Energy loss due to improper functioning of steam traps in Auxiliary steam pipe lines

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Abstract

Steam traps are automatic valves used in every steam system to remove condensate, air, and other non-condensable gases while preventing or minimizing the passing of steam. If condensate is allowed to collect, it reduces the flow capacity of steam lines and the thermal capacity of heat transfer equipment. In addition, excess condensate can lead to "water hammer," with potentially destructive and dangerous results. Air that remains after system startup reduces steam pressure and temperature and may also reduce the thermal capacity of heat transfer equipment. Non-condensable gases, such as oxygen and carbon dioxide, cause corrosion in the system. Steam lost through the trap because of improper functioning provides no heating service. This effectively reduces the heating capacity of the steam system or increases the amount of steam that must be generated to meet the heating demand. Where condensate is not returned to the system, water losses will be proportional to the energy losses associated with leaking steam.

The maximum steam loss rate occurs when a trap fails with its valve stuck in a fully opened position. While this failure mode is relatively common, the actual orifice size could be any fraction of the fully opened position. Steam traps were identified and evaluated to determine their performance and the amount of steam lost from malfunctioning traps.

Thermodynamic steam traps used in auxiliary steam lines of older power plants are found to be less energy efficient, high maintenance prone and has short service life. By replacing Thermodynamic steam with inverted bucket or bimetallic thermostatic steam traps in auxiliary steam lines lot of energy can be saved. This will not only save money but also avoid unnecessary burning of coal, hence less pollution to environment.

The case study indicates that payback period of replacement of steam traps are less than a month. Even if leakage through stem traps are one ton per hour the payback period will be six months only. Therefore, it is prudent to go for a replacement program of existing non performing steam traps by efficient steam traps. Hundreds of Crores of Rupees can be saved by implementing steam trap replacement and maintenance program across NTPC older units.

Keywords: *Steam trap, Auxiliary steam, condensate, Thermodynamic steam trap, inverted bucket.*

Introduction

The function of steam traps is to discharge condensate and non-condensable gases while retaining live steam in the system. This ensures that the system is able to operate efficiently without the detrimental effect of unwanted condensate. Unwanted condensate in the system lead to poor heat transfers, damage to system or process equipment due to water hammering.

Each steam application has its own steam trap requirements. Selecting the right steam trap for the application could have asignificant, positive impact on the process, potentially improving efficiency, reducing energy costs and giving a safer workingenvironment.

For overall efficiency and economy, a well-designed steam system must be provided with suitable steam traps meeting following requirements:

1. Minimal steam loss
2. Long life and dependable service
3. Corrosion resistance
4. Air venting
5. Operation against back pressure
6. Freedom from dirt problems

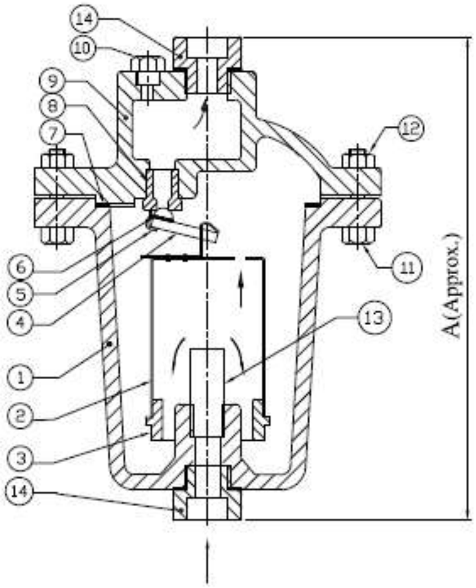
Types of steam Traps (Literature review)

There are three primary categories of steam traps:

1. Mechanical Steam trap
2. ThermostaticSteam trap
3. ThermodynamicSteam trap

1. **Mechanical traps.** They have a float that rises and falls in relation to condensate level and this usually has a mechanical linkage attached that opens and closes the valve. Mechanical traps operate in direct relationship to condensate levels present in the body of the steam trap. a) Inverted bucket and b) Float traps are examples of mechanical traps.

