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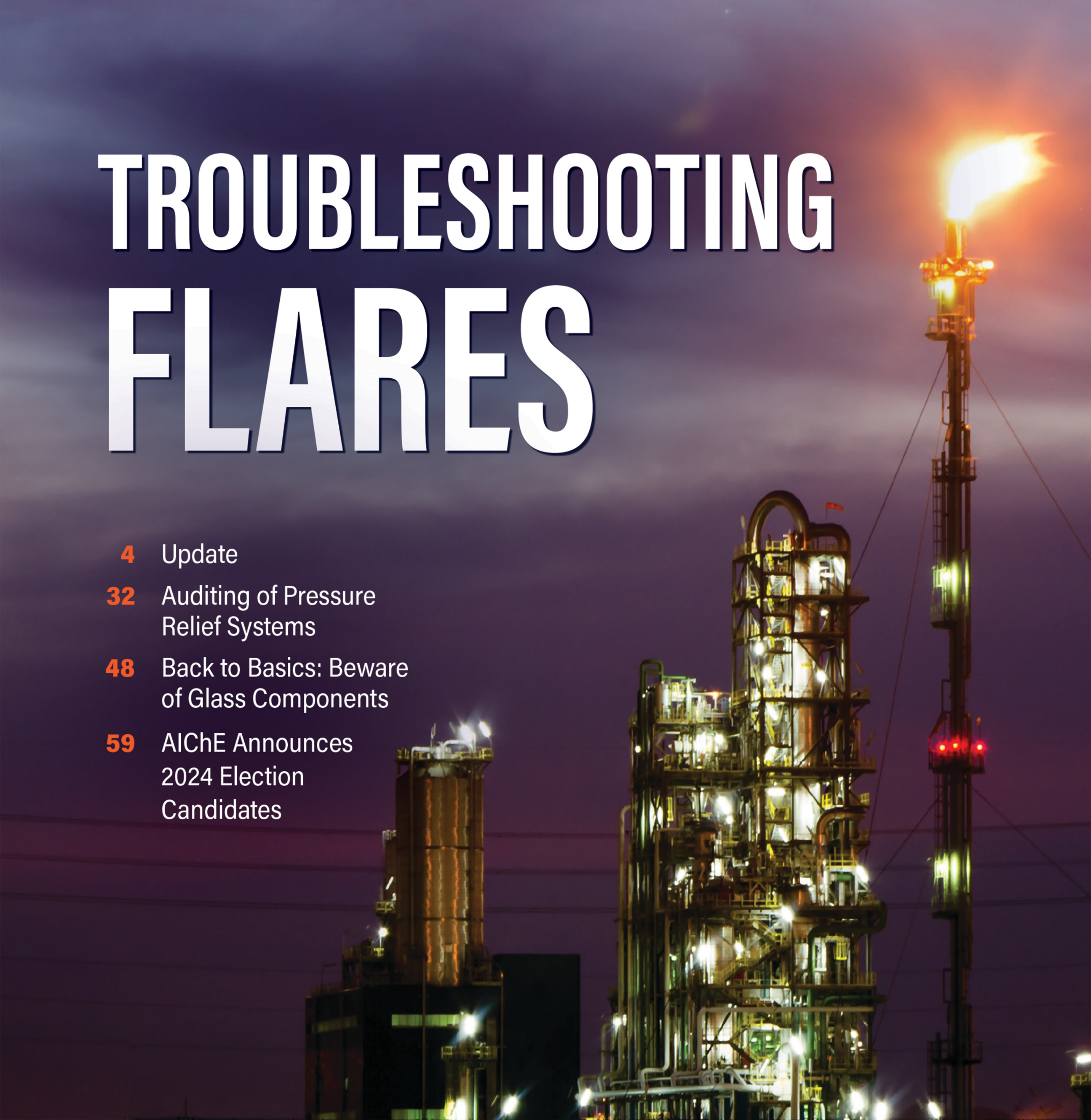

TROUBLESHOOTING FLARES

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Improve Performance of Steam-Assisted Flares

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Steam-assisted flares can be prone to troublesome issues. Ensuring a high-quality steam supply is an important step in mitigating these problems.

