Flare Details for Petroleum, Petrochemical and Natural Gas Industries

API STANDARD 537
PROPOSED THIRD EDITION, ADDENDUM 1

ANSI Public Comment and Ballot Draft for new Annex G.

Draft Development Record:

06-07-19: API staff developed the public review-ballot draft.

20181203 VV: Updated to reflect modifications following Technical Ballot comments / resolution from Spring 2018 meeting.

20180213 RW: Added Annex G with sections migrated from API 521 6th Edition. Bibliographic references in Annex G have not been updated.

20180126 RW: Updated file to reflect 3rd Edition publication.

API Staff NOTE: Newly proposed Annex G comprises this draft. No other text in Standard 537 is being proposed or changed. All text that follows is new and open for comment and approval.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Washington, D.C. 20001, standards@api.org.

Annex G
(informative)

API Standard 521 (*Pressure-relieving and Depressuring Systems*) Sixth Edition Migration

G.1 General

This Annex captures informative content migrated from API Standard 521 Sixth Edition through an API 521 / API 537 joint committee review. Any identified normative requirements contained in API 521 that were not already included in API Standard 537 have been added the normative section of this standard. The following table provides cross-reference to the same sections for the two standards. Eventually, all normative requirements in this Annex will be moved to the body (normative sections) of this standard.

Table G.1 — API 521 to API 537 Section Cross-reference

API Standard 521 Section Number	API Standard 537 Annex G Section Number (Informative)
5.7.2.2	G.2.1
5.7.2.4	G.2.2
5.7.3.2	G.3.1
5.7.3.2.2	G.3.2
5.7.3.2.3	G.3.3
5.7.3.2.4	G.3.4
5.7.3.2.5	G3.5
5.7.3.2.6	G.3.6
5.7.3.2.7	G.3.7
5.7.3.2.8	G.3.8
5.7.3.2.9	G.3.9
5.7.3.2.10	G.3.10
5.7.3.2.11	G.3.11
5.7.3.3	G.3.12
5.7.3.4	G.3.13
5.7.4.1	G.4.1
5.7.4.2	G.4.2
5.7.4.3	G.4.3
5.7.4.4	G.4.4
5.7.5.1	G.5.1
5.7.5.2	G.5.2
5.7.5.3	G.5.3
5.7.5.4	G.5.4
5.7.6.1	G.6.1
5.7.6.2	G.6.2
5.7.7.1	G.7.1
5.7.7.2	G.7.2
5.7.7.3	G.7.3
5.7.7.4	G.7.4

G.2 Combustion Properties

G.2.1 Smoke *(5.7.2.2)*

NOTE The blue bracketed numbers appearing in this annex indicate the section numbers in the 6th Edition of API Standard 521 that the text appearing after the number was taken from.

❖ The range of smokeless operation shall be defined based on the appropriate opacity Ringelmann number for all operational cases that require smokeless operation.

G.2.1.1 Introduction

Many hydrocarbon flames are luminous because of incandescent carbon particles formed in the flames. Under certain conditions, these particles are released from luminous flames as smoke. The exact reasons and mechanisms by which smoke is formed are still not fully understood. Many different processes have been suggested, but a discussion of them is beyond the scope of this standard. However, it can be stated that smoke is formed during the combustion of hydrocarbons only when the system is fuel rich, either overall or locally. Observation has revealed that suppression of the hydrogen-atom concentration in the flames accompanies the suppression of smoke formation [32] [33] [34]. Smoke formation can possibly be reduced by reactions that consume hydrogen atoms or render them ineffective.

G.2.1.2 Design Considerations

— Use of water vapor to reduce smoke: The ways in which water vapor reduces smoke from flares have been discussed by Smith [145]. Briefly, one theory suggests that steam separates the hydrocarbon molecules, thereby minimizing polymerization, and forms oxygen compounds that burn at a reduced rate and temperature that are not conducive to cracking and polymerization. Another theory claims that water vapor reacts with the carbon particles to form carbon monoxide, carbon dioxide and hydrogen, thereby removing the carbon before it cools and forms smoke.

— See G.3.1 for a discussion of smoke suppression methods.

— Causes of smoke: There are many possible causes for a smoking flare such as liquid carryover, flare gas flow rate change, change in flare gas composition, or incorrect flow of smoke suppression fluid. Smoking is a visual signal to check operation (e.g. adjust the flow of smoke suppression fluid). See Annex A, B, C, and D for operation and troubleshooting guidance related to smoke suppression relative to the various flare types.

— Destruction vs. Combustion Efficiency: Although a smoking flare flame is related to combustion efficiency, it is not directly related to destruction efficiency. The destruction efficiency of the highly branched hydrocarbons can exceed 99 %, while simultaneously the residual carbon soot emitted could cause a very opaque plume [60].

G.2.2 Flame Stability *(5.7.2.4)*

❖ Flare flame combustion shall be stable over the entire defined operating range, with a stable flame being defined as either “attached stable” or “detached stable”.

G.2.2.1 Introduction

Flame stability of the flare is critical to safe and reliable operation and for assuring proper destruction of volatile and combustible components in the flare gas. Flare gas composition and exit velocity are important considerations in flare burner design and stable operation.

There are four stages of observable flame stability:

— Stage 1—attached stable,

— Stage 2—detached but stable flame,

— Stage 3—detached unstable flame, and

— Stage 4—flame-out.

G.2.2.2 Design Considerations

Judgment of flame stability is best undertaken at night when blue sections of a flame are more visible.

Both Stages 1 and 2 are acceptable flames. Stage 3 is a flame in transition from Stage 2 to Stage 4 or from Stage 4 to Stage 2. Stage 3 flaring is often accompanied by a pounding low frequency noise. Burning Stage 2 can be accomplished using flame retaining devices located at or near the flare gas exit. Stability can also be achieved by using turbulence created by gas jets located at or near the exit to stabilize the flame.

G.3 Combustion Methods

G.3.1 Flares with Smoke Suppression *(5.7.3.2)*

❖ Smokeless operational range shall be as defined in the flare burner design sheet.

❖ Smokeless operation shall be as defined by opacity or Ringelmann number.

❖ Other operating requirements for the flare e.g. noise and regulatory requirements shall be set in the flare datasheet.

❖ Composition of the gas to be burned shall be listed on the flare datasheet for all defined operational smokeless cases.

❖ A common type of smokeless flare involves steam injection.

G.3.1.1 Introduction

Smokeless operation is normally the overriding requirement when designing the burner for a flare system. Almost every flare design is aimed at inducing smokeless operation under a certain set of flare gas or utility availability conditions.

To promote even air distribution throughout the flames (and thus prevent smoke formation), energy is required to create turbulence and mixing of the combustion air within the flare gas as it is being ignited. This energy can be present in the gases, in the form of pressure and velocity, or it can be exerted on the system through another medium, such as injecting high-pressure steam, compressed air or low-pressure blower air into the gases as they exit the flare burner.

G.3.1.2 Design Considerations

— Assist medium (e.g. steam or air) consumption at turndown firing rates below the smokeless design point may need to have a higher assist medium-to-hydrocarbon ratio than the smokeless design condition to mix sufficient air with the flare gas.

