White Paper

Steam Solved.

4 Steps to Improve Steam Trap Operation

EMERSON
Process Management

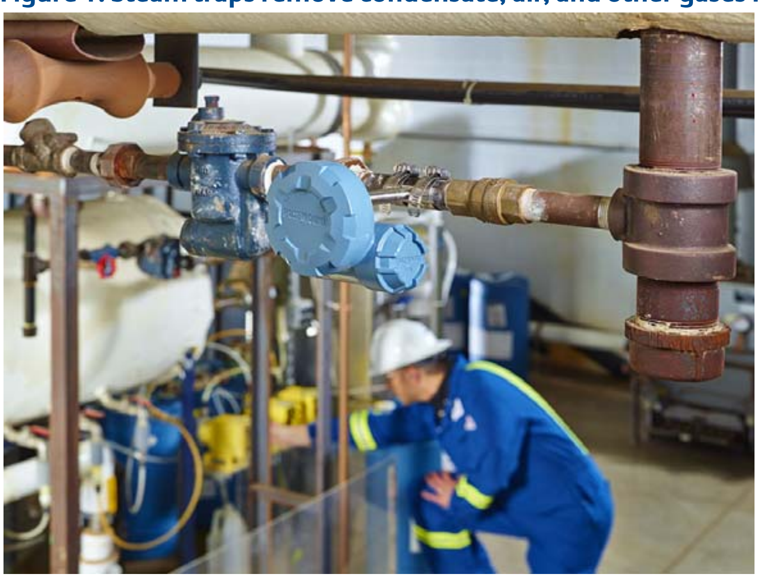
Steam Solved: Four Steps to Improve Steam Trap Operation

This paper explains the operation of steam traps, their failure modes and consequences, and the current methods to detect failures. It also gives a broad overview of legacy methods, and a detailed plan of new methods for implementing a steam trap health monitoring system. The four steps to improve steam trap operation are provided in detail in "How to optimize a steam trap monitoring system" on page 6.

Purpose of steam traps

High quality steam is generated at the boiler and distributed throughout the plant to transfer heat energy and perform work. Heat is distributed throughout a plant, and some of the steam condenses and collects in low points. Strategically placed steam traps (Figure 1) remove condensate, air and other gases from the steam system to optimize operation.

Figure 1. Steam traps remove condensate, air, and other gases from a steam system



Steam traps help protect a plant from these adverse conditions:

- Equipment damage, unplanned maintenance, and unexpected failures
- Unnecessary risks to plant personnel
- Increased rework, reduced plant throughput, and quality
- Increased fuel consumption
- Reduced ability to meet environmental standards and goals

Failed-shut steam traps

When a steam trap fails shut, it no longer passes steam and it no longer removes water, air, and other gases from the steam system. This causes several problems including:

Water hammer—This is a condition where slugs of liquid become trapped between steam packets and then accelerate to a high velocity. When accelerated, the slugs of water can create a hammer-like effect, which can cause extreme damage to plant equipment.

Reduced thermodynamic efficiency—Water and air not removed from the steam system reduce equipment efficiency and can lead to premature equipment failure. One common place is in heat exchangers. Buildup of condensate and air will create an insulating layer that reduces the rate of heat transfer in heat exchangers. This reduction in heat transfer can directly impact product quality and throughput.

In one example, a manufacturer was unable to accurately control the temperature of its manufacturing process because of a steam trap failure. When the process control temperature was out of tolerance, entire batches had to be reprocessed, costing millions of dollars.

Water impingement of plant equipment—If steam traps do not remove condensate from the steam system, water droplets will be entrained in the steam. This entrained water can cause wear and tear on internal components of plant equipment, causing expensive repairs and possibly placing plant personnel at risk. Low quality steam with water droplets present can also cause water impingement. This is a problem for valves where high velocity water droplets can score the surface of the bodies and seats, preventing proper operation. Consequences of water impingement include:

- Leaks in heat exchanger tubes
- Turbine blade deterioration or erosion (Figure 2)
- Wall thinning on the outside edge of pipe bends
- Eventual failure of soot-blower tubes

Figure 2. Damaged turbine blades caused by a failed steam trap

Pressure surges/steam line rupture—Condensate at saturation temperature is susceptible to flashing to steam if pressure in the system drops. Any valve opening has the potential to drop pressure, causing extreme pressure surges when the condensate flashes to steam. This can lead to equipment and piping failure, putting plant personnel and equipment at risk (Figure 3).