   a) Inverted Bucket Steam Trap: The inverted bucket is the most reliable steam trap. The heart of its simple design is a unique leverage system that multiplies the force provided by the bucket to open the valve against pressure. Since the bucket is open at the bottom, it resists damage from water hammers, and wearing points are heavily reinforced for long life.The inverted bucket steam trap consists of a chamber containing an inverted bucket (the opening at the bottom) which actuates a discharge valve through a linkage as shown in Fig.1. The valve is open when the bucket rests at the bottom of the trap. This allows air to escape during warm-up until the bottom of the bucket is sealed by rising condensate.The valve remains open as long as condensate is flowing, and trapped air bleeds out through a small vent in the top of the bucket. When steam enters the trap, it fills the bucket, causing the bucket to float so it rises and closes the valve. The steam slowly escapes throughthe bucket vent and condenses, thus allowing the bucket to sink and reopen the valve for condensate flow. Small amount of air and non-condensable gases (such as carbon dioxide) that enter the trap during normal operation are also vented through the small opening in the top of the bucket, which prevents the trap from becoming air-bound.



ItemNo.	Description	Material
14	Conn.Nipple	SA 105
13	Pipe	GI.
12	Nut	High tensile steel Gr.8
11	Bolt	High tensile steel Gr.8.8
10	Priming Plug	Carbon steel
9	Cover	ASTM A216 Gr.WCB
8	Valve Seat	AISI 304
7	Gasket	CAF-IS:2712 Gr.W/I
6	Ball Seat	AISI 304
5	Hook	
4	Valve Lever	
3	Bucket Holder	Carbon steel
2	Bucket	AISI 304
1	Body	ASTM A216 Gr.WCB

BILL OF MATERIAL

NOTE :-

1. Type : Inverted Bucket Type
2. Connection : Socket Weld to B 16.11, 800#
3. Inlet Pressure : 9/14 kg/cm2(g)
4. Back Pressure : Atmospheric
5. Hyd.test Pressure : 30 kg/cm2(g)*
6. Operating Temperature : 179/197°C
7. Design Pressure : 20 kg/cm2(g)
8. Design Temperature : 240°C

Fig. 1 Inverted bucket steam trap

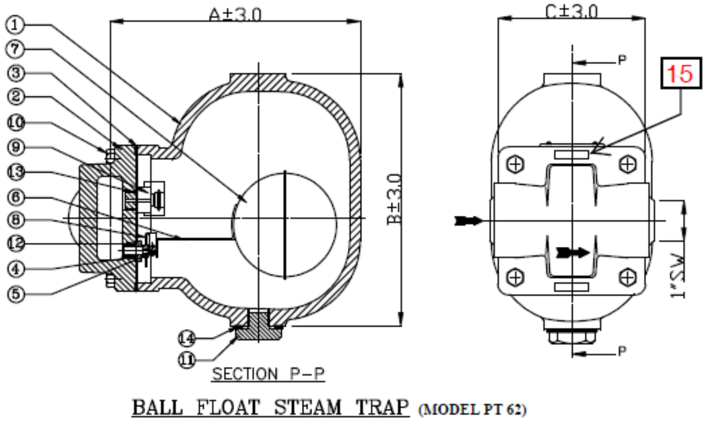
Advantages

a) Intermittent operation - condensate drainage is continuous, discharge is intermittent.
b) Small dribble at no load, intermittent at light and normal load, continuous at full load.
c) Excellent energy conservation.
d) Excellent resistance to wear.
e) Excellent corrosion resistance.
f) Excellent resistance to hydraulic shocks.
g) Vents air at steam temperature.
h) Excellent operation against back pressure.
i) Excellent ability to handle dirt.
j) Fair ability to handle flash steam

Disadvantages

a) Open at mechanical failure.
b) Large comparative physical size.

b) Float traps: The float type consists of a chamber containing a float-and-arm mechanism which modulates the position of a discharge valve as shown in Fig.2. As the level of condensate in the trap rises, the valve is opened to emit the condensate. This type of valve tends to discharge a steady stream of liquid since the valve position is proportional to the rate of incoming condensate. Because the discharge valve is below the waterline, float-type steam must employ a venting system to discharge noncondensable gases. This is generally accomplished with a thermostatic element which opens a valve when cooler non-condensable gases are present but closes the valve in the presence of hotter steam.



