FAILED STEAM TRAPS: FIRST STEPS TO REPLACEMENT

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ABSTRACT
Current Energy, Environmental and Economic concerns are exerting pressure on steam plant managers to re examine their plant maintenance practices.In South Africa, big components of the steam line such as boilers have always received legitimate attention. But, the smaller ones – especially Steam Traps – have tended to be taken for granted. A Literature search revealed lack of adequate Trap knowledge in industry - with the result that up to 55% of steam in some plants is lost through them! In this paper, traps are reviewed.Also, described,is Industrial experimentation carried out at two Cape Town factories on them. Based on the research and experimentation, current practice of replacing traps with identical ones was challenged- withone of the factories- advised to try a mix of old and newer Technology traps in its refurbishment.

KEYWORDS: *Steam Trap, Steam Trap replacement,Energy efficiency,Thermodynamic trap, Venturi Trap, Condensate removal*

I. INTRODUCTION

Regular Steam line maintenance in industry revolves around keeping heat transfer surfaces clean, preventing line steam leakages and preparing boilers, pressure vessels and heat exchangers for legal inspections. Steam traps tend to receive little attention partly because they are tiny items - often installed in quite obscure areas of the plant. But also, Sandeep [1] has observed that "lack of steam trap knowledge is the weakest link" in steam line maintenance. Moreover, when properly selected and installed – often with expert involvement – they give reliable service during their design life. This tends to shield attention from them. And if installed to discharge to the atmosphere – as was the situation in this case study – flash steam discharge is part of their normal operation. So, an ordinary observer may not easily detect trap progress to total failure. Figure 1 shows flash and live steam coming out of a trap. It takes a skilled eye to detect the gradual transformation from 'a' to 'b'.

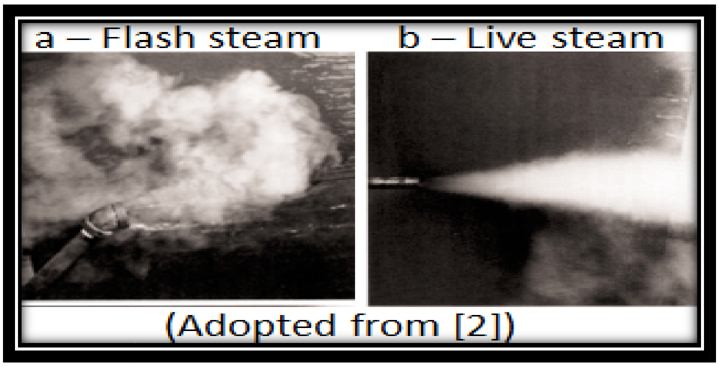


Figure 1: Normal operation 'a' to fully failed 'b' condition of a steam trap discharge to atmosphere

Many steam traps are designed for a 3 to 5 year life [2]. This fact is not always appreciated in industry. For example, at two leading East African Industries one of us worked in, the majority had not been replaced for over twenty years. Even in the South African factory under consideration in this paper, they have been on line since the pre 1994 days. Yet according Gardner [3] and other experts like in some of the US Federal Government departments[2& 4],by the 3rd to 5th year, 30 to50% of them may have failed.In an inspection of a Belfast oil refinery steam plant, McKay and Holland [5] found 25% of the traps leaking live steam. They estimated that up to £121 500 could be saved on annual basis by prevention of the steam waste.The implication is that at some stage, traps have to be replaced.

This paper illuminates the first steps on their replacement. It summarises the theory behind the functioning and failure of commonly available traps and then focuses on essential industry based (as opposed to laboratory) testing and experimentation before trap selection for replacement. First, a brief review of steam traps and their uses is presented. A discussion of three of commonly available ones follows. It is these types that are later referred to in the experimentation section of the paper. Bimetallic strip and Thermostatic traps are also quite common but are not discussed because the factories in point did not use them. Methods of investigating trap performance are reviewed before a description and discussion of experiments done during the research. Finally - after specific recommendations, several issues arising out of the results and needing further investigation are pointed out.

II. STEAM TRAPS

Steam trapsare devices installed in a steam-condensate circuit primarily to prevent steam from leaking through the drains provided for condensate - i.e. they 'trap' and block steam in a condensate sub circuit. By doing this, they are able to minimise energy wastage. And by draining condensate, they serve several purposes:

- Theyhelp keep the steam as dry as possible so that heat transfer rates at surfaces of steam use are maximised
- They help lower steam sub circuit heat losses to the atmosphere by thinning the liquid film in the pipeline
- They prevent steam pipeline annular flow, thereby availing maximum flow area and minimising line steam pressure losses
- They prevent water hammer downstream the steam line thereby protecting fittings and the entire pipeline from possible catastrophic failure. In a series of articles and papers, Kirsner[6 - 8] explains how condensation induced water hammer can be up to 100 times as destructive as ordinary steam induced water hammer in slug flow – which in itself is tens of times as destructive as ordinary liquid water hammer!