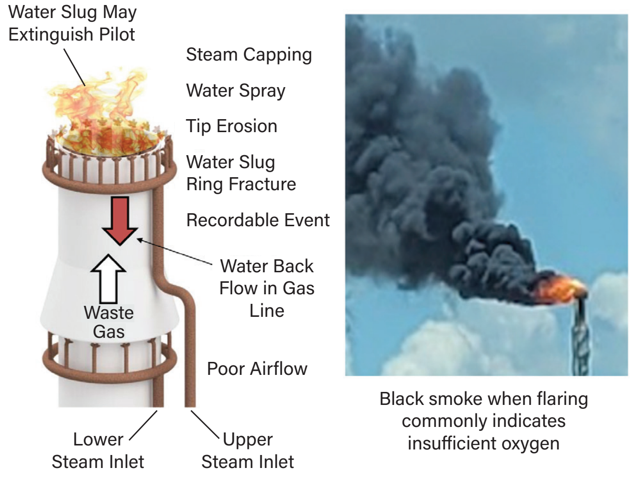
Flare systems are important safety and environmental systems for refining and petrochemical plants, and many of these facilities use steam-assisted flares to protect the flare tip and promote smokeless burning.

The primary goal of steam-assisted flares is to achieve complete and rapid destruction of the flare gas stream; much supporting design information is available that supports this goal. However, most of these guidelines relate to the handling of the gas stream and not the steam. This is unfortunate, because many reliability issues and incidents can be mitigated by improving the design of the steam system and the quality of the steam that is supplied to the flare (Figure 1).

Steam performs a variety of supporting actions that are critical to the overall combustion process. For example, steam promotes air induction and turbulent mixing with the gas stream, increases the waste gas momentum, and provides a more readily combustible mixture to the pilot flame. Steam enables lower temperature burning and facilitates a smokeless exhaust from optimal fuel and air mixing, which mitigates formation of the hot carbon/soot. It also acts as a cooling medium at the tip of the flare, protecting some components from overheating and damage. Even though steam is so important, it is often overlooked, which can lead to the reliability issues shown in Figure 1.

Two common factors that cause flare incidents are slugs from ineffective condensate removal and/or poor quality/wet steam from lack of moisture disentrainment. These two common factors, as well as a few other steam-related issues, can cause a host of problems in flares, such as:

- tip and ring erosion (from slugs or entrained water)
- improper or lack of precise steaming control (generally from slugs)
- flare-outs (caused by slugs)



Black smoke when flaring commonly indicates insufficient oxygen

▲ **Figure 1.** Troublesome issues can occur at multiple locations on a flare system, and condensate can be the cause.

- tip damage (caused by slugs or entrained water)
- smoke (caused by poor air mixing, poor burn)
- steam capping (caused by excessive steam flow)
- pipe damage (caused by slugs)
- water backflow (caused by poor condensate drainage)
- ring fracture (caused by slugs)
- falling ice (caused by condensate being discharged/ pushed through the tips and freezing).

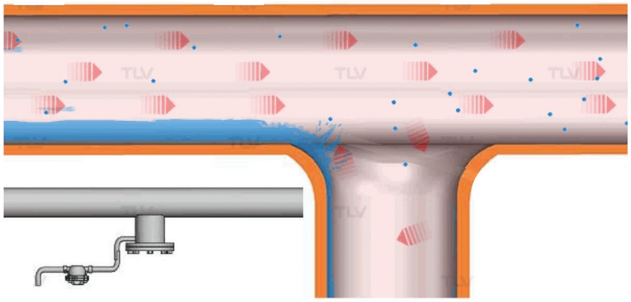
Many reliability issues associated with steam-assisted flares can be mitigated by incorporating some of the recommendations presented in this article, which will help improve the site's steam system quality.

Steam quality

Facility operators and engineers understand the importance of having optimized flaring capability, so you may be wondering why steam-assisted flares are not always kept in the best condition. Many of these systems are remote, so it may often be a case of "out of sight, out of mind." Or, the impact of less-than-optimal steam supply may not be understood. Often, operators believe that the steam in their systems is superheated or saturated and they do not understand that there may be wetness in the steam system *(1)*. If not superheated, steam contains substantial moisture that must be disentrained and drained. It is that moisture that causes many of the reliability problems mentioned previously *(2)*.

Steam lines transport this undesired condensate byproduct in two basic configurations: entrained in the steam flow, and disentrained and running along the bottom of the pipeline (Figure 2).

