A Practical Guide to Realising Cost Savings and Associated Energy Reductions Through Retrofitting Traditional Mechanical Steam Traps with Venturi Traps

Steam is used in nearly all industrial processes as a means to distribute heat. Steam systems require steam traps at regular intervals to drain the condensate produced as the steam gives up its heat and condenses. These steam traps traditionally contain moving parts that are prone to failure, requiring regular maintenance to ensure a reliable, safe, and efficient steam system.

This article looks at an alternative steam trap solution with no moving parts, the Venturi trap. We look at the scale of savings that can be achieved through converting existing mechanical traps to Venturi traps and the perceived barriers to their use. Included is a review of laboratory test results and field studies of a population of 1,000 Venturi traps identifying significant savings and performance benefits against existing well-maintained populations of mechanical steam traps.

Eliminating failed open steam traps from industry has the potential to save 4.5 Mt CO_2 per year in the US alone. [1]

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1 Introduction

Steam is used in nearly all major industrial processes, with the United Nations [2] stating that industrial steam systems account for around 30 % of manufacturing energy use worldwide. In these systems steam is primarily used as a heat transfer medium, transporting heat from the boiler plant to the point of use. Steam carries its useful energy in the form of latent heat which it gives up as it condenses to water. To maintain safe and effective steam system operation, this condensate must be discharged as it is formed, and this is the function of a steam trap.

Traditional steam traps

Traditionally steam traps have contained moving parts to allow condensate and air to be discharged, whilst restricting the loss of live steam. These moving parts cycle several times a minute, often operating over 8,000 hr/yr in hot, dirty conditions, resulting in known failure rates of around 10 % per year. [3] [4] Despite steam savings of 10–15 % [5] being achievable through effective steam trap maintenance programs, companies across all industries fail to implement such programs. This is evidenced by inspections of over 100,000 steam traps, finding that 30 % were malfunctioning upon first inspection. [6]

Venturi traps

Venturi, or multistage throat steam traps have been on the market for over 25 years, and with no moving parts to fail, offer a potential solution to the problem of steam trap maintenance. Market penetration is still low however, despite attractive fuel and maintenance savings. Two main concerns have been raised with the use of Venturi traps. The first is whether they can cope with variations in condensate flow rate and steam pressure seen in industrial processes. The second concern is whether the small orifices required for low flow rates are too susceptible to blockages for safe and practical usage plant-wide. With record fuel prices and carbon taxes, European companies are incentivised more than ever to use energy more efficiently. The potential advantages of this technology therefore warrant further investigation.

This article investigates the theoretical and actual savings realised through adopting Venturi trap technology and how commonly cited barriers to their use can be easily overcome in the field.

2 Mechanical Steam Trap Losses

The role of a steam trap is to remove condensate and non-condensable gases from the system, whilst retaining steam. A mechanical steam trap has traditionally been used for this function due to its large operating range which simplifies specification. Typically, a single steam trap model will serve many applications with spares held in stock onsite for when they fail. Density, temperature, and velocity are each used in different mechanical trap designs to operate this mechanism as discussed in detail in article 08007. [7] The most common mechanical trap types have been summarised in Table 1, along with their common modes of failure and functional steam losses in operation.

Tabelle 1: Summary of Mechanical Trap Types

Trap Design	Operating Principle	Flow Type	Failure Modes	Steam Loss in Operation
Thermodynamic	Thermodynamic	Intermittent/ blast	• Erosion of sealing faces • Debris deposited on disc	Steam loss as disc closes
Float & Thermostatic (TS)/ Free Float	Density	Continuous	• Ball crushed by water hammer or freezing • Erosion of seat in either TS or float mechanism • Debris stuck in TS mechanism	Steam loss under large load variation at start up
Inverted bucket	Density	Intermittent / blast	• Bucket knocked off mechanism • Susceptible to freezing	Steam loss under low loads through air vent/ steam lock

Trap Design	Operating Principle	Flow Type	Failure Modes	Steam Loss in Operation
Balanced pressure	Temperature	Continuous	• Erosion • Failure of capsule (maximum number of cycles)	Max number of cycles of thermostatic element

2.1 Failure Rates

A steam system is a hot and aggressive environment with high velocity steam, high density condensate, pressure fluctuations and dirt. This accelerates the wear on moving parts of steam traps that often cycle several times per minute, preventing proper sealing and discharge of condensate. Users of mechanical steam traps will be aware of the continuous failure and replacement cycle to maintain efficient system operation. Manufacturers estimate this annual failure rate to be around 10 %. [3] [4] An independent European steam trap auditor found most industries to have over 30 % functioning incorrectly across a significant sample size of over 100,000 steam traps. [6]

Steam losses

Failure rates are directly dependent on a variety of factors including system design, steam pressure, quality of water treatment and maintenance budget spent on monitoring and replacing failed steam traps. Steam traps can fail in blow through, leaking or closed conditions. Live steam passed into the condensate system is wasted energy and if left unchecked will result in pressurisation of the condensate return system, impacting the ability of other steam traps to function correctly. The steam losses through a trap are dependent upon the diameter of the orifice within the trap, the differential pressure across the trap and the operating hours. Large process traps have the largest potential for live steam loss upon failure but are often quickly identified due to their impact on the process. Smaller duty traps on line drainage applications are often cumulatively responsible for large steam losses due to their long operating hours, operation at higher steam pressures, and quantity.

