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Minimize facility flaring

Flares are safety devices that prevent the release of unburned gases to atmosphere

J. PETERSON, Flint Hills Resources, Corpus Christi, Texas, **N. TUTTLE, H. COOPER** and **C. BAUKAL,** John Zink Co., LLC, Tulsa, Oklahoma

To the casual observer, minimizing the flaring from a refinery or petrochemical facility may seem easy. **Remember:** Flares are safety systems designed to protect site employees, the public and the facility. New strategies can be applied to find cost-effective methods that *safely* minimize if not eliminate the need for flaring. A Texas refiner successfully used innovative methods to nearly eliminate flaring at its refinery.

Designed to protect. Flares are combustion devices designed to safely and efficiently destroy waste gases generated in a plant (Fig. 1). In refinery operations, flammable waste gases are vented from processing units during normal operation and process upset conditions. These waste gases are collected in piping headers and delivered to a flare system for safe disposal. A flare system often has multiple flares to treat the various sources for waste gases. There may be several different flare types used in a system, depending on site requirements. Flares are primarily safety devices that prevent the release of unburned gas to atmosphere; these gases could burn or even explode if they reached an ignition source outside the plant.

Two levels of flaring that are of interest. The first is flaring that occurs during a plant emergency. This can be a very large flow of gases that must be destroyed, where safety is the primary consideration. These flows can be more than a million pounds per hour, depending on the application. The maximum waste-gas flow that can be treated by a flare is referred to as its *hydraulic capacity.* The second level of flaring is the treatment of waste gases generated during normal operation, including planned decommissioning of equipment. While safety is still imperative, emissions are also important. The actual waste-gas flowrate and composition may vary significantly during normal operation, but the flare should still be capable of safely destroying the waste gases while minimizing emissions. The American Petroleum Institute has developed guidelines for handling waste gases.[1,2]

FIG. 1 Example of an air-assisted flare during testing.

Traditionally, there have been three important performance parameters of interest for most flares.[3] The first is the so-called *smokeless capacity.* This is the maximum flow of waste gases that can be sent to the flare without producing significant levels of smoke. A flare is typically sized so that the smokeless capacity is at least as much as the maximum waste-gas flowrate expected during normal operation. The second performance parameter is the *thermal radiation* generated by the flare as a function of the waste-gas flowrate and composition.[4] The radiation levels at ground level are typically limited to avoid injuring personnel and damaging equipment. After choosing the most remote, practical flare location, the height of the flare stack is determined so that the acceptable radiation levels are not exceeded at ground level. The third parameter is *noise*. Excessive noise can injure personnel, equipment and property both inside and outside the plant.

While the primary function of flares is to protect the facility, employees and the surrounding environment, flaring gases creates emissions such as nitrogen oxides (NO_x), sulfur oxides (SO_x), greenhouse gases (CO_2 and CO) and volatile organic compounds (VOCs). These emissions, in combination with any unburned hydrocarbons, contribute to the total facility emissions.

Historically, flare emissions have not specifically been a parameter of interest because they are very difficult to measure. Since nearly all flares burn in the open, there is no enclosure or combustion chamber with a well-contained exhaust stream to insert probes into for extractive or in-situ emissions measurements. Research is currently being done on using remote monitoring analyzers to measure flare emissions, but

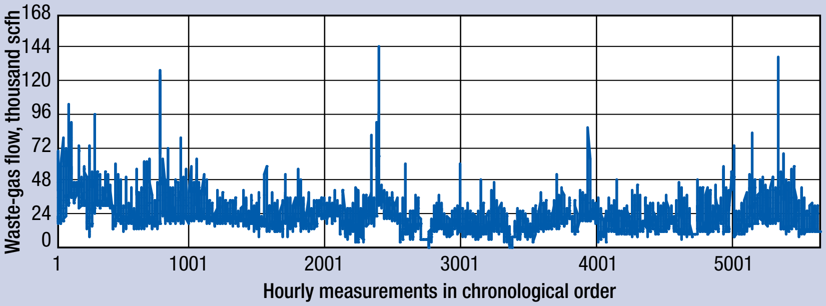

FIG. 2 Example of waste-gas flows to a flare in a typical refinery over approximately an eight-month period.

