White Paper

Improving the Sustainability of Steam Production

EMERSON

Introduction

Steam leaking to the atmosphere is not considered a pollutant, but fuel burned to generate it creates emissions. Petrochem plants must tighten up steam production and use.

To begin this discussion, let's ask a very basic question: Why do petrochemical plants (Figure 1) have steam distribution systems? It's because steam is a very versatile means to deliver energy, both as a motive fluid and through heat transfer, and it can be applied in a variety of ways and carefully controlled. There are large installations, such as steam turbines that use steam as a motive fluid, but in most plant environments, there are far more applications where steam adds heat to a process via a heat exchanger. It could be shell-and-tube, plate, jacketed reactor, or other configurations, but the purpose is to raise the temperature of a process fluid, either liquid or gas. A leading example is steam feed to cracking furnaces, a critical conversion process in petrochemical plants.

Figure 1. Petrochemical plants that produce bulk intermediates, such as ethylene, use steam for countless heating applications in multiple production units.

Using steam for such purposes is desirable because it avoids the need for numerous small combustion or electric heaters attached to all those heat exchangers. Using steam allows the boilers, or other heat source, to generate steam in a central location away from explosive environments, and then distribute it wherever it's needed. While handling steam has its own safety concerns, it is better than having all those heaters scattered around a facility. On the other hand, a large application, such as a main distillation column, will be supported by its own heat source, such as a fired heater. For now, we'll concentrate on smaller installations that are connected by the steam distribution system.

Heat Exchangers in a Petrochemical Plant

Figure 2. With a typical shell-and-tube heat exchanger, steam (red arrow) enters the shell and heats the process fluid in the tubes. Normally, it is designed to condense during these processes and leave the equipment (blue arrow) as condensate.

Steam will form condensate when it is introduced to the process and gives up its latent heat. At the same time, in most applications, live steam should not exit the heat exchanger because the heat is not transferred when this occurs. This isn't always the case, but at some point, steam condenses back to water after losing its heat.

Once steam has condensed back to water, it must be removed from the steam system. Normally, it is returned to the boiler via a condensate-return system, and then fed back into the boiler as feedwater. Since boiler water is heavily treated, as much of it should be recycled as possible. It is also desirable to keep it hot so the boiler will need the least heat to turn it back into steam, resulting in less energy use and reduced emissions. Separating condensate from live steam is the job of properly designed steam systems and steam traps (Figure 3). How well steam traps perform has an enormous influence on the efficiency and sustainability of an entire steam distribution system.

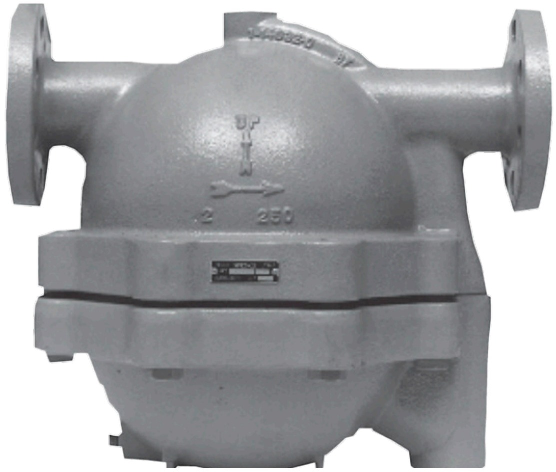

Figure 3. Steam traps, such as Emerson's Yarway Float and Thermostatic product family, serve applications where drainage is essential.

Steam traps remove condensate during operation of the steam system, and there are many discussions regarding their use, most of them focused on maintenance-related issues. Steam trap service is harsh, so when units have served for a certain amount of time they often fail. Therefore, they must be checked frequently to ensure they are operating correctly. This is a valid discussion as far as it goes, but it misses critical elements of overall sustainability. By digging deeper, we will see the picture in its full complexity, including the extent to which steam traps affect operations.

Condensate always needs to be removed from steam systems, however there are system designs that allow for the use of the heat that remains in the condensate. Condensate in a high-pressure steam line will have a high enough temperature to flash into steam if it reaches a point where the pressure drops enough to change the boiling point. Condensate carries a great deal of heat itself, so not using that energy in the condensate also wastes energy. Systems can be designed to pull out the energy from the condensate by using pressure cuts on this high energy condensate. Cascade systems can be used to pull energy from the condensate, which can be used for lower pressure steam applications.