— Smoke-free operation of flares can be achieved by various methods, including steam injection, injection of high-pressure waste gas, forced draft air, operation of flares as a premix burner, or distribution of the flow through many small burners.

G.3.2 Steam Requirements for Steam Assisted Flares *(5.7.3.2.2)*

❖ The manufacturer shall define the range of steam flow rate necessary to achieve smokeless flare operation at required design conditions. This shall be documented on the flare datasheet.

G.3.2.1 Introduction

The amount of steam required for smokeless burning depends on the vapor flow rate to be burned and the detailed composition of the mixture. Key parameters involving smokeless combustion include percentage of unsaturates, percentage of inerts, and the mixture relative molecular mass. Certain specific compounds require special consideration by the manufacturer. Examples include ethylene, butadiene, acetylene, and ethylene oxide. Datasheets from Annex F provide a convenient means for specifying the composition.

G.3.2.2 Design Considerations

Table G.1 may be used to estimate steam requirements as a function of composition. For mixtures, the estimate of steam requirements can be proportioned based on the specific mass fraction of hydrocarbon component in the mixture (i.e. exclude hydrogen sulfide, inerts).

NOTE The rate ratio will be higher with flares operating at turndown rates (30% or lower of design capacity).

Many state and federal regulations state the smokeless requirement in the form “No operator shall allow the flare emissions to exceed 20 % opacity for more than 5 min in any consecutive 2 h period.” This type of regulation is usually the basis for designing flares to achieve Ringelmann 1 (20 % opacity) performance.

Other applications can require Ringelmann 0 (zero opacity) for regulatory or community relations reasons. It is necessary for the user to understand the local regulatory requirements that govern smokeless requirements. High combustion efficiency and low opacity is an active research activity. There is not a universally accepted method at this time.

Table G.1-Suggested Steam Injection Rates

Gases Being Flared	Approximate Steam Rate Ratio [a b] kg (lb) of steam per kg (lb) of Hydrocarbon Gas
Paraffins	
Ethane	0.10 to 0.15
Propane	0.25 to 0.30
Butane	0.30 to 0.35
Pentane plus	0.40 to 0.45
Olefins	
Ethylene	0.40 to 0.50
Propylene	0.50 to 0.60
Butene	0.60 to 0.70
Diolefins	
Propadiene	0.70 to 0.80
Butadiene	0.90 to 1.00
Pentadiene	1.10 to 1.20
Acetylenes	
Acetylene	0.50 to 0.60
Aromatics	
Benzene	0.80 to 0.90
Toluene	0.85 to 0.95
Xylene	0.90 to 1.00

[a] These suggested steam factors have units of mass steam/mass hydrocarbon. Because flare gas can have significant quantities of hydrogen and nitrogen, it is important to account for this when using these factors by adjusting for the hydrocarbon content of the flare gas:

$$\sum_{i=1}^{n} w(i) \cdot \mathrm{API}(i)$$

Suggested Steam-to-flare-Gas Ratio =

where

n is the number of components in flare gas mixture. Both hydrocarbon and nonhydrocarbons are included in this count;

$w(i)$ is the weight fraction of component (i) in the flare gas mixture;

$\mathrm{API}(i)$ is the steam-to-hydrocarbon mass ratio for hydrocarbon (i) from this table. Note that nonhydrocarbons such as hydrogen, hydrogen sulfide, carbon monoxide, ammonia, nitrogen, carbon dioxide, etc. would have a steam ratio value of zero.

[b] These values provide only a general guideline because they can be affected by flare burner design configuration, gas flow rate, gas composition, gas pressure, steam injector design, steam pressure, steam velocity, steam control, sequence order of steam injection, gas velocity, inerts, wind speed effect (depending upon the flow regime flame that is present), flare equipment condition, etc.

G.3.3 Degree of Smokelessness *(5.7.3.2.3)*

- ❖ The level of smokeless operation required for different operating conditions shall be specified on the flare data sheet and consider regulatory requirements.

G.3.3.1 Introduction

The flare may be designed for various degrees of smokelessness.

G.3.3.2 Design Considerations

Many state and federal regulations state the smokeless requirement in the form "No operator shall allow the flare emissions to exceed 20 % opacity for more than 5 min in any consecutive 2 h period." This type of regulation is usually the basis for designing flares to achieve Ringelmann 1 (20 % opacity) performance.

Other applications can require Ringelmann 0 (zero opacity) for regulatory or community relations reasons. It is necessary for the user to understand the local regulatory requirements that govern smokeless requirements.

G.3.4 Steam Injection *(5.7.3.2.4)*

- ❖ Maximum steam limits shall be provided by the flare supplier for smokeless operation for the design flare gas.

G.3.4.1 Introduction

Flare burners that use steam to control smoking are a common for elevated single point flares. The steam can be injected through a single pipe nozzle located in the center of the flare, through a series of steam/air injectors in the flare, through a manifold located around the periphery of the flare burner or a combination of all three, as appropriate for the application [see Figure G.1, a) and b)]. The steam is injected into the flame zone to create turbulence and/or aspirate air into the flame zone via the steam jets.

The improved air distribution allows the air to react more readily with the flare gases to eliminate the fuel-rich conditions that result in smoke formation. Another factor assisting smokeless operation is the steam water-gas shift interaction where carbon monoxide and water vapor react to form carbon dioxide and hydrogen, which is more easily burned. Proprietary flare burner designs that offer unique steam injection methods and varying required steam-to-hydrocarbon ratios are available from various flare manufacturers.

