

✚ When the heat is on

Tom Farmer and Caleb Hurd, Zeeco Inc., USA, explain how efficient flaring can be achieved at various flow rates.

While flares are a necessary safety device in refineries and other petrochemical processing plants, flaring events are rarely welcomed. When a flaring event does occur, the facility's emissions control systems and air quality are scrutinised for compliance and operational efficiency. Ideally, the plant's flare system is designed to operate with a stable flame and little or no smoke during routine flaring events. It should also achieve high destruction removal efficiency (DRE).

However, recent studies and observations suggest that some steam and air assisted flares produce unacceptably poor destruction efficiencies when operating at turndown conditions. Improving the operating parameters of existing flares through training and control allows proper destruction efficiencies to be achieved, even at turndown rates. Meeting stringent DRE requirements of 98% or better keeps facilities in compliance and ensures the flare is ready to serve its intended purpose should the need arise. In this article, some common flaring efficiency and



Figure 1 A Zeeco AF air assisted flare visually observed to be operating smokelessly at a proper air to fuel gas ratio.

emissions challenges will be examined from an integrated standpoint, including flare system design control options, field observations and important field considerations. This will help to determine the best method for plant operators to evaluate flare efficiency and make adjustments to minimise emissions problems and meet necessary environmental regulations.

The flare system

The primary design purpose of a flare system is to serve as a pressure relieving safety device for the operating plant. A flare usually operates in standby mode, with just the pilots on in order to flare purge and leakage gas at low flow rates. Assist media, including steam or air, is often flowing at minimum cooling rates in this standby state. When in operation, the main objective of a steam assist or air assist flare is to have a stable flame with little or no smoke during normal or routine flaring with a high DRE. In order to achieve proper combustion, both steam assist and air assist flares induce air into the combustion zone, thoroughly mixing it with flare gas for smokeless combustion.

Given that both flares have similar operating principles, they also encounter similar operating issues. Frequently, these problems occur due to an incorrect ratio between the flare gas and the steam/air assist rate. This challenge holds true at low flow or purge rates too, and those rates represent the operating condition in which many flares spend the most time. Understanding potential operational problems is critical to achieving the best flare performance, regardless of flow rate.

A steam assisted or air assisted flare system achieves peak performance when using the correct ratio of steam or air to flare

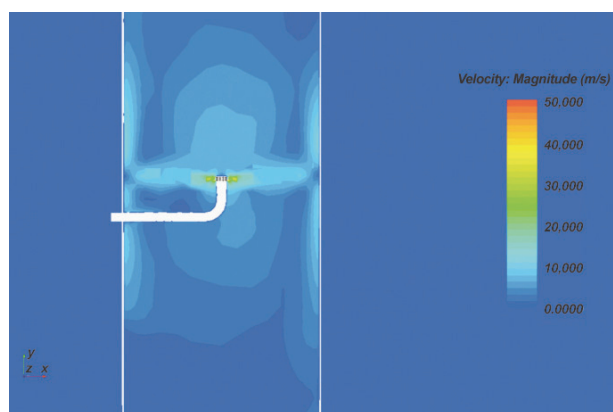


Figure 2. CFD model velocity magnitude profile limited to a scale of 50 m/sec.

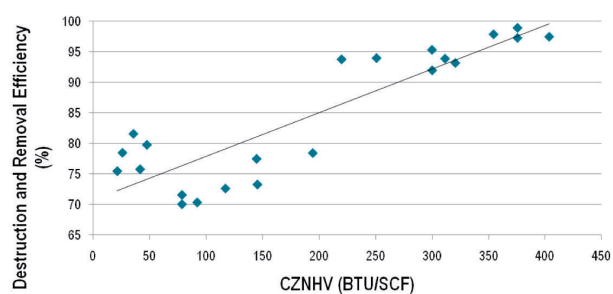


Figure 3. CZNHV graphed against destruction and removal efficiency with the use of centre steam only. The only points that have a DRE of 98% correspond to a combined CZNHV greater than 350 Btu/ft³.

gas. When using too much steam or air, the combustion process becomes incomplete or less efficient and leads to the release of unburned hydrocarbons and volatile organic compounds (VOCs) into the atmosphere. Over steaming occurs in steam flares when the steam to flare gas ratio becomes so high that the amount of steam and air being injected into the gas stream quenches the flame. A flare exhibiting over steaming could have a slightly visible flame or possibly no visible flame at all. Above the top of the tip, steam condensate appears to converge all the way to the centre of the flame area and condensate can often be seen trailing away from the flare. With over steaming, capping can result where the steam converges over the top of the flare, holding down the flame and forcing burning to take place inside the flare body, thus shortening equipment life. For air assist flares, injecting too much air can extinguish the flame by diluting the air/gas mixture beyond the flammability limits of the gas.

