SECTION 8.0

FLARES

This section provides readers with guidance and procedures for the proper operation and maintenance of flares. Flaring is a direct combustion control process that is used for the destruction of combustible gases, normally, volatile organic compounds (VOC). Typically flares are used to control emissions from intermittent sources or emergency relief vents; however, flares are receiving increasing use on continuous operating sources. Flares are capable of achieving high levels of VOC destruction (e.g., greater than 95 percent) if proper attention is paid to combustion process controls.

8.1 General Description

Flare systems are basically gaseous fuel burners designed to burn efficiently and smokeless. A gas flaring system converts combustible pollutants to nontoxic combustion products. Flare systems are broadly categorized in two ways: 1) enclosed ground flares, and 2) elevated flares. Elevated flares can be further subdivided according to the method of flaretip gas mixing (steam-, air-, non-, and pressure-assisted). Elevated flares mainly are designed to eliminate potential ground-level fire hazards. Ground level flares must be completely enclosed for obvious safety reasons.

Flares can present safety and operational problems. Some of the problems associated with operations of a flare system include:

- Thermal radiation: Heat given off to the surrounding area may be unacceptable.
- Light: Luminescence from the flame may be a nuisance if the plant is located in an urban area.
- Noise: Mixing at the flare tip is done by jet venturis which can cause excess noise levels in nearby neighborhoods.

- Smoke: Incomplete combustion can result in toxic or obnoxious emissions.
- Energy consumption: Flares waste energy in two ways: first, by keeping the pilot flame constantly lit and, secondly, by the potential recovery value of the waste gas being flared.

Enclosed Ground Flares--

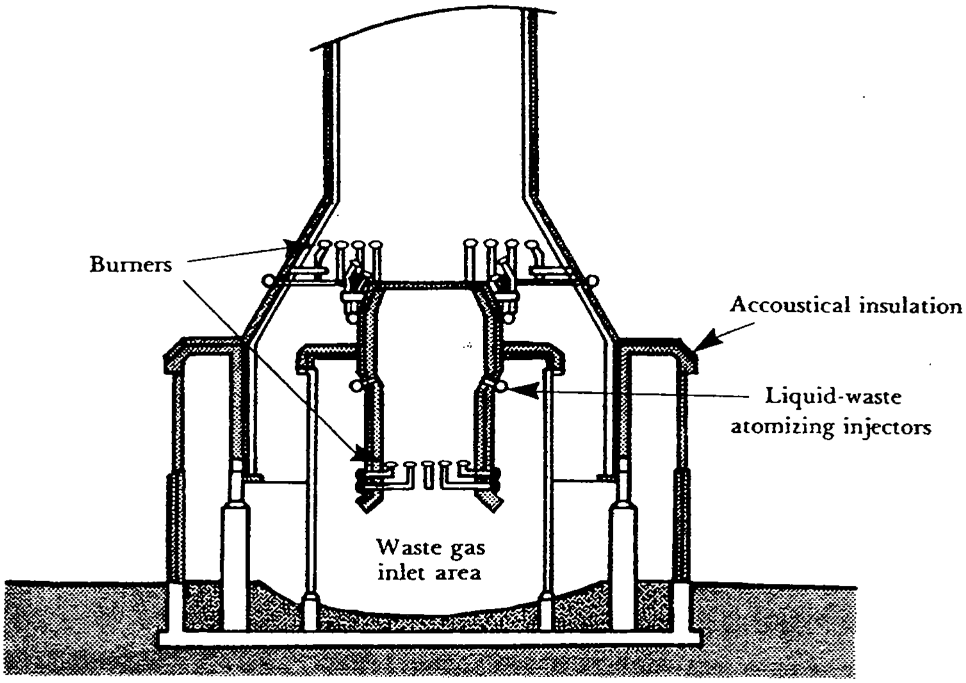
Ground level flares locate the flare tip and combustion zone at ground level. This type still requires an elevated stack for release of effluent gases.