The condensate entrained in the steam flow can cause erosion along the entire system (especially at the flare ring or tips), affect flame control, and cause freezing after the condensate is discharged from the tips. Ice that forms on the flare itself can pose a significant safety concern in freezing climates (Figure 3). Pools of condensate flowing along the bottom of the pipe can create water hammer in the utility lines, and can cause flare-outs, smoke, erosion, and significant physical damage to the flare ring and tips. It is not uncommon that a flare ring can be knocked to the ground from water hammer created by high-velocity slugs.



▲ **Figure 2.** All steam systems can have condensate flowing along the bottom of the pipe, and entrained moisture is expected in flowing wet steam supply.

In addition to these operational concerns, there is the added necessity of adherence to U.S. Environmental Protection Agency (EPA) Title 40, Section 63.670, which requires monitoring of the flare system's net heating value to prevent over-steaming, which can create a dangerous issue known as "steam capping" *(3)*. Steam capping can push burning flames down onto the flare tip to the point of excess heat causing severe damage to the flare.

A key reliability-focused recommendation for optimal quality in steam-assisted flare steam supply is to design and maintain adequate disentrainment separators as well as proper condensate discharge locations (CDLs).

Capturing and discharging condensate. To remove the condensate that has already been disentrained from the steam, facilities design and install appropriate CDLs with associated piping, steam traps, strainers to filter out dirt, and valve components needed for draining condensate out of the system (Figure 4). If not drained, this condensate can accumulate to a large amount of liquid mass that can be propelled at rapid speed downstream by steam, with velocities exceeding 100 mph.

CDLs should be located every 100 ft to 150 ft apart on horizontal runs at a maximum distance, and at the base of all vertical risers *(4)*. In addition to installing adequate CDLs, whenever the flare steam supply is not superheated, it is recommended that a separation system to disentrain moisture from wet steam is located before the steam enters the control valve station. Control valve station considerations are discussed in more detail later in the article.

Reducing risk

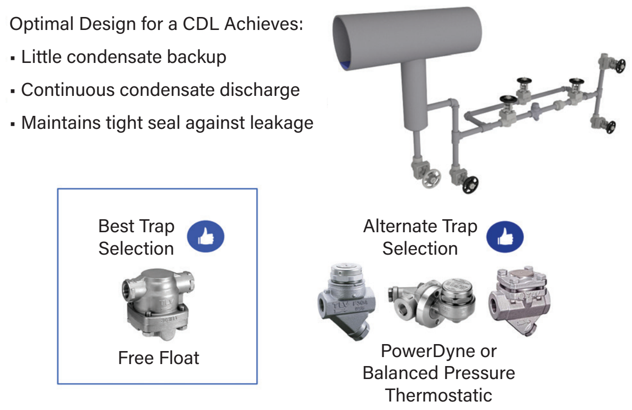
It is possible to reduce the chance of failure events by incorporating the principles of American Petroleum Institute (API) Recommended Practice (RP) 581 into a steam system

▲ **Figure 3.** Ice formation at the top of a flare can be evidence of excessive condensate in the steam supply; it creates a safety hazard that should be mitigated.

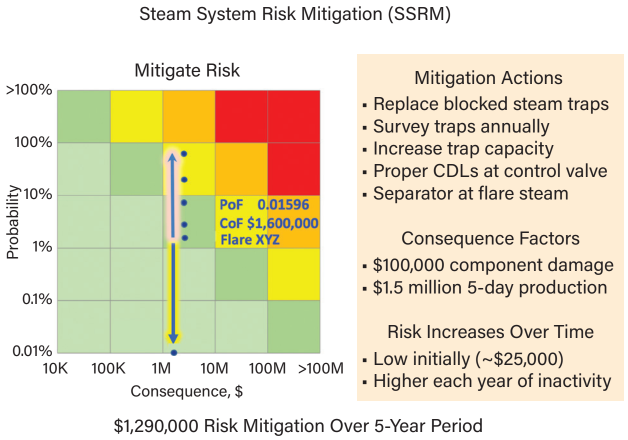
risk mitigation (SSRM) matrix. Such a matrix charts probability of failure (PoF) on the y-axis and consequence of failure (CoF) on the x-axis (Figure 5) *(5)*.

For the example shown in Figure 5, the CoF factors show a potential loss of $1.6 million for a failure event. The CoF remains constant unless the system design is modified. However, the PoF can be reduced by proactive planning and effort.