Figure 3. Steam line rupture due to steam trap failure

Condensate can also cause rust and corrosion, especially in carbon steel steam pipes, condensate recovery systems and tracing lines. With a properly functioning steam trap, condensate is removed so the steam stays dry. Little air and water is present in the system and rust is less likely to form.

If the trap fails shut, it cannot remove the condensate and rust and corrosion can quickly follow. When rust and corrosion occur, scale and other deposits can clog downstream components in the steam system.

Because of the safety and process issues caused by failed-closed steam traps, many operators elect to open the bypass of failed cold steam traps creating a failed-open trap. While this reduces the safety and process impact of the failure, it increases the fuel consumed by the boiler and reduces the overall steam system capacity. Subsequently, this increases the overall energy bill, and the impact to the environment.

Failed-open steam traps

When steam traps fail in the open or blow-through condition, they constantly pass steam. Even though steam traps are built with an internal orifice that limits the amount of steam loss, the amount of lost steam can still be significant.

Increased fuel costs—The primary impact of failed-open steam traps is its financial effect on the bottom line of the facility. A single steam trap on a large, high-pressure steam line can pass greater than 600lbm/hr of steam, costing a plant tens of thousands of dollars a year. (See “Napier’s Equation,” below).

Increased boiler load—As plants age, the number of failed-open steam traps and steam leaks often increases, and plant efficiency consequently decreases. This steam leak increase is often known as the “phantom” load. One executive estimated that 20% of boiler steam production went to this phantom load, with a majority of the leakage through failed steam traps.

Over time, without a plan to improve the health of degrading steam trap systems, many plants would have to increase boiler output or potentially even add another boiler. Reducing losses through steam traps can reduce this phantom load and eliminate the need for steam system capacity additions.

Any steam trap failure stresses the rest of the steam system, and can accelerate the failures of other traps in a downward spiral effect. Condensate back pressure increases as traps fail open, resulting in higher temperatures that stress condensate return pumps. High temperatures can cause pumps to cavitate, motors to burn out, and seals to leak.

Winter conditions can exacerbate steam trap failures (see Figure 4) because of increased stress on mechanical systems, and more repairs when issues occur. A good steam trap maintenance program with proper attention to critical and large-capacity steam traps will go a long way toward minimizing these and other issues.

Figure 4. Freezing Problems

Properly-functioning steam traps are essential for good performance of a steam system. Trap failures compound one another and lead to a range of potentially-serious operational issues. One such issue, common in processing facilities, is freezing of equipment during periods of cold weather. The following are some examples:

Frozen steam coils— In one plant, failure to identify steam traps that had failed closed on steam heating coils resulted in frozen coils that had to be replaced. This occurred on four different occasions and cost $18,000 per incident. Any steam-based heat exchanger equipment is subject to potential similar failures.

Frozen steam-jacketed pipe— A chemical plant was offloading rail cars of viscous raw material through steam-jacketed pipe, which heated the inner pipe and allowed the material to flow. Key steam traps failed to drain condensate from the pipe jacket, which eventually froze, collapsing the inner product delivery pipe and dramatically slowing raw material offloading times. Plant personnel detected the issue when offloading took four times longer than usual, but there was no externally-visible sign of damage. This incident cost $120,000 in piping system damage, but was much more costly in terms of lost production. Vessels and any other steam-jacketed equipment would be susceptible to similar types of failure.

Tracer traps—These traps drain condensate from steam tracing lines that enable pumping fluids that would otherwise be too thick to move through a pipe (similar to how the jacketed pipe in the above example was used). Tracer traps are generally small in size and may be considered insignificant or unimportant. In actuality, they can be among the most critical traps in a facility, since their failure can bring production to a standstill. Note that actual freezing is not necessary to cause issues; mere failure of the traps to drain condensate causes inadequate heating of the main process line, which can slow or stop production. Thawing a process that has frozen is extremely costly and may require manual heating of pipe sections with torches to re-flow the process fluid. This is dangerous for flammable process fluids, and in any process plant areas classified as hazardous.