NO.	PART NAME	MATERIAL	QTY.
01	BODY	ASTM A216 Gr. WCB	01
02	COVER	ASTM A216 Gr. WCB	01
03	GASKET	REINFORCED EXFOLIATED GRAPHITE	01
04	VALVE SEAT	AISI 420 (equivalent to [illegible])	01
05	VALVE	AISI 420	01
06	LEVER	AISI 304	01
07	FLOAT	AISI 304	01
08	BRACKET	AISI 304	01
09	AIR VENT	SS (BI-METALLIC)	01
10	BOLT(M12x1.75px35L)	ASTM A193 Gr. B7	04
11	DRAIN PLUG	SS 304	01
12	GASKET(Valve seat)	COPPER	01
13	GASKET(Air vent)	COPPER	01
14	GASKET(Plug)	COPPER	01
15	NAME PLATE FOR TAG NOS.	AISI 304 (2 mm THICK)	01

Fig. 2 Float steam trap

2. **Thermostatic steam traps**. The thermostatic steam trap contains a thermostatic element which opens and closes a valve in response to fluid temperature. Condensate collected upstream of the valve is sub-cooled, cooling the thermostat, which in turn opens the discharge port. When the cooler condensate is discharged and the incoming condensate temperature approaches the saturation temperature, the thermostat closes the discharge port. Because of this principle of operations, the thermostatic trap operates intermittently under all but maximum condensate loads.

   Types of Thermostatic Steam Trap

   A. Liquid expansion Steam trap
   B. Balanced Pressure Steam trap
   C. Bimetallic Steam trap

A. Liquid Expansion Steam Trap

An oil filled element expands when heated to close the valve against the seat. The adjustment allows the temperature of the trap discharge to be altered between 60°C and 100°C, which makes it ideally suited as a device to get rid of large quantities of air and cold condensate at start-up.

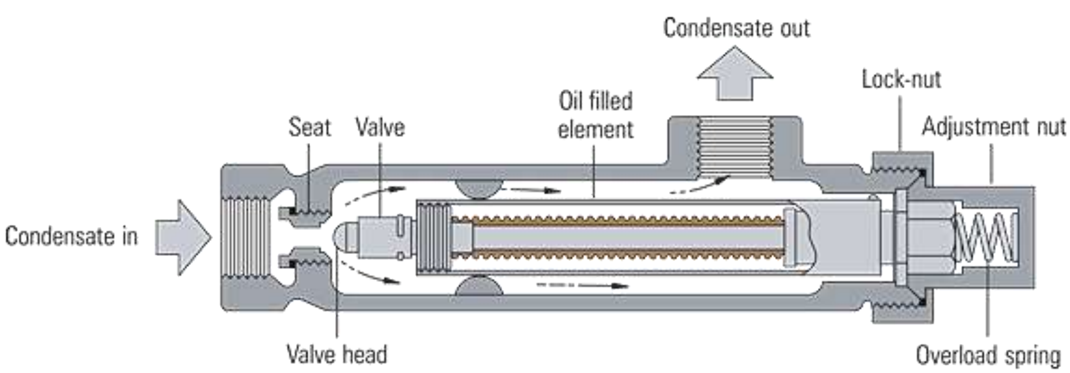


Fig. 3 Liquid Expansion Steam trap

The oil filled flexible thermostatic element which expands when heated by the fluid (i.e. steam/ condensate) surrounding it to exert the necessary amount of force to close the valve disc against the seat. It is possible by altering the gap between the disc and the seat by adjusting the spring fitted at the end of the thermostatic element, to effectively alter the maximum temperature of the condensate which is allowed to discharge through the seat. The moment the fluid entering the trap body is higher than the set temperature it will be stopped by the flexible thermostatic element by closing the disc. The Liquid Expansion Steam trap is suitable when pressure remains always constant and the trap is adjusted to discharge condensate at a particular temperature and Pressure.