Many steam trap maintenance programs focus on the cost savings that can be achieved through replacing leaking steam traps, with some sites even isolating leaking traps to save energy until they can be fixed. The consequences of cold traps can be far more serious, resulting in equipment damage, plant shutdowns and injury to onsite personnel. Risko, J. 2013 provides guidance on attributing costs to failed closed traps. [8]

2.2 Losses Through Failures

The orifice within a mechanical trap is oversized for its application, relying on its internal mechanism to regulate the flow of condensate. A mechanical trap failed in an open position will have no means of restricting this live steam discharge resulting in high energy losses. These losses can be quantified through the formulas detailed in ISO 5167-2, which are used to calculate steam flow through orifice plates, given in Equation 1.

$$Q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1}$$

$$\varepsilon_1 = 1 - (0.351 + 0.256\beta^4 + 0.93\beta^8)[1 - \left(\frac{p_2}{p_1}\right)^{\frac{1}{\kappa}}]$$

Equation 1

Where:

Q_m	-	The fluid mass flow rate	[kg/s]
C	-	Discharge coefficient	Dimensionless
d	-	Leak bore diameter	[m]
D	-	Pipework inner diameter	[m]
Δp	-	Differential pressure	[Pa]
ρ_1	-	Upstream steam density	[kg/m^3]
κ	-	Isentropic exponent	Dimensionless
p_1	-	Upstream pressure	[Pa abs]
p_2	-	Downstream pressure	[Pa abs]
β	-	Diameter ratio d/D	Dimensionless

To account for internal geometry and the choking effect of condensate also flowing through the orifice, a factor is applied to the calculated flow rate based on experience. A value of 0.45 is typically used for fully open traps in blow through condition, which is reduced to 0.18 for leaking traps in a partial failure condition.

Critical pressure Flow rate in this formula is limited at the critical pressure, when the velocity equals to the speed of sound. Any further increase in differential pressure will not cause an increase in velocity. Consideration must be made for this phenomenon when choosing values of p1 and p2.

2.3 Full Site Losses Through Failed Traps

Live steam losses and associated carbon emissions through failed steam traps can be extrapolated using typical steam trap populations and data from a study of 100,000 traps. [6] Of those deemed to be malfunctioning in the study, 46 % were identified as partially failed, and a further 13 % fully open in blowing through condition. Using industrial average failure rates [6] the average live steam losses per site can be calculated, shown in Table 2. These values were calculated conservatively, following the below assumptions.

Assumptions:

Average trap size:	DN20
Average operating hours:	5,000/yr
Average steam pressure:	6 bar(g)
Steam cost:	€25/tonne
Fuel – Natural gas:	0.185 $kgCO_{2e}/kWh$
Carbon cost:	€50/tonne CO_{2e}

Tabelle 2: Steam Trap Failure Rates Through Different Industries [6]

Industry	Number of Traps	Failure Rate	Failed Traps	Steam Loss tonnes/yr	Fuel Losses	CO_2 Equivalent tonnes/yr	CO_2 value	Total Losses
Petrochemical	5000	34 %	1,700	64,990	€ 1,624,754	10,295	€ 514,742	€ 2,139,496
Chemical	1000	29 %	290	11,087	€ 277,164	1,756	€ 87,809	€ 364,973
Steel Plant	500	39 %	195	7,455	€ 186,369	1,181	€ 59,044	€ 245,413
Pharmaceutical	1000	19 %	190	7,264	€ 181,590	1,151	€ 57,530	€ 239,120
Food & Beverage	500	36 %	180	6,881	€ 172,033	1,090	€ 54,502	€ 226,535
Hospital	300	34 %	102	3,899	€ 97,485	618	€ 30,885	€ 128,370
Brewery	200	32 %	64	2,447	€ 61,167	388	€ 19,379	€ 80,546
Dairy	200	23 %	46	1,759	€ 43,964	279	€ 13,928	€ 57,892
Laundry	100	24 %	24	918	€ 22,938	145	€ 7,267	€ 30,205

Clearly there are significant savings to be realised throughout all industries. Any site looking to meet its carbon and energy targets can relatively easily quantify the potential reductions through addressing this issue. Doing so will typically see a quick return on investment through energy savings, and also better process control throughout the plant

It should be noted that where sites have implemented effective steam trap maintenance programs these losses will be reduced.

3 Mechanical Steam Trap Maintenance

Regular steam trap checks

Once failed mechanical traps are eliminated from a plant, a regular maintenance schedule is required to ensure any live steam losses and failures remain at a minimum. Although a daunting initial investment, it is estimated that regular steam trap checks and maintenance can see overall efficiency savings of 10–15 %. This will usually have a return on investment of 0.5 years. [1]

Typically, each mechanical steam trap should be monitored at least once annually to keep failure rates to a minimum. It will require significant resources to maintain a failure rate below 3 %, particularly on larger sites. Failures will constantly be occurring around the site that cannot always be addressed immediately. Lack of resources, inability to safely isolate the steam trap, and production dependent processes are common reasons for known failed traps laying unattended around the site.

3.1 Mechanical Trap Diagnosing

3.1.1 Temperature Measurement

The easiest way to diagnose a steam trap's condition is by using temperature measurements. A functioning steam trap will have an upstream temperature corresponding to the saturation temperature of the upstream steam line. Downstream temperature of the trap should also correspond with the saturation temperature of the condensate return pressure. Elevation in downstream temperature above that associated with the saturation pressure described previously can indicate passing of live steam, whilst lower upstream temperature can be due to a failed closed trap.