TABLE 1. Example of waste gas compositions at a typical plant

Flare gas constituent		Gas composition range, % Minimum	Maximum	Flare gas, % Average
Methane	CH_4	7.17	82.0	43.6
Ethane	C_2H_6	0.55	13.1	3.66
Propane	C_3H_8	2.04	64.2	20.3
n-Butane	C_4H_{10}	0.199	28.3	2.78
Isobutane	C_4H_{10}	1.33	57.6	14.3
n-Pentane	C_5H_{12}	0.008	3.39	0.266
Isopentane	C_5H_{12}	0.096	4.71	0.530
neo-Pentane	C_5H_{12}	0.000	0.342	0.017
n-Hexane	C_6H_{14}	0.026	3.53	0.635
Ethylene	C_2H_4	0.081	3.20	1.05
Propylene	C_3H_6	0.000	42.5	2.73
1-Butene	C_4H_8	0.000	14.7	0.696
Carbon monoxide	CO	0.000	0.932	0.186
Carbon dioxide	CO_2	0.023	2.85	0.713
Hydrogen sulfide	H_2S	0.000	3.80	0.256
Hydrogen	H_2	0.000	37.6	5.54
Oxygen	O_2	0.019	5.43	0.357
Nitrogen	N_2	0.073	32.2	1.30
Water	H_2O	0.000	14.7	1.14

this technique is still under development.[5]

The size of flare flames and elevation above the ground make it very difficult to use a hood to collect exhaust gases and measure emissions. Another very challenging problem is that weather conditions, the waste-gas flowrate, and composition are highly variable and not generally controllable. For example, wind plays a very significant role in the performance of a flare.[6] High waste-gas flowrates, such as those that could occur during emergency conditions, are generally impossible to test in an operating plant because fortunately they rarely occur. There are some flare test facilities capable of simulating very high flow rates, but even these can rarely test the maximum flowrate that could occur at a plant.[7]

There is growing interest in reducing the pollutant emissions from flaring. For example, the Bay Area Air Quality Management District in California established Regulation 12, Rule 12, entitled "Flares at Petroleum Refineries" on July 20, 2005. The rule requires flare minimization projects and studies for area refineries. There is growing concern that emissions of VOCs from flares may be much higher than previously thought.[8] One possible reason is that wind effects can reduce flare destruction efficiency.[9] The estimated emissions from flares are often based on measurements made with little or no wind. Accordingly, the emissions may be much higher under windy conditions.

Another possible reason is improper operation of flares. Many flares use steam as an assist medium to increase air entrainment into the flame to increase the smokeless capacity. However, over-steaming, or providing too much steam to a flare compared to the waste-gas flowrate, can actually reduce the destruction efficiency. The cooling effect of excessive steam may inhibit dispersion of flared gases, particularly during weather inversions. In the extreme case, over-steaming can actually snuff out the flame and allow waste gases to go into the atmosphere unburned.

There is growing concern that many flares are being oversteamed to minimize smoking over a wide range of waste-gas flowrates. In most steam-assisted flares, the steam flowrate is manually controlled and sometimes set for the maximum expected waste gas flow during normal operation. However, this means the flare could be severely over-steamed during periods where the waste-gas flow is much lower. The International Flare Consortium has been formed to study emissions from flares.[10]

The problem. To the casual observer, it may seem relatively easy to minimize and even eliminate routine flaring from refineries and petrochemical/chemical plants. It appears that these plants are unnecessarily wasting energy and generating pollution. The main challenge is that it can be uneconomical to recover the gases, either for use in the plant or to sell as energy, for a variety of reasons.

The flowrate and composition of the waste gases going to the flare are often highly variable. The unsteady flow (Fig. 2) and variable composition (Table 1) make it difficult to use the waste gases elsewhere in the plant where the energy demand is normally steady. The variable composition makes it difficult to sell, unless a purification system is added to produce a more consistent composition.

