow demand can exceed the design or can become restricted. A high-temperature alarm and/or shutdown should be supplied to protect the combustion chamber. It is important to ensure that the possible shutdown of the fuel train of an enclosed-flame flare does not restrict safe discharge and disposal of relief gases. The high-temperature control action can disengage a burner stage and effect a diversion of the relief gases to other systems such as an elevated flare.



Key

1 exterior frame
2 wind fence
3 refractory lining
4 flare gas burners
5 gas pilots

Figure C.3—Wind Fence for an Enclosed-flame Flare

The enclosed-flame flare system can require a purge or sweep gas. As is typical for staged burner systems, only the first stage can require a purge gas flow. Some smaller enclosed-flame flares eliminate purge gas flows by opening and closing the first-stage burners to maintain a minimum pressure in the flare header. For relief gas compositions with a wide ratio of upper to lower flammability limit, an inert gas post-purge of a burner stage as it turns off is recommended. The post-purge sweeps the reactive gas out of the burners and burner piping, and mitigates flashback and combustion in the flare system piping. Gases of concern include hydrogen, ethylene, acetylene, and others as defined by a high ratio of upper to lower flammability limits.

Enclosed-flame flares can be tested for combustion performance. Flue gas can be sampled in the combustion chamber or an extractive sample can be drawn out of the combustion chamber. The emission factors for an enclosed-flame flare can, thus, be measured. The ability to measure can be significantly influenced by the physical configuration of the flare.

Relief gas compositions that are difficult to ignite and combust can be aided by the use of fuel enrichment. Flare gas analyzers combined with control systems can be implemented for fuel gas enrichment. With temperature control in an enclosed-flame flare, less enrichment gas is required to achieve higher combustion/destruction efficiencies than are typical for an elevated flare.

For enclosed-flare flames that are located in an area where gas vapors can be present, lower explosive limit (LEL) meters with an alarm should be located adjacent to the flare. Alternate choices are to shut the flare down and/or to divert the flare gases.

C.2.10 Enclosed-flame Flare Applications

Enclosed-flame flare applications include:

— flares for normally occurring relief rates for hydrocarbon processing and production facilities such as start-up/shutdown flows and normal process venting;

— petroleum terminal vapor control;

— biogas disposal: the products of anaerobic digestion (e.g. from landfills, industrial digestion processes, or sewage processing) are fed at a fairly steady and predictable rate;

— flare applications where combustion chamber temperature control ensures a high hydrocarbon-destruction efficiency;

— flare applications where the assist fuel gas quantity can be reduced by use of an enclosed flame;

— in refining or petrochemical applications where the flare acts as a lower stage to the complete relief system, designed to handle day-to-day loads (see Figure C.3);

— onboard floating-production storage and off-loading (FPSO) vessels, where the bulk of the flaring events are handled in a safe way in the confined space available.

C.3 Operating Considerations for Enclosed-flame Flares

C.3.1 Visible Flames

The purpose of the enclosed-flame flare is to hide the flame. Visible flame can be caused by the following:

— exceeding design heat-release capacity;

— undersized combustion chamber;

— burner performance or operation related to:

    — control of smoke-suppression medium,

  - burner arrangement/position,
  - burner plugging or damage, and
  - liquid carryover to the burner;
- air distribution to the burners and combustion chamber;
- wind effects;
- poor temperature control for units operating with a temperature-controlled combustion chamber.

In some cases, reported flame visibility is simply reflected light from the combustion chamber on a foggy or low-cloud night. High combustion chamber temperatures can produce a visible, ionized gas glow of the flue products exiting the combustion chamber that can appear to be visible flames.

During normal flare operation up to the maximum capacity of the units, it is necessary that the flame length be contained within the enclosure and not be directly visible from the outside. For the majority of specified operating cases, combustion is smokeless.

The flare should be designed to mechanically withstand certain overload cases for short duration. These cases cause a greater or lesser amount of flame to come out of the top of the enclosure and be visible to a remote observer. Generally, operating in an overload condition is discouraged.

C.3.2 Noise and Vibration

As some heat release energy in an enclosed-flame flare is converted to acoustical energy, high noise levels can be encountered. Burner design and burner stability are key elements to controlling enclosed-flame flare noise, with the following considerations.

a) Burners of moderate gas/air mixing intensity avoid creating excessive noise with typical volumetric heat release.

b) If burners of greater flame intensity are utilized, the ground flare has an increased tendency to produce excessive combustion-driven noise.

c) If burners of less intensity are used, the enclosed flare can be quieter since the combustion chamber is proportionally physically larger in size.