A secondary trap function is to purge and vent air and non condensable gases from the steam line. This helps keep heat transfer surfaces at point of use, air/gas- free so that overall thermal resistance is minimised. Non condensable gases include carbon dioxide which forms corrosive carbonic acid with water. Its expulsion along with that of oxygen in the air helps prevent corrosion in the entire steam - condensate circuit.

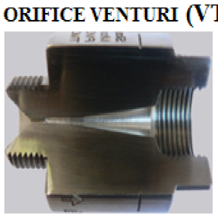
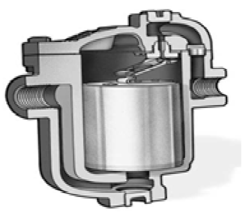
In effecting its discharge/expulsionduty, some steam inadvertently gets lost even from a brand new trap – as evidenced by trap manufacturers' catalogues [9 -10] and Swagelok Energy Advisors [11]. In steam systems energy audits, Bhatt for example emphasises correct choice of steam traps as one of ways to improve overallenergy circuit efficiency[12]. Einstein et al. [13] also advise adoption of more modern traps to reduce energy waste and improve system reliability.The loss – though normally small - is different for different trap types and makes.In trap selection therefore, there is a fundamental need for balance between effectiveness (i.e. duty) and efficiency (cost of duty in terms of steam leakage).

2.1 Brief Summary of available Trap types

Traditionally, there have been three major types of traps grouped according to their principle of operation [9, 10, and 12]. Mechanical – employing the buoyancy principle to shut out steam-laden lightcondensate; Thermodynamic – employing the Bernoulli steady flow energy (SFE) principle and Thermostatic –using temperature difference between condensate and steam as the driver. The Fixed Orifice Plate trap – being simple and cheap- used to be popular decades ago. But its propensity to leakage and blockageshas since led to its replacement by more effective and efficient types.

According to Trytten [16] and Hollscher [17], afourth type, the Venturi orifice trapwas first developed for the US navy in early 1960s. It has now been adapted for industry since the mid-1990saccording to the latter.Like the original plate orifice trap, ithas no moving parts. Itis a form of convergent-divergent nozzleemploying the first and second laws of Thermodynamics under meta- stable flow conditions to minimise steam leaks.It is the focus of this paper. The fifth and most recent entrant is a patented Electronic Condensate Controller [17].It is claimed to be able to monitor and respond to condensation and ensure zero steam discharge into the condensate line.
For purposes of this paper, Table 1 givesa summary commentary on three of the categories based on some manufacturers' literature [9, 10], and on our own experiences in industry.

Table 1: Three of the commonly available Traps

TRAP & PRINCIPLE	ADVANTAGES	DISADVANTAGES	COMMENTS
THERMODYNAMIC (TD)  Courtesy – Spirax Sarco	1. Within design range, independent of pressure and temperature; 2. Unaffected by water hammer, freezing and vibrations . 3. Simple and robust	1. Can air-lock during high pressure rise starting conditions. 2. Needs a thresh hold working pressure to operate. 3. Affected by back-pressure	1. Has one moving disk which - along with its seat is subject to wear and jamming. 2. Trap tends to fail open giving a clear signal to operatives and maintenance staff.
ORIFICE VENTURI (VT)  (Courtesy – Delta Industries SA)	1. Minimal maintenance and long life – 'Fit and forget'. 2. Unaffected by water hammer and vibrations 3. Readily passes air: no venting required 4. Continuous discharge of air 5. Simple and energy efficient	1. Precise load matching for sizing - required 2. Compromised effectiveness if line loads and pressures are varying 3. Will generally leak if on a superheated steam line 4. Needs Excellent straining and boiler water treatment	1. A fairly recent trap - often erroneously confused with the fixed orifice plate type. 2. Failure is largely by closure by entrapped particles thus causing sudden condensate backup and consequential problems downstream .
INVERTED BUCKET (IB)  (Courtesy – Armstrong)	1. Unaffected by back pressure and resists water hammer 2. Can handle superheated steam 3. Least affected by dirt and debris 4. Continuous discharge of air 5. Simple, virtually frictionless mechanism	1. Can freeze 2. Wastes steam at low loads	Arguably the most reliable and direct operating principle. Largely fails open but could also fail closed