The waste gases may have a low heating value, which means that equipment such as burners must be properly designed for the low heating value. The waste gases may be off-spec product that is being flared because it cannot be sold and is not easily reprocessed to produce on-spec product.[11] Off-spec flaring may occur for some time during startup until the product is within specification.

The waste gas pressure is low; thus, a compressor is needed to aid transporting the gases. In most refineries and petrochemical plants, the fuel gas is at a high enough pressure that it can be used to entrain the air needed for combustion so that the burners do not need a fan or blower.[12] Additional piping may also be needed to connect the waste gas to the fuel-gas system.

Potential solutions. A variety of strategies for minimizing flaring is possible and can be grouped into two broad categories: *plant practices* and *new equipment. Plant practices* involve controlling the processes producing waste gases using existing equipment in the plant. One example is simply ensuring that equipment is properly maintained to minimize leaks into the waste-gas header. Another example might be improved understanding of what waste gases are produced under a given set of conditions so either of those conditions can be avoided.

New equipment refers to adding hardware that reduces the amount of waste gases going to the flare. One example might be redesigning plant processes to minimize waste gas production. This might mean recycling waste gases back into the process or using alternative technologies that produce less waste. Another example is flare gas recovery units (FGRUs) that can capture waste gases that would have been flared, either for use in the plant or for sale.[13]

FGRUs. An FGRU is designed to capture waste gases that would normally go to the flare system. The FGRU is located upstream of the flare to capture some or all of the waste gases before they are flared. There are many potential benefits of an FGRU. The flare gas may have a substantial heating value and could be used as a fuel within the plant to reduce the amount of purchased fuel. In certain applications, it may be possible to use the recovered flare gas as feedstock or product instead of purchased fuel.

The FGRU reduces the continuous flare operation, which subsequently reduces the associated smoke, thermal radiation, noise and pollutant emissions associated with flaring. It also reduces the negative public attention drawn to the facility. Capturing waste gases may reduce odor levels. Reduced flaring also reduces steam consumption for steam-assisted flares and can extend the service life of the flare tips. In refineries with excess process-generated waste gas beyond fuel gas requirements, an FGRU can provide a means to scrub the hydrogen sulfide (H_2S) before the clean gas is flared.

A schematic of a typical FGRU system is shown in Fig. 3. When the recovered flare gas is to be utilized as a fuel and the flow is less than or equal to the capacity of the FGRU, the flare gas will be recovered and directed to the refinery-fuel-gas header. During these periods, there will be little or no visible flame at the flare, although the flare pilot may be visible. When the flare-gas flowrate is greater than the capacity of the FGRU, the excess flare gas will flow through the liquid seal drum and to the flare tip where it will be combusted. From flaring rates just above the FGRU capacity to a maximum flaring episode, the liquid seal drum will promote smooth, safe operation of the flare tip. The FGRU system is operated at a slight positive pressure to prevent air infiltration into the system that could create a flammable mixture.

The basic processes used in the FGRU are compression and physical separation. The basic operation of the FGRU is:

- Process vent gases are recovered from the flare header.
- Gas compressors boost the pressure of this gas.
- Recovered gas is discharged to a service liquid separator.
- Separated gas may pass through a condenser where the easily condensed constituents may be returned as liquids feedstock while the components that do not easily condense are returned for use as fuel gas after scrubbing for contaminant removal, such as H_2S.

Gas compression is performed by compressors selected for the specific application. For example, if a liquid-ring compressor is used, then separating recovered vapor phase from a mixed liquid is accomplished via a horizontal separator vessel. As flare gas flows into the header, an established hydrostatic head in the liquid seal drum will prevent flare gas from flowing to the flare. This causes a slight increase of pressure in the flare gas header, but not enough to significantly affect the capacity of the overpressure protection devices in the refinery. When the flare-gas header pressure reaches the gas recovery initialization setpoint in a batch operation plant, the compression system will begin to compress the flare gas. The FGRU will start and stop with control signals from the PLC. In continuous-operation plants with varying flare loads, additional parallel compressors can be automatically staged on or off to augment the capacity of the base-load compressor as needed. Based on the inlet pressure of the flare gas header, fine-tuning of FGRU capacity control is by the spillback (recycle) of recovered gas from the service liquid separator back to the suction.