For example, although the risk at initial analysis may have a low PoF factor of 1.5% (0.01596), risk can dramatically increase over time should no preventive maintenance be done. The current risk at the time of inspection may be low, equal to around $25,000 (PoF × CoF, 0.01596 × $1.6 million). However, should no action be taken to sustain the system to an optimized operating condition, the PoF increases to 80% over a five-year period, and the risk increases to almost $1.29 million (0.806 × $1.6 million). In this instance, the risk was evaluated and estimated based on historical data of comparable flare systems experiencing similar poor and deteriorating condensate drainage and disentrainment conditions. The recommended mitigation actions shown in Figure 5 reset the PoF to 0.01%.



▲ **Figure 4.** Best practice involves proper collecting leg and condensate discharge location (CDL) design, and appropriate steam trap selection and size.



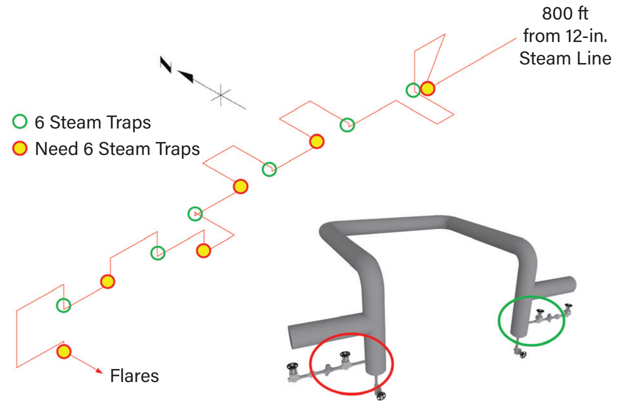
▲ **Figure 5.** If a steam system is not maintained regularly, the probability of failure (PoF) increases exponentially. Taking mitigation actions can help lower the PoF.

Another way to consider the risk abatement is by understanding that if a car's engine oil is changed using full synthetic oil every 5,000 miles, the chances of engine failure are slim. However, over time, if the oil is not changed for 50,000 miles, then the PoF for motor failure is much more likely. In both instances, the CoF remain virtually unchanged — *i.e.,* the cost of a new engine. But taking preventive maintenance with regular full synthetic oil changes mitigates the risk of engine failure dramatically. Owners are accustomed to the importance of regular oil changes for a car, and the same importance applies to site assets such as flare systems.

Best practice design

The best time to consider condensate drainage for a steam-assisted flare system is during the design phase. Consider someone building a new home — the best time to decide the size, number, and efficiency of the windows to be installed is before the home is built; after the home is constructed, it is much more costly to upgrade or change those items. The same principle applies to flare steam supply lines.

Consider the flare supply line shown in Figure 6. In this example, multiple CDLs are missing from what would be considered a recommended practice design. In multiple vertical rise locations, CDLs were not installed. Additionally, many of the tested traps had failed in some manner, with blocked traps being the worst case of failure, and many were undersized *(6)*. Because so many steam traps were missing or undersized — and the CDLs were located too far apart (as much as 350 ft) — the steam supply quality could not be optimized, and this flare system suffered from significant reliability issues.



▲ **Figure 6.** CDLs, which include steam traps, should be located at the base of all vertical risers and every 100–150 ft on horizontal runs. It is not uncommon that CDLs are missing on the downward side of expansion loops.

The expense to install a flare system is significant, so it is unfortunate that some installations cut corners with the collecting leg design, CDL installation, and trap selection that are so necessary to maintain high steam quality. The best practice is to design proper collecting legs with optimized condensate drainage capability *(4)*.

As a separate note of caution and consideration, it is common that some steam supply lines to flares have the piping run very close to grade. While this may reduce capital cost during the original installation, it precludes adequate collecting leg design and effective condensate drainage. Flares supplied from low-level steam supply lines can experience significant wetness, and while it is possible to mitigate, it can take a substantial effort to improve the condensate drainage. It is far better to have the steam supply line elevated above grade substantially enough so that effective collecting legs and CDLs can be installed for all ranges of condensate load, flow, pressure, steam quality, and velocity.

▲ **Figure 7.** When flow velocity is high, it is unlikely that condensate will be captured by this small pocket, nor drained by the horizontal take-off located too close to the main line.

Another issue occurs when the collecting leg diameter (*i.e.,* the pocket) is too small or when the horizontal take-off from the vertical collecting leg to the steam trap is located too close to the supply line (Figure 7). Both practices reduce the condensate collection volume of the CDL below an acceptable level.

