Minimize facility flaring

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

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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

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 (NOₓ), sulfur oxides (SOₓ), greenhouse gases (CO₂ 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
variable and not generally controllable. For example, wind plays a
conditions, the waste-gas flowrate, and composition are highly
emissions. Another very challenging problem is that weather
it very difficult to use a hood to collect exhaust gases and measure

There is growing concern that many flares are being over-

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

<table>
<thead>
<tr>
<th>Flare gas constituent</th>
<th>Gas composition range, %</th>
<th>Flare gas, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Methane CH₄</td>
<td>7.17</td>
<td>82.0</td>
</tr>
<tr>
<td>Ethane C₂H₆</td>
<td>0.55</td>
<td>13.1</td>
</tr>
<tr>
<td>Propane C₃H₈</td>
<td>2.04</td>
<td>64.2</td>
</tr>
<tr>
<td>n-Butane C₄H₁₀</td>
<td>0.199</td>
<td>28.3</td>
</tr>
<tr>
<td>Isobutane C₄H₁₀</td>
<td>1.33</td>
<td>57.6</td>
</tr>
<tr>
<td>n-Pentane C₅H₁₂</td>
<td>0.008</td>
<td>3.39</td>
</tr>
<tr>
<td>Isopentane C₅H₁₂</td>
<td>0.096</td>
<td>4.71</td>
</tr>
<tr>
<td>neo-Pentane C₅H₁₂</td>
<td>0.000</td>
<td>0.342</td>
</tr>
<tr>
<td>n-Hexane C₆H₁₄</td>
<td>0.026</td>
<td>3.53</td>
</tr>
<tr>
<td>Ethylene C₂H₄</td>
<td>0.081</td>
<td>3.20</td>
</tr>
<tr>
<td>Propylene C₃H₈</td>
<td>0.000</td>
<td>42.5</td>
</tr>
<tr>
<td>1-Butene C₄H₆</td>
<td>0.000</td>
<td>14.7</td>
</tr>
<tr>
<td>Carbon monoxide CO</td>
<td>0.000</td>
<td>0.932</td>
</tr>
<tr>
<td>Carbon dioxide CO₂</td>
<td>0.023</td>
<td>2.85</td>
</tr>
<tr>
<td>Hydrogen sulfide H₂S</td>
<td>0.000</td>
<td>3.80</td>
</tr>
<tr>
<td>Hydrogen H₂</td>
<td>0.000</td>
<td>37.6</td>
</tr>
<tr>
<td>Oxygen O₂</td>
<td>0.019</td>
<td>5.43</td>
</tr>
<tr>
<td>Nitrogen N₂</td>
<td>0.073</td>
<td>32.2</td>
</tr>
<tr>
<td>Water H₂O</td>
<td>0.000</td>
<td>14.7</td>
</tr>
</tbody>
</table>

The size of flare flames and elevation above the ground make it
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. High waste-gas
flowrates, such as those that could occur during emergency condi-
tions, 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.

There is growing interest in reducing the pollutant emissions
from flaring. For example, the Bay Area Air Quality Manage-
ment 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. One possible reason is that
wind effects can reduce flare destruction efficiency. 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 entrain-

The problem. To the casual observer, it may seem relatively easy to minimize and even eliminate routine flaring from refi-
neries and petrochemical/chemical plants. It appears that these plants are unnecessarily wasting energy and generating pol-
lution. 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 vari-

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
elsewhere in the plant where the energy demand is normally steady.
The variable composition makes it difficult to sell, unless a purifica-
tion 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
elsewhere in the plant where the energy demand is normally steady.

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 control-
ling 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

FIG. 2 Example of waste-gas flows to a flare in a typical refinery over approximately an
eight-month period.
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 (H2S) 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 H2S.
- 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 over-pressure 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.

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 the turning off suction header through a recycle control valve.
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. 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. 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 occurred in Wilmington, California, in September 2005 when brown and yellow smoke was emitted from several refineries (none occurred in Wilmington, California, in September 2005)).

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 flange 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 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.

**LITERATURE CITED**


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