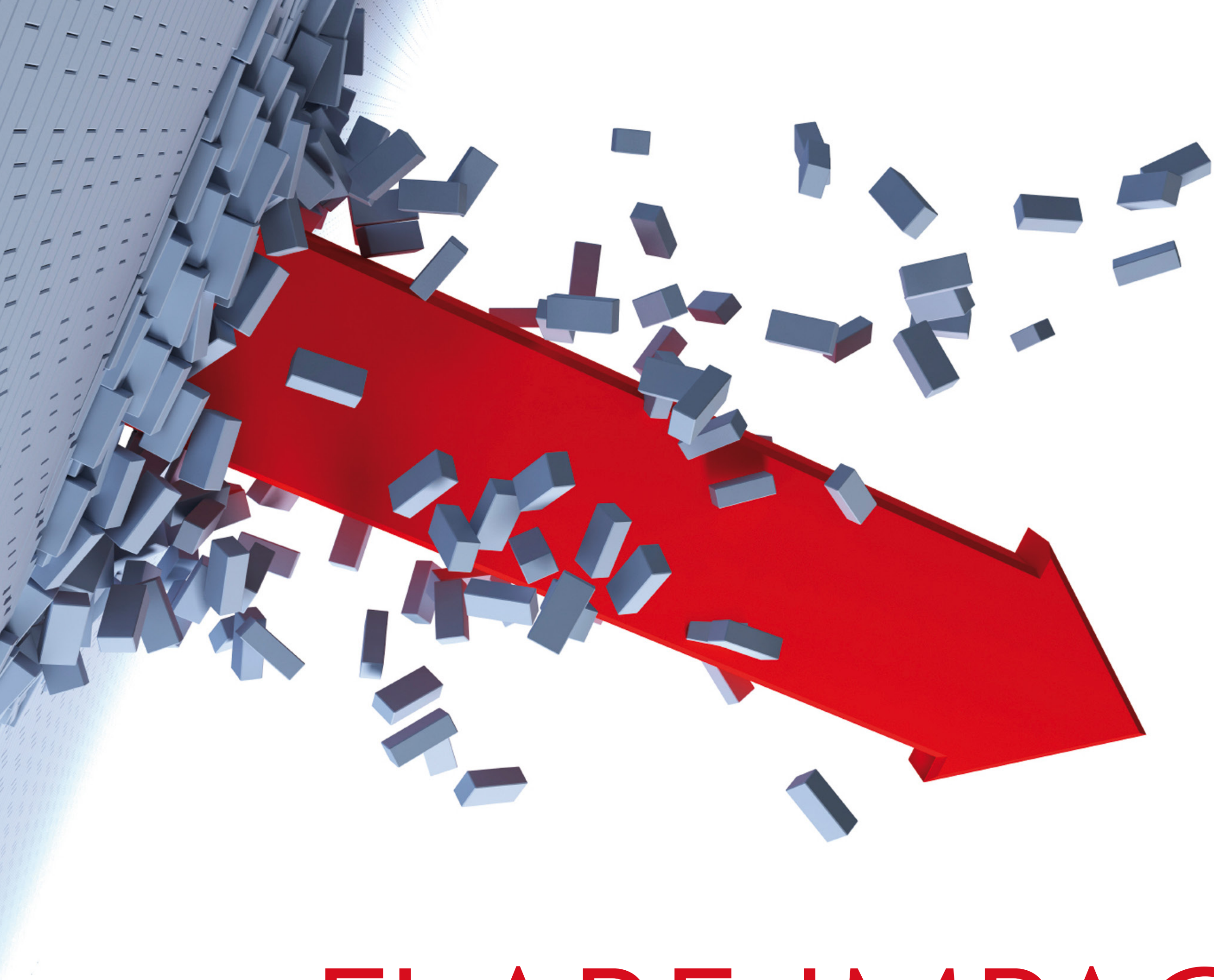

FLARE IMPACT MITIGATION

SCOT SMITH, NIGEL PALFREEMAN AND GREG SEEFELDT, ZEECO, USA, AND MAZEN MASHOUR, SAUDI ARAMCO, USA, DISCUSS WAYS IN WHICH TO MITIGATE THE IMPACT OF CONTINUOUS FLARING.