Advantages

a) Liquid expansion traps can be adjusted to discharge at low temperatures so that the trap allows attaining high thermal efficiency by utilizing the latent heat of steam as well sensible heat of Condensate.
b) The liquid expansion trap is fully open when cold, giving good air discharge and maximum condensate capacity on 'start-up' loads.
c) The liquid expansion trap can be used as a start-up drain trap on low pressure superheated steam mains where a long cooling leg is needed to flood with cooler condensate.

Disadvantages

a) The flexible tubing of the element can be destroyed by corrosive condensate or superheat.
b) Since the liquid expansion trap discharges condensate at a temperature of 100°C or below, it should never be used on applications which demand immediate removal of condensate from the steam space.
c) It can’t self adjust to varying steam pressure conditions.

B. Balanced Pressure Steam trap

A large improvement on the liquid expansion trap is the balanced pressure trap. Its operating temperature is affected by the surrounding steam pressure. The operating element is a capsule containing a special liquid and water mixture with a boiling point below that of water. In the cold conditions that exist at start-up, the capsule is relaxed. The valve is off its seat and is wide open, allowing unrestricted removal of air. This is a feature of all balanced pressure traps and explains why they are well suited to air venting. When steam enters the filled liquid will boil off and generate an internal vapor pressure in excess of the steam pressure surrounding it, by an amount required for expanding the bellow to close the flow passage.

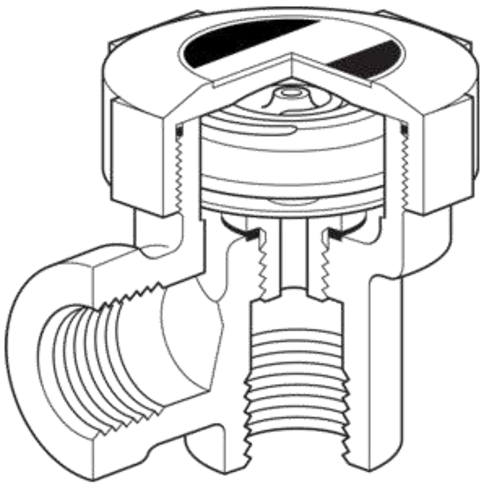


Fig. 4 Balanced Pressure Steam trap

As condensate passes through the balanced pressure steam trap, heat is transferred to the liquid in the capsule. The liquid vaporizes before steam reaches the trap. The vapor pressure within the capsule causes it to expand and the Valve shuts. Heat loss from the trap then cools the water surrounding the capsule, the vapor condenses and the capsule contracts, opening the Valve and releasing condensate until steam approaches again and the cycle repeats. That means that the live steam filling the trap must cool down to form a sub-cooled Condensate to cause the internal pressure of the bellow to diminish and thereby allowing passage for the Condensate through the discharge port.

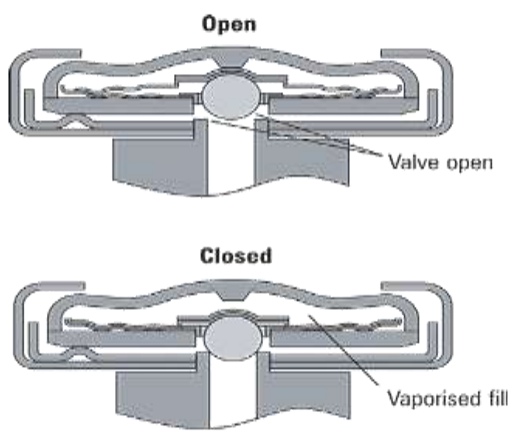


Fig. 5 Operation of balanced pressure steam trap capsule

Since the operating principle is based on the differential pressure between the internal and external pressure applied on the bellow it is independent of the operating pressure of the steam. The above Trap is therefore reasonably responsive to the varying steam pressure conditions. Due to the thin wall of the Bellow element, it is able to respond to temperature changes due to varying steam pressures fairly quickly.