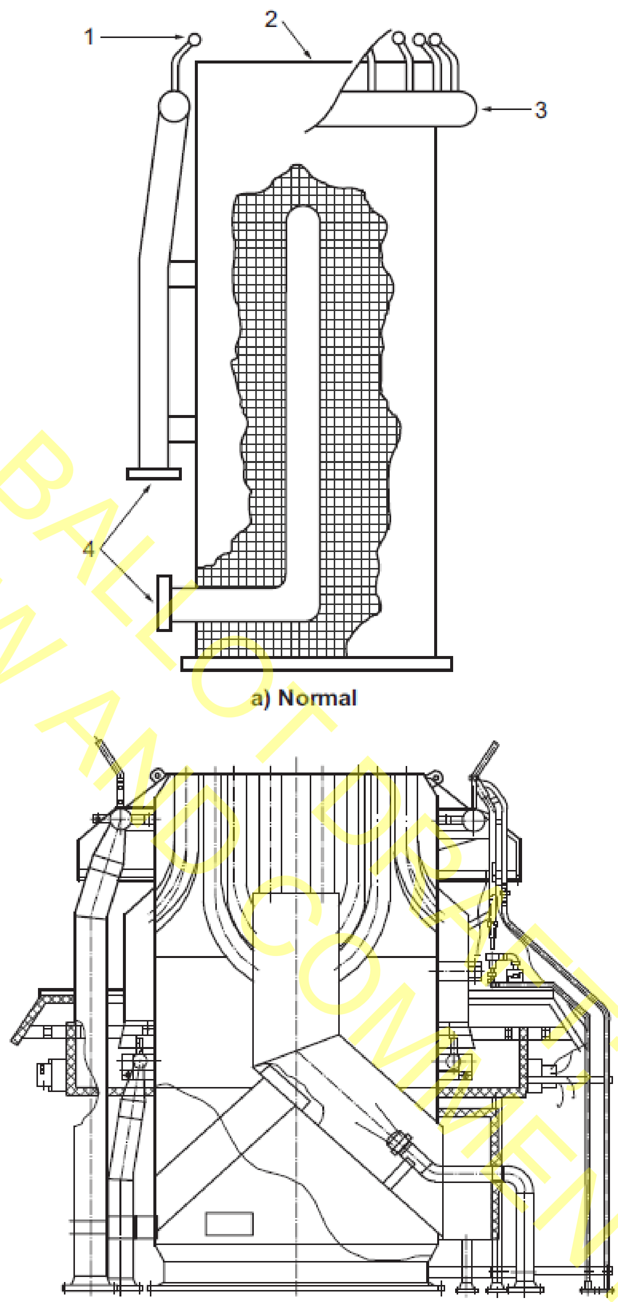
G.3.4.2 Design Considerations

The suggested amount of steam that should be injected into the gases being flared to promote smokeless burning can be estimated from Table G.1 for several components. These values provide only a general guideline because they can be affected by flare burner design, relief or waste gas flow rate, composition, pressure, steam velocity, gas velocity, etc. The flare manufacturer should be consulted for a detailed assessment of steam requirements for smokeless combustion at varying flare operating loads and process conditions.

Although increasing the steam to flare gas ratio would benefit smoke control, it should be noted that a flare can be over-steamed (over-aerated). If too much steam is added, the combustion efficiency of the flare will decrease, particularly during turndown conditions. Excessive steam can also lead to "capping", forcing gas / flame to areas not designed for this condition.

While there is usually a significant range of steam-to-flare-gas ratios that will produce high combustion efficiencies, the combustion efficiency declines abruptly when excessive steam to flare gas ratios are applied. The upper-boundary of steam-to-flare-gas ratio to maintain a high combustion efficiency is affected by the many factors noted above.

Currently, there is insufficient information to provide specific guidance on upper steam limits in this standard. It should be noted that Table G.1 is not intended to specify maximum steam rates for any defined combustion efficiency. The steam rates and combustion efficiencies vary as a function of the process design conditions and the flare burner proprietary design.



a) Normal

b) Low noise

Key

1 steam tips
2 flame holder
3 upper steam ring
4 steam connections

Figure G.1 — Steam-injected Smokeless Flare Burners

Although steam is normally provided from a supply header at 700 kPag to 1000 kPag (approximately 100 psig to 150 psig), special designs are available for utilizing steam pressure as low as 200 kPag (~30 psig). The major impact of lower steam pressure is the need for a higher steam-to-hydrocarbon ratio during smokeless turndown conditions. The steam pressure at the point of injection directly affects air inspiration. Hence, steam piping pressure drop from the supply header to the injection point should be considered in designing the piping layout.

G.3.5 High-pressure Air *(5.7.3.2.5)*

G.3.5.1 Introduction

High-pressure air can also be used to prevent smoke formation as a substitute for steam, however, is less effective. Air used like steam can educt atmospheric air into the combustion zone and promote mixing at a reduced efficiency. This approach is less common because compressed air is usually more expensive than steam. However, in some situations with low smokeless capacities, it can be preferable, for example, in arctic or low-temperature applications where steam can freeze and plug the flare burner/stack. Also, other applications include desert or island installations where there is a shortage of water for steam, or where the waste-flare gas stream reacts with water.

G.3.5.2 Design Considerations

The same injection methods described for steam (see G.3.4) are used with compressed air. The air is usually provided at a pressure of 689 kPag (100 psig). The mass of air required is approximately 1.2 times the steam mass, because the compressed air does not produce the water-gas shift reaction that occurs with steam.

In general, high-pressure air assist is useful for retrofit of an existing flare or where the required smokeless flow is small, and steam is not economically available

G.3.6 High-pressure Water *(5.7.3.2.6)*

Normative Requirements for Consideration:

❖ Freeze protection of high-pressure water lines in cold climates is required.

G.3.6.1 Introduction

High-pressure water, while quite uncommon, is also used to control smoking, especially for horizontal flare applications and when it is necessary to eliminate large quantities of waste water or brine. A water to flare gas ratio of approximately 1:1 is typically used, e.g. 0.45 kg (1 lb) of water at 350 kPag to 700 kPag (approximately 50 psig to 100 psig) is usually required for each 0.45 kg (1 lb) of gas flared.

G.3.6.2 Design Considerations

Due to the difficulty in controlling the water flow at low flaring rates, a staged water-spray injection system is usually specified.

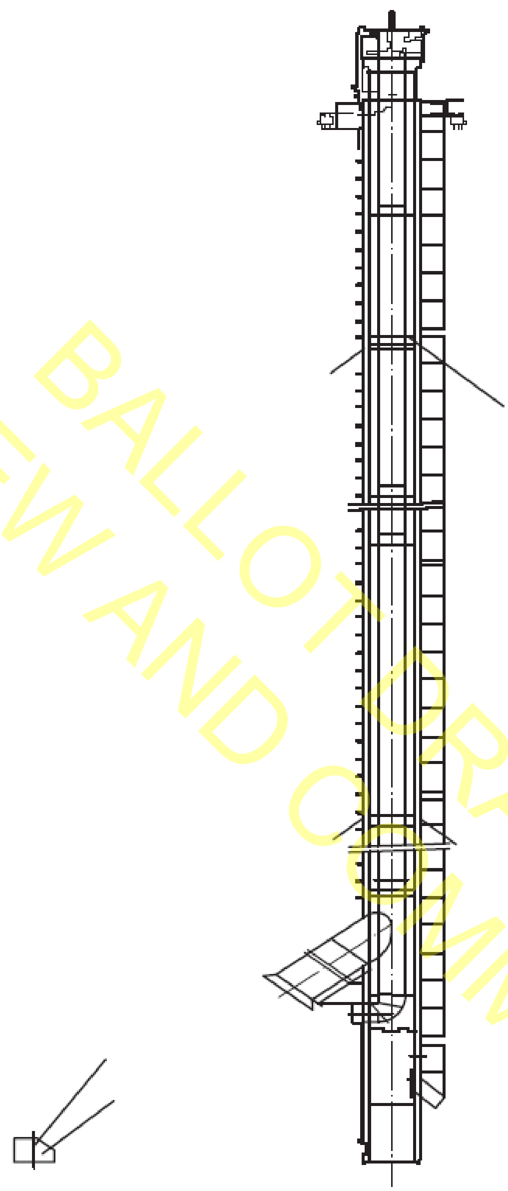
G.3.7 Low-pressure Forced-air System *(5.7.3.2.7)*

G.3.7.1 Introduction

A low-pressure forced-air system is usually the first alternative evaluated if insufficient on-site utilities are available to aid in producing a smokeless operation. The system creates turbulence in the flame zone by injecting low-pressure air supplied from a blower across the flare burner as the gases are being ignited, thus promoting even air distribution throughout the flames. Typically, air at a gauge pressure of 0.5 kPa to 5.0 kPa (2 in. H_2O to 20 in. H_2O) flows coaxially with the flare gas to the flare burner where the two are mixed.