III. TRAP PERFORMANCE INVESTIGATION

Steam trap performance is receiving much attention these days mainly because of current world energy crisis and carbon foot print concerns. According to the May 2010 International Energy Outlook release, [18] about 86%of world energy production is from fossil fuels. Most of this energy is produced with help ofsteam plants.Yet according to a new computation by Shafiee and Topal [19], it is estimated that current knownoil, gas and coal reserves will have been fully depleted by 2040, 2042 and 2112respectively. At the same time, the same plants are responsible for the present annual 30 Billion Tonnes of carbon dioxide (CO_2)load into the atmosphere. The concerns on proper steam plant management to minimise not only their need but also the overall energy cost component in industrial products and services are therefore well founded. Locally - in South Africa - other reasons for proper energy management were highlighted by Fawkes, [20]. They include: Profitability, Competitiveness in an increasingly open world economy and capital cost constraints necessitating delays in investments. While the latter may need further scrutiny in light of increasing demand by non

industrial sectors and of capital equipment cost inflation, the fact remains: every positive effort on steam trap maintenance will reward the organization and society handsomely – and in a short period.
Estimates by SpiraxSarco[10]indicate that in a given steam plant, if no trap preventive maintenance activities are done, up to 30% of the traps may fail within 3 to 5 years – and that at any one time, up to 50% may be blowing live steam! Experts further agree that suitable Preventive Maintenance can reduce resulting steam losses to between 1 and 3% [1, 2 and 21].In a report on adoption of Trap Maintenance in 10 Textile industries in India for example, Sandeep [1] reports a 2008 annual steam saving of 2000 Tonnes from a combined 64 Tonne/hr capacity – working 6000 hours a year. In 1999, the US Department of Energy issued a Federal Technology Alert on trap testing. In that alert, a case study on three plants in which a total of 103 traps - out of 511 tested - had failed open wasdescribed. Total annual steam losses were estimated at 20 885 000 lb (Appr. 9500 Tonnes) and subsequent savings on adoption of simple maintenance were estimated at US$ 92 323. Clearly, there is money to be saved (and made too!) by taking a closer lookat maintenance of steam traps. There are also many Tonnes of CO_2, Nitrogen and Sulphur oxides (NO_x and So_x) not to be offloaded into the atmosphere.
The issue we discuss in this paper however is: after identifying a failed trap, do we simply replace it with a new one of the same specifications?If not, how do we go about comparing performances of different traps – which may - or may not be of the same type?
Best Practice procedures on steam trap maintenance and testing have been described by many authorities e.g. [1, 2, 9-11].Four approaches are now available to trap-testing: Visual – using site glasses and/or discharges to atmosphere (the latter - for traps discharging to atmosphere or at return to a hot well); Temperature checks for steam and condensate pressures before and after the trap respectively; Ultrasonic listening devices for flow through the traps; and a most recent one – fluid conductivity testing inside the trap.Usually, a combination of some of these approaches – with varying sophistication – is used depending on the numbers of traps, the skills available and the overall economics of the maintenance programme. First rate organisations and manufacturers like, Armstrong, SpiraxSarco and NASA [9-10 and22] recommend suitable actions to take depending on the results of the inspections and tests. Most of these actions involve repairs and internal cleaning. However, in many sub Sahara African steam plants – such as those in East Africa referred to in I above, and the particular case in Cape Town - previous maintenance may have been inadequate. In such cases, simple repairs and cleaning will not be the option because of severe pipeline corrosion and/or previous water and steam hammer effects on the traps.New traps (and probably piping and insulation) become imperative. Normal practice would be to replace failed traps by identical ones (especially if some are held in stock). But this can lead to fresh failures if not well thought out. Also, it cuts out new technology traps which might be able to perform better. It is therefore necessary to take a fresh look at the replacement options available. In this endeavour, theASME code PTC 39.1 - 2005 is helpful. It describes a method for determining condensate flow rate and steam leakage rate through the trap. These two are the most important (but not the only ones) parameters in comparison of trap performance. In Europe and South Africa however, International Standard ISO 7841:1988 guidelines are the more used procedures. Experimentation in this paper was influenced by this standard.

3.1 Examples of Previous setups on Trap performance comparison

Several researchers and practitioners e.g. [21, 23 -26] have in the past reported comparative performances of different traps. Tsyrulnikov [24] and Shada Abu-Halimeh [25] carried out their tests under laboratory conditions Tucker [21] and Joy on the other hand did their experiments on line but tended to compare industrial performances after replacement of faulty traps with those immediately before. On one hand, therefore, traps were being tested in their prime – giving no indication of how comparative performance would change after several months/years of running. Yes - it is accepted that a trap's steam leakage rate will increase with time of service. But internal wear or ageing characteristics of different traps can be different. Hence laboratory conditions on their own cannot give conclusive data on trap overall performance. This is why code PTC 39.1-2005 lists three other attributes to be factored into overall performance. They are: Air discharge rate; Susceptibility to failure and Effects of back pressure.

On the other hand, the commonestcomparisons are those of lines with some failed traps before and after refurbishment. These are exemplified by practitioners such as Sandeep[1], Webb [23], Dickerson [27] and Hanekom [28]. It is to be expected in such cases that performance would improve. The more realistic approach is to install two new correctly sized traps on a line and monitor their performance over a period of time. Examples of such attempts in the literature includeWardell [29] and Currie [30].It is significant to note that these particular practitioners were motivated by a Technology change in the traps. The same change in South Africa is the reason behind this paper.