Advantages:

a) Small, light and has a large capacity for its size.
b) The Valve is fully open on start-up, allowing air and other non-condensable gases to be discharged freely and giving maximum condensate removal.
c) The modern balanced pressure trap automatically adjusts itself to variations of steam pressure up to its maximum operating pressure. It will also tolerate up to 70°C of superheat.
d) Trap maintenance is simple. The capsule and Valve seat are easily removed, and replacements can be fitted in a few minutes without removing the trap from the line.

Disadvantages:

a) The balanced pressure steam traps had bellows which were susceptible to damage by water hammer or corrosive condensate.
b) The balanced pressure type does not open until the condensate temperature has dropped below steam temperature a disadvantage if the steam trap is chosen for an application in which water logging of the steam space cannot be tolerated.
c) The Trap is generally not suitable for super-heated steam

C. Bimetallic Steam Traps

Bimetallic steam traps are constructed using two strips of dissimilar metals welded together into one element. The element deflects when heated. Bimetallic steam traps operate on the same principle as a heating thermostat. A bimetallic strip or wafer connected to a valve bends or distorts when subjected to a change in temperature. When properly calibrated, the valve closes off against a seat when steam is present, and opens when condensate, air, and other non-condensable gases are present (Fig. 6)

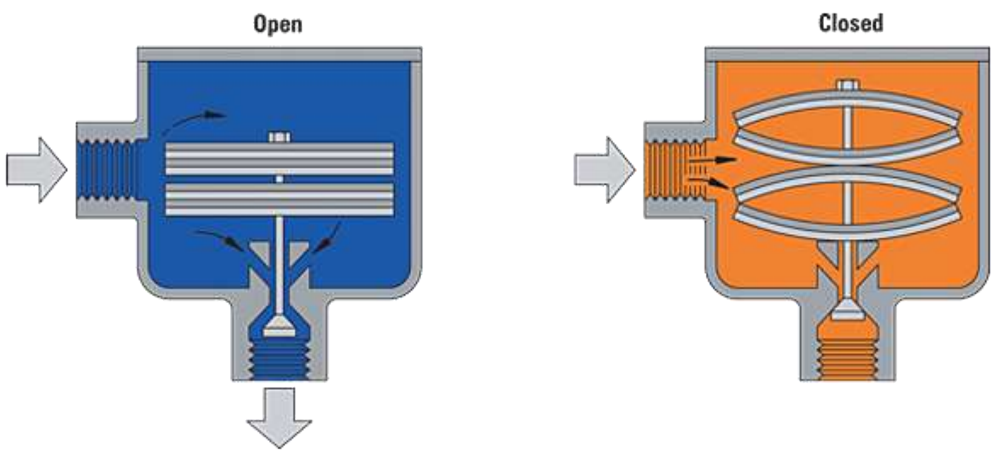


Fig. 6 Operation of a bimetallic steam trap

Advantages

a. Relatively small size for the condensate loads they handle.
b. Resistance to damage from water hammer, corrosive condensate, and high steam pressures.