3.1.2 Ultrasonic Testing

Ultrasonic techniques are commonly used to monitor mechanical steam trap conditions. This method involves the use of a contact probe module to record ultrasonic vibrations and shift them into the audible range. The operator then listens for the cyclic operation of a mechanical steam trap. As the steam trap opens to discharge condensate and closes to trap steam, a distinct sound pattern can be heard. This will vary from trap type to trap type due to the different operating principles. This method of testing allows checking of this cycle, and whether the sealing is maintained when in a closed position. An experienced user will be able to diagnose a failed trap based on experience.

3.2 Remote Monitoring Techniques

Many major steam trap manufacturers have recently developed systems to monitor the condition of steam traps live. These will have sensors around the trap assembly to alert maintenance members of any failures as soon as they occur. On sites where traps are installed in difficult to access locations, such as tunnels, this can be extremely useful. Failures in traps can then be instantly diagnosed and serviced, instead of waiting to be identified during the next physical survey. This technology works using the above techniques and is typically powered by long-life batteries or by harvesting heat from the hot pipework.

Priorisation possible

Use of these systems allows maintenance teams to manage their resources much better. Instead of surveying all steam traps at regular intervals, only those required can be prioritised. Instant diagnosis of traps can see an additional 5 % in energy savings, with paybacks of around 1 year typical. [1]

4 Venturi Steam Traps

4.1 Function

In the search for a more reliable steam trap the US Navy in the 1960's started replacing steam traps with orifice plates, eliminating moving parts entirely and relying on a calibrated orifice to discharge a fixed flow rate of condensate. The size of the orifice is determined by the differential pressure across the plate and the flow rate of condensate. When a mixture of steam and condensate comes up against a restriction, in this case the orifice, the condensate is preferentially discharged due to its significantly greater density. This invention is credited in saving the Navy 10.5 million USD, resulting in a Presidential Award from President Jimmy Carter, one of only six awarded in over 20 years. [9] Orifice plate technology did not translate well to industry, due to the variable condensate flow rates and steam pressures found in industrial processes.

In the 1980's basic Venturi traps were introduced to the marketplace. A development on the orifice plate technology, they also rely on relatively accurate calibration and preferential discharge of denser condensate across the orifice. The Venturi design has an elongated stepped throat, designed to create variable restriction to the dual phase mixture of flash steam and condensate. The Venturi design uses the flash steam generated from the pressure drop across the orifice to choke the flow of condensate in a stepped discharge throat, commonly referred to as a Venturi trap.

Flash steam naturally forms as saturated condensate undergoes a pressure reduction, with the excess energy causing a percentage of the condensate to flash, or re-evaporate, into steam. Equation 2 shows the proportion of flash steam generated, where h_f denotes enthalpy of saturated liquid, and h_{fg} the

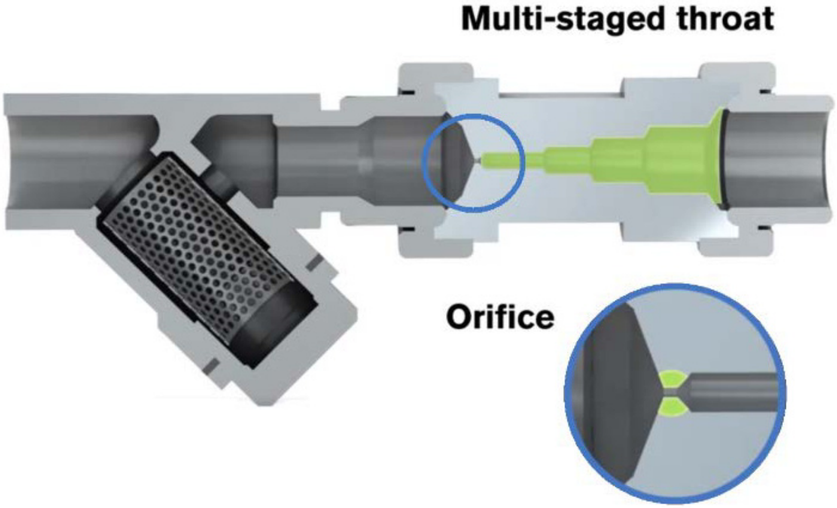

Abb. 1: Single Piece Venturi Section [10]

latent enthalpy of the fluid. Subscripts 1 and 2 denote initial and final pressures respectively.

$$\%\, Flash\ Steam = \frac{(h_{f1} - h_{f2})}{h_{fg2}}$$

Equation 2 – Flash Steam Formation

The Venturi section of the trap is designed to restrict the expansion of flash and choke the bi-phase flow of flash steam and condensate. The interactions that go on here are complex and most easily envisaged through experimental results. Figure 2 shows for a single Venturi trap how it can effectively prevent the discharge of live steam as the condensate flow rate reduces from its design condition. These tests have been completed across several different steam pressures and clearly demonstrate that live steam loss is minimal down to around 25 % of its design condition, resulting in an effective 4:1 turn down in the worst-case scenario of a fixed steam pressure.