Risk of leaks and safety issues— In cold weather, steam leaks or vapor clouds from receiver tank vents condense and then freeze, creating slipping hazards for personnel. One refinery assembled a “steam team” that identified these system issues so they could be repaired.

Issues with manual steam trap audits

Annually, process plants with preventive maintenance plans typically experience failures in about one in five of their steam traps. Of those who perform annual audits, they expect a failure rate of anywhere from 12 to 25%. According to Risko[1], "Average-quality traps may have just a four-year life expectancy (which implies a 25% failure rate), while higher-quality steam traps may have an eight-year life expectancy (12.5% average failure rate)."

For decades, the best known method to identify trap failures was conducting manual steam trap audits using acoustic and temperature sensing methods. Many plants have adopted this practice on an annual basis, which leaves the plant vulnerable to long periods of failures between audits—along with negative consequences to safety, reliability, and plant operations in general.

The best manual steam trap audit programs measure temperature and the ultrasonic acoustics generated by the flow of steam and condensate through the orifice. Trained field technicians go from trap to trap performing each analysis individually. In the best case—where trap type, size, and operating pressure are recorded or entered into the measuring instrument—actual parameters are compared to ideal parameters. Some measurement instruments make this comparison in as little as 15 seconds.

A 15-second interval only allows for, at most, one or two cycles of condensate discharge. More often, intervals are much longer and can take many minutes between discharges. Therefore, it is important to allow adequate time to test a trap's operation to reduce the likelihood of a false reading. Unfortunately, a 2-, 5-, or even 15-minute test can miss irregular patterns and failures. Early stage failures in particular are extremely difficult to identify within such a small time period.

Another issue that can arise is that some parts of the steam system may not be in service when the audit is performed. Only those traps that are in service can be tested. This can leave as many as 30% of the traps on a site untested until the next annual audit, when they might be offline again.

Finally, steam trap audit performance is dependent on the technician's experience and judgment. Technicians must decipher dynamic readings that differ according to the type, pressure, and capacity of the trap. Each type of trap has a different operational acoustic signature. Consistently getting steam trap audits to reflect the actual health of the system is a problem as the training and judgment of the technician will differ. Not only will the audit be inaccurate, but it will be inconsistently inaccurate.

1. *Risko, J., Understanding Steam Traps, Chemical Engineering Progress, Feb 2011*

How to optimize a steam trap monitoring system

The more insight operators have into the health of steam traps and steam systems, the better they are able to manage maintenance activities, lessen the impact of failures, and improve the health of the steam system. There are advances in measurement and transmitter technology (Figure 5) that allow continuous monitoring of steam traps rather inexpensively. These new technologies deliver two significant benefits:

- Knowing the status of steam traps in real time allows replacement before they have an impact on plant processes and efficiency.
- Continuous monitoring is better at analyzing the status of steam traps since it does not rely on a small time slice of steam trap operation.

Figure 5. An acoustic transmitter can monitor steam trap performance continuously

Wireless transmitters measure the ultrasonic acoustic behavior and temperature of steam traps, and send this information to maintenance personnel via a wireless mesh network ensuring high reliability of transmitted data. Because no wiring is required to the transmitters, they can be installed for a fraction of the cost of a wired instrument.

Addressing the problem of failed steam traps requires a four-step program:

1. Perform a regularly scheduled manual steam trap survey by including a temperature and ultrasonic test to help determine various failure modes.

2. Determine critical traps using at least one of the following methods:

- Steam loss calculation using Napier's equation (see Figure 6)
- Failure Modes and Effects Analysis (FMEA)

3. Apply real-time wireless monitoring and data analysis to these critical traps.

4. Take action to repair or replace steam traps as they fail.

Essentially, operations people must identify which traps are most critical to the process and identify how much it will cost if the traps fail, and how the failed traps will affect the process. Assigning a risk priority number[(1)] is a technique for assessing the risk of potential problems identified during an FMEA evaluation. An FMEA evaluation helps to determine which traps are critical.