IV. EXPERIMENTS: VENTURI TRAP VS. THERMODYNAMIC TRAP

4.1Background

Company **'A' Ltd.** in Cape Town (details of which - including processes - we are not allowed to disclose for confidentiality reasons) was considering replacing some of the steam traps along its extensive steam distribution network. It runs two boilers with a combined capacity of 18 Tonne per hour at a name plate pressure of 1034 kPa (gauge). Normally it fires them to 800 kPa (gauge) or 903 kPa absolute. Saturated steam is then transported to various usage points over a large area. Some of the lines are longer than 1 km.They were old and in many places, insulation was broken down. A big fraction of condensate was not returned – and for the particular trap stations in this experiment, discharge was to the atmosphere. Prior to their inviting us, plant management had done comparative tests between thermodynamic (TD) and venturi (VT) type traps at two trap stations on different lines leaving the boiler house. They had also set up the stations for our observation.After observing the alternative traps on line in action, we were presented with results of their previous experiments for interpretation (Tables2 and 3). Using an analysis we illustrate below in 4.4, it seemed – within limitations of the data - that the Venturi traps were leaving condensate in the lines and therefore it was not possible to determine their energy efficiencies at that stage. The Thermodynamic traps appeared to perform with respective energy efficiencies of 82% and 90% on lines 1 and 2. It was therefore suggested and agreed that the experiments be repeated at a later date with our involvement.

Table 2: LINE 1: 1 1/2" (40 mm line: D3 VT Vs. 1/2" TD Trap:

Reported steam pressure: P_{sat} = 4 bar (gauge) = 501.3 kPa (abs); Temperature: T_{sat} = 151.9°C; $\rho_{g\text{-}sat}$ = 2.681 kg/m^3

	THERMODYNAMIC (TD)			VENTURI (VT)	
Initial bucket mass m_1 (kg)	4.42	5.13	4.93	5.526	5.34
Initial bucket Temperature T_1 (°C)	19.2	25.3	17.4	18.2	18.2
Final bucket mass m_2 (kg)	7.53	10.16	10.53	10.453	10.15
Final bucket Temperature T_2 (°C)	96.3	97	95.2	76.5	74.8
Condensate Temp. before trap $T_{cond\text{-}trap}$ (°C)	135	138	135	139	138
Condensate collection time t (s)	600	189	149	600	600

Table 3: LINE 2: 8" (200 mm line: D2 VT Vs. 1/2" TD Trap:

Reported steam pressure: P_{sat} = 5 bar (gauge) = 601.3 kPa (abs); Temperature: T_{sat} = 158.9°C; $\rho_{g\text{-}sat}$ = 3.178 kg/m^3

	THERMODYNAMIC (TD)		VENTURI (VT)	
Initial bucket mass m_1 (kg)	5.12	4.1	5.01	4.41
Initial bucket Temperature T_1 (°C)	17.2	17.4	18.7	17.6
Final bucket mass m_2 (kg)	9.57	8.26	9.01	8.31
Final bucket Temperature T_2 (°C)	85.9	92.3	70.4	72.5
Condensate Temp. before trap $T_{cond\text{-}trap}$ (°C)	148	149	150	146
Condensate collection time t (s)	300	300	600	600

4.2 Theory

Figure 2 gives a sketch of a general arrangement of drip traps along a steam main. If dry saturated steam enters the pipeline at Pressure $P_{sat\text{-}in}$, it soon loses heat q_l per metre length of run - and condensate begins to form at a rate q_l/h_{fg} per metre length. Earlier on in the mains, a big percentage of this condensate will bypass the traps along the mains because the conveying velocity is in the range of 20 – 40 m/s [9].Further downstream however, sufficient condensate will have formed to get appreciable quantities and fractions into the drip legs – and hence into the traps. The issue then is to discharge as much of this condensate as possible while passing minimal steam.

