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Ejector Technology for Efficient and Cost Effective Flare Gas Recovery

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ABSTRACT

Flare systems are a common sight in the GCC region at oil and gas production, processing, and refining facilities. They offer a safe and reliable method for burning gases during emergency release cases. While flares will always be needed for these emergency cases, the last decade has seen a stronger push to reduce flaring rates during normal, non-emergency conditions by adding Flare Gas Recovery (FGR) systems. The main goals are to increase efficiency of the facility and reduce air emissions. This paper discusses using ejectors for FGR systems. While ejector technology has been utilized for many years in other services, the concept of utilizing it for FGR is relatively new. A variety of compressor technologies have been utilized for FGR systems including Liquid Ring, Screw, Reciprocating, and Sliding Vane. Each type offers its own advantages and disadvantages; however, some common disadvantages shared by all of these compressor technologies include high operating costs, specialized maintenance requirements, and costly spare parts. Ejector systems are now being considered for many FGR applications as they offer distinct advantages in some applications, especially in smaller Gas-Oil Separation Plants in the GCC region. To compress flare gases to a higher pressure, ejectors utilize a high-pressure medium, commonly water, steam, or fuel gas. In some facilities, this high-pressure medium is already available with existing fuel gas supply or water pumps. This paper will explore the benefits of ejector technology for FGR in detail, including case studies of existing equipment.

Keywords: FGR, FGRU, Flare, Flare Gas Recovery, Ejectors, Eductors, Compressors

BACKGROUND

In recent years, some refinery owners and operators have recovered the gas in their flare networks in lieu of flaring. FGR offers real and tangible benefits:

- Recovered flare gas can be re-used in process heater burners and boiler burners
- Reduced amount of natural gas purchased by the facility
- Extended life of flare system
- Lower greenhouse emissions from facility

FGR also provides some intangible benefits. Reducing the amount of flaring overall reduces the visibility of the flare, improving public perceptions of the facility. This typically results in fewer complaint calls to the refinery from surrounding communities due to flaring.

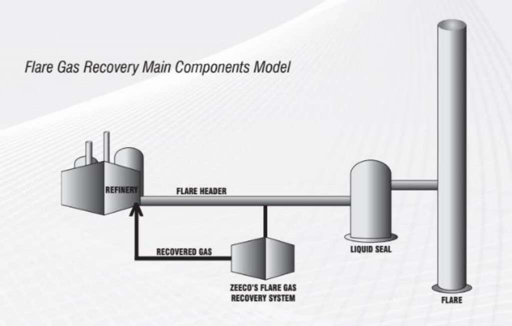

Figure 1. Typical FGR Arrangement in a Refinery

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MAIN COMPONENTS OF AN FGR SYSTEM

Liquid Seal or Staging Valve: In order to divert the gases from the flare stack to the FGR, 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 FGR. At times when the gas flowrate exceeds the capacity of the FGR system, the device opens (the water seal is broken or the valve opens) to provide a safe relief path to the flare. Liquid seal drums also provide some flashback protection of the flare system, since the flare tip provides an open source for air infiltration and the flare pilot provides an ignition source. It should be noted that the standard liquid seal design described in API 521 will not work properly in a FGR application due to its intended 6” seal depth [1]. FGR applications require seal depths of 24” to 100” or more, and improper design will result in surging.

Figure 2. Deep Liquid Seal Drum for FGR

Compressors or Ejectors: These units compress gas from lower to higher pressures. The higher gas pressure allows gases to be used elsewhere in the plant as pilot gas, burner fuel gas, or for other purposes. Smaller FGRs sometimes utilize a single compressor/ejector. However, larger systems may use multiple compressors/ejectors operating in parallel.

Turndown and Control System: Flare gas rates entering an FGR will vary over time. To ensure the suction pressure, or pressure in the flare header, remains constant, a proper control system must be utilized. The control system constantly adjusts the various system settings to ensure the FGR consistently operates within the ideal range.