One industry theory is that while constant steam injection (cooling steam) provides thermal protection to steam injection equipment, improper steam injection can become an impediment to the DRE of hydrocarbons. Testing data shows that the combustion zone net heating value (CZNHV) is a key component for complete combustion. Along with CZNHV, the temperature profile can be useful to determine if proper combustion is occurring. Profiles with a higher temperature along the perimeter and lower temperatures inside the stack indicate little to no tip burnback and higher DRE. Previous emissions calculations and thermocouple logs show that the DRE is not only influenced by the amount of steam introduced into the flare system, but also by the location of steam assist applied to the flare. Achieving the desired 98% DRE levels using centre steam requires the highest CZNHV because it dominates the flow in the centre of the tip, as shown by the velocity magnitude diagram in Figure 2. Figure 3 shows DRE plotted against CZNHV when using centre steam only.

According to the US Environmental Protection Agency (EPA), the variables of flare type; presence of a continuous burning pilot flame; flare gas lower heating value; and exit velocity of the flare gas out of the flare tip are the factors that determine if a flare is operating at the minimum 98% DRE (US EPA 40 CFR 60.18). If a flare is operating with these constraints, the emissions factors presented in AP 42 I3.5 can then be used to predict the actual emissions of CO, NO_x, unburnt hydrocarbons and particulates from the flare.

The first step to better flare operation and reduced VOC emissions is to understand all of the parameters of the current flare system. Improving a system's efficiency could depend on a number of factors: modifying the existing flare system; allowing better monitoring of flare gas flow; educating operators and plant personnel as to the flare flame condition that indicates the best destruction efficiency; and adding better steam controls or upgrading blower controls to provide better air control. The following methods can be used to identify incorrect flare control conditions for air and steam assisted flare systems:

- Visual observation.
- Optical/infrared (IR) monitor.
- Handheld IR camera.
- Emissions sampling stations.

Visual observation

Through direct visual observation, the operator can monitor the flare and determine if it is set to the proper ratio of assist media through the appearance of the flame and smoke production. Operators should be educated on the types of flare flames that

result in high destruction efficiencies. However, even with proper education, this monitoring method is not continuous and emissions can still occur. When operating at a very high steam/air to flare gas ratio, a flare will not typically produce smoke if a flaring event should occur while the operator is not visually monitoring the flare system. Unfortunately, flares operating with a high ratio are most likely to have higher emissions of unburnt hydrocarbons and VOCs, even though the flare might appear to be operating properly from visual observation alone.

An in service air inspection by manned or remote control helicopter can identify problems in the flare system that cannot be identified from the ground level. A facility will typically have criteria to determine the proper timing for an in service inspection, and they are usually performed months in advance of a turnaround. The primary concentration area for this type of inspection is the flare tip and upper structure, as these areas are impossible to properly observe from the ground.

A flare tip inspection is an important indication of any material failures, including welds on steam manifolds, welds on the flare tip body, the muffler, pilots and the internal steam/air tubes. Visual indication of internal burning could reveal a steam/air tube internal weld failure, insufficient centre steam or capping of the flare. These are indicated by discoloration of the flare body and/or muffler area, and seen as a 'hot spot' in low lighting. If operation continues with internal burning, it can severely damage the flare body and internal steam or air tubes. This type of inspection requires the owner to interpret the photos, usually in conjunction with the original equipment manufacturer (OEM), and can provide important feedback to plant operators trying to ensure their flare is operating at the required 98% DRE or better.

Optical/IR monitor

Optical/IR monitors or flame scanners are used to monitor the opacity of the flame or smoke output of the flare. They are proven successful for large flaring situations where steam vapour is indistinguishable from a flame. However, signal reliability issues have been discovered when using IR smoke monitors to evaluate steam flares during low flow or purge rate conditions. When viewing steam with IR monitors in these operating conditions, operators have found that steam vapours and smoke particles appear similar to the monitor and can result in a false positive signal of smoke production. Standard control logic would then increase the steam to compensate for the perceived smoke, possibly leading to further or worsening false positive signals of smoke. Continuing to 'correct' the situation leads to over steaming, and unacceptable VOC emissions levels.

Handheld IR camera

An IR camera can detect and identify hydrocarbon gas frequencies that are escaping the flame without being burned. The camera cannot quantitatively assess the emissions, but instead provides a qualitative report. Operators must then evaluate the data and decide whether or not to adjust parameters. There is currently no long term cost effective continuous IR technology camera available for monitoring unburned hydrocarbons, but using a non-continuous one in conjunction with other methods of monitoring and control can help verify findings and prevent adjustment errors.

Emissions sampling stations

Stationed at a fixed location, these systems detect local concentrations of emitted gases and determine if the emission

levels at that point are in compliance or not. These systems are not designed to determine the location of the emission source, but rather to provide a quantitative report on local concentrations of certain contaminants. Due to their fixed location, they are not capable of specifically determining the location of a source, only the direction from which the emissions are coming. Dependent upon wind conditions, they may be ineffective at determining an emitting source that is adjacent to the station itself. When used in conjunction with other methods of emission monitoring (such as an IR camera), sampling stations help plant operators catch potential out of spec operational conditions early.