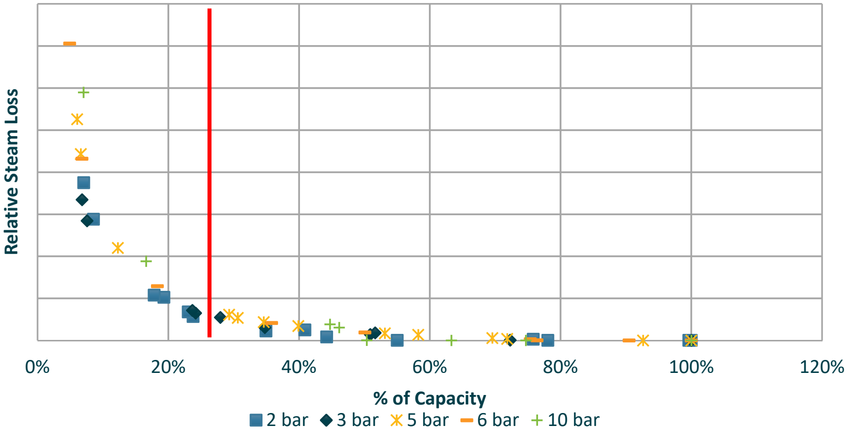

Abb. 2: Variable Flow through Venturi Steam Traps [11]

This 4:1 turndown dictates the operating range at a constant pressure. Process applications with larger variations in steam consumption are typically configured with a modulating control valve before the heat exchanger to regulate the heat transfer.

Modulating the steam pressure As saturated steam temperature increases with pressure, heating can be controlled through modulating the steam pressure. When more heat is required the control valve opens, increasing the temperature of the steam, and therefore heat transfer and rate of condensation. At this point the Venturi trap is seeing an increased differential pressure and has a greater capacity and a new 4:1 turndown. As shown in Figure 3, operation with a control valve significantly extends the operating range of the Venturi trap. On applications with varying steam pressure, the operating curves will therefore follow this profile. As this is the case for most heat exchangers, Venturi technology is suitable for the vast majority of industrial processes.

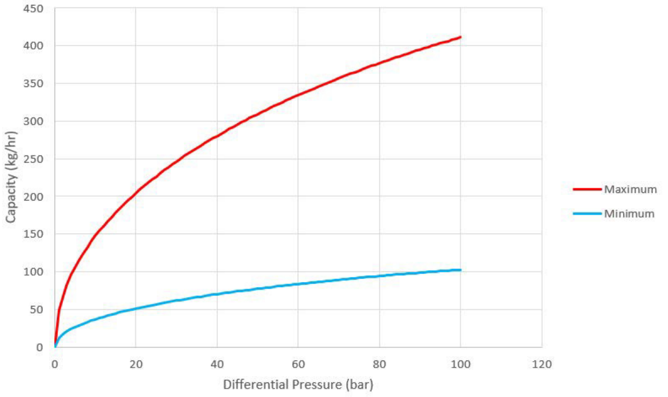

Abb. 3: Venturi Operating Curve [12]

4.2 Operation at Start Up

Following a shutdown, on the next start-up, a steam trap is required to remove cold condensate and any other non-condensable gases from the system. This is commonly thought of as a scenario where Venturi traps are unsuitable.

Venturi steam traps can remove air. They have an open orifice and so air will flow through without any restriction. As the system warms up, the density of air decreases below that of steam and it will collect at high points of the steam distribution system. A well-designed system will have air vents installed at these high points to remove air.

Cold Start-up

During a cold start-up, there will be much more condensate in the system than under operating conditions. The steam trap will therefore have to drain a higher load than usual. This condensate will be sub-cooled and below saturation temperature, meaning no flash steam will be created across the pressure drop. Under these single-phase conditions, the condensate can jet through a Venturi trap without restriction. CFD analysis has shown that cold condensate will flow through a Venturi around twice as quickly as saturated condensate. Figure 4 shows an example Venturi configuration from that study. When calibrating Venturi technology, consideration should always be made for running and operating conditions, however this factor should be considered.

Abb. 4: Saturated vs. Cold Condensate Capacity [13]

4.3 Increased Efficiency

During normal operation, mechanical traps will inherently lose a small amount of live steam as the mechanism cannot react immediately. Venturi steam traps have no internal mechanism and so do not carry this inefficiency. An independent study by the Queen's University Belfast looked to quantify this loss, comparing Venturi steam traps against mechanical types. [14] These results in Figure 5 show the steam losses at different flow rates at a constant pressure. These tests conducted to EN 27841: 1991 utilised a climbing film evaporator where the liquid level could be adjusted on the secondary side adjusting the heat transfer area and altering the load on the heat exchanger.

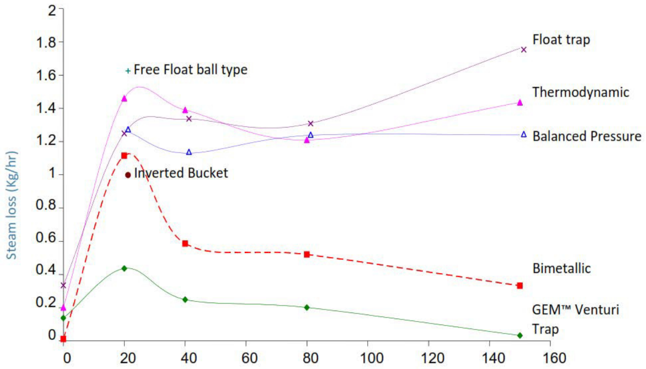

Abb. 5: Queen's University Belfast Results [14]

These results support the efficient operation of Venturi traps over variable loads, demonstrating their increased efficiency throughout. These tests were conducted under laboratory conditions against new traps.