G.3.7.2 Design Considerations

A low-pressure forced-air system has a higher initial cost due to the requirement for a dual stack and an air blower. See Figure G.2. However, this system has a much lower operating cost relative to a steam-assisted design (requiring only power for a blower).



Guy-wire supported air-assisted with ladders/platforms and dual blowers.

Figure G.2 — Typical Forced-air Assisted Smokeless Flare

The additional quantity of air supplied by the blower for smokeless operation is normally 10 % to 30 % of the stoichiometric air required for saturated hydrocarbons and 30 % to 40 % of the stoichiometric air required for unsaturated hydrocarbons.

G.3.8 High-pressure Flaring *(5.7.3.2.8)*

G.3.8.1 Introduction

A high-pressure system does not require any utilities such as steam or air to promote smokeless flaring. Instead, these systems utilize pressure energy available within the flare gas itself [typically 35 kPag to 140 kPag (5 psig to 20 psig) minimum at the flare burner] to draw in and mix atmospheric air, which eliminates fuel-rich conditions and resulting smoke within the flames.

G.3.8.2 Design Considerations

High-pressure system limitations are also present but vary by manufacturer and nature of design. By injecting the flare gas into the atmosphere at a high pressure, turbulence is created in the flame zone, which promotes even air distribution throughout the flames.

Since no external utilities are required, these systems are normally advantageous for disposing of very large gas releases, both from the economics of smokeless operation and the control of flame shape.

Single-point flare burners used in high-pressure applications are relatively small in capacity, with larger system designs requiring a multi-burner flare designed in a manifolded arrangement and often a pressure staged design.

Maintaining sufficient pressure at the burner during turndown conditions is critical and often requires that a staging system be employed to proportionately control the number of flare burners in service relative to the amount of gas flowing.

Multi-burner staged-flare systems can be mounted either at grade or elevated with the larger systems requiring a ground-level design given the large number of individual flare burners that are often required. It is not uncommon to have more than 300 burners in a large ground level staged-flare system. Properly spaced burners are required to allow adequate air entry into the system for proper smokeless combustion.

Staged flares should provide backup for system failures by inclusion of bypasses or emergency vents. A failsafe pressure-relief bypass around individual staging control valves are a commonly used safety measure. A rupture disk or similar device is typically used as a failsafe pressure-relief bypass.

If environmental regulations allow, high-pressure flares have been used in burn-pit applications to burn liquids.

G.3.9 High-pressure Fuel Gas Flaring *(5.7.3.2.9)*

G.3.9.1 Introduction

High-pressure fuel gas can also be used to prevent smoke formation by entraining outside air into the flare flame and generating turbulence to assist overall combustion.

G.3.9.2 Design Considerations

Typically, high-pressure fuel gas injection methods are similar to steam assisted flare burners, however special high-performance flare burners are used to reduce the amount of assist gas.

If natural gas is used as the assist gas, typically 0.23 kg to 0.34 kg (0.5 lb to 0.75 lb) of assist gas per kg (lb) of flare gas is required, based on a flare gas consisting of normal paraffins such as propane and butane. The supply pressure for natural gas assist is typically 500 kPag (~75 psig) (minimum) with 1000 kPag (~150 psig) preferred.

G.3.10 Control of Fluid Injection for Smoke Suppression *(5.7.3.2.10)*

- ❖ At low flaring rates, fluctuations in either pressure or flow may be so minute that very sensitive instruments are required for accurate measurements. In order to provide sufficient steam for smokeless operation while avoiding waste, an instrumentation and control system shall be selected that is adequate for the service at turndown.

G.3.10.1 Introduction

The following methods of controlling steam (or compressed air, high-pressure water or fuel gas) for smokeless flare control are commonly applied with many other control strategies possible.

— Manual Operation: Manual control usually involves remote operation of a steam valve by operating personnel assigned to a unit from which the flare is readily visible. This method is satisfactory if short-term smoking can be tolerated when a sudden increase in flaring occurs. With a manual arrangement, close supervision is required to ensure that the steam flow is reduced following the correction of an upset. Operating costs can be excessive if monitoring is not timely.

— Video Monitoring with Manual Control: The philosophy is the same with manual operation except that a video monitoring system is added so that the control room operators can monitor and control the steam flow more effectively.

— Feed Forward Control System for Pressure, Mass Flow, or Velocity: By measuring the amount of flare gas flowing to the flare, the steam rate can be automatically adjusted to compensate for rate changes. This system might not be desirable if the composition of the gas being flared varies widely over time e.g., paraffins to olefins or aromatics, hydrogen, or various mixtures thereof.

— Feedback System Using an Infrared Sensor: Infrared sensors can be used to detect smoke formation in the flames and automatically adjust the steam control valve to compensate. A disadvantage of this system is that infrared waves are absorbed by moisture and the resultant feedback signal is reduced in rainy or foggy conditions. See also A.5.4 Optical Systems

— Some automatic, infrared steam control systems can result in excessive steam injection which can be undesirable.

G.3.10.2 Design Considerations

Proper steam (or other assist media) control is important to achieve the maximum reaction-efficiency potential oh the flare burner.

Proper steam control is particularly true at low flaring rates where it is possible to over-aerate the flare flame to the point of near flame extinguishment. Such operation may be based on the belief that it is preferable to over-aerate a flame to a point that it becomes difficult to see. This premise is not correct. Studies and tests of flare reaction efficiency have established that an over-steamed flare has a lower reaction efficiency than a properly aerated flare flame.

G.3.11 Noise Caused by Smokeless Flaring *(5.7.3.2.11)*

G.3.11.1 Introduction

Smokeless flares using steam can produce noise due to excessive steam usage [147].

G.3.11.2 Design Considerations

For steam assisted flare burners, if the steam flow rate is increased above the recommended flow rate, flame instability can occur. The flame instability, such as flame pulsation, is generating additional noise.

The noise associated with the over-steaming tends to be low frequency and carry for long distances. Over steaming shall be avoided as this can cause flameout.

Smokeless operation using compressed air can also produce pulsation.

Flares using high-pressure fuel gas assist generally do not have this pulsation or flame-out problem due to the secondary flame produced by the assist gas ring or burners.

Air blower flares can produce a similar flame quenching with resulting flame instability and low frequency pulsation when large amounts of excess air are used.

Improper sequencing of the steam on a multiple steam injection burner can cause noise associated with pulsation. If the upper steam ring is used before the lower steam-air tubes, the upper steam may "cap" the flare burner outlet resulting in flare instability and pulsation. This "cap" steam rate itself may not be at excessive steam rates compared to the flare gas flow rate but flame instability and pulsation may still occur.

G.3.12 Flares Without Smoke Suppression *(5.7.3.3)*

❖ Flare burners of this style shall include a flame-retention device (to increase flame stability at high flow rates) and one or more pilots (depending upon the diameter of the burner).