Studies suggest that normal life expectancy for a steam trap is four to eight years, depending on the application, so in a large-scale petrochemical plant, it's common to have 25% of all installed units fail in a given year. A typical ethylene complex can have several thousand steam traps, so if steam trap maintenance is not kept up to date, the negative effects can be huge.

Steam Traps Behaving Badly

Steam traps are placed strategically throughout steam distribution systems to remove condensate. As described earlier, this may be associated with a specific heat exchanger or other piece of equipment. It may also be at a low point in the piping where condensate tends to accumulate due to gravity. Whatever the case, steam traps are designed to release water without losing live steam. They must be able to open to downstream pressure, while maintaining the steam-line pressure.

Steam system designs assume all traps are functioning normally all the time, which is not always the case. Since they have an internal valve mechanism with moving parts, they can malfunction in two ways.

First, some do not seal completely or can fail open, allowing condensate to sputter out, while also releasing live steam. According to a U.S Department of Energy survey, 5-20% of steam traps fail annually in this manner, with the percentage of steam lost through trap opening equal to 33-50% of line capacity, which is very costly. We'll examine this in more detail momentarily.

This condition can also cause issues in systems where condensate is being returned. Some systems use a collection tank to gather condensate from multiple traps, while others use a closed system with multiple steam traps feeding into a header.

Injecting live steam into a closed system can be a problem if it can't handle the pressure. Pressurizing the outlet side of a steam trap can cause it to malfunction and not release condensate as it should, multiplying the effect to all the steam traps connected to the header. This can be a common problem when steam traps are leaking live steam through the traps, as shown in Figure 4A.

Second, some mechanisms get stuck closed. Condensate then accumulates and does not release at all, backing up into the steam line (Figure 4B). This has different effects based on the steam trap's location. If it is attached to a heat exchanger, eventually it will fill with condensate and block steam flow, which can lead to heat exchanger stalls. Heating of the process fluid will slow and perhaps stop entirely if not corrected, which should be detectable via the process automation system. How much damage to the process this causes depends on the overall criticality. Accumulated condensation in the steam pipe distribution system can also cause water hammer, leading to pipe erosion and cracks, and/or accelerated corrosion.

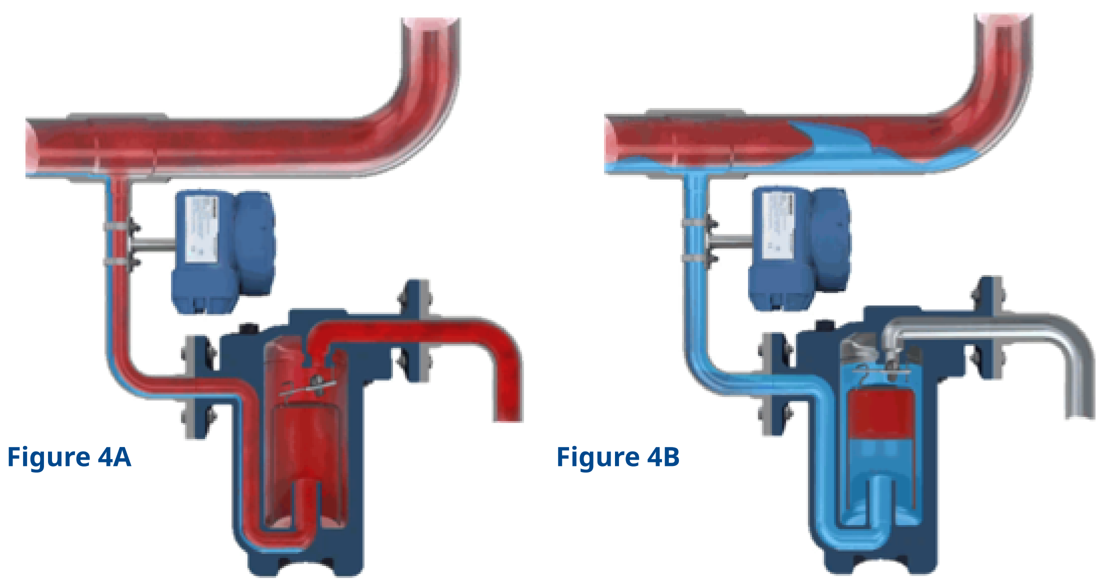

Figure 4A. When a steam trap fails in the open position, hot steam, shown in red, leaks
Figure 4B. When a steam trap fails in the closed position, condensate, shown in blue, accumulates

Similarly, if the steam trap is at a low point in the piping, slugs of condensate can be carried with the steam and cause equipment damage downstream. Water hammer effects can be particularly troublesome.