With an FMEA, each failure mode is given a score that attempts to quantify:

- Occurrence: likelihood the failure will occur
- Detection: likelihood the failure will not be detected
- Severity: amount of harm or damage the failure mode may cause

This data is used for comparison within a single process only and should not be used to compare across multiple processes or organizations.

The following section shows how to analyze the impact of steam trap failures.

Financial impact of failed steam traps

It is difficult to place a number on the financial impact of failed cold steam traps, although it's anecdotally easy to find examples of everything from steam line ruptures causing millions of dollars of damage, to unplanned outages for equipment repair. For example, one large company experienced severe water hammer because of four plugged steam traps, resulting in a six-hour site shutdown and $250,000 in repairs.

As cited previously, a manufacturer was unable to accurately control the temperature of a vital manufacturing process because steam traps failed. This resulted in batches of product being reprocessed, costing millions of dollars of lost production.

Steam line ruptures and failures in vital plant equipment due to failed cold steam traps can cause outages lasting anywhere from hours to months. While it is impossible to predict the exact nature of the failures that can occur if water is not removed from the steam system by steam traps, plant managers agree that the costs of a failed cold steam trap far outweigh the lost energy from blowing through open steam traps.

This makes sense as steam traps are installed to remove water and air. Appreciation for this can be seen when field operators open the bypass of failed-cold steam traps so the condensate can be removed, at the expense of increasing steam loss.

The financial impact of a failed-open steam trap is much easier to calculate. Since the financial impact is so much smaller than a failed cold steam trap, a simplified and conservative assumption is often made to use the cost of a failed-open steam trap in calculations, as opposed to the potentially larger but much harder to calculate cost of a failed cold steam trap.

1. *"Examining Risk Priority Numbers in FMEA," http://www.reliasoft.com/newsletter/2q2003/rpns.htm*

John Napier authored the equation for calculating critical steam flow through an orifice. Since every steam trap has an internal orifice, the equation is widely used to estimate the losses through a failed trap (Figure 6).

Figure 6. Napier's Equation

$W = 24.24 \times P_{abs} \times D^2$

where

W = steam loss in lbm/hr

24.24 = constant

P_{abs} = Absolute steam pressure in psia

D = Diameter of the internal orifice (inches)

If we take the example of a steam trap operating on a 100psi steam system with an internal orifice of $^3/_8$ inches, we can calculate the steam loss through a blow-through or failed-open trap.

$W = 24.24 \times P_{abs} \times D^2$

$W = 24.24 \times (100 \text{ psi} + 14.7 \text{ psi}) \times (^3/_8)^2$

W = 391 lbm/hr

We can then apply the cost of steam for a process unit to find the financial impact of a blow-through trap. A typical cost of steam is $10/1,000lbm.

Cost ($/yr) = Steam Loss (lbm/hr) x Cost of Steam ($/1,000 lbm) x 8,760 (hrs/yr)

Cost ($/yr) = 391 lbm/hr x $10/1,000 lbm x 8760 hr/yr

Cost = $34,250/yr

The cost of failing open for this particular steam trap is over $34,000/year.

Distribution of steam trap sizes

Using the method in the previous example, we can calculate the impact of a failed-open steam trap. Along with an FMEA, this allows us to prioritize and identify critical traps requiring continuous monitoring with wireless instrumentation.

As seen in Napier's Equation, steam loss is dependent on both the pressure of the steam and the orifice size. While each plant is uniquely designed, we can estimate the criticality of steam traps in a facility based on steam loss. For simplicity, we can break down the distribution of the steam traps by their financial impact when they fail open. Typically, 5-10% are deemed critical (>$10,000 in annual blow-through loss) and another 10-20% are considered high value (>$5,000) as shown in Figure 7.