G.3.12.1 Introduction

The simplest flare burner design is commonly referred to as a utility or pipe flare burner and can consist of little more than a piece of pipe fitted with a flame retention device for flame stability at higher exit velocities (the upper portion is typically stainless steel to endure the high flame temperatures) and a pilot system for gas ignition.

G.3.12.2 Design Considerations

A utility flare burner is a plain design that has no special features to prevent smoke formation, and consequently should not be used in applications where smokeless operation is required, unless the gases being flared, such as methane or hydrogen, are not prone to smoking.

Flare burners of this style should include a flame-retention device (to increase flame stability at high flow rates) and one or more pilots (depending upon the diameter of the burner).

Windshields or heat shields are usually added on flare burners to reduce flame lick on the outside body of the burner.

An inner refractory lining is occasionally specified with larger diameter burners to minimize thermal degradation caused by internal burning at low rates (known as burnback).

G.3.13 Flaring of Gases with Low Heating Value *(5.7.3.4)*

❖ Gases with low heating value shall have low exit velocities to avoid creation of high excess air conditions that could over aerate a combustible mixture causing incomplete combustion and flame instability (see G.2.2)

G.3.13.1 Introduction

All the preceding descriptions for combustion methods have been for flare burners used in the disposal of exothermic flare gases; that is, gases that have sufficient heating value (usually greater than 7.5 MJ/m^3 (200 Btu/scf) for unassisted flares and 11.2 MJ/m^3 (300 Btu/scf) for assisted flares) for self-sustaining combustion without any fuel gas addition.

Flares gases with heating values below the threshold for self-sustaining combustion require fuel gas additions. Fuel gas assisted flares are generally referred to as endothermic flares.

G.3.13.2 Design Considerations

Endothermic gases can be disposed of in thermal incineration systems; however, there are situations where the preferred approach is to use a special flare design. These flares utilize auxiliary fuel gas to burn the flare gases.

With small gas flow rates, simple enrichment of the flare gases by adding fuel gas in the flare header to raise the net heating value of the mixture can be sufficient. In other situations, it can be necessary to add a fuel gas injection manifold around the flare burner (similar to an upper steam ring) and build a fire around the exit end of the flare burner through which it is necessary for the gases to flow.

Dilute ammonia or high CO_2 composition flare gases with small amounts of H_2S are common applications where the addition of fuel gas is required.

G.4 Flare System Design

G.4.1 Ground Flares *(5.7.4.1)*

G.4.1.1 Introduction

Ground flares encompass a broad range of vastly different types of flare systems. In general, any of the flare burners or systems discussed in G.3.1 through G.3.13 can be mounted atop an elevated stack or mounted at grade.

G.4.1.2 Design Considerations

With increasingly strict requirements regarding flame visibility, emissions, and noise, enclosed ground flares can offer the advantages of hiding flames, monitoring emissions, and lowering noise.

However, the initial cost often makes them undesirable for large releases when compared to elevated systems.

With an enclosed ground flare system, a variety of burners may be utilized and are enclosed or hidden behind a refractory-lined carbon steel shell.

A significant disadvantage with a ground flare is the potential accumulation of a vapor cloud in the event of a flare malfunction. As a result, special safety dispersion systems are usually included in the ground flare system. For this reason, instrumentation for monitoring and controlling ground flares is typically more stringent than for an elevated system.

These flares are typically the most expensive because of the size of the shell or fence and the additional instrumentation that can be required to monitor these key parameters.

Another significant limitation is that enclosed ground flares have significantly less capacity than elevated flares.

If emissions monitoring is not required, a fenced ground flare system can be designed with very large capacity. A radiation/wind fence can partially or totally hide the flames from view to a person located near grade. By restricting the amount of flame visible to a point of interest at grade level locations, it is possible to greatly reduce the external radiation load from the flare. Fenced ground flares frequently use multiple, high-pressure burners to obtain smokeless performance at firing rates that cannot normally be handled smokelessly by elevated flares.

A complete description of an enclosed ground flare can be found in this standard, Chapter 6. Options exist for bottom or side firing, staged or unstaged control, and steam-assisted, air-assisted, pressure-assisted, or non-assisted burners.

This type of flare system is often relatively complex and may involve many independent burner systems. Accounting for the various interactions between burners, fences, stack, smoke suppression equipment, piping, and wind/weather requires considerable experience and can involve detailed flow modelling before a workable design can be achieved.

G.4.2 Elevated Flares *(5.7.4.2)*

G.4.2.1 Introduction

The most common type of flare system currently in use is an elevated flare. In these systems the flare burner is mounted atop the stack, which reduces ground-level radiation and improves the toxicity-dispersion profile. There are three common stack support methods: self-supported, guy-wire supported, and derrick supported.

- Self-supported stacks are often used for shorter stacks with limited plot space. They are normally limited to a stack height 100 m (~330 ft). See Figure G.3 a).

— Guy-wire-supported stacks typically require larger land area than self-supported or derrick-supported stacks. Extreme process temperatures require special considerations when designing guy-wires. The typical guy-wire radius is equal to one-half the overall stack height. Guyed stack height is normally limited to a stack height of 250 m (~800 ft). See Figure G.3 b).

— Derrick-supported stacks are used only on larger stacks where self-supported design is not practical or available land area excludes a guy-wire design. Some derrick designs allow the flare stack and burner to be lowered to grade on movable trolleys for inspection and maintenance. This self-lowering design is especially useful when multiple stacks are installed on the same derrick. In locations where land is not available, the multi-flare derrick can be used. See Figure G.3 c).