Auxiliary Equipment: A variety of auxiliary equipment can be supplied with a FGR depending on the specific application. This can include the following:

- Suction scrubbers
- Coolers
- Separator systems
- Pumps
- Noise enclosures
- Vibration monitoring systems

DESIGN PARAMETERS OF FGR SYSTEMS

Many factors are considered in the design of an FGR system. An incorrectly designed FGR is not only an inconveniency to operators, but also impacts the safety of the facility due to its close interface with the flare system. Below is a listing of the main system design parameters for an FGR system:

- System Capacity
- System Suction and Discharge Pressure
- Flare Gas Composition and Temperature
- Location of FGR
- Availability of Utilities
- Number of Flares Connected to FGR
- Required System Turndown
- Required Service Life of Equipment and Frequency of Shutdowns
- Access of Equipment for Maintenance
- Customer Specifications and Approved Manufacturer Lists
- Extent of Modularization
- Available Plot space
- Required Delivery Date
- Project Budget

SPECIAL DESIGN CONSIDERATIONS FOR THE MIDDLE EAST REGION

Availability and Processing of Water: The selection of the heat exchanger type (shell and tube, air-cooled, etc.) is based on the availability of cooling water and the ambient temperature. To ensure proper operation, liquid seals, liquid ring compressors, and liquid ejectors require water. In addition to using water, these items also have some amount of water output that must be processed in the facility. The situation is further complicated if there is H_2S in the gases, resulting in sour water.

High Ambient Temperatures: The Middle East experiences higher water evaporation rates in FGR systems due to the region's hot ambient temperatures. These temperatures impact the need for continuous water usage and may require special motors, or motors that have been de-rated to adjust to the high temperatures. To protect FGRs from extensive heat and sunlight, instruments and controls have to be properly specified and designed.

Sand Storms and High Sand Content: In addition to temperatures, the Middle East's sandy environment must be considered in the design and selection of components. These factors must be taken into account because many compressors and pumps have close tolerances between parts.

Sour Flare Gases: Because many facilities experience problematic, high H_2S content, there are chances for contamination of oil and water, which requires the use of special construction materials.

EJECTORS

In recent years, there has been a larger push to utilize ejectors to recover flare gas. Ejectors are often called Eductors, Jet Compressors or Jet Pumps. In certain situations, ejectors may offer distinct advantages over traditional compression technologies. They have no moving parts in the compression zone, and can handle a wide range of process conditions. They also may offer significant cost savings.

Figure 3 shows the basic operating principle of ejectors. The operation is based on Bernoulli's principle, which states that as the speed of a flowing fluid is increased, it's pressure decreases. Conversely, as the velocity of a flowing fluid decreases, its pressure must increase. In an ejector the velocity of the motive (or HP) fluid increases as it passes through the nozzle, creating a low-pressure region within the ejector. This region entrains the low pressure flare gas stream. As the combined HP and LP streams pass through the ejector's diffuser section, the velocity decreases and the pressure is regained, resulting in an intermediate pressure, which lies somewhere between the LP and HP. The HP stream needs to be at a high enough pressure to ensure the resulting intermediate pressure achieves the required system discharge pressure for the recovered flare gas. If high-pressure water or steam is used, a separator is required downstream of the ejector to separate gas from water. If high-pressure gas is used, there is no need for any downstream separator.

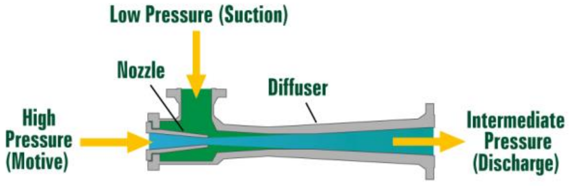

Figure 3. Ejector

<u>Advantages:</u>

- Low cost
- Simple construction and installation
- No moving parts in the compression zone
- Up to 150:1 compression ratio achieved without staging
- Ability to handle both solids (such as sand), liquid slugs, and sour gases
- Ability to handle wide range of process conditions
- Low maintenance
- Can be performance tested at shop
- 0 to 100% flare gas turndown
- Small plot space (See Figure 4)

Figure 4. Installed Ejector

Disadvantages:

- Low volumetric efficiency compared to some compression technologies.
- High motive fluid flowrate
- High motive pressure required

OTHER TECHNOLOGIES

Other compression technologies available include:

- Liquid Ring Compressors
- Dry Screw Compressors
- Flooded Screw Compressors
- Reciprocating Compressors
- Sliding Vane Compressors

COMPARISON OF LIQUID EJECTOR TO LIQUID RING COMPRESSOR:

In this section, we will compare liquid ejectors to liquid ring compressors (the most common type of compressor for FGR applications). We are considering a typical application with a recovered gas flowrate of about 2200m$^{3/}$hr at 7.5 bar discharge pressure. That is sufficient pressure to push the recovered gas through an Amine system to remove any H2S, allowing it to be injected back into the facility fuel gas system as sweet gas. Table 1 compares the space, power, and capital cost requirements for the overall FGR package with each technology.

Technology	Plot Space	Required System Power	System Capital Cost
Liquid Ejector	18m X 20m	600KW	$3.5MM USD
Liquid Ring Compressor	18m X 27m	600KW	$4.0MM USD

Table 1. Comparison of Ejector and Liquid Ring Compressor FGR Package

WARNINGS

Although the concept of FGR appears simple, it is a critical package directly connected to the flare and the two should be viewed as a single system. The flare system and FGR should also be designed, supplied, and guaranteed by a single responsible supplier. While some compressor vendors may try to package and sell FGRs, they lack crucial knowledge and experience acquired when working with flare systems. The improper design of a compressor, recycle system, or liquid seal drum may 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, resulting in a flashback and equipment damage, as shown in Figure 5.

Figure 5. Destroyed Flare Stack as Result of Flashback

DETAILED EJECTOR TECHNICAL DISCUSSIONS

While ejectors can be used in a variety of applications, ejectors may be the optimum solution for FGR in some circumstances, including:

- Existence of “free” motive fluid at the facility: Ejectors require motive fluid at a much higher pressure than the desired recovery pressure. This is often provided by a liquid pump or high-pressure gas. While the motive flowrate is relatively high some facilities have spare capacity in their existing fuel or pumps that can provide this.
- If water is used as the motive fluid, it is necessary to separate it from the recovered gas. Some locations such as Gas Oil Separation Plants have large 3-phase separators on site already. If the capacity is large enough in these separators, it may be possible to route the discharge line from the ejector to this separator, eliminating the need for a dedicated separator for the FGR.

FLOWRATES AND STAGING

A very important consideration in ejector design is the ratio of the motive fluid pressure to the required discharge pressure. The larger this ratio, (i.e., the higher the motive fluid pressure) the smaller the motive flowrate can be. When the pressure of the motive fluid is closer to the required discharge pressure, the motive flowrate becomes much higher. It is typically preferred to have a motive pressure at least 5-10 times larger than the required discharge pressure. Ejectors employed on Flare Gas Recovery applications fall into one of two categories, depending upon the motive fluid which is used to drive them: gas ejectors and liquid ejectors.

Gas Ejectors: For gas motivated ejectors, the following potential sources are commonly used for the high pressure motive gas: gas routed from a production separator, fuel gas, nitrogen, or a small sidestream from a gas lift or gas injection compressor discharge. Gas ejectors tend to be very simple systems that require little ancillary equipment, since the discharged fluid is in all gas form and thus a separator is not required. However, the discharged fluid is typically a very high flow rate (since it includes both motive fluid and recovered flare gas). Thus, the downstream facilities must be able to handle this high flow rate.

Single stage Transvac Gas Ejectors can achieve up to 8:1 compression ratio (absolute discharge pressure divided by absolute suction pressure of flare gas) in a single stage. Typically, ejectors from other suppliers are limited to about 4.5:1. Higher pressures of up to 40:1 compression ratio can be achieved with staging. In a gas ejector the amount of motive gas required depends upon the amount of flare gas to be handled, the amount of compression required and the available pressure of the motive gas. The bigger the difference between the motive gas pressure and the ejector discharge pressure and the smaller the required compression, then the smaller will be the amount of motive gas required. In general, gas ejectors require motive flowrates somewhere in the range of 2-8kg of motive gas for every kg of flare gas compressed.