5 Venturi Calibration

5.1 Operating Range of Steam Traps

Mechanical traps have a much wider range of operation than Venturi traps. This enables simple selection of models often based upon the line size and connection type. Even where mechanical trap models have high and low-capacity orifice variations, a single steam trap will be suitable for a large number of applications.

Calibration crucial

Each process will have a range of condensate flow rates specific to the application. Mechanical traps will typically not require most of their capacity range for a specific process. Venturi traps will have a much smaller efficient operating range and great care must be taken to calibrate each trap to ensure that its variable capacity overlaps with the process on which it is installed. Figure 6 shows a correctly calibrated Venturi trap.

Where Venturi traps are not correctly calibrated or are unsuitable for the application, they can either be undersized or oversized. An undersized trap would result in condensate backing up before the trap and inhibiting heat transfer. Oversized traps would spend much of their life operating less efficiently and passing live steam.

Engineers are conservative by nature and gain comfort through building in margins. Whilst oversizing a Venturi trap reduces the risk of impacting the process and is unlikely to be noticed by the user, it will result in all traps passing a small amount of live steam. The cumulative effect of this will significantly reduce the energy saving benefits of the investment. Undersized traps will impact heat transfer and are typically identified as a problem by the end user.

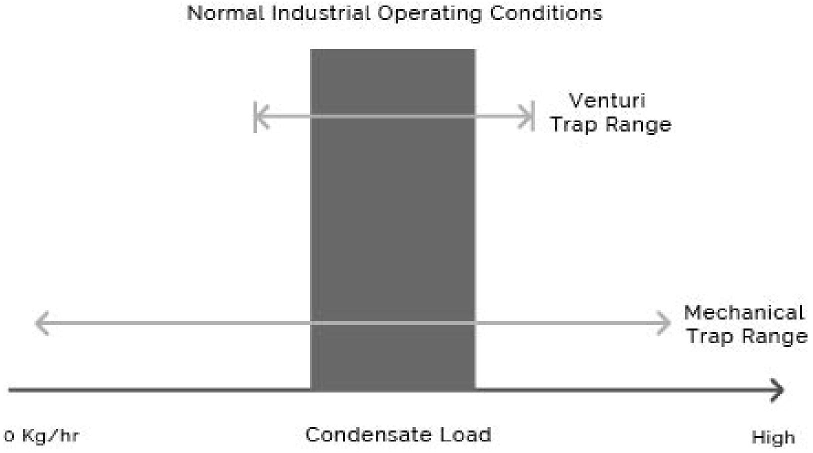

Abb. 6: Steam Trap Operating Range [15]

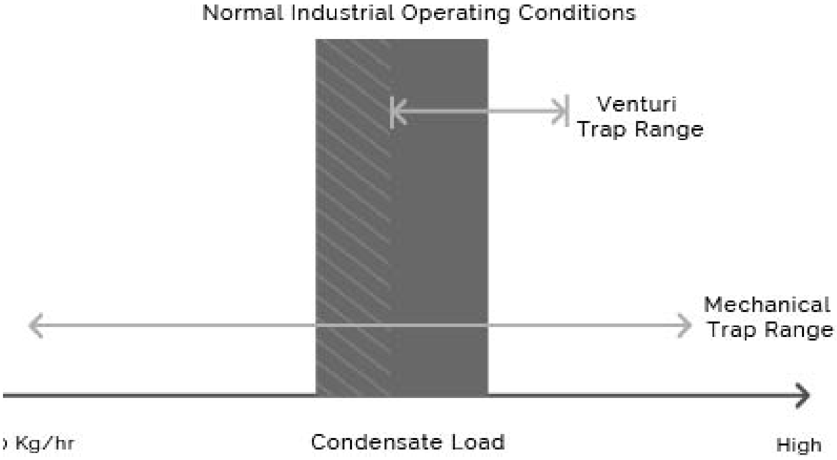

Abb. 7: Incorrectly Calibrated Venturi Trap [15]

A lot of the cited issues about Venturi traps' ability to operate across varying flow rates will likely have their roots in misapplied or incorrectly calibrated traps. Production is the first objective for all plants, with any impact to process quickly negating any energy savings. The justification for most Venturi trap conversions is energy saving, and so it is important to work with a supplier that will take the time to understand the system, has extensive application experience and will commission the project post installation to ensure optimal performance. The value of a Venturi trap is not the piece of metal but the accurate calibration.

5.2 Single piece vs. Inserts

Insert designs

There are two main types of Venturi traps available on the marketplace. Insert designs use a removable nozzle, containing the orifice and Venturi as shown in Figure 8. This design makes re-sizing from a selection of inserts low cost and simple. However, there is no way to be certain which insert is contained within the trap making it difficult for the site or the supplier to take responsibility for performance.

Single piece body

The second main type of Venturi trap uses a single piece body allowing full traceability between the internal configuration of the trap and the external markings. Figure 1 shows a single piece Venturi trap design. Other advantages include no potential for an internal leak path and full Venturi profile to be customised to the application. Single piece designs are more expensive to deliver but allow the manufacturer to have full traceability and offer a performance guarantee for the application. Correct sizing of Venturi traps is an investment and once completed correctly will efficiently serve the plant for many years to come.