Figure 7. Steam Traps by Failure Cost

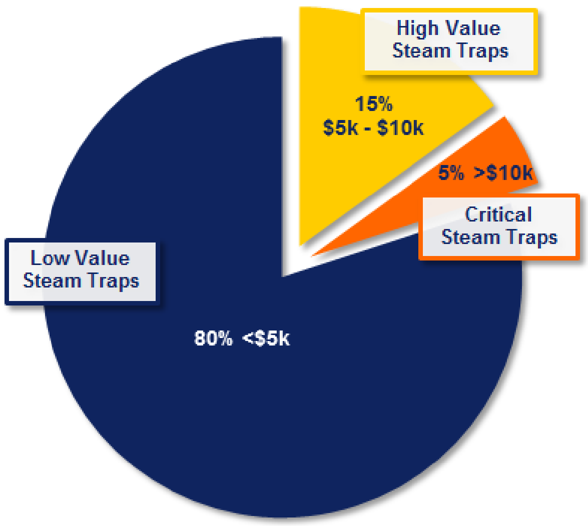


Figure 7 shows about 80% of steam traps in a typical plant do not have nearly the combined financial impact of the other 20% of relatively higher value traps. There are a relatively small number of traps with a very large combined financial impact, and these are referred to as high value steam traps. High value traps are not only those which cause significant steam loss, but also those which can severely and negatively impact plant operation because they:

- protect important plant equipment
- have a large negative effect on plant processes in the event of failure
- are located on larger, higher pressure steam lines
- have a known high failure rate
- are out of reach or are in hazardous locations, making maintenance difficult

Results of wireless monitoring of critical steam traps

The following are examples of specific problems caused by failed steam traps. In each example, we identify the high value traps and show the beneficial results from real-time wireless steam trap monitoring.

When a steam trap fails open, steam is blown directly into the atmosphere in an open condensate return system. In a closed condensate return system, the pressure is increased, inhibiting the discharge capability of other traps and causing system-wide inefficiencies. If a trap fails closed, the system will flood, causing a loss of heat transfer and stressing downstream traps that must remove more condensate. Steam trap failures also increase the potential for water-hammer that may lead to equipment damage and downtime.

At a major process plant, steam traps were identified as a primary culprit of energy loss. In an effort to prevent steam trap failures, an annual preventive maintenance schedule was developed. On average, it took the maintenance crew at least one hour per unit to check each steam trap, amounting to approximately 100 hours of maintenance labor annually.

“We found 22% of our traps needed to be replaced during our last preventive maintenance check. By installing wireless acoustic transmitters on the critical steam traps, we prevented steam loss with early detection of steam trap failure. Not only does this minimize energy loss, it also frees up maintenance to focus their time and attention on things that need to be fixed to further improve our productivity,” said the project engineer.

A plant operated by Fluor also had steam trap issues. Its audit showed that 25% of the steam traps were failing for unknown causes. Fluor installed wireless acoustic transmitters on 187 steam traps and 63 pressure relief valves. “A simple cost analysis based only on energy savings showed the installation of the steam trap monitoring system was easily justified because the solution paid for itself within one year,” said a Fluor engineer. “Not to mention the savings from avoiding equipment damage, and avoiding safety or environmental incidents.”

Food facility results

Anything companies can do to lower the amount spent on fuel has a large positive impact on the bottom line. At a corn milling plant, an analysis on the plant's steam trap system was performed to help identify high value steam traps, their impact on the bottom line, and the financial impact of a real-time monitoring and maintenance program.

Analysts looked at the plant information concerning the facility's top 100 steam traps out of 400-plus total traps. The plant had two sizes of steam traps on its 150 psi distribution system. When looking at the cost of failure (Table 1), it quickly became apparent where to start a continuous monitoring program.