Effects on Sustainability

The two conditions just mentioned both affect sustainability adversely, but in different ways.

Steam loss, due to a failed-open steam trap, is a link in a direct energy loss chain. The boiler must work that much harder to make up for the loss, so it consumes more fuel and creates more emissions. Most boilers burn fossil fuels, either oil or natural gas. Even those that burn some type of process off-gas or low-value byproduct are burning a fossil fuel, since everything in the petrochemical industry ultimately stems from a fossil source, all of which create emissions. Leaking steam can also lead to a shortage, which can sometimes require additional boilers, leading to even more emissions.

Discussions of steam leaks from steam traps and elsewhere in the system usually point to the costs of additional fuel required to make up for the losses. There are formulas that help calculate this cost to illustrate the point, and the numbers are often alarming to plant managers. This is a valid point, but it needs to go a step further and examine the corresponding increase in the carbon footprint of the facility.

For example, a typical 1 MT/year ethylene plant uses ethane as the primary feedstock, with roughly estimative of steam required to produce at least 2.5MMBTU annually, but typically closer up to 3.2MMBTU due to boiler inefficiencies. If steam traps are inspected every other year instead of being continuously monitored, and thus forced to use reactive instead of proactive maintenance, then an additional 0.075 MMBTU/Year is needed to compensate for steam losses. Most of this surplus steam use could be avoided by implementing continuous steam trap monitoring and proactive maintenance, potentially reducing CO2e (equivalent) emissions by about 3,500 tons/year, and resulting in $300,000/year in overall savings due to reduced steam leaks.

The problems caused by failed-closed steam traps are more subtle. Discussions around this topic tend to emphasize hazards caused by slugs of water shooting through the steam system and causing damage to equipment. When water hammer occurs in heat exchangers, it can cause damage, often requiring shutdowns for maintenance and repairs. This is certainly relevant, but it misses another critical element: overall loss of process efficiency that also contributes to increased carbon footprint.

Consider the heat exchanger example mentioned earlier. If the steam trap supporting that heat exchanger is stuck closed, either due to malfunction or over-pressurization of the condensate recovery system, steam can't flow through the heat exchanger in sufficient amounts to deliver the heating step that the process needs. Perhaps some steam is flowing, but condensate is backed into the heat exchanger, reducing the amount of working exchange surface area. Whatever the situation, the process fluid is not being heated sufficiently. Operators observing the effect in the control room may assume it is caused by fouling (Figure 5) because the results are similar. The effect on the process of such a situation can't be good:

- Some other heating stage of the process may have to make up the difference
- A reaction rate will be slowed and made less efficient
- Distillation will be less effective

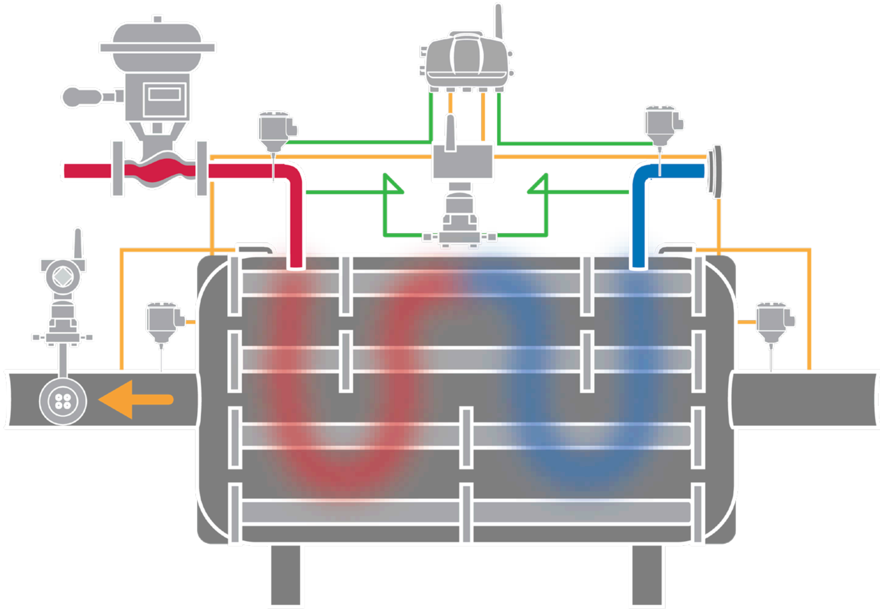

Figure 5. If a heat exchanger is fully instrumented, operators can determine if steam is flowing through it per design, or if the amount of heat transferred is reduced due to some other cause, such as fouling or heat exchanger stalls. If such instrumentation is not available, the cause will be harder to pinpoint.