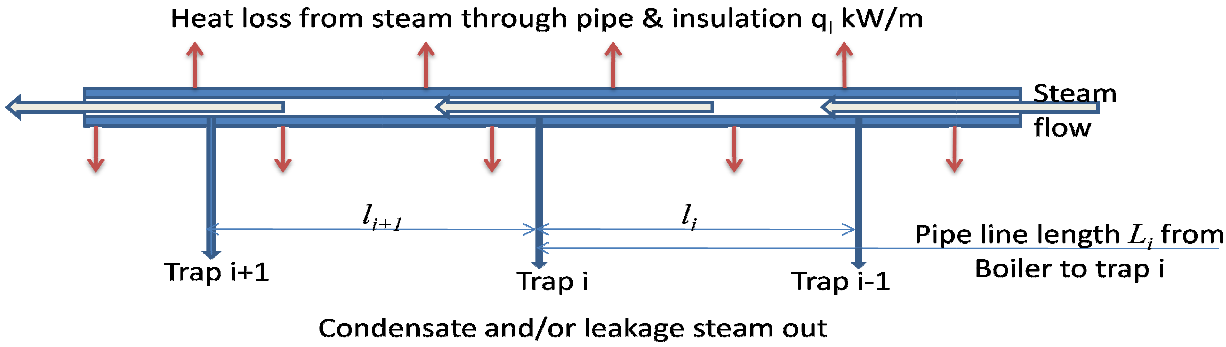


Figure 2: Condensation and Drip Traps along a steam main

Thermodynamic and Venturi traps achieve this in totally different ways. Referring to sketches with in Table 1, condensate pressure in a TD lifts the disc off its seat and flows out through the resulting opening. This continues until condensate has reduced so much that wet steam begins to pass through the opening. But then, the big gain in velocity through the opening lowers the static pressure below the disc and consequently, the latter shuts off until another sufficient load of condensate accumulates. The VT on the other hand passes condensate as a normal venturi device handling an 'incompressible' fluid – until saturation (point a' in Figure 3). After saturation, meta-stable – or flash flow results as pressure continues to drop. Then the flow rate drops rapidly owing to partial conversion of both liquid kinetic energy and static enthalpy to vapour stagnation enthalpy. Either of wet or dry steam passesthrough as a compressible fluid. In that case, the expansion at the VT throat to a critical pressure P_{cr}limits the throughput to negligible values. The processes are illustrated on a T-s diagram as in Figure 3. Bailey (1951) is reported by Tucker [18] to have determined the mass flow rate variation with inlet dryness fraction. His results showed that the flowrate dropped threefold on reaching liquid saturation (point b_{in}), halved further at 10% dryness inlet. By dry saturation (point d_{in}), it had reduced to less than 4% of the initial sub cooled rate.

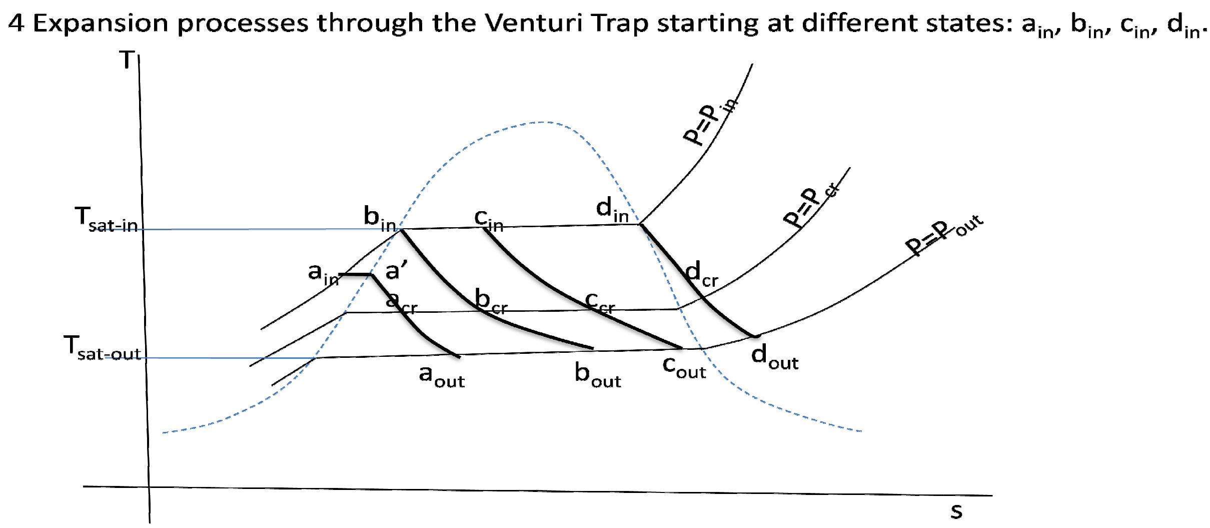


Figure 3: Effect of Venturi inlet state on the thermodynamic Temperature (T) – Entropy (s) process diagram

The above brief explanations show that both TD and VT operate by opening for condensate but shut out steam differently. One closes while the other remains open – utilising the back pressure created by fluid acceleration to retard oncoming steam. The concern at Co. **'A' Ltd** was whether, it was true the

VT was wasting less steam and if so, whether it was not leaving condensate in the line. On our second visit, therefore experiments to answer these concerns were set up.