c. The valve is wide open when the steam trap is cold, giving good air venting capability and maximum condensate discharge capacity under 'start-up' conditions.
d. The bimetal elements can work over a wide range of steam pressures without any need for a change in the size of the valve orifice.
e. If the valve is on the downstream side of the seat, it will tend to resist reverse flow through the steam trap. However, if there is any possibility of reverse flow, a separate check valve should be fitted downstream of the trap.
f. As condensate is discharged at varying temperatures below saturation temperature and, provided water logging of the steam space can be tolerated, some of the enthalpy of saturated water can be transferred to the plant. This extracts the maximum energy from the condensate before it drains to waste, and explains why these traps are used on tracer lines where condensate is often dumped to waste.
g. Maintenance of this type of steam trap presents few problems, as the internals can be replaced without removing the trap body from the line.
h. The flash steam produced whenever condensate is discharged from a higher to a lower pressure will tend to cause an increase in backpressure in the condensate line. The cooling leg allows the condensate to cool down, producing less flash steam in the condensate line and thus helping to reduce the backpressure.

Disadvantage

a. As condensate is discharged below steam temperature, water-logging of the steam space will occur unless the steam trap is fitted at the end of a long cooling leg, typically 1 - 3 m of un-lagged pipe. Bimetallic steam traps are not suitable for fitting to process plants where immediate condensate removal is vital for maximum output to be achieved. This is particularly relevant on temperature controlled plant.
b. Some bimetallic steam traps are vulnerable to blockage from pipe dirt due to low internal flow velocities. However, some bimetallic traps have specially shaped valve trims that capture the discharge energy to open the valve more. These tend to give an intermittent blast discharge characteristic rather than a continual dribble discharge, and as such tend to be self-cleaning. These valve trims are sometimes referred to as dynamic clacks.
c. If the bimetallic steam trap has to discharge against a significant backpressure, the condensate must cool to a lower temperature than is normally required before the valve will open. A 50% backpressure may cause up to a 50°C drop in discharge temperature. It may be necessary to increase the length of cooling leg to meet this condition.
d. Bimetallic steam traps do not respond quickly to changes in load or pressure because the element is slow to react.

3. **Thermodynamic (TD) traps**. Thermodynamic traps work on the difference in dynamic response to velocity change in flow of compressible and incompressible fluids. As steam enters, static pressure above the disk forces the disk against the valve seat. The static pressure over a large area overcomes the high inlet pressure of the steam. As the steam starts to condense, the pressure against the disk lessens and the trap cycles. This phenomenon essentially makes a Thermodynamic trap a "**time cycle" device**: it will open even if there is only steam present in the pipe line, this can cause premature wear and loss of live steam from the system. If non condensable gas is trapped on top of the disc, it can cause the trap to be locked shut. The working principle of stem trap can be understood with the help of Fig.7.

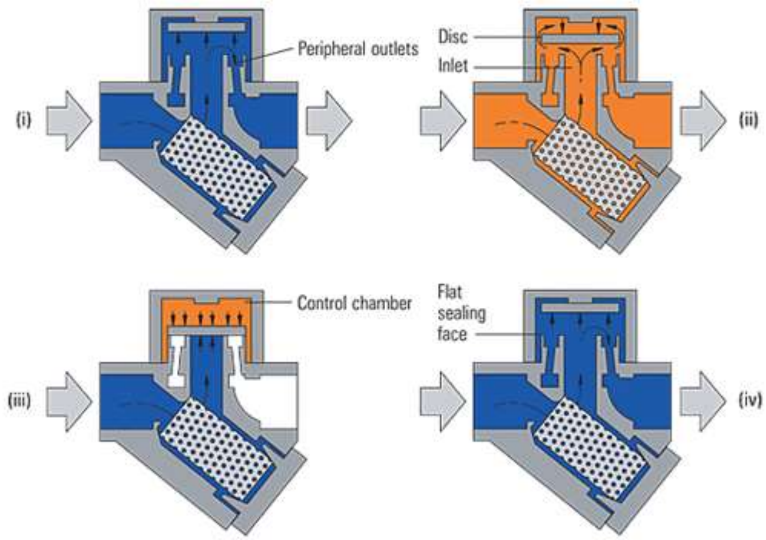


Fig. 7 Operation of Thermodynamic steam trap

Advantages

a) Intermittent operation
b) Excellent corrosion resistance
c) Excellent resistance to hydraulic shocks
d) Small comparative physical size
e) Open at mechanical failure.
f) Low cost