In enclosed ground flare systems the burner heads are enclosed within a refractory shell that is internally insulated. Figure 8-1 illustrates a typical enclosed ground flare. The shell reduces noise, luminosity and heat radiation, and it provides protection from wind. Enclosed flares generally have less capacity than open flares and are normally used for low volume, constant flow vent streams. Reliable and efficient operations can be obtained over a wide range of inlet conditions. More stable combustion can be achieved with lower Btu content gases with enclosed flares than with open flare designs. Enclosed flares are typically found at landfills, and in industrial settings that are densely populated.

Elevated Systems--

A typical elevated flare is composed of a system which first collects the waste gases and passes them through a knockout drum to remove any liquids. Water seals or other safety devices are placed between the knockout drum and the flare stack to prevent a flashback of flames into the collection system. The flare stack is essentially a hollow pipe. The diameter of the flare stack determines the volume of waste gases that can be handled. At the top of the stack is the flare tip which is comprised of the burners and a system to mix the air and fuel.

In elevated systems, combustion takes place at the top of the discharge stack. The gases are vented through an elevated stack from a gas collection system. The flare is unconstricted and is subject to wind driven flame blowout. Elevating the flare can prevent potentially dangerous ground conditions especially where the open flame poses



Source: Straitz, 1980.

Figure 8-1. Ground flare.

a safety hazard. Further, products of combustion can be dispersed above working areas to reduce the effects of noise, smoke, odors, etc.

As with all combustion processes the VOC control efficiency is controlled by flame temperature, residence time in the combustion zone, and turbulent mixing of gaseous components. Combustion is complete if all (most) of the VOC are converted to carbon dioxide and water. Incomplete combustion results in unwanted by-products (e.g., smoke, CO, products of incomplete combustion-PICs) are generated. However, with proper design and good operation and maintenance, undesirable combustion products can be minimized.

The various flare designs differ primarily in their method of mixing. Elevated flares are the most common type used in industry.

Steam Assisted--

These units are the predominant design used in industry. They are mostly used in heavy industry. To ensure an adequate supply of air and good mixing this type of flare injects steam into the combustion zone. The steam promotes turbulence for mixing and induces air into the flare. These units are often designed to handle a turn down ratio of 1000:1 and have flow rates in excess of 30,000 m^3/hour and as low as 30 m^3/hour. Figure 8-2 shows a flare tip from a steam-assisted flare unit.

Air Assisted--

These units are common in facilities where steam may not be available. A forced air fan located at the base of the elevated stack is used to provide combustion air. Typically these flares are small because it is not economical to move large volumes of combustion air. The amount of combustion air is varied by changing fan speeds and, in some systems, by varying the diameter of the air nozzles.

Non-Assisted--

The non-assisted unit is a burner head without any provision for enhancing the mixing of air into the flame. These devices are restricted to low heat content and low carbon/hydrogen ratio gas streams that burn readily without forming smoke. These units

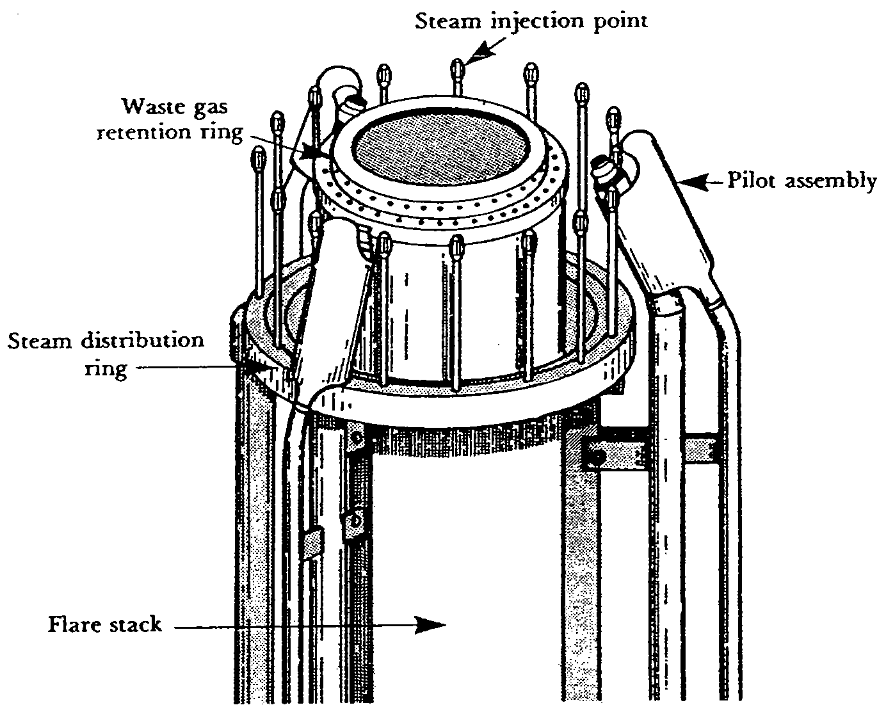


Figure 8-2. Steam-assisted flare tip.