4.3 Experimental set up

We used the bucket condensate collection method to compare the two traps on both lines. The equipment used was:

- Infra red thermometer with thermocouple probe: Make:Omega Professional; Resolution to 0.1°C; Accuracy: Ambient Temp: 25ºC (77ºF) ±1ºC (±1.8ºF); 33 to 1000ºC to±2% of reading or 2ºC (4ºF) whichever is greater
- Electronic weigh scale: Make: LBK 12; Capacity;12 kg; Readability to 2 gm; Repeatability; SD 2 gm; Linearity; ±4 gm; Stabilisation time; 2 s
- 2 Plastic buckets: Capacity – 15 litres; Empty weight – 0.51 kg and 0.50 kg
- Digital Stop watch: Make - Casio; Precision to 0.01 s
- 2 New Delta Venturi traps (D3 and D4 – with D4 as the larger capacity trap); 1 new ½" Spirax SarcoThermodynamic trap; 1 old but functional Spirax Sarco inverted bucket (IB) trap installed downstream Test station Number 2.

The set up at a trapping station is shown in Figure 4. The mass of the empty bucket with its cover was taken and recorded as m_b in kg. Some ordinary tap water was poured into the bucket and a mass m_1 obtained.The initial water temperature was taken with help of the probe to give T_1. Then the water bucket was placed to collect discharge from one of the traps and covered. The pipe inlet hole on the cover was a running clearance fit with the pipe – and so discharge in the bucket was at atmospheric pressure. The isolating valve to the alternative trap was confirmed closed and then that to the test trap opened. Simultaneously, the stop watch was started and run until closure of the valve. This gave a discharge time t s. The water bucket was then removed and the final water temperature T_2, recorded immediately.Finally, the water bucket was weighed to give a mass m_2. During the course of the experiment at least 3 readings of the pipe surface temperature at the bottom of the drip leg were taken using the infra red option on the thermometer - and the average of these approximated to the condensate temperature, $T_{cond\text{–}trap}$. The average bucket surface temperature T_s, was determined in like manner. Also, the site glass was constantly watched for trap cycling.

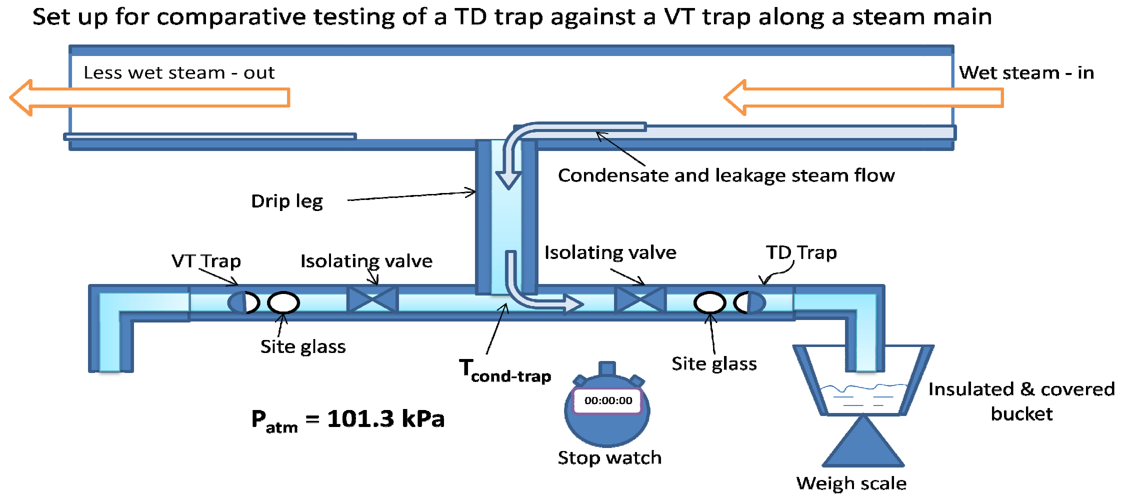


Figure 4: Setup at a trapping station

The above procedure was repeated for the second trap but with the second bucket – as the first one had to be given time to cool. This was repeated on each of two steam lines three times. Some of the precautions taken to get consistent results included:

- Starting off with as nearly equal amounts of cold water as possible – so that the initial bucket thermal masses and wetted areas were nearly the same

- Running the experiments for the same amount of time (except where it was evident water quantities and flashing were being quite excessive) - so that bucket heat leakages to the atmosphere were as nearly equal as we could try to make

On the second line, we also checked operation of the inverted bucket trap downstreamwhile the test traps were running. This was to verify whether any of the two alternative traps' performance was having an effect downstream. The results of these investigations, together with computations for energy efficiency are given in the sample spreadsheet for line 2 in Table 4.