There are many possible outcomes, but each invariably reduces product quality, adds cost, and increases carbon footprint. Maintenance may even call for a shutdown to check the heat exchanger for fouling when the actual cause is much simpler and easier to fix without a shutdown. If the steam distribution system is well instrumented, the problem will be easier to identify because steam flow to the heat exchanger will be abnormally low.

Diagnosing and Solving the Problem

This situation is interesting to analyze because steam traps are easy to understand and simple to service, and new units are not expensive. Problems result largely from a lack of monitoring, even though steam traps are recognized as maintenance headaches.

Some plants perform monitoring manually, sending technicians on rounds with thermal imagers and acoustic devices to determine which units are performing correctly. The thermal approach looks at the temperatures in the system to determine operation, but it requires a skilled technician to interpret the readings.

When operating, a steam trap releases condensate, creating noise, particularly in the ultrasonic frequencies. Technicians can carry a portable listening device able to capture these frequencies and transpose them to audible sounds. Typically, this uses a probe that must be in contact with the steam trap. This approach can be very effective, but again, it requires a human technician with sufficient training to carry out the inspection and interpret the results.

Most steam traps will need both methods, thermal and acoustic, to determine if they are operating properly. This approach is problematic because it depends on the expertise of the technician, is costly, and requires personnel to be out in the plant on a regular basis for training.

Given personnel constraints at petrochemical plants these days, it is difficult to picture how effective such manual methods can be. How often can an inspection happen to a given steam trap? Given general performance statistics, inspections should happen at least several times per year for each steam trap, a practical impossibility in most plant environments.

Automated, Continuous Monitoring

Ultrasonic wave propagation detection and characterization can be used when a fluid passes through pipes by using an acoustic sensor. When done manually, this technique will invariably miss some issues due to operator error and infrequent inspections. To address these issues, acoustic sensors are available that can be mounted permanently on the piping adjacent to a steam trap (Figure 6), able to sense to its operation continuously. Such sensors are internally powered and use WirelessHART networks to send data to maintenance and reliability departments for analysis. This avoids the need for wiring of any kind, and these devices can be mounted with hose clamps, so there is no need for a shutdown.

Figure 6. Emerson’s Rosemount 708 Wireless Acoustic Transmitter can be mounted adjacent to a steam trap where it listens to its activity and measures temperature. It sends this data to a central collection platform via WirelessHART, so there is no need for wiring.

Ideally, every steam trap should be monitored, but for most plants, this isn't practical. Maintenance and reliability teams usually have a good sense of which steam traps are the most critical, along with the bad actors. Critical steam traps typically include those used in high-pressure and high-quality steam systems, and with highly sensitive equipment, such as turbines, heaters, and radiators. Naturally, these will be the first to be outfitted with acoustic monitors.

In many plant environments, once savings from improved performance begin to accumulate, this money is used to add to the population of monitoring sensors, so success builds on itself. This type of investment can be categorized as an operating expense in many cases, or of course as a capital investment if desired.

Data collection and analysis software tracks individual steam traps and presents a picture of performance in real time via preconfigured dashboards (Figure 7). At a glance, technicians can see which steam traps are working correctly, and which are in one failure mode or the other. The software can estimate lost energy and resulting costs at any time, including the effect on carbon footprint. Maintenance can see which steam traps need attention and plan activities appropriately, dealing with small problems before they become serious issues.