Flares are an important safety feature of most oil and gas producing and processing facilities, providing a safe and effective means for burning waste gases during a plant emergency. These emergency conditions often coincide with power outages, loss of steam, fire in the plant, or a variety of other scenarios. Flares are also used to safely burn any continuous relief cases that can result from ongoing processes, control valve leakage, purge, etc. In recent years, local governments, air quality agencies, environmental groups, and end users have pushed to reduce the amount of continuous flaring. These particular flaring cases are often viewed as wasteful, polluting, and potentially hazardous to humans. This article will elaborate on several different methods for reducing and/or mitigating the impact of continuous flaring as part of a flare impact mitigation plan (FIMP).

In a FIMP, one of the first steps should be to better understand the continuous flaring sources in a facility. This can be a challenging process, as the local operators may have a tendency to underestimate the amount of continuous flaring that occurs at a facility. A realistic estimate of the flaring must be obtained in order to determine the best and most economical course of action.

After collecting the data, each facility (or end user) should make their own determination of what flow rate is considered the normal, continuous rate and what flow rate is considered emergency flaring. This evaluation should take into account any regular or planned maintenance scenarios that occur on a frequent enough basis to be considered normal conditions. Location of the facility should also be evaluated. If the plant is located in a remote area, then flaring events may not affect local communities. A preferred solution in these particular cases is to upgrade the flare to ensure that the continuous rates operate without producing any visible smoke. If the facility is in close proximity to urban areas, it may be necessary to completely eliminate any continuous flaring due to public concern.

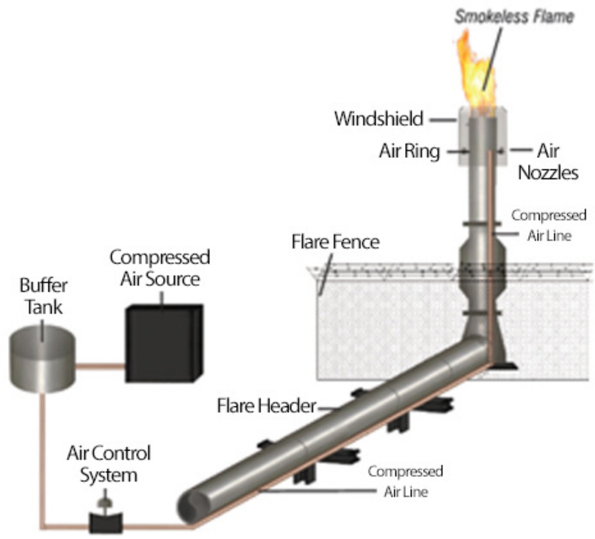

Figure 1. HPAAS system components.

Figure 2. HPAAS flare tip components.

After data and location are considered, continuous flow rates should be mitigated. The most common methods for flaring mitigation include improvements to the facility such as:

- Reducing flare header sweep rates.
- Installing purge reduction devices to reduce the continuous purge rate.
- Replacing leaking pressure safety valves (PSVs) and control valves that relieve to the flare header.

As there can be a large number of PSVs and control valves in a facility, upgrading these devices may not be an economical solution. In some cases, it may be more practical to leave the existing equipment in place and install a flare gas recovery unit (FGRU) to recover the flare gas.

After making all reasonable improvements to the facility, operators should review the new average continuous flaring rates to determine next steps. One end user in the Middle East region applied the following criteria as company procedure:

- At facilities with continuous flaring flow rates up to 1 million ft^3/d, apply a smokeless air assisted flare technology to reduce the visibility of flaring and reduce smoke production. An FGRU in these cases is not likely cost effective.
- At facilities with continuous flare flow rates greater than 1 million ft^3/d, an FGRU is considered cost effective and should be used.

Each end user or facility will need to perform their own evaluations to determine the appropriate breaking point between technologies.

Over the last 10 years, Saudi Aramco has been implementing its own FIMP. One of the first steps they took is eliminating the continuous smoke produced from the flares in some of their gas oil separation plants (GOSPs). In collaboration with Saudi Aramco, Zeeco upgraded these flare systems with a new smokeless flare technology called high pressure air assist system (HPAAS).

FIMP solution 1: HPAAS flare systems

The HPAAS system is a patented Saudi Aramco flare technology, licensed to Zeeco. The main components of a HPAAS system include a flare tip with supersonic air injection nozzles, an air supply line on the flare stack (normally 2 in. or 3 in. diameter), a flow control system, an air receiver tank, and an air compressor. As an alternative, in some cases the system can also be supplied with air from the existing plant instrument air header.