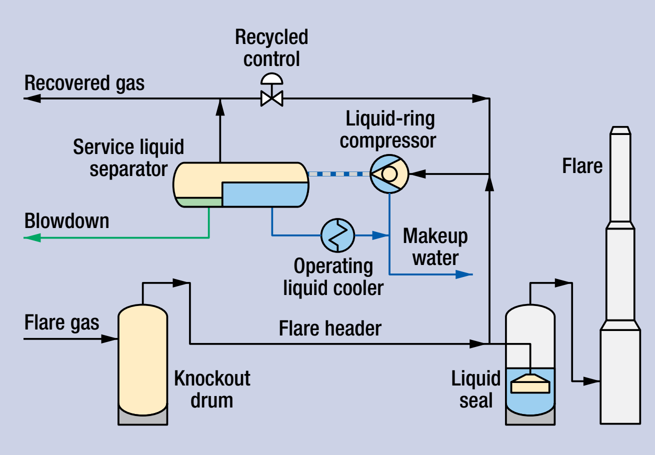

FIG. 3 Generalized flare gas recovery process schematic.

Discharge of the liquid-ring compressors will flow into the service liquid separator vessel where the gas and service liquid are disengaged and the compressed recovered flare gas is delivered to the facility fuel gas scrubbing and distribution system. The compressor service liquid, usually water, is used in the compressor as a seal between the rotor and the compressor case. The service liquid is separated from the recovered gas stream, cooled and recirculated to the gas compressor train for reuse.

The gas processing capacity of the FGRU adjusts to maintain a positive pressure on the flare header upstream from the existing liquid seal drum. This positive pressure will ensure that air will not be drawn into either the flare system or the FGRU. If the volume of flare gas that is relieved into the flare system exceeds the capacity of the FGRU, the pressure in the flare header will increase until it exceeds the back-pressure exerted on the header by the liquid seal. In this event, excess gas volume will pass through the liquid seal drum and on to the flare where it will be burned. This will be the case when there is a rapid increase in flare gas flow due to an emergency release. Since the liquid seal serves as a backpressure control device for the FGRU, a properly designed deep-liquid seal is critical to the stable operation of the FGRU and flare. A deep-liquid seal, typically 30-in.W.C. minimum, is required to permit a suitable control range for the capacity control of the FGRU. As the flow transitions to the flare, this must be done with a very stable liquid level or else unstable flare header pressure could result, affecting FGRU control and proper flare operation.

If the volume of flare gas relieved into the flare header is less than the total capacity of the FGRU, the capacity of the FGRU adjusts to a turndown condition. This is accomplished by turning off compressors and/or by diverting discharged gas back to theturning off suction header through a recycle control valve.

FIG. 4 An FGRU at the FHR West Plant in Corpus Christi, Texas.

Compressor speed can also be varied. Control of the FGRU is automated with minimal requirement for direct operator intervention.

Flint Hills Resources' experience. Most FGRUs have been installed based primarily on economics, where the payback on the equipment was short enough to justify the capital cost. Such systems were sized to collect most, but not all, of the waste gases. The transient spikes of high gas flows are typically very infrequent, meaning normally it is not economically justified to collect the highest flows of waste gas because they are so sporadic. However, there is increasing interest in reducing flaring not based strictly on economics, but on environmental stewardship.

Flint Hills Resources (FHR) has made a strong commitment to dramatically reduce flaring at all of its facilities.[14] Overall, flaring at FHR facilities has been reduced by more than 95% since 1997. This is part of the company's commitment to strive to be the operator of choice within its communities. The company won a Clean Air Award from the US Environmental Protection Agency (EPA) in 2004 for its efforts to reduce refinery flaring and thus the emissions created during flaring. FHR has worked with the EPA in a consent decree to minimize all pollution emissions from FHR plants.[15] Specific focus is on startups, shutdowns and malfunctions (SSMs), which often lead to significant flaring events. An example of a flaring event caused by an unplanned shutdown occurred in Wilmington, California, in September 2005 when brown and yellow smoke was emitted from several refineries (none of which were FHR facilities) for more than eight hours after an area power outage.[16] FHR will provide the EPA and state regulators with information on its SSM practices across the regulated community to minimize such emissions.