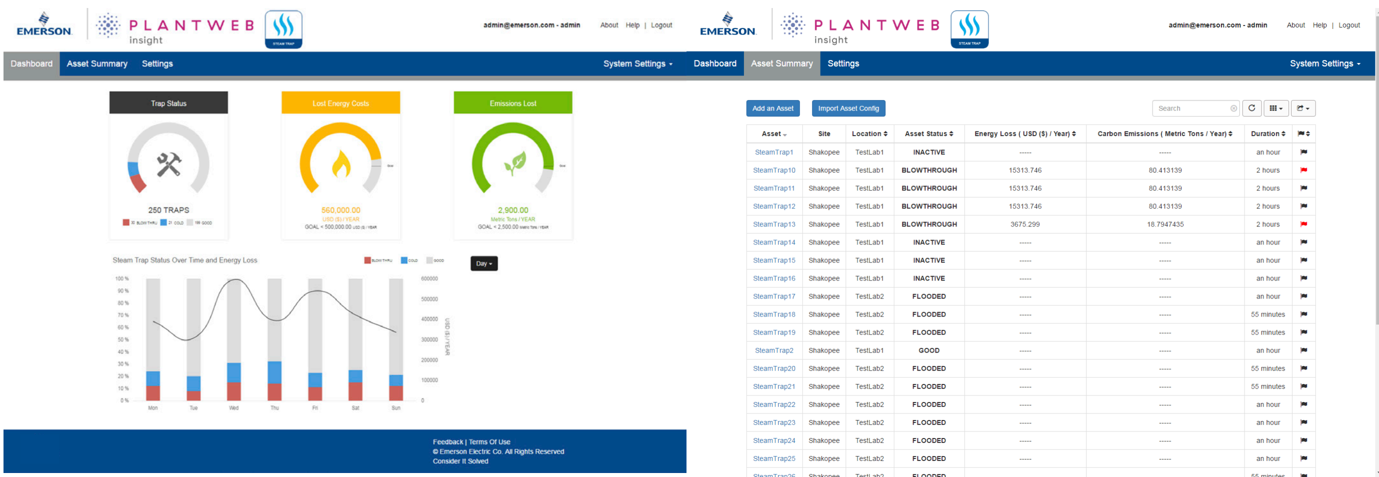

Figure 7. Emerson's Rosemount 708 Wireless Acoustic Transmitter can be mounted adjacent to a steam trap where it listens to its activity and measures temperature. It sends this data to a central collection platform via WirelessHART, so there is no need for wiring.

Naturally, the data may need some interpretation. For example, a steam trap reported as cold could be malfunctioning, or it could be because the equipment only operates intermittently and may simply be shut off. On the other hand, a steam trap attached to a process that runs continuously, or at least regularly, should develop characteristic discharge patterns. If these indicators change, such as a sudden increase in condensate volume, there is probably some other cause for this deviation from normal process operation.

Some facilities, even those that use steam trap monitoring, choose to farm out steam system evaluation and maintenance to a service provider. Emerson and its partners are frequently called upon to consult and work with a plant's maintenance team, helping it evaluate overall steam system performance, including repair and replacement of individual steam traps if required. This type of service typically includes suggestions for alternative designs better suited to specific applications.

Basic Operation Versus System Improvement

When all the steam traps in a facility are working properly, a steam system will run as well as possible based on its original design. Malfunctioning steam traps can make it less efficient, but even when operating correctly, they can't improve on it. Most steam distribution systems are under-instrumented, so it is difficult to determine where energy is being lost, either simply through heat dissipation in the piping, leaks, or where specific applications are consuming more steam than is necessary.

If a facility is serious about sustainability, moving beyond steam trap performance monitoring is the next step. Maintaining high-quality steam throughout a distribution system (Figure 8) requires additional supervision, which is difficult without proper measurement. Maintaining steam delivery within a facility without losses from steam leaks is a major challenge, particularly in larger facilities with aging infrastructure. Measuring steam system temperature, pressure, and flow rates at strategic points delivers insights into plant performance, and technicians can use this information to perform adjustments, increase efficiency, and quickly pinpoint issues.

Figure 8. Adding instrumentation to a steam distribution system provides information on consumption patterns to identify steam hogs and other bad actors. Fixing these advances sustainability efforts.

Recent improvements in flow metering technologies (Figure 9) deliver reliable information, even in the most challenging installations. Tying flow and other variable measurements into supervisory software delivers valuable, concise information to simplify steam system operations.

Figure 9. Emerson's Rosemount 8800 Series Vortex Flow Meters are excellent for steam service, providing high accuracy across a wide turn-down ratio.

Implementing an effective sustainability program in a well-run plant environment will invariably require adding instrumentation for measuring and monitoring purposes.

Journey to Sustainability

Making a facility more sustainable requires paying attention to a wider range of operating parameters than may have been the case previously. Small energy losses might have been tolerated in years past rationalizing the situation by saying, "It isn't worth fixing." Such situations are becoming more difficult to ignore because there is a cost when doing nothing that can escalate quickly, and steam traps and steam systems are a prime example. Adding monitoring capabilities is a critical first step, but they only identify that a problem exists. Solving the problem means acting on the information and fixing the steam trap and related systems before they contribute further to ongoing waste. That's the path to sustainability.

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