Wide range of pressure, condensate load, flowrates, and velocity

When the flare is idle, the steam line pressure downstream of the control valve is often very low, approaching atmospheric pressure and sometimes vacuum. This low line pressure can make it difficult to drain condensate through a steam trap during ramp-up, when the initial pressure differential across the trap to the discharge area is almost zero, but the condensate load is high. Tables 1 and 2 highlight some of the challenges for trap selection.

The normal condensate load from radiant loss may be quite low but increase ten to forty times during ramp-up, as the piping mass condenses a great amount of steam when rapidly brought up to flaring temperature. This requires careful trap selection — the CDL and trap must be able to handle the wide range of load and pressure conditions required for effective and rapid condensate removal from the steam line.

Steam flow during flaring can increase over 100 times compared to a normal idle condition (Table 1). It is essential that the steam line is designed to sustain effective condensate removal from the steam header for all conditions — with proper CDL components, sizing, and trap selection.

Article continues on next page

Table 1. During the ramp-up process, the condensate load can be many times greater than the normal load. In addition, the CDL distance is too far apart in three areas in this example, indicated by the text in red.

Steam line, in.	Length, ft	Normal Radiant Loss Condensate Load, lb/hr	Ramp-Up Condensate Load, lb/hr	Current Number of CDLs	Distance Between CDLs (average), ft
12, Header	1,760	458	5,280	7	251
8, Lower	810	67	2,820	11	74
8, Upper	810	67	2,820	5	162
8, Center	810	40	1,125	5	162

Table 2. A velocity of 1.7 ft/sec cannot sustain superheat. In all four areas, the maximum flowrate and velocity can push condensate past the CDLs, indicated by the text in red in the last column.

Steam line, in.	Length, ft	Normal Flowrate, lb/hr	Normal Flowrate Velocity, ft/sec	Max Flowrate (Flaring), lb/hr	Max Flowrate Velocity, ft/sec
12, Header	1,760	2,300	1.7	140,000	132
8, Lower	810	800	15	89,150	189
8, Upper	810	1,000	19	80,000	169
8, Center	810	5,000	37	5,000	41

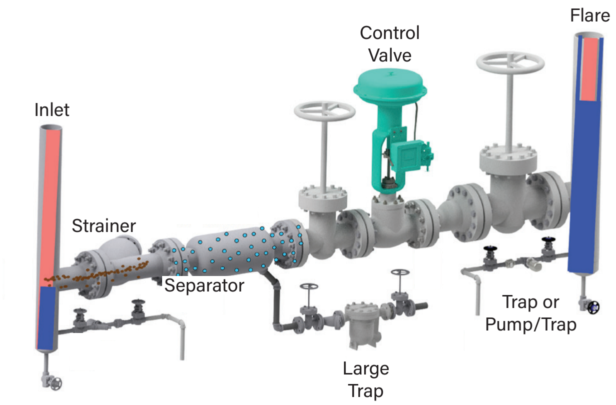
An additional consideration while idle is that the velocity may slow to the point where superheat can no longer be sustained in the steam flow. This occurs by transfer of heat to the piping system, which acts as a heat sink. When this occurs, the increase in condensate load can be substantial and the system should be evaluated for effective drainage.

Control valve station considerations

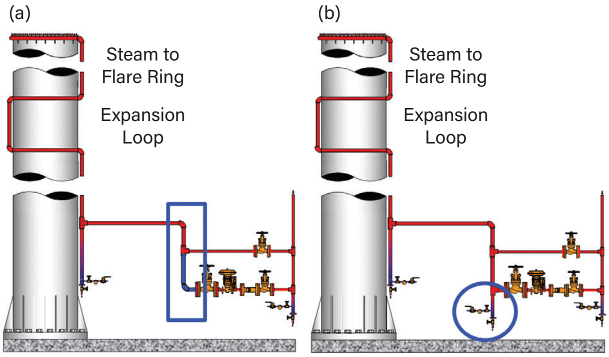
Many existing control valve stations provide opportunity for localized improvement during a revamp (and/or new design) action. Recommendations include effective condensate drainage for the wide range of pressures and condensate loads, as well as strainer and separator installation that can handle the high flowrates expected. A generic example of one possible flare control valve station configuration is provided for overall visualization (Figure 8). It is notable that some of the steam traps used are substantially larger than standard main line drip traps.