require less air for complete combustion, have lower combustion temperatures and are less likely to cause cracking.

Pressure-Assisted Flares--

Pressure-assisted flares use a high pressure drop burner tip to enhance atomization and fuel-to-air mixing. These units typically have multiple burner heads that are often located at ground level. Each head is staged to operate according to a specific inlet gas volume and back pressure setting.

Auxiliary Equipment--

The major components of all flare systems are the relief, safety and depressurization valves, pressure control valves, condenser, water seals, stack, gas pilots, and the burner gas management system.

Process Description--

Figure 8-3 shows the basic elements of a steam-assisted elevated flare system. The vent stream is sent to the flare through the collection header. The vent stream entering the header can vary widely in volumetric flow rate, moisture content, VOC concentration, and heat value. The knock-out drum removes water or hydrocarbon droplets that could create problems in the flare combustion zone. Vent streams are also typically routed through a water seal before going to the flare. This presents possible flame flashbacks, caused when the vent stream flow rate to the flare is too low and the flame front pulls down into the stack.

Purge gas (N_2, CO_2, or natural gas) also helps to prevent flashback in the flare stack caused by low vent stream flow. The total volumetric flow to the flame must be carefully controlled to prevent low flow flashback problems and to avoid a detached flame (a space between the stack and flame with incomplete combustion) caused by an excessively high flow rate. A gas barrier or a stack seal is sometimes used just below the flare tip to impede the flow of air into the flare gas network.

The VOC stream enters at the base of the flame where it is heated by already burning fuel and pilot burners at the flare tip. Fuel flows into the combustion zone, where