Liquid Ejectors: For liquid motivated ejectors, the motive fluid is typically provided by spare capacity or sidestream from an existing water pump or from a dedicated water pump. Single stage Liquid Ejectors have been designed and tested to achieve compressions of up to 150 bar, which would be a suitable pressure for gas reinjection. However, for most standard FGR applications the maximum compression requirement is only around 10 bar. Liquid ejectors tend to be more complicated systems since the discharged fluid is a mixture of liquid motive fluid and recovered flare gas that must be separated as can be seen in Figure 6. However, the main advantage is that the higher flow rate motive fluid can be separated out and recycled. This results in a net system discharge of only the recovered gas, which is typically easier for the downstream facilities to handle. Liquid ejectors normally require around 0.03 to 0.10 m^3 of motive liquid for every m^3 of flare gas compressed.

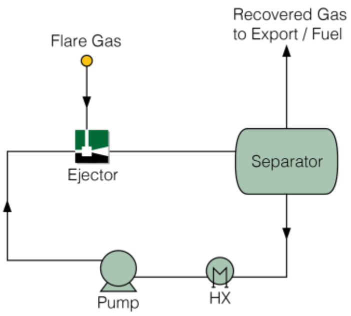

Figure 6. Liquid Ejector System

CONFIGURATION AND CONTROL

Multi-Ejector Solutions: Where high turndown is expected on the LP (flare gas) flow rate, ejectors can be placed in parallel to spread the duty demand to one or both units, thereby allowing motive fluid to be saved. This is important in some applications, particularly where HP fluid usage has an associated cost. See Figure 7.

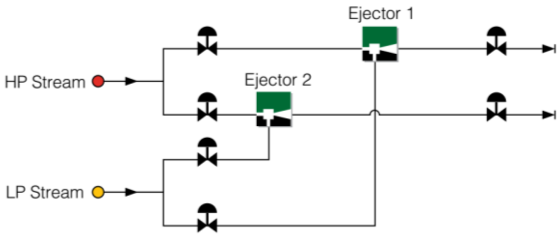

Figure 7. Multi Ejector Solution

Control: Different techniques are employed to control turndown of ejectors in FGR applications, including controlling the flow of motive liquid, recycling discharge gases, bypassing motive gas on the suction line, and throttling motive fluid pressure. The proper control method must be determined on a case-by-case basis after evaluating the specific parameters of each project.

SPECIAL CONSIDERATIONS FOR EJECTOR TECHNOLOGY DESIGN

Sour Service: The benefits of using ejector technology for sour gas applications are significant. For sour gas applications, ejectors are available in most standard materials, including carbon steel and stainless steel, and also in more exotic materials such as alloy 625, duplex or super duplex. In some cases, there may be concern with production (and disposal) of sour water when using liquid ejectors in H_2S service. Most of the water is recycled. However, over time, the water can become too sour, requiring disposal. If the facility has issues with processing this water, an alternate solution can be to utilize amine as the motive fluid instead of water. This eliminates the need for sour water disposal and provides an integral method for removing H_2S from the recovered gas.

Noise: Gas ejectors can generate significant noise in some instances, due to the high flowrates and high pressure drops. This can be reduced to normal noise limits (~80dba at 1m) by acoustically cladding the ejectors and installing inline silencers. Liquid ejectors generally have lower noise levels and do not require insulation or silencers.

Universal Design Ejectors: Transvac's patented Universal Design Ejector technology offers the end-user the opportunity to change the performance of an ejector by replacing its internals without changing the Ejector body. Universal design internals allow standardization of ejector bodies while providing customized application-specific internals. The patented design comprises an external pressure retaining shell holding two replaceable components that give the ejector its operating characteristics. These two components are called the nozzle and the diffuser (See Figure 8) and they can be easily changed out to optimize the operating characteristics of the ejector.