Careful drainage design consideration should be given to condensate downstream of a control valve at the base of the riser (Figure 9). Due to very low pressure during idle conditions, which sometimes can be in vacuum, condensate can fill the downstream leg and be propelled up the vertical supply to the flare tips during ramp-up (Figure 9a). A rapid upshot of condensate to the flare itself can be very destructive and damage the flare ring and tips.

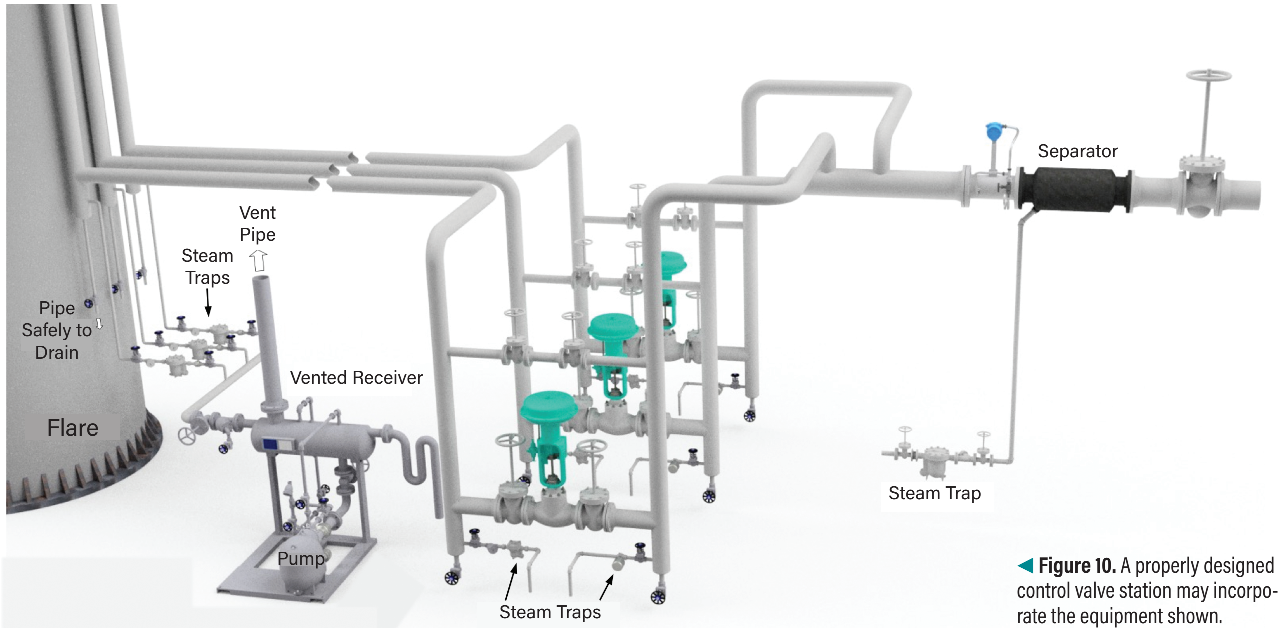
Some manufacturers can provide trap, pump, or pump/trap recommendations for this location at the base of the riser to reduce the chance of hammer and erosion at the flare (Figure 9b). A recommended mitigation practice is to



▲ **Figure 8.** At a minimum, proper location and sizing of CDL at the steam inlet, separator drain, and flare upward supply locations should be considered for all flare control valve installations.



▲ **Figure 9.** (a) Pooled condensate downstream of a closed control valve can cause significant damage upon valve opening. (b) A best practice is to ensure a stream trap or pump/trap device is installed downstream of the control valve.



◀ **Figure 10.** A properly designed control valve station may incorporate the equipment shown.

carefully consider the wide pressure range downstream of the control valve during all periods of idle, ramp-up, and flaring, and select a drainage device carefully. A detailed example of a control valve station configuration is provided in Figure 10.

Poor steam trap practices cause issues

When considering all the piping, supports, and other equipment that go into the installation of a flaring system, it can be difficult to imagine that simple steam traps can have a dramatic effect on the system's performance. However, many damage incidents or poor flare performance can be attributed to an improper design and/or failing health of the steam traps installed in the line.

▲ **Figure 11.** Improper steam trapping is at least part of the cause for the pond that formed beneath this flare.

