High Pressure Air Assist System and Flare Gas Recovery Technology for Continuous Flare Management

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Introduction

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 emergency condition. 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 on-going 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 viewed as wasteful, polluting, and potentially hazardous to humans. This paper will discuss several different methods for reducing and/or mitigating the impact of continuous flaring as part of a Flare Impact Mitigation Plan (FIMP).

One of the first steps in any FIMP 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 takes place at a facility. A realistic estimate of the continuous flaring must be obtained in order to determine the best and most economical course of action.

Some facilities have flare gas thermal mass or ultrasonic-type flowmeters installed in the flare lines that measure and record flare gas flowrates on a continuous basis. Each type of flowmeter has a limited turndown capability, so it can be difficult to obtain accurate flowrate readings in large flare headers (36" and larger).The flowrate should be averaged over a period of several weeks or months to capture both emergency and continuous flaring conditions. The operation of the facility should also be evaluated to determine if there are any regular or planned maintenance scenarios that occur on a frequent enough basis to be considered normal conditions.

The data should be evaluated and each facility (or end user) should make their own determination of what flowrate is considered the normal, continuous rate and what flowrate is considered emergency flaring. Local regulations should also be considered, as they may only allow a certain number of hours of emergency flaring within a 24-hour period.

Another important consideration is the location of the facility. 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. However, if the facility is in close vicinity to urban areas, it may be necessary to completely eliminate any continuous flaring due to public concern.

After the data and location considerations are evaluated, the continuous flowrates should be mitigated. The most common methods for flaring mitigation include improvements to the facility consisting of the following:

- Reduce flare header sweep rates
- Install purge reduction devices to reduce continuous purge rate
- Replace leaking pressure safety valves (PSV) and control valves that relieve to the flare header

There could be a large number of PSV's and control valves in a facility, and 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) in the downstream piping that will recover these gases.

After making all reasonable improvements to the facility, it is important to review the new average continuous flaring rates to determine what method should be utilized as the next step. For one end user in the Middle East region, it was decided that as a company procedure the following criteria would be applied:

- At facilities with continuous flaring flowrates up to 1MMSCFD, apply a smokeless air-assisted flare technology to reduce the visibility of flaring and reduce smoke production. FGRU in these cases is likely not cost effective.
- At facilities with continuous flare flowrates greater than 1MMSCFD, a FGRU is likely 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.

In the last 10 years, Saudi Aramco has been implementing its own FIMP. One of the first steps they have taken is to eliminate the continuous smoke produced from the flares in their Gas Oil Separation Plants (GOSP) in the Southern Area. It was determined that the continuous flaring at these remote facilities was not enough to justify installation of a FGRU system, but elimination of the continuous flare smoke was needed. 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 a Zeeco Joint Venture company. 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” or 3” diameter), a flow control system, an air receiver tank, and an air-compressor [1,2]. As an alternative, in some cases the system can also be supplied with air from the existing plant instrument air header.

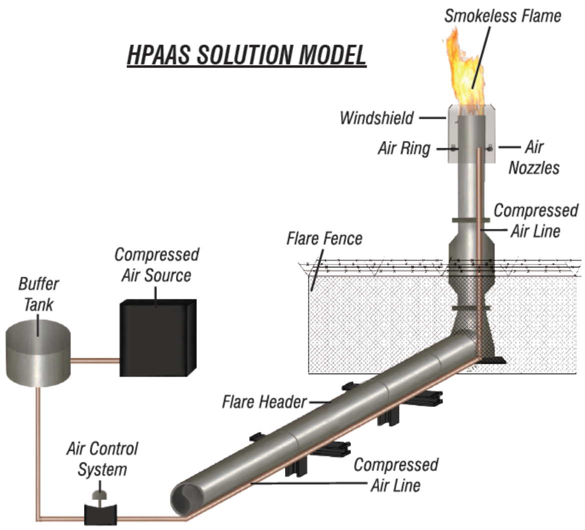

Figure 1. HPAAS System Components

The HPAAS flare tip includes a utility-type 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 below shows the main components of a HPAAS flare tip.

Figure 2. HPAAS Flare Tip Components

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 upwards 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.