The HPAAS includes a utility flare tip with a large windshield. In the gap between the windshield and the flare tip barrel, a high pressure air injection manifold is mounted. The air manifold includes supersonic nozzles that are directed upward toward the combustion zone at the flare tip exit. Figure 2 shows the main components of a HPAAS flare tip.

Compressed air is supplied to the high pressure air line, which feeds supersonic nozzles that are located on the air manifold inside the flare tip windshield. These nozzles inject air upward into the combustion zone. The air supplied by the nozzles provides only a small portion of the air required for smokeless combustion. Most of the smokeless assist air is pulled in from the surrounding environment by the high velocity of the air nozzles. The path of air within the windshield space, air jet pattern, air momentum, windshield design, and nozzle orientation are all critical design features of the HPAAS tip. The air mixes with the combustion gas at the tip exit to produce smokeless flaring.

Key design advantages/concerns

Easy retrofit

The HPAAS flare tip easily bolts to the existing flare stack. The air supply line attaches to the flare stack with pipe support brackets. For most applications, this supply line is a 2 in. or 3 in. diameter pipe, which has a minor structural impact to the existing flare stack. Normal shutdown time for a full HPAAS flare upgrade is one week or less.

Robust design

The main air injection nozzles used in the HPAAS design are located several feet down from the top of the flare tip, outside of the high heat zone. This durable design produces a robust flare tip design that can continue operating for periods when the cooling air supply is lost.

Adaptability

Each HPAAS flare tip is provided with multiple connection ports for the supersonic nozzles. A variety of nozzles can be installed in these

Figure 3. Jobsite A before (left hand image) and after (right hand image) HPAAS upgrade.

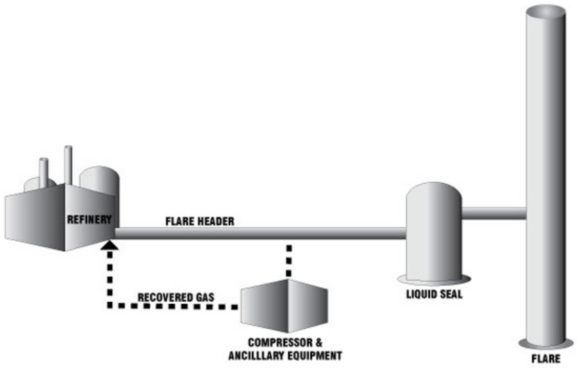

Figure 4. Typical FGRU arrangement in a refinery.

connection ports to provide different air flow rates, flow patterns, and exit velocities. This allows a significant number of modifications to a single flare tip in order to adjust to a wide variety of process conditions, even if they change after many years of operation. Changes to the nozzle design can be made during turnarounds without removing the flare tip from the stack.

Cost and delivery

When compared to the option of completely replacing an existing smoking flare with a new smokeless flare, the HPAAS design offers a significant cost and schedule advantage. Additionally, when compared to installing an FGRU system, the HPAAS system is also a much lower cost option and can be provided in a significantly shorter timeframe.

Field example

The flare at Jobsite A is located just over the hill from one of the major personnel compounds in this area of Saudi Arabia, which puts it in close proximity to a populated area. The original flare system produced considerable smoke on a daily basis, which was noticed by the surrounding personnel. Additionally, due to the short height of the flare system, it presented a possible hazard with smoke impacting driver visibility on a nearby highway. Figure 3 shows the system before the current HPAAS upgrade.

After replacing the flare tip with a HPAAS flare tip, the improvements were immediately noticeable. The new design provided a clean, smokeless flame that was virtually unnoticeable from the highway.

FIMP solution 2: Flare gas recovery

In cases where the user wants to completely eliminate continuous flaring, the flare gas recovery unit (FGRU) is the ideal solution. An FGRU is a useful means to reduce the amount of flaring, while still maintaining the proper safety and operations within a facility. Gases that are recovered by an FGRU can be used within the facility to offset fuel gas usage. This provides a net reduction in fuel gas usage as well as an environmental improvement by decreasing CO_2 and hydrocarbon emissions.

In a typical facility (without an FGRU), gases are constantly sent to the flare from a variety of sources. In a facility with an FGRU, the continuous operation bypasses the normal gas flow rates into the FGRU system where they are compressed and sent back into the plant (Figure 4). During these continuous conditions, the only gas being burned at the flare system is the standing pilots, as well as any combustible gas that the customer is using for the flare stack purge. If nitrogen is available, it can be used as a non-combustible purge gas to further reduce flaring. A specially designed liquid seal or staging valve ensures that the smaller, continuous relief cases can be sent to the FGRU, but during emergency reliefs, the gas can still be sent to the flare system for safe burning.