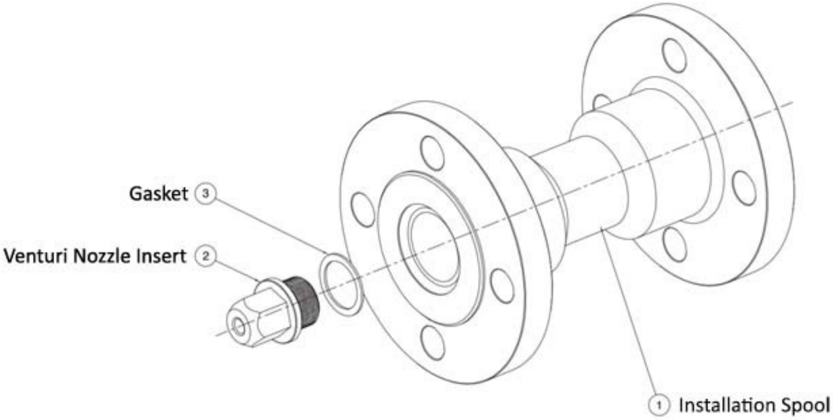

Abb. 8: Venturi Insert Trap [16]

5.3 Unsuitable Applications

As the operating profile in Figure 3 follows a similar shape to most heat exchangers, Venturi technology is suitable for most industrial processes. There are some applications that do not follow this profile, where Venturi steam traps would not be suitable.

These applications typically fall into three categories:

1. **Super-heated steam process applications:**
   In applications with superheated steam significantly above the saturation temperature, there can be insufficient condensate to plug the orifice and prevent the loss of live steam. There can however be advantages of using Venturi traps on small duty line drainage application which should be discussed with an expert.

2. **Fixed steam pressure application with a large load variation:**

   Examples include clean steam generators, separators after steam generators, traps after desuperheaters or steam accumulators.
3. **Rare applications** where the steam pressure is not proportional to condensate flow rate.

6 Blockage Mitigation Features

Venturi traps will typically have a smaller orifice than an equivalent mechanical trap. Standard Y-strainers can provide good debris protection for most mechanical trap applications and larger condensate flow rates for Venturi traps. Applications with smaller orifices, such as steam line drainage, steam trace heating and other low duty applications will require additional protection from blockages.

6.1 Diagnosing Venturi Traps

Failure Mode "plugged"

Once correctly sized the only failure mode for a Venturi Trap is to become plugged or partially plugged. That is most simply diagnosed with an upstream temperature test. A low temperature upstream below the steam saturation temperature indicates the trap is flooded. Note that for heat exchangers with control valves the temperature at the inlet of the heat exchanger should be the reference point.

Using an ultrasonic trap tester for Venturi steam traps does not work as there is no internal mechanism to listen to, and the Venturi throat is designed to restrict the expansion of flash steam causing it to accelerate within the Venturi throat, which the Ultrasonic tester cannot differentiate from live steam.

The maintainable parts of a Venturi Trap are the internal strainers and the orifice itself. Strainers can be fitted with blowdown valves to allow the filters to be cleaned.

6.2 Filtration and Blockage Prevention

6.2.1 Strainer Filtration

Most Venturi manufacturers will have some sort of internal strainer upstream of the orifice for protection. This will have a mesh finer than the orifice size and can be cleaned as any strainer should it become blocked on a dirty system. This is a simple, yet proven system for filtration on steam systems. The mesh size for smaller orifice traps is finer than industry standard Y-Strainers. A well-designed filter will be reinforced to prevent becoming damaged in the field and have a tight seal around the top and bottom to prevent any debris from bypassing the filter. The interval between maintenance is determined by the surface area of the filter. More surface area allows more debris to be collected before maintenance.

Some manufacturers will include a second strainer in series inside the trap. The initial strainer will have a coarser mesh, with the second having a finer mesh directly before the orifice. The initial filter will only remove larger particles from the system, with the second still having a significant amount of debris to remove. These will typically require regular cleaning intervals as their smaller surface area leaves them prone to blockage. A single, fine, large surface area filter is more beneficial in terms of filtration and required maintenance.

6.2.2 Magnetic Filtration

The most prevalent form of debris within a steam system is corroded iron from the pipework. As this is highly magnetic, these particles can be captured through magnetic filtration systems. Optimal installation of this technology is following a strainer filter, and before the orifice. In these setups, the magnet will only capture particles that have evaded the fine strainer screen, acting as a last line of defence for the orifice. Installing this technology in a less impactful location before, or within the strainer basket will require much more regular servicing. Any particles that would be filtered through the strainer are instead caught by the magnet, leading to the need for cleaning with compressed air.

6.2.3 Inverted Cone Technology

An internal feature that has the orifice machined through a cone shape is shown in Figure 9. This deflects debris away from the orifice and breaks up particles into smaller components. This simple technology was developed in the tyre industry, proven to deal with grease and rubber particles inherent in the system.

6.2.4 Unblocking Steam Traps Inline

Despite the above technologies to mitigate blockages, lower duty applications will still be at risk. As there is no internal mechanism to repair, Venturi steam traps are very easy to service. Suppliers have developed inline servicing tools that can be used without the need to remove the trap from the steam system. The trap can simply be isolated, and cap removed for access to clean out the orifice. This service takes around 5 minutes, and is significantly quicker than repairing, or replacing mechanical counterparts.