Advantages of HPAAS

The key advantages of the Saudi Aramco HPAAS design are as follows:

Easy Retrofit- The HPAAS flare tip is easily bolted to the existing flare stack. The air supply line easily attaches to the flare stack with pipe support brackets. For most applications, this supply line is a 2" or 3" diameter pipe, which has a minor structural impact to the existing flare stack. Normal shutdown time for a full HPPAS flare upgrade is 1 weekor 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 even continue operation for periods of time when the cooling air supply is lost

Adaptable- Each HPAAS flare tip is provided with multiple connection ports for the supersonic nozzles. A variety of nozzles can be installed in these connection ports to provide different air flowrates, 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.

Low Cost and Fast 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.

The following section shows one of the jobsites where this HPAAS technology was successfully implemented [3].

Field Example

The flare at Jobsite C 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 noticeable by the surrounding personnel. Additionally, due to the short height of the flare system, it also presented a possible hazard with smoke impacting driver visibility on a nearby highway. **Figure 3** shows the system before the current HPAAS upgrade.

Figure 3. Jobsite C Without Smokeless HPAAS

In 2009, the flare tip at Jobsite C was replaced with a HPAAS flare tip. The improvements were noticed immediately. The new design provided a clean, smokeless flame that was virtually unnoticeable from the highway. Saudi Aramco personnel have been especially happy with the performance of this flare system given its highly visible location.

Figure 4. Jobsite C With HPAAS Upgrade

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 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 5)**. 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.

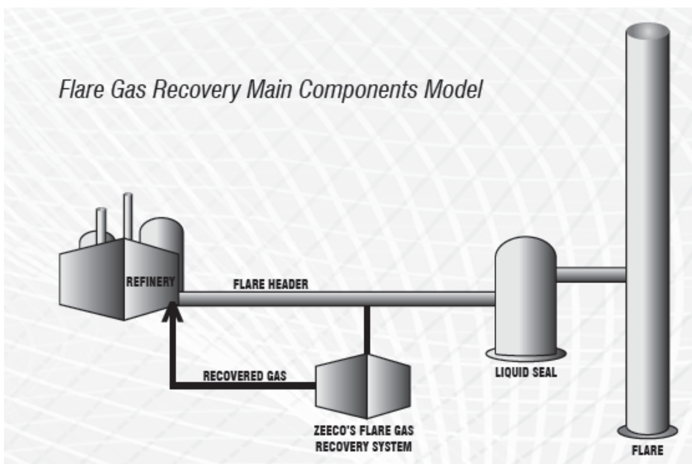

Figure 5. Typical FGRU Arrangement in a Refinery

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 flowrate 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. It should be noted that the standard liquid seal design described in API 521 will not work properly in a flare gas recovery application due to its intended 6" seal depth [4]. Flare gas recovery applications require seal depths of 24" to 100" 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).

Figure 6. Deep Liquid Seal Drums for an FGRU System

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 FGRU's, 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 PLC or in the plant 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. This can include the following:

- Suction scrubbers can be supplied to remove any liquids from the incoming flare gas.
- Coolers are 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.

Figure 7. Air-Cooled Heat Exchanger for an FGRU System

- Separator systems are normally provided downstream of liquid ring compressors and flooded screw compressors to separate working liquid from recovered flare gas.
- Pumps are 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 are often utilized to ensure reliable and safe operation of the rotating equipment.

Compressor Technologies

In this section, we will discuss the common types of compressor technologies, including the advantages and disadvantages of each. Selection of the proper type of compressor is a key part of the FGRU design.

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.

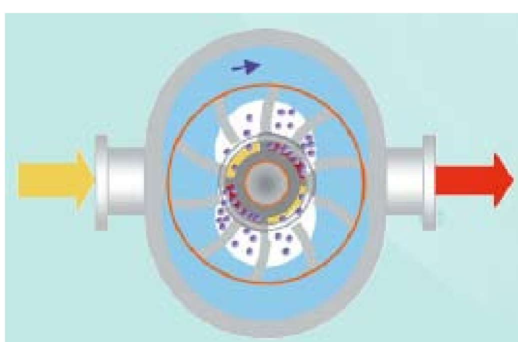

Figure 8. Typical Liquid Ring Compressor Operation

Advantages:

- Handles liquid slugs and dirty gases well
- Handles a wide range of gas temperatures and compositions
- Low-speed operation (900-1800 RPM), resulting in low noise and low vibration levels
- Proven technology in FGRU applications
- Manages dirty gases
- Easy access and maintenance of compressor when system is supplied with a back pullout bearing frame design compliant with API 681
- Low heat of compression— service liquid removes most of the heat

Disadvantages

- Typically limited to maximum discharge pressure of around 150psig
- Compressors operate at single speed, so turndown is achieved by staging compressors and/or using a recycle line.
- Requires water for operation.