Estimating required system capacities can be difficult, with that challenge compounded by changing process conditions over time. With the Universal Design approach, the internals can be replaced at any future date to better suit the new conditions and maintain peak system efficiency. Another advantage of this approach is if process conditions are not completely finalized at the start of a project, the main pressure components of the ejector can still be manufactured. Near the end of the manufacturing phase when the process conditions are finalized, the nozzle and diffuser can be manufactured to spec, giving project schedules a little breathing room. For systems in the field, the internals can typically be installed in one day, keeping FGR shutdown time to a minimum.

Figure 8. Universal Design Diffuser and Nozzle

Research and Development: As ejectors become a more viable technology for FGR applications, additional effort and resources have been committed to improving and developing the technology. Transvac leads these efforts at their Research and Development Center located in the United Kingdom, (See Figure 9) performing full-scale testing of ejectors under a variety of conditions including motive pressures up to 310 bar. The results of this R&D work have been significant, with efficiency being improved by up to 30% in just the last 12 months.

Figure 9. Transvac Ejector R&D Center

CASE STUDY – GAS MOTIVATED EJECTOR FGR SYSTEM

User: Offshore Platform – North Sea

Date of Supply: 2014

Application

The customer wanted to reduce overall emissions by recovering gases from the flare system, the reject separator, and produced water flash tank. Recovered gas would be boosted to 13 barg and utilized in the facility.

Basis for Selecting Ejector Technology

During the project FEED stage, various forms of gas compression technologies were considered. However, gas ejector technology was selected for the following reasons:

1. Lift-gas at the injection pressure was available and could be used as the ejector motive fluid to perform the compression duty.
2. The ejector system could be configured to effectively entrain and compress suction gases from various sources at different pressures.
3. The ejectors and associated pipework could be constructed from suitable corrosion resistant materials (Super Duplex).
4. The ejector solution would be compact and relatively light-weight.
5. The system would be reliable, simple to operate, and would require no maintenance.
6. The system would be low noise, staying below 80 dB(A) at 1m.

Operating Conditions

The application required gases to be compressed to 13 barg from various sources at different pressures. These included the following:

- Produced Water Flash Tank: 1.0 barg
- Flare Knock-out Drum: 0.15 barg
- Produced Water Reject Separator: 3.5 barg

The Design Flow for the complete system was 500 kg/h with varying flowrates from the different sources.

Mechanical Design

In addition to applying the standard ASME B31.3 piping code, the client's specific Piping Standards and Pressure Equipment Directive (PED) were also applied. Design conditions for the package are shown below.

- Design Pressure: Full Vacuum to 345 barg
- Design Temperature: -46C to 120C
- Connections: ASME B16.5 2500# RTJWN

NACE MR0175 standards were applied for sour service, and the customer required that NORSOK be applied and the gas/liquid contacting materials be supplied in 25 Cr Duplex Stainless Steel (Super Duplex). Figure 10 illustrates a completed skid package.

Figure 10. Completed Ejector Skid

Design Considerations

A Transvac Two Stage Ejector solution was selected to reach the 13barg discharge pressure. The client wished to minimize the quantity of lift-gas to be used as the motive fluid for the ejectors. After an assessment of the maximum, normal, and minimum flows from each suction gas source, it was determined that using a 30% / 70% split flow ejector configuration gave the most flexibility while minimizing the required motive gas flow. With this solution, the client could operate the system for the majority of the time using the 70% two stage ejector set and only use the 30% two stage ejector set during periods of high suction flow. See Figure 11.

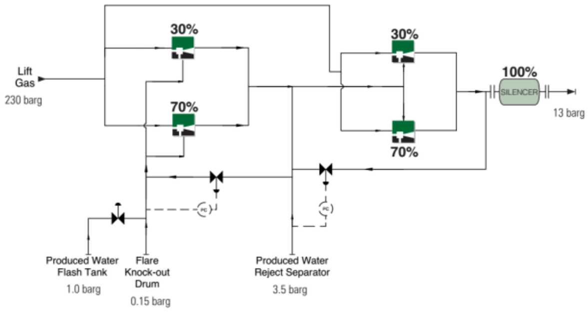

Figure 11. System Schematic

Without some simple precautions, the proposed ejectors would have produced noise emissions in excess 80 dB (A) at 1m. To avoid this, the ejectors and interconnecting process pipework were acoustically insulated and an inline silencer installed to prevent noise being transmitted down the discharge pipework.