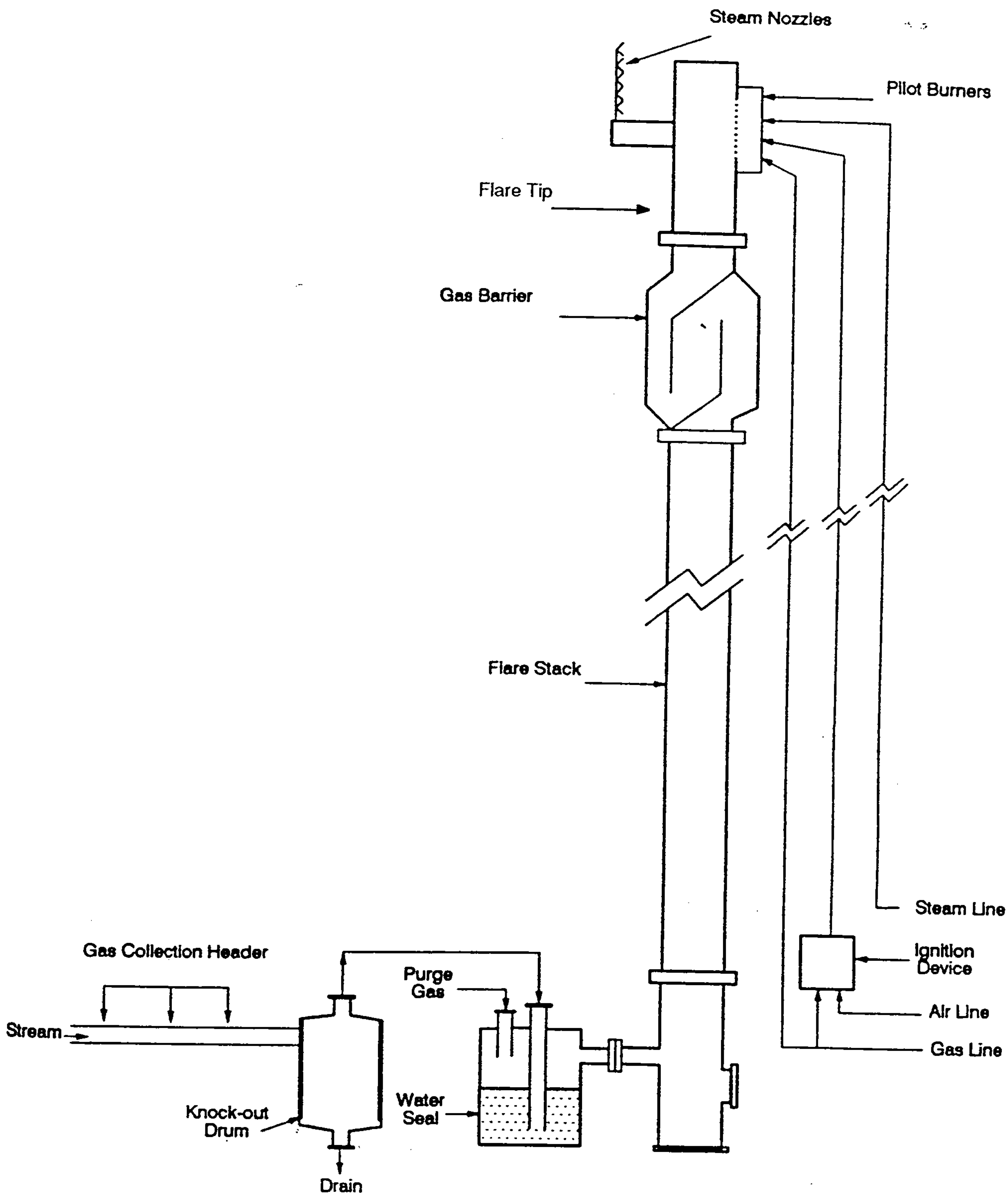


Figure 8-3. Steam assisted elevated flare system.[13]

the exterior of the microscopic gas pockets is oxidized. The rate of reaction is limited by the mixing of the fuel and oxygen from the air. If the gas pocket has sufficient oxygen and residence time in the flame zone, it can be completely burned. A diffusion flame receives its combustion oxygen by diffusion of air into the flame from the surrounding atmosphere. The high volume of flue gas flow in a flare requires more combustion air at a faster rate than simple gas diffusion can supply. Thus, this flare design adds high velocity steam injection nozzles to increase gas turbulence in the flame boundary zones, drawing in more combustion air and improving combustion efficiency. This steam injection promotes smokeless flare operation by minimizing the cracking reaction that forms soot.

Key Combustion Parameters--

The major factors affecting flare combustion efficiency are:

- Vent gas flammability
- Auto ignition temperature
- Gas heating value
- Gas density
- Flame zone mixing

The flammability limits of flared sources influence ignition stability and flare extinction. The flammability limits are stoichiometrically controlled by the gas composition and the oxygen demand (i.e., the gas must be between its upper and lower flammability limits in order to burn). When flammability limits are narrow, the flame may be starved for oxygen and cracking will occur. Cracking is the formation of soot, and if the soot is cooled below its ignition temperature smoking occurs.

The auto ignition temperature is the temperature at which the fuel/air mixture will flame. Flame stability is necessary to ensure that safe burning is occurring. Flame instability may occur when the gas discharge velocity exceeds the flame velocity or when the gas velocity falls below the burning velocity. Blow out occurs in the former condition and flash back occurs in the latter.

The heating value required to maintain endogenous conditions varies with burner design. Large flames require higher heating value fuel than would be required for combustion in a focused burner. The lowest heating value needed to sustain a flame is approximately 200 Btu/scf.

The density of the gas also affects the stability of the flame. Buoyant gases are easier to mix, have a rapid flame speed, and burn better. By design most flares have a low gas exit velocity. Thus, the gas density mix establishes the operating pressures and the purge gas required to prevent flash back.