Dry Screw Compressors: A common type of compressor used in FGRU's. in which 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.

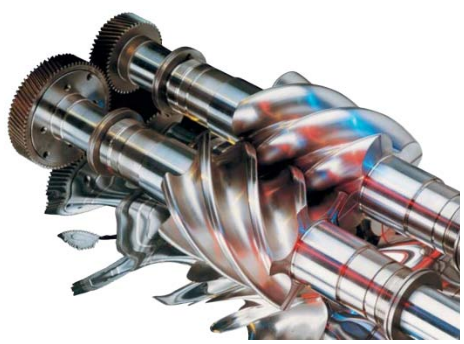

Figure 9. Typical Dry Screw Compressor Internal View

Advantages:

- No water required
- High discharge pressures available
- Multiple stages of compressors can be combined to achieve very high discharge pressures
- Handles some entrained liquid content in the flare gases
- Manages dirty gases
- Can be turned down to about 70-75% of maximum capacity with the VFD to conserve power usage
- Recycle line is used for additional turndown

Disadvantages:

- High-speed operation (7,000 to 9,000 RPM), resulting in higher noise and vibration levels than liquid ring compressors
- High heat of compression, resulting in the need for multiple stages of compression (with intercooling) to achieve high pressures
- High cost

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.

Figure 10. Typical Flooded Screw Compressor Internal View

Advantages:

- No water required
- High discharge pressures available
- Turndown is possible to about 20% capacity using an internal slide valve in the compressor

Disadvantages:

- Lubrication oil can be contaminated by flare gas.
- High cost for oil replacement.
- Water in the flare gas or condensation during compression can cause premature bearing or rotor failure.
- Medium-speed operating (3,000-5,000 RPM), resulting in higher noise and vibration levels than liquid ring compressors.

Reciprocating Compressors: Can be used in FGRU's and use multiple crankshaft driven pistons to compress the flare gas.

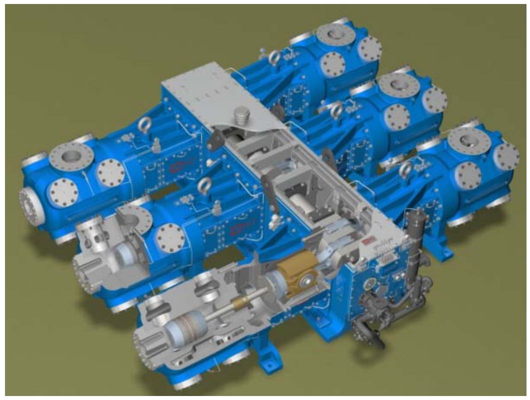

Figure 11. Typical Reciprocating Compressor

Advantages:

- High discharge pressures available
- High volumetric flow available

Disadvantages:

- Large size, noisy, and high vibration levels
- Frequent maintenance required
- Significant auxiliary equipment is required— includes interstage and discharge KO drums, interstage coolers, aftercoolers, and jacket water cooling
- High heat of compression

Sliding Vane Compressors: Use a rotating hub with vanes or fins to help compress gases.

Figure 12. Typical Sliding Vane Compressor Internal View

Advantages:

- Small plot space
- Low cost
- System turndown with a VFD

Disadvantages:

- Typically limited to maximum discharge pressure of around 150psig
- Material of construction of the compressor housing is cast/nodular iron and is not an acceptable material for some end users due to fire risk
- Small continuous oil usage
- Inability to meet demanding customer specifications or material requirements

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. However, 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 flowrate 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.

Access of Equipment for Maintenance: Important to the equipment layout and design.

Figure 13. Zeeco Flooded Screw Compressor Skid

Customer Specifications and Approved Vendor Lists (AVL): Can directly affect system cost, materials, and the delivery schedule.