FHR's refining complex in Corpus Christi, Texas, has dramatically reduced its flaring from the refinery. The West Plant recently set a plant record for going 155 days without flaring. A combination of equipment and operating practices was required to achieve this record. The West Plant has an FGRU system that was installed in the early 1980s (Fig. 4). As shown in Fig. 4, three parallel compressors are used to accommodate the wide range of flowrates. The system was originally installed based on economics, where most but not all of the waste gases were recovered.

After the decision was made to dramatically reduce flaring at the refinery, plant engineers analyzed all processes venting waste gases into the flare header. This aided in determining ways to reduce the waste-gas base load so the volume of gases could be handled by the existing FGRU. For example, an improved coker blowdown process minimizes vapor generation with no resultant flaring. Nonroutine waste flows to the FGRU are ceased during coker blowdown operations. Operators began tracking flaring time to identify processes that needed to be modified.

A daily report was reviewed to continually monitor flare events. In some cases, hardware changes were needed to repair or replace leaking equipment. In other cases, this meant procedural changes to plant practices. This took a coordinated effort of operators, engineers and management to make the changes necessary so that no additional capacity was required in the existing FGRU system. Refinery computer controls were upgraded and centralized, which significantly improved communication and management of the flare system ensuring FGRU capacity availability if a significant flow of waste gas was going to be generated. Alarms were added to alert operators when potential flaring conditions may occur to give them time to adjust operations. Root-cause analysis also is used to analyze significant unplanned emissions events to eliminate future occurrences.

As an example of FHR's commitment to reducing flaring, only 1.77 hours of flaring were required in the first half of 2006. Most of that flaring occurred during a planned event. Typically, during an outage at a plant, there would be significant flaring to de-inventory and decommission (purge) the process equipment so that maintenance can be safely performed. To minimize flaring during outages, FHR developed a comprehensive plan to bring down certain equipment at different times so that nearly all of the waste gases could be captured by the FGRU. Most of the 1.77 hours of flaring occurred when the FGRU itself was shut down for flare line maintenance.

Potential realized. There is growing interest in minimizing flaring, in part due to the pollution emissions generated by flaring and potentially significant emission sources within a plant. Flint Hills Resources has approached this problem through equipment modifications and new operating practices, in combination with an existing flare gas recovery unit. The FHR West Plant in Corpus Christi, Texas, has achieved 155 consecutive days without any flaring. FHR partnered with the US EPA to help develop best practices that can be applied at other plants to minimize flaring and the associated pollutant emissions that come with flaring. **HP**

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Jim Peterson is a process engineering advisor for Flint Hills Resources at its Corpus Christi, Texas, refinery. Mr. Peterson provides process engineering support for overpressure protection and flare systems as well as other projects. He holds a BS degree in chemical engineering from Michigan Technological University.

Nick Tuttle is a consultant in the flare gas recovery group at John Zink Co., LLC, Tulsa, Oklahoma. He has more than 40 years of industry experience and is a registered professional engineer. Mr. Tuttle holds a BS degree in chemical engineering from New Mexico State University, and has completed additional work toward an industrial management degree from the University of Houston. He has authored numerous papers and is an inventor on four US patents.

Harley Cooper is the director of the flare gas recovery group at John Zink Co., LLC, in Tulsa, Oklahoma. He has more than 20 years of vapor control and recovery experience in the petrochemical industry. Mr. Cooper holds a BS degree in mechanical engineering and an MBA, both from the University of Tulsa. He is a registered professional engineer in the state of Oklahoma.

Chuck Baukal is the director of the John Zink Institute at John Zink Co., LLC in Tulsa, Oklahoma. He has more than 25 years of experience in industrial combustion in a wide range of industries. Dr. Baukal holds a PhD in mechanical engineering from the University of Pennsylvania and is a registered professional engineer in the state of Pennsylvania. He has authored/edited six books on industrial combustion. He has authored 10 US patents.