Flame zone mixing plays a major role in combustion efficiency. Good mixing or high turbulence assumes that the fuel-to-air ratio is maintained in proper proportion and under conditions that prompt ignition and maintain combustion. The management of fuel-to-air ratios is accomplished by:

- underfeed - Raw fuel is under the flame, fuel and air flow same direction
- cross feed - Raw fuel is sprayed into the flame to maintain ignition
- vortex - Air is supplied to the flame from above the fuel
- overfeed - Air is mixed with the fuel near the flame

8.2 Monitoring Flare Operation

The key operating parameters to be monitored to assure proper gas flow through the system and appropriate conditions for thermal destruction of the combustible pollutants are:

- Flame presence
- Pressure and pressure differentials of system components (e.g., knockout drums, seals, fuel gas, steam, and blower)
- Temperatures at flare inlet and outlet and combustion zone
- Liquid levels in water seals and knockout drum
- Exit gas velocity

8.2.1 Monitoring Devices

Flame Presence--

Visual inspection is one method of determining whether a flame is present; however, if the flare is operating smokelessly, visual inspection would be difficult. An inexpensive heat sensing device, such as an ultra-violet beam sensor or a thermocouple, is recommended for use at the pilot light to indicate continuous presence of a flame.

Automatic ignition panels (e.g., electric arc ignition systems) sense the presence of a flame with either visual or thermal sensors and reignite the pilot light when flameouts occur.

Pressure--

The measurement of certain pressures and pressure differentials is needed for safe and efficient operations. Knockout drums, water seals, operating equipment and piping are designed for a specified system pressure. The maximum allowable working pressure is typically 10 percent higher than the normal operating pressure. For a flare control system, pressure indicating gauges should be monitored at least once per shift and located at:

- suction side of compressor or blower
- knockout drums (condenser) front and back
- fuel gas to pilots
- steam, air, and purge gas lines
- water seal (front and back)

Pressure measuring instruments take various forms depending on the magnitude of the pressure and the accuracy desired. Manometers that may contain a wide variety of fluids are commonly used. Differential diaphragm gauges using magnetic linkage are also available for low pressure systems. Pressure measuring devices should be located in positions that avoid errors caused by impacts, eddies, fluid hammers, etc. For differential pressure readings, it is preferable to use a differential pressure device rather than take the difference between the readings of two instruments.

The pressure level of flare system components depends on the type of pressure relief valve employed and the pressure levels of the equipment connected to the flare system. Over pressurizing flares cause a discharge of vapors and liquids, flame out, and/or a build up of back pressure. Excessive back pressure causes upstream process failure and unsafe conditions. The principal types of pressure relief valves are: conventional, balanced bellow, piston and pilot operated.

Conventional pressure relief valves are those where the disk of the valve is held tightly against an inlet nozzle by means of a spring. This type of valve is least expensive, but is limited to a back pressure that is 10 percent of the maximum allowable working pressure. The other types of pressure relief systems do not depend on back pressure for performance. However, to ensure that these safety devices work properly at their maximum capacity, the back pressure should not exceed 50 percent of the relief valve set pressure. Relieving excess pressure via the pressure relief valves should be kept to a minimum. These valves are not self-venting and will leak continuously once operated.

Special attention should be focused on maintaining the proper operating pressures at the water seal which is used to prevent flash back. Cooling of gases by the liquid seal will create a partial vacuum in the cooler disengagement portion of the seal drum creating a siphon effect which drains the water seal and creates an unsafe condition.

Temperature--

Heat exchange rates (where applicable), heat balance, partial pressures and destruction efficiencies are all controlled by temperature. Continuous temperature monitors (thermocouples) should be installed in the following locations.

- inlet stream to flare
- outlet stream from flare
- flame center
- pilot center

Liquid Levels--

Flame arrestors and water seals are intended to prevent fires, once started, from spreading throughout the flare system. Under normal operating conditions one of the most important conditions is the stability of the liquid seal. This seal affects the flash back protection and flame stability at low flow rates. Stability of the liquid seal is affected by the ratio of the inlet or outlet gas areas, dispersion of the gas into the seal liquid, temperature of the gas inlet stream and maintenance of the liquid level by means of alarms and control devices. There are two types of seals: pipe and drum. Pipe seals usually consist of a loop in the flare inlet line or a trap built into the face of the flare. Pipe seals provided limited space for removal of water or condensed hydrocarbons. Seal drums are larger, more expensive, and contain more liquid. Hence drums are generally less susceptible to pulsation and have a lower likelihood of the seal being blown by over pressurization. Liquid levels should be checked at least once per shift. In addition, high or low level alarms (as applicable) and level controls for the accumulating liquids (water and hydrocarbons) are necessary to prevent accumulation of flammable liquids (condensates) or to maintain the integrity of the liquid seals.