Table 4: Results of Tests on Line 2: (200 mm main steamline)

COMPANY 'A Ltd' STEAM TRAPS TESTS OF 15th OCT 2009

15TH OCTOBER 2009; 13 30 TO 16 00; MODERATE WINDY, 20.9°C	**TD Trap**			**(VT) D3**			**(VT) D4**		**INV. BKT NEXT TO:**		
Empty Bucket mass: 0.5 kg; Conv. & Radiation Surf. area: 0.2992 m^2									**TD**	**D3**	**D4**
Initial bucket mass m_1 (kg)	3.2	3.29	2.95	3.13	3.03	3.01	2.98	3.09	3.04	3.2	3.37
Initial bucket Temperature T_1 (°C)	22.6	22.9	23.5	18.9	21.9	22.3	23.1	24.1	23.3	22	23
Initial specific enthalpy h_1 (kJ/kg)	*94.8*	*96.1*	*98.6*	*79.3*	*91.9*	*93.5*	*96.9*	*101*	*97.7*	*93.1*	*96.5*
Final bucket mass m_2 (kg)	5.2	5.39	4.98	6.95	7.22	6.75	6.72	7.13	5.35	4.46	6.19
Final bucket Temperature T_2 (°C)	93.6	95.3	97.1	95.5	98.1	97.5	93.5	95.6	86	69.6	89.4
Final specific enthalpy h_2 (kJ/kg)	*392*	*399*	*407*	*400*	*411*	*409*	*392*	*401*	*360*	*291*	*375*
Condensate Temp. before trap $T_{cond\text{-}trap}$ (°C)	157	154	157	166	165	166	156	160	154	NA	160
Average bucket surface Temperature T_s(°C)	53	54.1	57	58.2	56	57.7	57	55.3	50.2	NA	51.2
Cond. spec. enthalpy at Trap h_f (kJ/kg)	*671*	*650*	*672*	*702*	*697*	*699*	*662*	*676*	*650*	*NA*	*676*
Live steam spec. enthalpy at Trap h_g (kJ/kg)	*2754*	*2751*	*2754*	*2764*	*2763*	*2763*	*2753*	*2758*	*2751*	*NA*	*2758*
Condensate collection time t (s)	300	300	300	600	600	600	600	600	300	300	300
Average trap discharge rate: $m=(m_2-m_1)/t$ (10^{-3}kg/s)	*6.67*	*7.00*	*6.77*	*6.37*	*6.98*	*6.23*	*6.23*	*6.73*	*7.70*	*4.20*	*9.40*
Appr. Bucket heat loss rate to atm.: $Q_s = 0.022*0.2992*(T_s-20.9)$ (kW)	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*NA*	*0.2*
Energy rejection rate: $Q_{rej} = Q_s+[(m_2-0.5)h_2-(m_1-0.5)h_1]/t$ (kW)	*5.5*	*5.8*	*5.5*	*4.2*	*4.4*	*4.1*	*3.9*	*4.2*	*5.2*	*NA*	*6.4*
Energy rejected per kg discharge: q_{rej} (kJ/kg)	*824*	*832*	*813*	*658*	*636*	*657*	*624*	*625*	*673*	*NA*	*678*
Trap Energy efficiency: h_f/q_{rej} (%)	*81.4*	*78.1*	*82.7*	*107*	*110*	*106*	*106*	*108*	*96.6*	*NA*	*99.7*
Hourly live steam rejected: $m_g=3600(Q_{rej}-mh_f)/(h_g-h_f)$ (kg/hr.)	*1.8*	*2.2*	*1.6*	*-0.5*	*-0.7*	*-0.5*	*-0.4*	*-0.6*	*0.3*	*NA*	*0.0*

4.4 Results Discussion and Follow up Tests elsewhere:

From Table 4, the key findings were:

- Both Venturi Traps D3 and D4 were undersized for the duty on line 2 as evidenced by the unexpected 100+ % efficiency (and consequent meaningless negative steam discharge rate) highlighted in the table. Trap D3 was actually observed to be continuously discharging – and that is the reason D4 was tried. Though D4 was observed to cycle, it still left condensate in the line as evidenced by the increased load onto the inverted bucket trap downstream (see last column of table).
- The thermodynamic trap was effective in its duty of removing condensate. However, it passed steam at a rate up to eight times the manufacturer'sloaded condition estimation of 0.25 kg/hr! (No load condition = 0.75kg/hr) [9].Whether this was due to wrong sizing or otherwise – is not within of the scope of this report.
- The inverted bucket trap – though old and not a primary target of this investigation – did its duty very well and efficiently too! This opens a window for marginally undersized Venturi traps to be used in conjunction with an efficient, resilient trap. Such a combination could combine the positive attributes of both to optimise the total line performance. However, some consideration would have to be given to the effects on part of the line between the traps.

After the above findings on an old and long steam line several hundreds of metres from the boiler house, a second set of experiments was done in another factory (Co. **'B' Ltd.**) just a few metres after the steam stop valve in the boiler house itself. The results of this investigation are given in Table 5.

