Today’s process industries expect more from flare systems than ever before. Chemical and petroleum processing plants depend on flares to burn hydrocarbons, such as propane, propylene, ethylene, butadiene, butane and natural gas, found in waste gases. Landfills and wastewater treatment plants, oil-and-gas exploration and production facilities, and loading terminals also use flares to destroy potentially harmful gases.

In each case, the flare system must separate the gases from any liquids present, ignite the gases, and provide the stable combustion necessary for destruction, while minimizing smoke, thermal radiation and noise. And, it must operate reliably and safely under a wide range of operating conditions, including weather extremes.

With a greater demand for increased smokeless capacities, higher turndown and more-efficient plant production, a flare failure can carry a big price tag. Factor in the essential role flares play in the safe and environmentally acceptable disposal of waste gases produced from industrial operations (1, 2), and it’s easy to understand why processing industries can benefit from flare testing as a safeguard against unexpected problems in the field. Testing a flare before installation is a proactive measure to minimize the uncertainty of flare performance, emission levels, and the expense of repairs in the event of a problem.

But testing flares in the field is generally difficult or impossible for several reasons. Operating flares usually do not have the instrumentation required for assessing performance. Operating conditions are not easily modified or controlled, and taking the plant off-line to test the flare is impractical. In addition, flares are nearly impossible to test under critical design conditions once installed.

Characterizing flare performance for reliability and safety requires comprehensive, accurate testing at full-scale and under controlled conditions to collect and analyze critical data. Although flare performance might be estimated based
on scaled-down experimentation and empirical data, industrial-scale testing is the most reliable method due to the complexity of the process. While testing custom-designed burners for process heaters has been common for decades, that has not been true for large industrial flares, primarily due to the lack of adequate testing facilities. With the advent of state-of-the-art flare test facilities, large-scale flare testing is recommended to ensure proper performance.

**Advanced flare testing**

Just as flares have evolved into modern-day, technology-based systems, flare test facilities must also mature into state-of-the-art, full-scale operations, offering extensive capabilities with sophisticated tools and instrumentation. While flare manufacturers view these flare test facilities as the vehicle for developing cleaner, more-efficient flare innovations, global industries and environmental agencies recognize them as a valuable resource to measure flare performance, system reliability and environmental compliance.

In the past, industry lacked the ability to test flares in a comprehensive manner. Today’s test facilities (such as in Figures 1 and 2) should offer industrial-scale testing and measurement of smokeless capacity, required purge rate, blower horsepower or steam requirements for assisted flares, radiation and noise. To properly characterize flare performance, a test facility must have the capability and flexibility to evaluate a wide range of ground, enclosed and elevated flares, including a variety of flare sizes, operating conditions at full-scale, fuel compositions, flowrates, assist media and other factors. Advanced flow control and data acquisition systems are required to control the tests and ensure accurate measurements.

Safety is one of two critical features of a world-class flare test facility. In addition to in-plant safety protocols, equipment safety features and trained specialists, a test facility should include exhaustive, redundant safety measures within its controls, automation software and operating procedures to protect against potential problems.

The second critical feature is flexibility. A test facility should support a wide range of fuel flowrates and test fuels, such as propane, propylene, ethylene, butane, natural gas, and blends of these, including inerts such as nitrogen. Higher flowrates can be achieved with a storage vessel filled with fuel
gases at an elevated pressure to increase the available hydraulic capacity. A compressor can circulate the gases in the storage vessel to ensure that blends are well-mixed. The fuel flows should be accurately controlled and measured before going to the flare. Multiple metering runs of different sizes can significantly increase the available flow range. Between tests, the lines should be purged with an inert gas for safety and to prevent fuel contamination in subsequent tests.

A test facility should offer a variety of flare testing venues to accommodate virtually every flare size and type used in industry. In Figure 2, flare-testing venues are in place to test enclosed flares, multi-point ground flares, air-assisted flares, steam-assisted flares, high-pressure flares, and flare pilots.

A facility should have the capability of testing flares with capacities up to 300,000 lb/h or more of fuel. Flare-pilot test stands should be capable of simulating wind speeds in excess of 150 mph (blowing against both the pilot and the pilot mixer) and rain at more than 30 in./h (3).

Because many flares use some type of assisting media, typically steam or air, to meet the specified smokeless capacity, a test facility must be able to provide adequate quantities of both media. For flares that do not require any assisting media, such as high-pressure flares, the facility should be able to produce the higher gas pressures encountered in those applications.