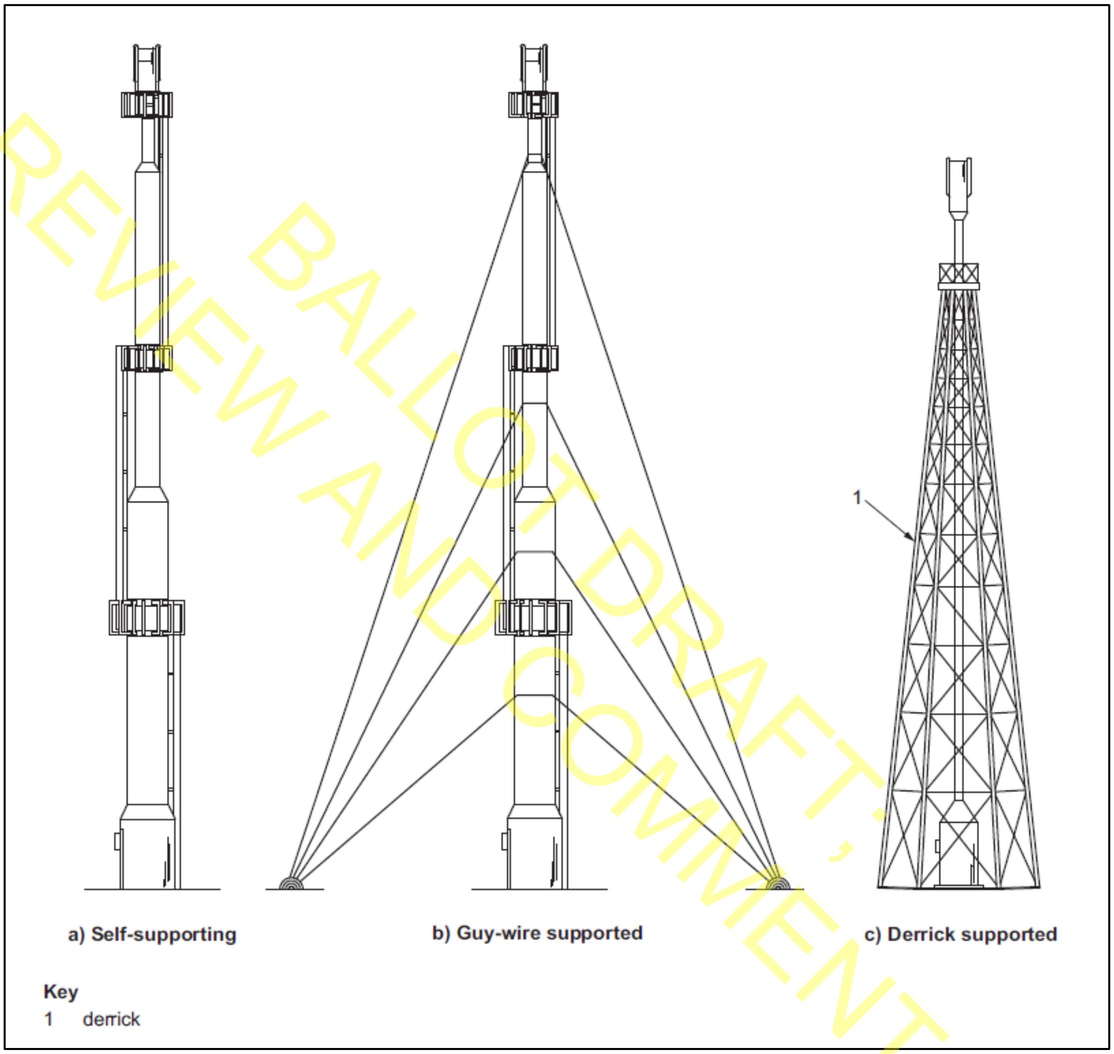


Figure G.3-Flare Structures

G.4.2.2 Design Considerations

None.

G.4.3 Unassisted Pipe Flares *(5.7.4.1)*

❖ The relief gas discharging from the flare burner shall occur within the hydraulic design for the flare system (within the allowable pressure drop and flame combustion velocity limits).

❖ It shall be ignited and burned with the designed flame characteristics

G.4.3.1 Introduction

An unassisted pipe flare is used where smokeless burning assist is not required. Pilots and a pilot ignition system provide flare flame ignition.

The pipe flare burner may have a mechanical device (e.g. flame retention ring) or other means of establishing and maintaining a stable flame. The ignition fire from the gas discharge is initially ignited by interaction with the pilot(s) flames. Once the pilot lights and the flame stabilize, the flare should maintain flame stability over the operating design range. Flame stability for a pipe flare is primarily dependent upon the selection of the gas exit velocity.

See Annex A.2.2 for additional information.

G.4.3.2 Design Considerations

The form of the flame produced by an unassisted pipe flare is a function of the relief gas composition and the gas exit velocity. At greater gas exit velocities, the flame uses the gas discharge energy to pull combustion air into the flame. It produces a shorter, more erect flame that has greater resistance to wind deflections. At lower gas exit velocities, air is drawn to the flame by the buoyancy of the heated products of combustion. A buoyant flame is typically softer, longer and more affected by wind than a flame that uses higher gas exit velocities.

Low gas exit velocities and buoyant flames are preferred for successful combustion of low heating value relief gas.

High gas exit velocities are preferred for higher heating value hydrocarbon relief gases or for relief gases rich in hydrogen. Because of the high flame velocity, wide flammability range, buoyancy effects and noise, hydrogen flares require special design considerations. The manufacturer should be consulted for details.

Flare combustion noise is influenced by gas exit velocity. Increased relief gas exit velocity can produce greater combustion turbulence and higher combustion noise. The highest combustion-noise levels are realized when a flare burner operates at gas exit velocities where combustion instabilities occur.

G.4.4 Burn Pits *(5.7.4.4)*

G.4.4.1 Introduction

Burn-pits normally require excavation or bermed areas to contain liquid hydrocarbons or other objectionable materials produced by incomplete combustion.

G.4.4.2 Design Considerations

Seepage from a poorly designed or maintained burn-pit can pose a threat to groundwater supplies.

G.5 Sizing

G.5.1 General *(5.7.5.1)*

- Flame retention devices may significantly restrict the available cross-sectional area for waste gas flow. Blockage due to flame retention devices shall be considered during flare sizing.

G.5.1.1 Introduction

Factors governing the sizing of flares are addressed in G.5.2 and G.5.3. General considerations involved in the calculation of these requirements are discussed in 5.7.1 through 5.7.4 of API Standard 521, Sixth Edition.

G.5.1.2 Design Considerations

Examples covering the full design of a flare stack are given in C.2, API Standard 521 Sixth Edition.

NOTE Flare diameter calculations are based on a basic flare.

Most commercial flare burners include flame retention devices that restrict the relief gas flow area by 2 % to 10 %. Flow area restrictions should be accounted for in the flare and header sizing.

G.5.2 Flare Stack Diameter *(5.7.5.2)*

❖ The user shall maintain proper purge rates, as provided by the manufacturer, to prevent burnback and burning inside the flare burner.

G.5.2.1 Introduction

The flare stack diameter is generally sized on a velocity basis, although pressure drop should be checked.

G.5.2.2 Design Considerations

A stack velocity (not flare burner velocity) of up to 0.5 Mach is typically allowed for a peak, short-term, infrequent flow for both low- and high-pressure flares. This depends on the following:

— volume ratio of maximum conceivable flare flow to anticipated average flare flow;

— probable timing, frequency, and duration of those flows;

— design criteria established for the project to stabilize flare burning.

Sonic velocity operation can be appropriate for high-pressure flare burners but not within the flare stack.

Smokeless flares should be sized for the conditions under which they are to operate smokelessly. Equation 32 or Equation 33 (section 5.5.5) in API Standard 521, Sixth Edition, can be used to calculate the Mach number.

Velocity limitations imposed by regulatory agencies [45] may not apply to flares in emergency relief service.

Pressure drops as large as 14 kPa (2 psi) have been satisfactorily used at the flare burner. Modern conventional flare burners with proper flame stabilization can operate well above this level.

Too low a flare burner exit velocity can cause heat and corrosion damage. The burning of the gases becomes quite slow, and the flame is greatly influenced by the wind. The low-pressure area on the downwind side of the stack can cause the burning gases to be drawn down along the stack for 3 m (10 ft) or more.

G.5.3 Flare Stack Height *(5.7.5.3)*

❖ **For flare radiation, a number of techniques are available to set the height of the flare against recommended radiation levels required. At least one of the techniques listed shall be used.**

G.5.3.1 Introduction

The flare stack height is generally based on the radiant-heat intensity generated by the flare flame.