▲ **Figure 12.** Generally, trying to uplift condensate to a steam trap will create a steam lock; this type of improper installation should be avoided.

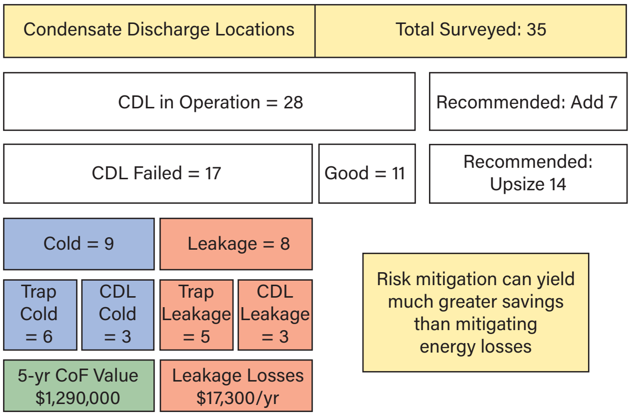
Figure 11 shows one such issue with a pond evident at the base of a flare, a result of condensate spillage from the flare tips. The circle shows three installed steam traps of proper size and type selection. The question then arises, why is the condensate not being effectively drained? Figure 12 shows a close-up of the installation and provides the answer — condensate is being uplifted to the traps, and this creates a steam lock condition *(6, 7)*.

When condensate must rise vertically to reach the steam trap, a steam lock occurs after condensate is discharged through the trap and the vertical line (and sometimes the horizontal line before it) subsequently fills with steam. The steam-filled section holds back condensate and locks the trap shut. That steam must dissipate before any additional condensate can enter the trap. Without an outlet for drainage, condensate in the steam supply line moves downstream of the CDL.

Mitigation, valuation, expense, and budget

Whenever steam traps are discussed, the common thought process is to consider the energy loss associated with leaking traps, and this can become the focus of valuation to determine repair priority. However, leaking traps are still performing the critical function of condensate drainage. Yes, energy loss occurs, and the leakage can lead to hammer in the condensate header — which should be avoided — but prioritizing leaking traps misses the greater issue of cold or blocked traps, which are not draining condensate. Lack of drainage tends to be a much higher cause factor for system damage in a steam system, so the repair of blocked and cold traps and those CDLs where the traps are "valved out" (isolated) should be of the highest priority in most instances *(8)*.

Consider the flare system in Figure 13. If only leaking traps are repaired, the mitigated energy loss is estimated at $17,300 annual savings. However, risk mitigation analysis determines that adding seven CDLs, repairing 17 CDLs,



Condensate Discharge Locations
Total Surveyed: 35

CDL in Operation = 28
Recommended: Add 7

CDL Failed = 17
Good = 11
Recommended: Upsize 14

Cold = 9
Leakage = 8

Trap Cold = 6
CDL Cold = 3
Trap Leakage = 5
CDL Leakage = 3

5-yr CoF Value $1,290,000
Leakage Losses $17,300/yr

Risk mitigation can yield much greater savings than mitigating energy losses

▲ **Figure 13.** The potential benefit of mitigating energy loss from leaking traps is often much lower than the value of risk mitigation.

upsizing 14 steam traps, and increasing the collecting leg diameters on the main 12-in. header can be estimated to provide a $1.29 million CoF avoidance benefit over five years, while providing much more reliable flaring. Risk mitigation can provide significant opportunity over simple energy loss consideration.

It is unclear why some sites do not sustain proactive optimization of the total steam trap population. When repairs to the steam trap population are necessary, consider that the implementation of a functional steam trap system can lead to an internal rate of return (IRR) that exceeds 112% *(9)*. Separately, flares are so crucial to plant operation that the steam traps associated with flare performance should be designated as "safety critical" or "very critical" and their condition evaluated more than once per year.

Closing thoughts

The best opportunity to achieve an optimized steam-assisted flaring system is during original design and implementation, but shutdowns and revamps also provide a chance for significant improvement where needed. To increase the reliability of steam-assisted flare systems, follow these best practices:

- sustain a high-quality steam supply
- install proper CDLs and collecting legs
- choose the correct trap for the application, and size and install it as appropriate
- implement a separator before the control valve
- design for low-pressure differential issues during ramp-up
- design for high loads during ramp-up
- design for high velocities during flaring
- install pumps and pump/traps where needed
- sustain the drainage capability of CDLs.

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