Exit Gas Velocity--

It is recommended that the exit gas velocity of the flared stream be determined by a flow indicator in the vent stream of the affected facility. This should be performed at a point closest to the flare and before the stream is joined with any other vent stream.

8.3 Inspection and Maintenance Procedures for Flares

8.3.1 Inspection

Flare systems are typically custom designed units consisting of common equipment. Because of the nature of the materials handled and the conditions under which components operate, the flare system is subject to corrosion, erosion, thermal stress, cracking, spalling and plugging. Most of the maintenance costs and problems, however, arise from instrumentation and process control devices. Daily, monthly and annual inspections are recommended.

On a daily basis, the auxiliary fuel, pressure seals, knockout drum, and monitoring and electrical devices should be physically inspected to verify that they are clean, functioning and calibrated. Pressure seals should be tight and intact. Gas jets should be free of corrosion and cleaned of deposits and blockages. Valves and electrical devices should be checked for proper position and condition. Such things as dirty contacts, moisture leaks, deteriorating insulation and plugged drains should all be repaired. Pressure gauges, thermometer and/or thermocouples and level indicators should all be inspected for physical integrity and calibrated as necessary. Figure 8-4 presents an example daily inspection form.

DAILY FLARE INSPECTION FORM		
Facility Name:	Date of Inspection:	
Facility Location:	Time of Inspection:	
Process:	Name of Inspector (Print):	
Flare ID:	Signature of Inspector:	
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS	
1) Temperature strip charts functioning properly? - inlet - outlet - combustion chamber		
2) Flame monitor		
3) Pressure gauges		
4) Positions of valves and dampers?		
5) Check liquid level indicators for signs of clogged drains. (knockout drum, water seals)		
6) Pressure seals		
Temperatures	Range	Current
Flare inlet	______ °F	______ °F
outlet	______ °F	______ °F
combustion chamber	______ °F	______ °F
Differential Pressures Knockout Drum ______ in. WG	Blower ______ in. WG	
Seal No. 1 ______ in. WG	Seal No. 2 ______ in. WG	Seal No. 3 ______ in. WG
Fuel Gas Pressure ______ in. WG	Steam Pressure ______ in. WG	
Exit Gas Velocity ______ ft/min	Opacity ______ %	

Figure 8-4. Example daily flare inspection form.

On a monthly basis moving parts such as fans and blowers, solenoids, check valves and dampers should be lubricated and cleaned of any foreign matter that may interfere with operation. Figure 8-5 presents an example form for monthly inspections.

Annually or during each equipment shut down, structural components including anchors, straps, foundations and guy wires, should be inspected for integrity. Refractory lining should be checked for cracks and spalling. The outer shell of the stack and flare system components should be checked for cracks and fatigue caused by over pressurization or temperature stress. Flares are typically utilized in harsh environments and corrosion/erosion problems should be carefully monitored and attended whenever found.

As always, inspection forms should be tailored to system specific components (e.g., electric arc ignition system) and operational and regulatory requirements. All maintenance activities and inspections should be recorded and studied for trends and variances from design and/or normal operating conditions. Figure 8-6 shows an example maintenance report form.

8.3.2 Routine Maintenance

Most of the problems that occur with flares have a direct impact on emission rates. Flares are not immune to physical problems caused by overloading. Excessive flow rates may cause explosions, uncontrolled fire, and ventilation of toxic or obnoxious gases. Hence routine maintenance to assure that safety devices are intact and that process controllers are functioning properly is critical. Fouling and plugging is the deposition of foreign material on the exterior and/or interior of nozzles, valves, monitors, controllers and burner heads. Cleaning of deposits is generally performed only during major shutdowns.

8.3.3 Spare Parts

Generally flares are moderate maintenance systems. A facility should maintain a ready supply of antifouling agents, gauges, valves, floats, and gasket material.