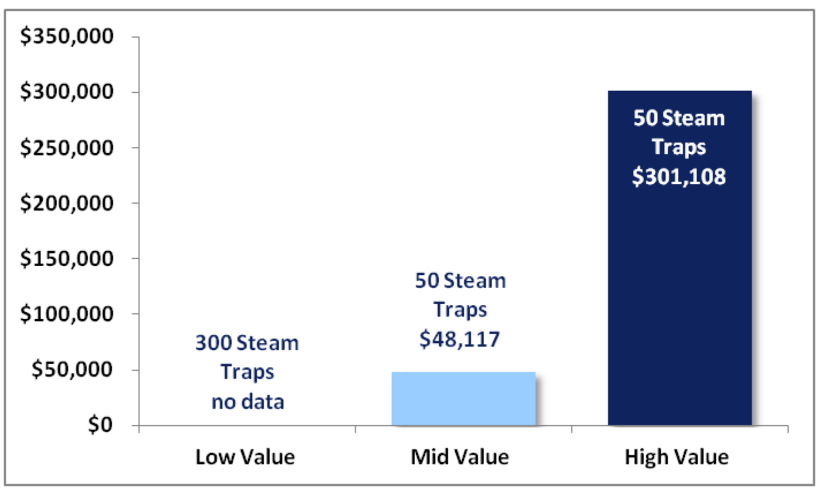
Table 1. Steam Trap Cost of Failure

	150 psi	
Office size	1/2-in.	1/8-in.
Number of traps	50	50
Cost of failure	**$40,148**	**$6,424**

The plant was experiencing a 15% annual steam trap failure rate, so the financial impact of the high value traps versus the general population of steam traps was calculated as shown in Figure 8. In this case, the top 12.5% of the plant's steam traps were responsible for 38% of the steam loss.

Correcting this issue through the installation of wireless steam trap instruments resulted in an annual savings of over $300,000.

Figure 8. Financial impact of steam trap failures for a corn milling plant



Chemical plant results

A chemical alkoxylation plant with 40 batch reactors had to cut emissions and reduce its energy consumption due to the June 2012 European Commission Energy Efficiency Directive. The chemical company calculated that it was losing more than $45,000 per year from leaks in its low pressure steam traps, and even more from its high pressure systems. With 98 wireless acoustic transmitters on steam traps and pressure relief valves (PRVs), the low pressure system will pay for itself in less than two years, and the high pressure system payback will be significantly shorter.

Power plant results

Tony Turp, Senior Control Engineer at Barking Power Station in the UK was faced with a problem: the power plant, originally built for base load generation, was now competing in the peaking power market. This meant the plant had to lower its operating costs and become more flexible to meet short-term contracts.

"Our main area of concentration is our steam lines," Turp explains. "We need to minimize steam loss on any steam lines that go to drains, or any steam traps, anything that vents to the atmosphere, start-up vents, blow-down lines... anything that will increase our effluent waste or cause us to generate more water to replenish any losses."

Barking Power Station tried manual rounds at first to check steam traps, but was losing as much as four metric tons of steam per hour from steam trap failures, so needed a more effective method for monitoring their critical traps. Barking Power Station wanted to identify failed steam traps and leaks caused by malfunctioning valves before they impacted operation.

Wireless acoustic transmitters were non-intrusively installed on critical vent valves, steam traps and PRVs. Within the first week of operation, the new technology identified a leak from a high pressure superheated steam trap. The cost of that leak was estimated to be more than $1,500 for every 24 hours of operation—or $45,000 per month—not including the loss of pressure when the operation moved to hot standby mode, lost nitrogen if the plant moved to cold standby, increased discharge waste, and increased water and chemical use. Barking Power now has 100 wireless transmitters installed, realizing substantial savings.

Conclusion

Steam systems are designed with steam traps to remove condensate and air, protecting plant equipment and allowing for efficient operation of plant processes. When steam traps fail, there are significant negative impacts to plant operations in terms of energy use, throughput, safety and equipment life.

The traditional method of checking steam traps is contracting with a third party to perform manual audits. These audits measure the ultrasonic acoustic behavior and temperature of the steam traps to determine the condition of the traps. This method has drawbacks in that it only considers a short snapshot of the operation, and therefore cannot always be a good predictor of trap condition. This method is also highly dependent on the skill and judgment of the test technician. In addition, annual audits leave the plant operator susceptible to long periods of failed steam traps between audits.

With the advent of wireless transmitter technology—repeatable, accurate and reliable monitoring of the highest value steam traps is now cost-effective. To implement a continuous steam trap monitoring program, it is important to know where the largest negative impact is on plant processes from steam trap failure, which identifies the high value steam traps. Continuous 24/7 monitoring of these high value steam traps will typically result in a quick payback from energy savings alone, in addition to delivering many other ancillary benefits.

For more information on improving steam trap operation, see www2.emersonprocess.com/en-us/brands/rosemount/wireless/708-acoustic/pages/index.aspx.

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