The combustion chamber can amplify any noise produced by unstable burners or unstable gas or airflow. Excessive low-frequency noise and vibrations can be encountered if a resonance is set up in the combustion chamber. Typically, the combustion chamber prime resonant frequencies are sub-audible. This low-frequency noise can travel significant distances without attenuation and can induce vibrations in structures remote from the enclosed-flame flare. Resonance problems are best avoided by empirical experience. If a problem does occur, the most readily available remedy is modification of the burners and burner operating systems and/or a reduction in operating capacity.

Noise levels from an operating enclosed-flame flare are a function of heat release and equipment design. Noise levels are affected by the design factors listed above, including the number of stages that are operating. Wind fence designs can serve to acoustically isolate the combustion chamber noise. Some flares can achieve an 85 dBA noise level or less at a distance of 0.9 m (3 ft) from the wind fence.

C.3.3 Refractory Failure

Refractory failures can result in hot spots on the shell of the combustion chamber. How the refractory fails, the nature and extent of its failure, and its consequences and repair are a function of the type of lining used.

For ceramic-fiber linings, shell hot spots often develop initially at the seam of the blanket lining where high-temperature contraction has opened a gap. This is avoided by proper design of the refractory lining that considers such shrinkage. Ceramic-fiber shrinkage rates can increase when subject to cyclic service and proximity to flames in enclosed-flame flares. Ceramic-fiber lining can also fail due to overtemperature and/or excessive-velocity operations. For high-velocity failures, particles of the high-temperature lining can be discharged from the top of the combustion chamber. High-temperature, high-velocity failures are avoided by proper material selection, proper anchoring design, good installation, and by good operating and maintenance practices. When using rigidizers to improve the velocity rating of ceramic-fiber linings, consider the cyclic temperature operation of enclosed-flame flares and thermal expansion difference of the rigidized material and the base material. Ceramic-fiber linings should be avoided on horizontal surfaces where liquid hydrocarbons can collect. If a pool fire develops on a flat horizontal surface, the fiber material's insulating capabilities can be significantly reduced.

For castable or other hard material linings, hot spots on the combustor shell typically occur first at expansion-joint or seam locations. These are avoided or mitigated by eliminating expansion joints where practical and/or by proper expansion-joint design and maintenance. Castable-type refractory materials are also subject to failure by reason of improper initial curing. Castable refractory should be cured in accordance with the manufacturer's recommendations. Cosmetic cracks produced during curing/initial operation can be expected and generally do not affect long-term performance. Larger cracks that are 3 mm ($^1/_8$ in.) or greater in width and penetrate more than 50 % of the castable thickness should be considered unacceptable and be repaired. See API 560 regarding repair techniques. Some phosphate-based castable refractories do not require a high-temperature bake-out. Castable-refractory strength and durability can be enhanced by the addition of metal needles. Polypropylene fibers have been successfully used to enhance the thermal cycling and cure-out for castable refractories.

It is necessary to include a proper anchoring means in any hard refractory system. Repairs to hard refractory systems should be made in accordance with the manufacturer's recommendations.

The use of high-temperature alarms and shutdowns can mitigate some refractory failures.

C.3.4 Pre-commissioning

Pipework associated with the flare should be tested prior to the installation of the flare burners and pilots, with consideration of the following.

a) All flare lines should be free from debris and obstruction. All lines should be blown down prior to installing the flare burners, pilots, and steam nozzles (if fitted). All lines should be blown down with a velocity greater than that which is encountered during normal operation. Typically, such velocity exceeds 90 m/s (300 ft/s).

b) Ensure that the pilot orifices are not blocked.

C.3.5 Commissioning

C.3.5.1 Initial Commissioning

When initially commissioning the flare header or following any shutdown where the flare header is gas-free and positively isolated, the following procedure is applicable.

a) It is necessary that all scaffolding, supports, tools, etc. be removed from within the perimeter of the wind fence or other barrier that indicates restricted access.

b) The flare line downstream of the main header blind should be purged with inert gas to reduce the oxygen levels to safe proportions. The header should be purged with at least 10 times the free volume of the header with a noncondensable, inert gas. As a result of this purge, a maximum oxygen concentration of less than 6 % volume fraction is recommended, unless process conditions indicate a more conservative level should be reached. The use of inert gas as the purge medium prior to pilot ignition precludes the possibility of a gas/air mixture forming within the flare enclosure that can ignite explosively when the pilots are ignited. After the pilots are ignited, a hydrocarbon gas purge can be used.

c) In consideration of the inert gas purge, normal safety precautions should be taken within the flare area.