Table 5: Results of Tests at Company 'B Ltd' just after the steam header in the boiler house:

Company 'B Ltd' Steam Trap Tests of 22nd Nov 2009

22nd Nov 2009; 14 30 TO 16 30; BOILER HOUSE STEAM HEADER; 22.4°C	**THERMODYNAMIC (TD)**			**VENTURI (VT) D3**		
Empty Bucket mass: 0.5 kg						
Initial bucket mass m_1 (kg)	3.697	3.418	3.704	3.614	3.485	3.682
Initial bucket Temperature T_1 (°C)	21.6	22.1	19.5	21	19.6	19.5
Initial specific enthalpy h_1 (kJ/kg)	***90.6***	***92.7***	***81.8***	***88.1***	***82.2***	***81.8***
Final bucket mass m_2 (kg)	5.334	4.648	4.652	4.339	4.215	4.599
Final bucket Temperature T_2 (°C)	92.3	89	73.8	55.6	56.1	57.1
Final specific enthalpy h_2 (kJ/kg)	***386.7***	***372.8***	***309.0***	***232.8***	***234.9***	***239.0***
Condensate Temp. before trap $T_{cond\text{-}trap}$ (°C)	174.8	177	172.2	176.7	175	173
Condensate spec. enthalpy at Trap h_f (kJ/kg)	***740.1***	***749.8***	***728.7***	***726.5***	***741.0***	***732.4***
Live steam spec. enthalpy at Trap h_g (kJ/kg)	***2772***	***2774***	***2767***	***2774***	***2772***	***2769***
Condensate collection time t (s)	300	300	300	300	300	300
Average trap discharge rate: $m=(m_2-m_1)/t$ (kg/s)	***0.0055***	***0.0041***	***0.0032***	***0.0024***	***0.0024***	***0.0031***
Energy rejection rate: $Q_{rej} = (m_2-0.5)h_2-(m_1-0.5)h_1)/t$ (kW)	***5.266***	***4.253***	***3.403***	***2.064***	***2.090***	***2.398***
Energy rejected per kg discharge: q_{rej} (kJ/kg)	***965.0***	***1037.4***	***1076.8***	***854.2***	***858.9***	***784.6***
Trap Energy efficiency: h_f/q_{rej} (%)	***76.7***	***72.3***	***67.7***	***85.1***	***86.3***	***93.3***
Live steam rejected: $m_g= 3600*(Q_{rej}-mh_f)/(h_g-h_f)$ (kg/hr.)	***2.16***	***2.09***	***1.94***	***0.54***	***0.50***	***0.29***

The main finding here was that the Venturi trap D3 had the necessary capacity for this particular trap location and that it was more energy efficient than the TD it was being compared with. The steam losses through D3 were well within what manufacturers of other traps specify for their properly selected traps. However again, whether the TD was oversized for the location or not is outside the scope of this report.

V. CONCLUSION AND RECOMMENDATIONS

From the results above, it can be said that a Venturi trap can be an energy efficient trap if properly sized for specific locations. It would also appear that the VT would most likely work best under constant load conditions much upstream the steam line.
The theoretical and other practitioners' and researchers' work cited in this paper however cannot be ignored. There is sufficient evidence to justify installation of VTs in properly maintained plants with well treated boiler feed water. Even downstream a steam main - provided the pipe line insulation is sound - they could be installed. In that case however, we would recommend that they be alternated with more resilient traps like the inverted buckets to maximise total line effectiveness and energy efficiency. To Company '**A' Ltd.**, we therefore recommended as follows:

- Begin by looking at the steam line ahead of the stations where you would wish to install new traps. Renew the piping and/or insulation in that part. This is anyway necessary irrespective of which trap type you will select.
- Aim to use a trap mix (including a suitable VT upstream) along the line. We know this can be problematic in terms of having more than one competing suppliers on site and also in terms of stocking spares etc. But this is your plant – and the potential benefits of using the best offers from each can be significant. In any case, work out a total life cycle cost-benefit analysis for various proposals before final selection.

VI. FURTHER WORK FOR RESEARCH

In this paper, we have reviewed some of the literature on steam traps and given a bit of our own experiences with various traps. An industry based experiment to compare performance of two different traps was described and some of the key results analysed with a view to making specific recommendations to one factory. This work was by no means exhaustive. There are issues it raised but are not answered here-in. For example; in Table5: why did the Venturi condensate temperature appear consistently higher than that for the Thermodynamic trap – yet results suggested the formerwas leaving condensate in the line? And if it was leaving condensate in the line, what mechanism was at play to cause it to visibly cycle? Other areas for investigation are more economic than scientific. The use of sub optimal Traps with oversized resilient neighbours to maximise total line utility could be an interesting area to look into.
That notwithstanding, we hope we have shed some light on initial steps towards failed trap replacement. The key point is: Do not simply replace the failed trap with its replica. Apply a bit of thought and experimentation where necessary. The results could be more rewarding than you might expect.

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