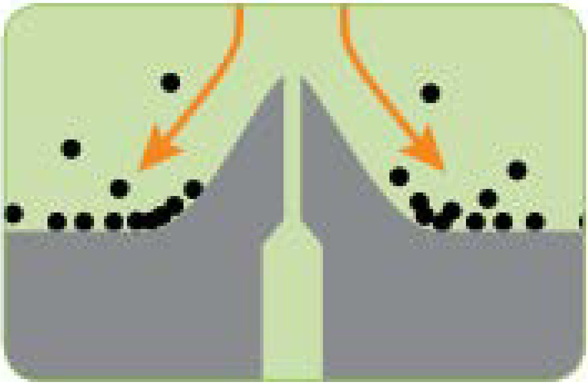

Abb. 9: Inverted Cone Technology [17]

7 Field Results

The adoption of Venturi traps has been limited due to concerns in the industry over their ability to operate over varying loads, and their resistance to plugging. We have looked at how leading manufacturers have developed their designs to minimise plugging and developed processes to accurately calibrate the steam profile to the operating range of the Venturi trap. However, as any engineer knows the real proof is in the field.

Case study tyre plants

Using the tyre industry as a case study we take three tyre plants as an example; each has an installation base of over 400 Venturi traps and has used the technology for at least 5 years. Steam use accounts for 2/3 of energy use in rubber production processes. Typical applications run 24/7, consume medium pressure steam between 6 and 15 bar(g), require variable capacities, and use smaller orifices, making it an ideal industry to explore the issues discussed.

Tyres are typically cured in platen presses with steam providing the heat to warm up the tyre and then cure the rubber. This process has a larger load at start up as the tyre is cold and heated to curing temperature, whilst steam consumption is reduced during the cure. Temperature control is critical in this process, with back up of condensate not permitted.

7.1 Energy Savings

7.1.1 Functional steam loss test

Calorimeter tests

A simple and effective method to demonstrate the efficiency of small capacity steam traps is a calorimeter test as described in ISO 7841. These tests capture the condensate, flash steam and any live steam passing though the trap and condense it in calorimeter partially filled with cold water. The temperature and mass of the calorimeter is measured before and after the test. Such tests are suitable for steam line drainage applications where the load is relatively constant, or applications such as tyre curing where the cycle is repetitive and short enough to collect in a calorimeter.

The greater enthalpy of live steam over condensate causes a disproportionate temperature to rise in the calorimeter for a given mass, when live steam passes through the trap. Tests should be conducted against mechanical traps that have been assessed to be functioning correctly. To account for the variation in mechanical trap flow, an average of three tests is recommended. The test is then repeated with the Venturi trap.

Results

Table 3 shows results of a calorimeter test performed on a 5 bar(g) line drainage application, comparing the efficiencies of a thermodynamic trap against a Venturi.

Tabelle 3: Calorimeter Test Results

	Mechanical	**Venturi**
Time (mins)	6	6
Initial Mass (kg)	5.35	5.35
Final Mass (kg)	6.8	6.7
Initial Temperature (°C)	15.8	16.3
Final Temperature (°C)	57.8	48
Mass Change (kg/hr)	14.5	13.5
Condensate Load (kg/hr)	13.35	13.42
Steam Loss (kg/hr)	1.15	0.08
Steam Loss (tonnes/yr)	9.2	0.64
Equivalent CO_2 (tonnes/yr)	1.5	0.1

Following ISO 7841 formulae, a steam saving of 1.1 kg/hr can be seen, which is in line with the Queen's University study. [14] These losses are scaled up to give annual results based on 8,000 hours of operation and a natural gas fired boiler. To estimate the savings on a site with 200 line drainage traps, this would equate to 1,760 tonnes of steam and 280 tonnes CO_2. Note that this represents the savings due to increased efficiency alone, against fully functioning mechanical traps and not through failed mechanical traps.

7.1.2 Retrofit Savings

Calorimeter tests give a good estimate on savings for low duty, constant load applications. To see the benefit on steam using processes, a steam metered trial is more suitable. This study shows the steam consumption of 15 tyre presses and 90 steam traps before and after installation. Each tyre press was supplied with around 10 bar (g) steam, with results given in Table 4.

Tabelle 4: Energy Savings Through Tyre Press Trial

Steam Use – Thermodynamic Traps	52,500	kg/day
Steam Use – Venturi Traps	49,100	kg/day
Savings	3,400	kg/day
Total savings	1,173	tonnes/yr
Gas savings	912,594	kWh/yr
CO_2 savings	169	tonnes/yr

These savings represent a 6.5 % reduction of total steam consumption and an average saving per trap of 1.6 kg/hr. Prior to conversion this site had a proactive maintenance program for existing mechanical steam traps.

7.2 Quality Improvements

Curing temperature in tyre production is critical, with most tyre presses having a thermocouple installed upstream of the trap, with a variation of no more than 1°C permissible. Cures that do not follow an ideal cure profile require further quality inspection, rework and potential scrap, incurring significant costs to the manufacturer. An additional benefit of Venturi traps is that their continuous flow operation improves temperature control. A German tyre manufacturing facility quantifies this reduction in Figure 10. Following the conversion of over 400 traps, monthly rejections were reduced by 69 %. Although not all rejections are due to steam trap failures, the data shows a clear improvement following the installation.