A dispersion analysis <u>may</u> be used to aid calculating the required flare height in the event of a flare flame being extinguished. The user shall specify if required on the data sheet. See also API 521, 5.8.10.2.

G.5.3.2 Design Considerations

From the manufacturer obtain radiation isopleths for their best technology flare burner for a given flow rate, composition, temperature and pressure.

For radiant heat intensity Equation (45) in 5.7.2.3.3, API 521, Sixth Edition applies. The recommended levels of radiation intensity, K, are given in Table 12, API 521, Sixth Edition.

The quality of combustion affects the radiation characteristics. Use of the fraction of heat radiated, F, based on the U.S. Bureau of Mines data given in Table 13, API 521, Sixth Edition, is considered to result in a reasonable but conservative stack height.

Another factor to be considered is the effect of wind in tilting the flame, thus varying the distance from the center of the flame, which is considered to be the origin of the total radiant-heat release, with respect to the plant location under consideration. A generalized curve for approximating the effect of wind is given in Figure 7, API 521, Sixth Edition.

Where there is concern about the resulting atmospheric dispersion (both flammable and toxic) if the flare were to be extinguished, dispersion analyses (see 5.7.10.2, API 521, Sixth Edition) may be used to calculate the probable concentration at the point in question and required flare height.

G.5.4 Flare Burner Pressure Drop *(5.7.5.4)*

❖ The pressure-drop across the flare burner including accessories (e.g. seals) shall be included in the hydraulic assessments to ensure backpressure limitations are not exceeded

G.5.4.1 Introduction

The pressure-drop across the flare burner including accessories (e.g. seals) is needed in the hydraulic assessments to ensure backpressure limitations are not exceeded.

G.5.4.2 Design Considerations

The pressure drop across the flare burner will vary depending upon burner type, size selection, mass flow and fluid flow conditions properties.

Review of all operating cases should be done to ensure definition the design case related to system back pressure. The use of V_{eq} is a quick method to compare all operating cases to determine which ones may be controlling developed back pressure.

Higher pressure drops across the flare burner generally promote combustion performance (including smokeless performance) but increase the backpressure on the pressure -relief device. The flare burner manufacturer should be consulted flare burner hydraulic assessments.

G.6 Purging

G.6.1 General *(5.7.6.1)*

❖ For safety purposes, a pre-commissioning purge and subsequent continuous purge with a non-condensable oxygen-free gas is required through the flare system.

❖ Following the pre-commissioning purge a continuous purge of auxiliary gas shall be required unless the gas from the normal process vents can provide the required flow rate to keep the flare stack oxygen free.

❖ A continuous purge is not required, provided the following conditions are met.

- A liquid seal is provided at the base of the flare stack. This should include considerations of the effect of air on the liquid seal medium.
- The design of the stack includes suitable precautions against the consequences of a deflagration occurring.
- The stack design has design elements to prevent back flow of air into the stack during no purge operation or that a purge of the flare stack is included before for instance ignition sources such as pilots or direct ignition systems are activated.

- Buoyancy seals: The drain shall be kept open and protected from freezing in cold climates.
- Velocity seals: A hole shall be made in each baffle plate to permit drainage of possible liquids in order to avoid corrosion and/or freezing.
- See also this standard, Section 4.11.

G.6.1.1 Design Considerations

G.6.1.1.1 General

The pre-purge displaces any existing air from the stack and the continuous purge ensures that atmospheric air does not enter the stack through the flare burner during low-flow conditions. There should, then, be a continuous purge of auxiliary gas, which may be gas from normal process vents (provided that the required flow rate can be maintained).

The requirements for a continuous purge can be eliminated if a liquid seal is located near the base of the stack. This requires special precautions in the design of the stack to ensure viability in the event of an internal explosion. It also can allow air to infiltrate to the liquid seal, which, for some seal mediums, carries other requirements.

Air present in the stack can create a potentially explosive mixture with incoming flare gas during low-flare gas flow rate conditions.

There are two common types of purge-reduction devices, usually located at/or below the flare burner, that are used to reduce the amount of continuous purge gas required to prevent air infiltration into the flare stack: the buoyancy seal and the velocity seal.

G.6.1.1.2 Buoyancy Seal

The buoyancy seal uses the difference in the relative molecular masses of the purge gas and air to form a gravity seal that, at the proper purge gas flow, prevents the air from entering into the stack.

A baffled cylinder arrangement forces the incoming air through two 180° bends (one bend up and one bend down) before it can enter into the flare stack.

If the purge gas is lighter than air, the purge gas accumulates in the top of the seal and prevents the air from infiltrating the system.

If the purge gas is heavier than air, the purge gas accumulates in the bottom of the seal and prevents air from infiltrating.

This seal normally reduces the purge gas velocity required through the burner to 0.003 m/s (0.01 ft/s). Also, with most purge gas compositions, this rate limits oxygen levels below the device to less than 0.1 %.

Higher purge gas velocities can be required to avoid burnback within the flare burner.

The two 180° turns in a buoyancy seal can cause liquid collection in the seal (see Figure G.4) in which case a drain equipped with a loop seal (for example) is required. There is a potential for plugging of the buoyancy seal due to corrosion products, combustion products (coke), water freezing, or refractory debris from the refractory-lined flare burner resulting in an unsafe condition. The drain shall be kept open and protected from freezing in cold climates.

G.6.1.1.3 Velocity Seal

The velocity seal works under the premise that infiltrating air enters through the flare burner and hugs the inner wall of the flare burner.

The velocity seal is a cone-shaped obstruction, with single or multiple baffles, which forces the air away from the wall. It subsequently encounters the focused purge gas flow and is swept out of the burner.

This seal normally reduces the purge gas velocity through the burner to between 0.006 m/s to 0.012 m/s (0.02 ft/s and 0.04 ft/s), which keeps oxygen concentrations below the seal to 4 % to 8 % (~50 % of the limiting oxygen concentration required to create a flammable mixture).

Higher purge gas velocities can be required to avoid burnback within the flare burner. Caution should be exercised when the waste-gas stream can contain hydrogen, ethylene, or other gases with wide explosive limits. In such cases, a higher purge rate can be required to avoid an explosive mixture with air.

A hole should be made in each baffle plate to permit drainage of possible liquids in order to avoid corrosion and/or freezing.

Without either one of these seals, the purge gas velocity in the burner required to prevent air infiltration into the stack should be determined using the procedure described in 5.7.6.2, API 521, Sixth edition.