Main components of an FGRU system

Liquid seal or staging valve

In order to divert the gases from the flare stack to the FGRU, a liquid seal or staging valve (with a buckling pin bypass device) is normally required. These isolate the flare system from the flare header and divert normal flows to the FGRU. At times when the gas flow rate exceeds the capacity of the FGRU system, the device opens (the water seal is broken or the valve opens) to provide a safe relief path to the flare. The standard liquid seal design as described in API 521 will not work properly in a flare gas recovery application due to its intended 6 in. seal depth. Flare gas recovery applications require seal depths of 2 in. to 100 in. or more. An improperly designed liquid seal drum will result in excessive sloshing inside of the seal, which can cause surging at the flare, smoke signals, internal damage to the seal device, or even large liquid carryover at the flare.

Liquid seal devices provide several other benefits for the FGRU system. First, they allow the flare header to operate with some backpressure. This increases the efficiency of the flare gas recovery compressor(s). Secondly, they provide some protection against air pulling into the system (through the flare tip) during an operation malfunction of the compressor turndown system (the compressor systems are capable of pulling a vacuum on the flare header).

Compressors

These units compress the gas from lower pressures up to a higher pressure. The higher gas pressure allows the gases to be used elsewhere in the plant as pilot gas, assist gas, or for other purposes. For smaller FGRUs, this can be a single compressor, while for larger systems it can be multiple compressors operating in parallel.

Turndown and control system

Flare gas rates coming into an FGRU can vary over time. A proper turndown system must be provided to ensure that the suction pressure (i.e. the pressure in the flare header) remains at a relatively constant level. This turndown is normally handled by the monitoring and control system with logic in a local programmable logic controller (PLC) or in the plant distributed control system (DCS). A typical FGRU will include many different instruments that are continuously monitored in the control system. The control system makes constant adjustments to the different system settings to ensure that the FGRU is always operating within the ideal range.

Auxiliary equipment

A variety of auxiliary equipment can be supplied with a FGRU depending on the specific application, including:

- Suction scrubbers: Can be supplied to remove any liquids from the incoming flare gas.
- Coolers: Required for a variety of purposes including cooling of recycled service liquids for the compressors, interstage cooling of flare gases, and aftercooling of compressed gases. These are typically air cooled heat exchangers or shell and tube heat exchangers, depending on the jobsite location and the availability of cooling water.
- Separator systems: Normally provided downstream of liquid ring compressors and flooded screw compressors to separate working liquid from recovered flare gas.
- Pumps: Often supplied for moving oil in flooded screw compressor systems or for evacuating water or hydrocarbon condensate from separator vessels or liquid seal drums.
- Noise enclosures: Can be installed around compressors and/or motors to reduce the overall noise from the FGRU when low noise levels are needed.
- Vibration monitoring systems: Utilised to ensure reliable and safe operation of the rotating equipment.

Compressor technologies

Selection of the proper type of compressor is one key part of an FGRU design. There are several common types of compressor technologies and each is discussed below.

Liquid ring compressors

Liquid ring compressors are most common in FGRU applications. An impeller rotates inside the casing, pushing the service water to the outside of the casing. The shape of the housing produces an open space near the top and bottom of the impeller. Flare gas is injected from the inside of the impeller. As the impeller rotates, the gas is compressed as the open space reduces, and the gas is then discharged out of the compressor.

Dry screw compressors

A common type of compressor used in FGRUs, where a male and female rotor rotate inside of the compressor housing. The motor shaft drives the male rotor and a timing chain/gear drives the female rotor.

Flooded screw

These compressors are a similar concept to a dry screw, but there is no timing chain/gear to drive both screws. Instead, only the male rotor is connected to the drive motor and it turns the female rotor. Oil is used in the compressor housing to allow contact between the rotors without damage.

Reciprocating compressors

Can be used in FGRUs and use multiple crankshaft driven pistons to compress the flare gas.

Sliding vane compressors

Use a rotating hub with vanes or fins to help compress gases.

Design parameters of FGRU systems

Many factors are considered in the design of an FGRU system. An improperly designed FGRU is not only a hindrance to operators, but also impacts the safety of the facility due to its close interaction with the flare system. Below is a listing and brief description of the main system design parameters for an FGRU system:

System capacity

Proper sizing is critical. An undersized system will have frequent releases to the flare system, while an oversized system will be inefficient and unprofitable.