MONTHLY FLARE INSPECTION FORM	
Facility Name:	Date of Inspection:
Facility Location:	Time of Inspection:
Process:	Name of Inspector (Print):
Flare ID:	Signature of Inspector:
INSPECTION ITEM	COMMENTS/CORRECTIVE ACTIONS
1) Inspect, lubricate, and clean: - Fans and blowers - Solenoids - Check valves - Dampers	
2) Calibrate: - Temperature monitors - Pressure gauges - Level indicators	
3) System exterior observations (e.g., rust, connections, leaks) - Ducts - Knockout drum - Seals - Flare tip - Fuel line - Steam lines - Fan housing - Fan motor	

Figure 8-5. Example monthly flare inspection form.

MAINTENANCE REPORT FORM

Department	Unit	System	Subsystem	Component	Subcomponent

Originator: ______________ Date: ________ Time: ________

Assigned To:

1	Mechanical
2	Electrical
3	Instrumentation

Priority:

1	Emergency
2	Same Day
3	Routine

Unit Status:

1	Normal
2	Derated
3	Down

Problem Description: ______________________________

Foreman: ______________ Date: ________

Job Status:

1	Repairable
	Hold for:
2	Tools
3	Parts
4	Outage

Cause of Problem: ______________________________

Work Done: ______________________________

Supervisor: ______________ Completion Date: ________

Materials Used: ______________________________

Labor Requirements: ______________________________

Figure 8-6. Example maintenance report form.

8.4 Malfunctions

Operational failures and malfunctions include both equipment and personnel induced accidents. A brief discussion on problems associated with flares is provided in Table 8-1 to alert readers of issues that may cause safety problems and/or excessive emissions.

8.5 Operator Training

Similar to any piece of equipment, a flare will not receive proper maintenance without management's support and the willingness to provide its employees with proper training. Efficient operation of a flare, promoted by adequate inspection and maintenance procedures, is important. Management and employees must be cognizant of proper procedures necessary to prevent equipment malfunctions or failures.

System training should be received from the manufacturer when a new system is commissioned. The manufacturer's start-up services will generally include introductory training for facility operators and maintenance personnel. The field service engineer involved in startup procedures will instruct plant personnel in the methods to ensure proper assembly and operation of the system components and instrumentation and controls. Training should also include procedures to perform simple troubleshooting.

Following start-up training, regular courses should be held by in-house personnel or through the use of outside expertise. The set of manuals typically delivered as part of a new installation will include manufacturer-recommended maintenance procedures. Annual in-house training should at a minimum include a review of these documents and confirmation of the original parameters. Training should include written instructions and practical experience sessions on safety, inspection procedures, system monitoring equipment and procedures, routine maintenance procedures, and recordkeeping.

TABLE 8-1. MALFUNCTION MECHANISMS, SYMPTOMS AND CORRECTIONS

Mechanism	Symptom	Correction
Over pressurization	Relief valves open, compressor overheating, condenser out jet temperature low, condenser flooded, flame out, leaks	Set valves and dampers to correct position. Clean condensate removal system.
Cross and open connections	Back fire, soot/smoke, open valves, leaks, submerged pipes	Verify connection and valve position.
Burner fouling	Flame out, flame instability, soot/smoke	Clean burner tips more frequently.
Improper flame temperature	Soot/smoke, flame instability, flame color change	Adjust fuel/air mixtures ratio. Verify flame heat content.
Refractory failure	Cracks, spalling, crumbling, hot spots on shell, paint blisters	Ramp up to operating temperature. Properly limit peak temperatures. Limit heat/cool cycles. Protect from corrosion.
Self fueling	Increased temperature, maximum turn down, extended flame length, unusual noise	Purge with inert gas. Flood knockout drum.
Internal explosion/ flashback	Vibration, noise, vacuum in seal line, pulsation in knock out drum, relief valves open, metal incandescence	Water seals not maintained. Adjust fuel/air ratio. Increase refractory thickness. Erect wind shields. Increase exit velocity.
External burning	Flame flickering, extended flame front	Lower exit velocity.
Secondary fire	Submerged stack drain, large pilot gas consumption	Adjust condenser, adjust pilot.

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