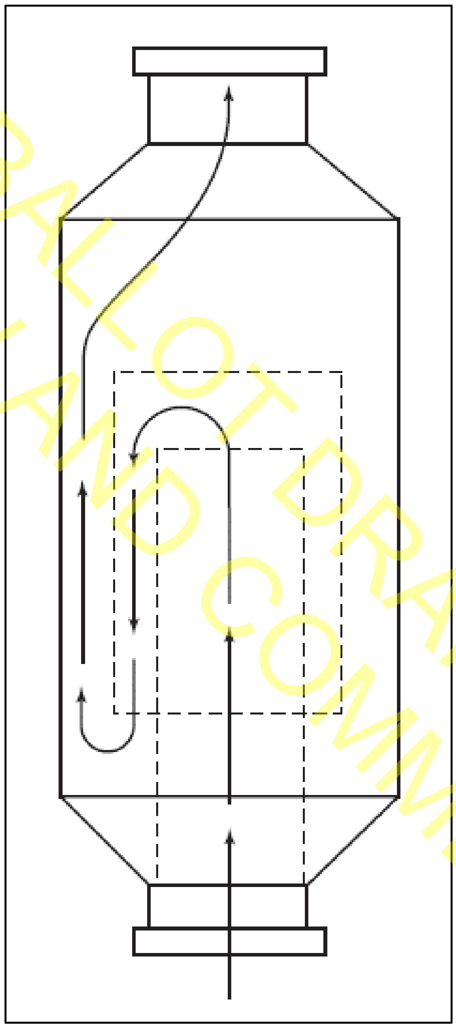


Figure G.4-Purge reduction Device – Buoyancy Seal

G.6.2 Air Infiltration/Continuous Purging Requirements for Stacks Without a Purge Reduction Seal *(5.7.6.2)*

❖ If purge gas is required, the user shall ensure the reliability of its supply.

G.6.2.1 Introduction

Air infiltration down the flare stack from wind or density effects can be mitigated by use of purge gas.

G.6.2.2 Design Considerations

If purge gas is required, the user shall ensure the reliability of its supply.

The amount of purge gas required can be reduced by the use of a purge-reduction seal (e.g. buoyancy seal or velocity seal; see G.6.1).

For lighter-than-air purge gases, Equation G.1 and Equation G.2 can be used to determine Q, the purge gas rate, expressed in normal m^3/h (standard ft^3/h) for continuous purge requirements in open flares without the effect of buoyancy seal or velocity seal [86] [87].

In SI units:

$$Q = 190.8 D^{3.46} \frac{1}{y} \ln\left(\frac{20.9}{O_2}\right)\left(\sum_{i}^{n} C_i^{0.65} \cdot K_i\right) \tag{G.1}$$

In USC units:

$$Q = 0.07068 D^{3.46} \frac{1}{y} \ln\left(\frac{20.9}{O_2}\right)\left(\sum_{i}^{n} C_i^{0.65} \cdot K_i\right)$$

G.2)

where

- D is the flare stack internal diameter, expressed in m (in.);
- y is the column depth at which the oxygen concentration (O_2) is predicted, expressed in meters (feet);
- O_2 is the oxygen volume fraction, expressed as a percentage;
- C_i is the volume fraction of component i, a number between 0 and 1;
- K_i is a constant for component i.

The following are typical values for K_i (independent of wind except where noted).

Hydrogen: $K = +5.783$.

Helium: $K = +5.078$.

Methane: $K = +2.328$.

Nitrogen: $K = +1.067$ (no wind).

Nitrogen: $K = +1.707$ [with a wind speed of approximately 7 m/s (15 mph)].

Ethane: $K = -1.067$.

Propane: $K = -2.651$.

CO_2: $K = -2.651$.

C_{4+}: $K = -6.586$.

NOTE 1 Steam or other condensables are not suitable purge gases.

NOTE 2 The reference temperature for standard conditions [15.6 °C (60 °F)] is not the same as the reference temperature for normal conditions [0 °C (32 °F)]. The conversion between standard and normal conditions has been incorporated when reporting the results in the different unit systems. The user is cautioned that the volumetric rates reported in the different unit systems might not appear to be equivalent because of this temperature conversion.

NOTE 3 It is possible to calculate a negative purge rate if the overall K value is negative. The minimum purge rate shall not be less than zero.

Equation G.1 and Equation G.2 can be simplified to Equation G.3 and Equation G.4 using the typical criteria of limiting the oxygen volume fraction to 6 % at a distance of 7.62 m (25 ft) down the flare stack (except that lower oxygen concentrations should be used for certain compounds such as hydrogen) and assuming a single component:

In SI units:

$$Q = 31.25 D^{3.46} \cdot K \tag{G.3}$$

In USC units:

$$Q = 0.0035283 D^{3.46} \cdot K \tag{G.4}$$

where

Q is the purge gas rate, expressed in normal m^3/h (standard ft^3/h);

D is the flare stack diameter, expressed in meters (inches);

K is a constant (see above).

Based on recent test data involving natural gas production facility flares [40], a significant reduction in purge rates as predicted by Equations G.1, G.2, G.3, and G.4 may be taken under certain constraints.

The user is cautioned not to extrapolate outside the bounds and conditions under which the tests were conducted. If the purge gas is heavier than air, then no significant positive buoyancy force exists. For this condition, the purge rate for nitrogen should be used [87].

If the gas in the stack (e.g. hydrogen or methane) is lighter than air, the pressure in the bottom of the stack can be lower than atmospheric, even with some outflow from the top of the stack. This condition creates a situation in which any flange leaks, open drains/vents or other openings in the flare header draws air into the flare header, resulting in potential for an internal explosion. For this reason, the users are cautioned to maintain the integrity of their equipment and follow proper safety precautions when opening an active header.

G.7 Ignition of Flare Gases

G.7.1 General *(5.7.7.1)*

G.7.1.1 Introduction

To ensure ignition of flare gases, continuous pilots with means for remote ignition shall be provided for all flares as per this standard, sections 4.7 and 4.8.

G.7.1.2 Design Considerations

Most regulations can require the presence of a continuous pilot flame to be proven by thermocouple or equivalent means.

The most commonly used type of igniter is the flame-front propagation type, which uses a spark from a remote location to ignite a flammable mixture.

Pilot-igniter controls are located near the base of elevated flares and at least 30 m (100 ft) from ground flares (see G.7.3).

G.7.2 Pilot Fuel Gas Supply *(5.7.7.2)*

G.7.2.1 Introduction

The fuel gas supply to the pilots and igniters should be highly reliable.

G.7.2.2 Design Considerations (see also 4.7 and 4.8)

Since normal plant fuel sources can be upset or lost, it is desirable to provide a backup system connected to the most reliable alternative fuel source, with a provision for automatic cut-in on low pressure.

- The use of a waste gas with low-energy content or with unusual burning characteristics should be avoided. Parallel instrumentation for pressure reduction is frequently justifiable.
- The flare fuel system should be carefully checked to ensure that hydrates cannot present a problem.

Because of small lines, long exposed runs, large vertical rises up, and the stack and pressure reductions, the use of a liquid knockout pot or scrubber after the last pressure reduction is frequently warranted.

If at all feasible in terms of distance and relative location, a low-pressure alarm should be installed on the fuel supply after the last regulator or control valve so that operators are warned of any loss of fuel to the pilots.

G.7.3 Pilot Monitoring *(5.7.7.3)*

G.7.3.1 Introduction

Several methods of pilot monitoring are available, including thermocouples installed within the pilot head; ionization monitoring within the pilot head; and remote acoustic, infrared, or optical monitors.

G.7.3.2 Design Considerations (see also 4.9)

Experience has shown that thermocouples can fail due to high-temperature exposure.

The user should base the pilot-monitoring system on relevant experience for the specific application.

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