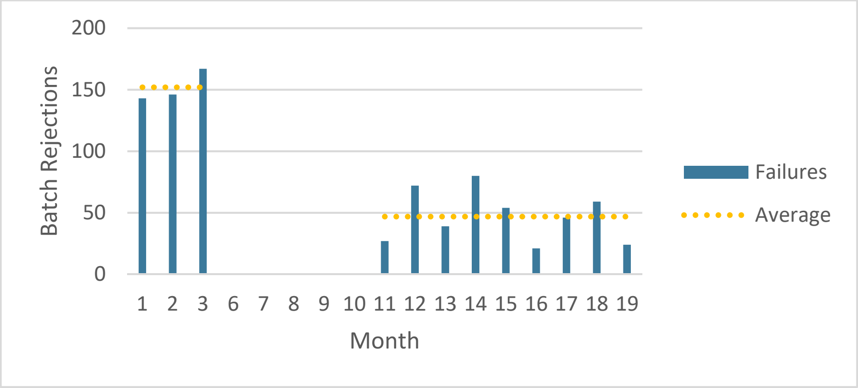

Abb. 10: Tyre Press Rejections [18]

This is a site that was already spending significant resources monitoring mechanical steam traps, not a site with a high failure rate. The site now only experiences occasional blockages that can quickly resolved inline by the press operator.

7.3 Servicing Requirement

Quality of water treatment

Analysis of installed Venturi traps has found the servicing requirement directly proportional to the quality of water treatment and existing maintenance procedure. Good practice would be to check the condition of each trap once a year via the methods described in section 3.1.

A site with good water treatment that is on top of maintenance can expect very little requirement for servicing of Venturi traps.

Based on a three-year analysis of service records of a Venturi trap supplier, sites with good maintenance regimes experience annual blockage rates between 0 and 3 % of traps. On sites that take much less care, servicing requirements are around 7–8 % per year. Note that these rates are in line with blockage rates found in the 100,000 steam trap study [6] which found 6.3 % of mechanical traps in a low temperature or blocked condition. It should also be noted that the sites with good practices see a reduction in maintenance requirement of other, larger pieces of steam equipment.

7.4 Reliability

Warranty periods of ten years are common with Venturi traps reflecting the lack of points of failure.

17 years in continuous operation

To demonstrate that performance does not degrade over time through erosion of the orifice, a leading Venturi trap manufacturer was able to recover several of its steam traps from a tyre manufacturing plant following its closure in 2018. At this point the traps had been installed for 17 years in continuous operation. The fact that this site had over 600 Venturi traps in use until its closure demonstrates that when correctly sized, the technology can cope with variable loads in industry and any issues with plugging are manageable.

Figure 11 shows that the orifice has no signs of erosion and the calibration gauges used during manufacture still fit tightly in the orifice. This trap has not degraded in performance over 17 years and could be expected to continue to deliver reliable and efficient service for many more years to come.

Abb. 11: Venturi Steam Trap from Tyre Press [19]

8 Conclusion

This article has focused on Venturi steam traps as a potential long-term solution to steam trap failure. Despite being on the market for over 25 years this technology has struggled to achieve the levels of adoption the benefits warrant.

Mechanical steam trap failure, and their repair or replacement, has always been an accepted cost of running a steam system. Mechanical steam trap users are in a perpetual cycle of steam trap failure, identification, and replacement, trying to find a balance between steam auditing frequency and the value of steam lost between steam trap failure and replacement.

An article by the Lawrence Berkley National Laboratory [1] investigating potential energy efficiency improvements across US steam systems found 19 % of the energy used in generating steam could economically be saved through projects with a three-year or less return on investment. Steam trap related losses accounted for 36 % of the 1,260 PJ of energy identified and eliminating these losses would save 4.5 Mt CO_2 annually if implemented across the US.

A field-based study of over 1,000 Venturi traps installed across three sites on steam main drainage and process critical tyre curing presses have identified:

1. Steam meter savings of 1.6 kg/hr per trap, yielding an annual saving of 1,173 tonnes/yr across 90 traps in a German plant who had previously engaged in a pro-active steam trap maintenance program
2. Better cure temperature control evidenced by a reduction in low temperature alarms during the cure process of 69 %
3. 17 years of reliable operation with no erosion. Steam traps returned to the manufacturer following a plant closure 17 years after installation showed no signs of erosion and would have functioned the same as the day they were installed.
4. Analysis of maintenance records shows that blockage rates are no more frequent than with mechanical steam traps

Calibration is the key to the success of any Venturi trap project, undersized traps will back up condensate, and oversized traps will be less efficient. The priority for any energy or carbon reduction project is to not impact production as downtime costs will quickly erode any savings realised. The second is to achieve the energy savings.

When selecting a Venturi steam trap supplier, you are purchasing a calibration service. A good supplier will be able to identify suitable applications and take a holistic view of the steam system, making recommendations to ensure its suitability for Venturi traps. They will spend the time on site and with your engineers to understand your process and system to calibrate the traps, then commission post installation to check they are operating correctly. The return on investment of converting a site to Venturi technology is typically fast, with the traps having a long lifetime. To minimise total cost of ownership, suppliers should be selected on their ability to accurately calibrate the Venturi traps and not on upfront costs. Reducing the sizing and commissioning scope increases the risks of projected energy savings not being realised, or the project impacting production.

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