Test parameters

Depending on the information required, the variables typically measured during a flare test include flame length, smokeless capacity, blower horsepower for air-assisted flares, steam consumption for steam-assisted flares, and cross-lighting distance for multi-point flares. Two types of measurements are taken — inputs and outputs.

Inputs are the controlled parameters set by the test objectives. These include, for example, the gas flowrates, fuel pressures and compositions specified by the test protocol. For assisted flares, the steam or air flowrate to the flare is generally controlled for a given test point. Atmospheric conditions (wind speed and direction, ambient temperature and pressure, and relative humidity), while not controllable, need to be measured because they may have a significant effect on flare performance.

Outputs, on the other hand, include noise, thermal radiation, flame stability, smokeless capacity and flame quality. Some of these measurements (e.g., flame stability) are subjective and require the expertise of qualified engineering staff, while others (e.g., noise) can be measured with appropriate instrumentation.

To ensure data accuracy and to minimize testing costs, the facility’s flow control system must be capable of reaching the target flowrate very quickly and maintaining that rate. This is best accomplished with automatic controls (Figure 3). Because a wide range of flows may be tested — from purge rates up to the maximum hydraulic capacity of a large flare tip — multiple sets of flow metering and control runs are recommended to ensure accuracy and controllability for both extremes.

Thermal radiation

Thermal radiation is one of the most important considerations in flare design. Stack height is often chosen so the flare is tall enough to meet certain radiation heat-flux criteria at specified locations. Effective tip design, however, can have a tremendous impact on the radiation characteristics of a flare, as it can reduce the radiation fluxes from the flame and make it possible to use a shorter flare stack, which reduces the cost of the flare system.

To test a flare’s radiation flux, multiple radiometers (Figure 4) are recommended to measure the radiation field, which is typically non-uniform due to wind effects and varies with distance from the flare. Through sophisticated mathematical analysis, the measured radiant fluxes can be used, as part of an array, to determine the radiation field from a flare.
used to determine the coordinates of the effective epicenter of the flame and the radiant fraction (i.e., the fraction of heat released from combustion that is emitted as thermal radiation).

Numerous calculation methods have been proposed for estimating the radiation from a flare. Predictions can vary over a wide range, depending on which model is used and what assumptions are made (4). Overestimating radiation results in a flare stack that is taller and more costly than necessary. Underestimating radiation means the radiant flux at the ground will be higher than desired, which may be dangerous to personnel and equipment in the area during a flaring event.

Figure 5 is a plot of constant radiation lines (isoflux lines) at ground level for a high-pressure flare test. This plot was generated using measurements from an array of radiometers positioned at various distances and angles from the flare.

Noise

Noise from a flare must be adequately controlled to protect personnel in the vicinity of a flare event. To study the effects of noise from flares, a test facility requires a sound measurement system that includes multiple microphones, such as the one shown in Figure 6. The duration of measurements, microphones, type of data recorded, and
type of spectrum analyzers used are among the numerous conditions that can be varied for noise testing.

Figure 7 illustrates the sound pressure data recorded by two microphones at different locations during a typical flare test. The spikes at 0 s and 10 s are not related to flare noise, but represent noise from the safety horn alerting personnel in the area of an impending flare test. In this example, there is a rapid rise in the sound level at the start of the test, followed by a steady decline as the fuel flowrate is reduced according to the test plan.

Collecting accurate data for measurement and analysis requires a sophisticated data-acquisition system. In the control room pictured in Figure 8, three time-synchronized computers capture critical test information, which is recorded on a single test record. The first computer collects general data, such as ambient conditions, fuel temperature and flowrates, tip pressure, radiation fluxes, and locations of radiometers and microphones. Another computer records digital video from multiple cameras strategically positioned at various locations, while the third computer records noise data.

A new era in problem-solving

In the past, flares have been designed using semi-empirical and simplified analytical models that can sometimes produce less-than-optimum results. This has primarily been due to the inability to gather comprehensive experimental data from industrial-scale flares and the lack of industrial-scale flare testing capabilities. Today, industrial-scale test facilities should provide important data for greatly improving flare design and in-field performance of existing flares.

The quest for flare knowledge has taken many leaps forward with the advancement of these test facilities, and hydrocarbon and chemical processing industries will benefit from this progress. Through a better understanding of combustion science, full-scale testing and real-world simulation, cleaner, more-reliable flare performance can stay a step ahead of industry requirements.

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**Literature Cited**