System suction and discharge pressure

The design of the liquid seal device and the piping design between the liquid seal and the compressor skid set the suction pressure. The processing requirements (for H_2S removal), delivery location, and final use for the recovered gas will set the necessary discharge pressure from the FGRU.

Flare gas composition

The usefulness of the gas in the plant is dependent on the composition of the gas, its heating value, its cleanliness, and H_2S content. Additionally, the range of flare gas compositions will impact the type of compressor that can be used, the compressor's performance, and the required materials of construction.

Gas temperatures

The expected range of gas temperatures coming into the system affects the compressor selection, the design/selection of oil for flooded screw compressors, the system shutdown points, and the design of heat exchangers.

Location of FGRU

The physical location of the FGRU and the available plot space influences the equipment selection, design, and placement.

Availability of utilities

The availability of low voltage and/or medium voltage power for the FGRU is an important consideration.

Number of flares connected to FGRU

It is common for multiple flare systems to be tied into the same FGRU system. This complicates the system design, layout, operating strategy, and control system. The proper isolation of flare headers from one another must be a consideration to ensure safe plant operation.

Payback period

Unlike smokeless flare improvements, FGRU projects do have the potential of becoming cash flow positive. To determine the payback period, the following items are typically evaluated:

- Expected normal flow rate of gas that will be recovered.
- Monetary value of recovered gas in the plant.
- Capital cost of the FGRU.
- Installation cost of the FGRU.
- Operating cost of the FGRU.

Required system turndown
Affects the compressor selection and the system design.

Required service life of equipment and frequency of shutdowns
Impacts the compressor selection, the amount of redundancy included, and the selection of materials and components.

Customer specifications and approved vendor lists (AVL)
Can directly affect system cost, materials, and the delivery schedule.

Extent of modularisation
Depending on the size of the units, FGRU systems can be supplied as individual pieces of equipment that are assembled together onsite, as multiple skids, or even as a single skid.

Figure 5. Zeeco FGRU system installed in a facility in the Middle East.

Figure 6. Destroyed flare stack as a result of flashback.

Design concerns: Flare gas recovery units
The concept of flare gas recovery seems simple, but this is a critical piece of equipment that is directly connected to the flare system. The flare and FGRU should be viewed as a single system that should be designed, supplied, and guaranteed by a single responsible supplier (Figure 5). While some compressor companies may try to package and sell FGRUs, these companies may have no knowledge of or experience with flare systems. This limits their ability to properly combine the FGRU and flare systems to ensure safe and seamless operation. Compressor companies also may have no experience designing liquid seal vessels and cannot offer equipment assistance. Below are some of the serious problems that can occur in an improperly designed FGRU system:

Manifolding of multiple flares to common FGRU
If not designed properly, this can result in backflow of flare gases from one flare system into another flare system. If the process conditions differ between flares, this can have dangerous results.

Air flow into flare system
If the compressor, recycle system, or liquid sea drum is improperly designed, it can result in air being pulled back into the flare header through the flare tip. This can produce an explosive mixture in the flare or flare header that can have disastrous results if there is a flashback, as shown in Figure 6.

Bypass device
Proper design of the liquid seal or staging valve/buckling in valve is necessary to help ensure safe and smooth transitioning from the FGRU to the flare during emergency relief flow rates. Zeeco has a proprietary liquid seal design for FGRU systems with an internal component design that has been developed based on experience. This design helps to avoid surging that can lead to unstable burning at the flare, and even equipment damage. Improperly designed seals can also result in liquid overflow at the flare system during emergency releases.

Conclusion
Flares play an important safety role at a facility, providing a safe and effective means for burning waste gases during emergency conditions. When continuous flaring is required, there is a preference for flaring to be mitigated or eliminated. The proper solution for this change should be determined as part of a flare impact mitigation plan (FIMP).

Two different types of solutions were chosen as a result of one end user's FIMP. The first was implementing HPAAS smokeless flare technology. The second was adding FGRU systems to some of the larger facilities. Both of these solutions provide an attractive method for reducing the negative impacts of flaring. The energy industry is continuing to move forward with more effective solutions, such as flare gas recovery and advanced flaring technologies. Implementing the best method for mitigating the impacts of continuous flaring requires adequate, accurate operational data, a clear understanding of normal operating conditions, and a flare technology provider with end to end system knowledge and experience.