Once a ratio control issue has been identified, the proper use of a pressure switch/transmitter, flow switch (FE)/transmitter or gas analyser may correct the issue. When using a pressure switch, the switch turns the two speed fan from low to high, or the next air stage is initiated to increase/decrease the air flow rate and compensate for the additional gas flow when the flare header pressure reaches the set point. A flow switch measures gas flow directly, but is typically based on a set gas and corresponding properties. The steam or air flow can be regulated based on flare gas flow and its required ratios. Flare systems routinely receive different flare gases with varying lower heating values, which require different amounts of steam or air assist to combust effectively. A gas analyser can determine which gas is flowing and resolve the corresponding ratio of air or steam to fuel. In most cases, the best solution is a combination of multiple technologies to adequately cover all possible operating conditions and scenarios.

Applications

There are several designs for new and retrofit applications to eliminate the over airing or over steaming that can cause VOC emissions. A simple and short term solution is to increase the amount of purge gas to avoid over airing or over steaming at minimum assist rates. However, it is costly to continuously inject large amounts of purge gas. The flare's available capacity for relief rates can also be decreased if there is a significant increase in the constant purge gas flow.

One method that allows the proper ratio of steam to flare gas to be met on a steam assisted flare tip is to use a control valve to vary the steam flow. An automated steam control valve allows for more control than a simple on/off valve, but is not able to give the turndown required on large systems to prevent over steaming at low flare gas flow rates and purge rates.

In cases where a single control valve is not sufficient to prevent over steaming, the best practice is to employ multiple valves in parallel and use a split range control philosophy to deliver the proper amount of steam. The most common design type typically requires two valves: one control valve handles the higher range of flows, while a separate valve controls the steam flows for lower steam/flare gas flow requirements. The combination of valves still provides the flare tip with the maximum steam rates required to handle major flare relief cases without smoke, yet it also allows for control at small releases and purge rates without over steaming.

Based on observations of steam assisted flare systems in operation around the world, the use of two or more steam control valves is probably warranted more than 85% of the time. However, very few steam assisted flare systems currently in operation have this dual steam control valve arrangement and therefore a large number have inadequate steam regulation for lower flare gas flow conditions.

An air assisted flare system using a single speed fan running constantly at full speed can cause over airing situations at small and purge gas flare flow rates. By using a two speed fan or multiple smaller fans, air flow can be better regulated for smokeless flaring at low flow rates. Another alternative is a single speed motor with a variable frequency drive (VFD), which varies the speed of the fan motor and controls the airflow at different rates. This control option allows for a turndown of 10:1 and frees the fan to run at approximately 10% of its maximum rate when required.

A variable inlet vane damper can be installed on the inlet of the fan to allow for better air control. This damper is suitable for multiple fans, multi speed fans or a VFD. It can be adjusted to restrict the amount of air sent to the flare tip; can be manual or automated; and can be retrofitted to an existing system that is over airing at low flare gas flows or purge rates. If the flare system has a very high smokeless flow condition with a high turndown range for flare gas flow, it may be necessary to use a variable inlet vane damper unit in conjunction with multi speed blower motors or a VFD system to get precise control of the air.

A more efficient control option for the ratio of steam or air to flare gas ratio is to stage the gas flow itself. This design results in multiple flare tips but eliminates the problematic low flow exiting through the same flare as maximum flow. Staging the flares allows for better and more efficient control at low flow rates, while preserving maximum flare capacity when all stages are operating.

There are several methods available to achieve flare system staging. Automated valves can open and close at predetermined points based on measured gas flow or pressure. Liquid seal drums

for staging serve as a passive system that eliminates the need for monitoring the flow or pressure. Liquid seal staging is based on the backpressure created by a vertical column of liquid that prevents the gas from flowing. The seal's depth is designed to allow flare gas to flow to the first stage only until the capacity of that system is met. Then, the flare gas pressure will equal and overcome the backpressure created from the liquid level in the liquid seal drum and flow will begin to bubble to the next stage in the flare system.

Conclusion

There is currently no existing method to precisely measure emissions from an elevated flare. Sophisticated methods such as predictive emissions monitoring (PEMS) have evolved, allowing the measurement of the feed stream into the flare. From this information, calculations and records of predicted emissions can be made. Unfortunately, emissions monitoring is still an inexact science and plants can sometimes be penalised by reporting stations or calculated emissions estimates, even when the flare system is operating within specifications.

Controlling the inputs into the system is the best way to ensure 98% or better DREs, even when the flare is in standby or low flow condition. Using staged gas inputs, staged steam, variable air controls and multiple methods of monitoring in combination can appreciably reduce emissions, lengthen equipment life and reduce flare gas flow rates necessary for smokeless operation.

Technological developments and a heightened awareness of VOC emissions monitoring will continue to change current environmental regulations, meaning facilities may need to put more emphasis on ways to efficiently meet regulations sooner rather than later. 