Project Outcome

The system was successfully commissioned in 2014 and the client has reported the system is working well. Their actual gas flow rates are lower than originally reported for system design, so they are only utilizing 30% of the ejector rated capacity at this stage.

CASE STUDY – LIQUID MOTIVATED EJECTOR FGR SYSTEM

User: Onshore Middle East

Date of Supply: 2015

Application

The client wanted to reduce continuous flaring at an oil and gas gathering facility and decided to install a Transvac liquid ejector downstream of the dehydration tanks. The recovered gas was to be routed to the existing plant bulk separator and then to be sent to the gas lift compressors.

Basis for selecting Ejector Technology

During the project FEED stage, various forms of gas compression technologies were considered.

However, liquid motivated ejector technology was selected for the following reasons:

1. A small sidestream from an existing Water Injection Pump could be used to provide the motive water to the ejector.
2. The existing bulk separator had sufficient capacity to accept the multi-phase discharge flow from the ejector.
3. Liquid ejector had no moving parts and minimal maintenance.
4. Liquid ejector package offered the lowest cost solution, by utilizing the existing pump and separator.
5. Simpler installation versus alternatives.
6. Transvac could performance test the full-size ejector at its UK test facility under the client supervision.
7. Transvac's Universal Design technology allows the internals (Nozzle & Diffuser) to be changed if the process conditions change.

Operating Conditions

The application required tank gas to be compressed from 0 barg to 3 barg. The Design Flow was 5,750 Sm^3/d at a temperature of 40 ^{0}C. Motive Liquid Flow was 285 m^3/d at a pressure of 169 barg.

Mechanical Design

In addition to applying the standard ASME B31.3 piping code, the client's specific DEP Piping Standards were also applied. Design conditions for the package are shown below.

- Design Pressure: Full Vacuum to 420 barg
- Design Temperature: 5C to 82C
- Connections: ASME B16.5 2500# RFWN

NACE MR0175 standards were applied for sour service, and the customer required that the gas/liquid contacting materials be supplied in 22 Cr Duplex Stainless Steel.

Design Considerations

To minimize the motive water flow, per the client's requirements, the ejector needed to operate at a low flow ratio between the motive water and suction gas. Following extensive product development and testing, Transvac provided a custom liquid motivated ejector requiring only 285 m^3/d of motive water to perform the gas compression duty. The suction gas flow from the dehydration tanks varied according to operating conditions. To prevent the ejector from lowering the pressure of the tank during times of low suction gas flow, the client introduced secondary 'make-up' gas into the tanks. This method of controlling performance was simple and reliable, but carries a small risk of the motive water containing sand particles. Therefore, to prevent potential erosion, the motive nozzle and diffuser both included ceramic inserts.

Factory Acceptance Test (FAT)

Transvac performed a full scale FAT test of the liquid ejector at its Test facility in the UK, which allowed the liquid ejector to be fully performance mapped at Design and Off-Design Cases. This meant the client was fully aware of how the ejector would behave under any set of operating conditions. See Figure 12.

Figure 12. Photo of FAT Test of Liquid Ejector

Project Outcome

The system was successfully commissioned in early 2016.

CONCLUSION

Flare systems remain a necessary component for safe operation of many oil and gas production, processing, and refining facilities. However, with tighter emissions requirements, the next decade will see an increase in the number of FGR systems installed to reduce continuous flaring. The sizing, proper selection, and design of FGR systems require a careful and organized approach, utilizing an experienced designer. In many cases, ejectors may be the ideal compression technology for these systems.

REFERENCES

[1] ANSI/API Standard *Pressure-relieving and Depressuring Systems*. Fifth Edition, January 2007 – Addendum, May 2008