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

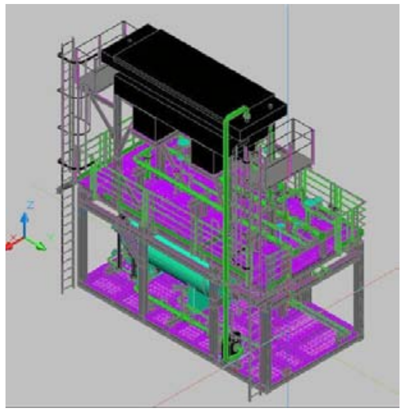

Figure 14. Zeeco Liquid Ring FGRU System

Required Delivery Date: Affects the system design and layout, as well as the compressor selection.

Project Budget: Can impact many of the choices made in equipment selection and design.

Special Design Considerations for the Middle East Region

The following design considerations should be evaluated:

Facility Type: FGRUs can be installed at a variety of facilities including refineries, chemical plants, gas plants, production platforms, etc. Each facility is different, and identical FGRUs cannot be used for all applications. An FGRU must be specifically designed for each application, using the proper technology that is tailored for that facility.

Availability and Processing of Water: Liquid seals and liquid ring compressors require water for proper operation. If water is not available or is very expensive, it can impact the choice of a compressor. Additionally, the water from a liquid seal overflow line must be processed in the facility, which is further complicated if there is H_2S or other contaminants in the gases. The selection of the heat exchanger type (shell and tube or air-cooled) is based on the availability of cooling water and ambient temperature.

High Ambient Temperatures: High ambient temperatures in the Middle East region can result in higher water evaporation rates in liquid seal vessels and liquid ring compressors, which impact the continuous water usage. It can also require the use of special motors, or motors that have been de-rated to be suitable for high temperatures. Instruments and controls have to be properly specified and designed to protect them from the heat and sunlight.

Sand Storms and High Sand Content: The sandy environment of the Middle East must be considered in the design and selection of components, since many compressors and pumps have close tolerances between parts.

Sour Flare Gases: High H_2S content is problematic at many facilities. This will cause contamination of oil and water, and will require the use of special materials of construction.

Warnings

The concept of flare gas recovery seems simple, but this is a critical piece of equipment that is directly connected to the flare. The flare system and FGRU should be viewed as a single system that should be designed, supplied, and guaranteed by a single responsible supplier. While some compressor companies may try to package and sell FGRU's, these companies have no knowledge or experience of flare systems. This limits their ability to properly combine the FGRU and flare systems to ensure safe and seamless operation. Compressor companies also have no experience designing liquid seal vessels and cannot offer equipment assistance. Below is a listing of just a few 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 seal 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 15**.

Figure 15. Destroyed Flare Stack as Result of Flashback

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 flowrates. Zeeco has a proprietary liquid seal design for FGRU systems with internal component design that has been developed over the years based on our experience. Our 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.

Zeeco Capabilities: Flares and FGRU Systems

Zeeco is a world leader in the design and supply of both FGRUs and flare systems. We have an experienced and knowledgeable staff that can help design and provide a system suited for almost any application. Zeeco has extensive experience with smokeless flare technology, and our company has a special focus on the Middle East Region including an office in Saudi Arabia. Zeeco can be consulted during any stage of a Flare Impact Mitigation Plan (FIMP) to help provide direction and guidance.

Zeeco can offer full support services during all stages of an FGRU project. During the feasibility study stage, we can send FGRU engineers to a facility to collect and analyze critical data from the facility to help determine the proper system design and sizing. Zeeco engineers will evaluate the system pricing, operating cost, and value of recovered gases, to determine the payback period. This information can be used by the facility to determine if a FGRU is economically feasible. Zeeco can then provide the detailed engineering design of the system before moving into the fabrication stage to build the complete engineered package. Our field specialists can provide support for operator training, equipment installation, pre-commissioning, commissioning, and startup of the completed FGRU system.

Figure 16. Zeeco Complete FGRU System

Conclusion

As discussed previously, flares play an important safety role at a facility, providing a safe and effective means for burning waste gases during emergency conditions. However, for continuous flaring conditions, 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 discussed as a result of an end user's FIMP. The first is upgrading their GOSP facilities with HPAAS smokeless flare technology. The second is 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. Zeeco is an experienced Flare and FGRU supplier, and can provide a variety of assistance for customers requiring economical and effective solutions.

References

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