Disadvantage

a) Poor energy conservation
b) Poor resistance to wear
c) Excellent corrosion resistance
d) Excellent resistance to hydraulic shocks
e) Do not vent air at steam temperature
f) Not recommended at low pressure operations
g) Poor ability to handle start up air loads
h) Poor operation against back pressure
i) Poor ability to handle dirt
j) Poor ability to handle flash steam

Maintenance of steam traps

Dirt is one of the most common causes of steam traps blowing steam. Dirt and scale are normally found in all steam pipes. Bits of jointing material are also quite common. Since steam traps are connected to the lowest parts of the system, sooner or later this foreign matter finds its way to the trap. Once some of the dirt gets logged in the valve seat, it prevents the valve from shutting down tightly thus allowing steam to escape. The valve seal should therefore be quickly cleaned, to remove this obstruction and thus prevent steam loss.

In order to ensure proper working, steam traps should be kept free of pipe-scale and dirt. Strainer is provided to prevent the scale and dirt from getting into the trap. Strainer is a detachable, perforated or meshed screen enclosed in a metal body. It should be borne in mind that the strainer collects dirt in the course of time and will therefore need periodic cleaning. It is of course, much easier to clean a strainer than to overhaul a steam trap.

In most industries, maintenance of steam traps is not a routine job and is neglected unless it leads to some definite trouble in the plant. In view of their importance as steam savers and to monitor plant efficiency, the steam traps require considerably more care than is given. One may consider a periodic maintenance schedule to repair and replace defective traps in the shortest possible time, preferable during regular maintenance shut downs in preference to break down repairs.

Average service life of different type of steam traps

ICI Engineering Huddersfield and Grangemouth Works (England) has performed extensive study to work out the service life of steam traps and published a report as below in Table1.

Trap Type	HP 650 psi (45 bar)	IP 200 psi (14 bar)	LP 30 psi (2 bar) (g)
Thermodynamic Disc	10 - 12 months	12 months	5 - 7 years
Float and Thermostatic	*1 - 6 months	*9 months	/ 4 years
Inverted Bucket	18 months	5 - 7 years	12 - 15 years
Balanced Pressure Thermostatic		6 months	5 - 7 years
Bimetallic Thermostatic	3 - 12 months	2 - 3 years	* 7 - 10 years

Table-1 Average service life of different type of steam traps

Following are the recommendation of ICI Engineering on selection of steam traps for different application:

Inverted bucket (IB) traps: Select as first choice for all process duties and steam mains drainage i.e. where the steam space must be kept clear of condensate.

Float and thermostatic traps: Use on process applications especially on temperature controlled duties below 3.5 bar(g) or if an IB installation would lead to problems with excessive air loads.

Balanced pressure traps: Select for non-critical tracing systems and heating systems.

Bimetallic thermostatic traps: Select for low temperature or frost protection on traced pipelines or heating systems. The recommended model is adjustable to allow maximum use of sensible heat in the condensate products.

Thermodynamic disc traps: Limit use to steam mains drainage and tracing systems up to 17 bar(g) as an alternative to inverted bucket traps and for replacement purposes on higher pressures if previous experience has shown that they have operated satisfactorily. Because of their poor energy efficiency and relatively poor service life they are not recommended.

NTPC Perspective:

In our plants steam traps have been installed in auxiliary steam lines, steam tracing lines, Fuel oil heaters, and SCAPH. Most of these steam traps are thermodynamic or disc type design. As discussed above Thermodynamic steam traps are basically a time cycle device and not essentially a real steam trap that discharge only condensate and not live steam during operation. Every time thermodynamic steam trap opens it discharges some amount of live steam. The operation of steam traps depends up on condensation of steam in the control chamber. During rainy season or winter season heat loss through control chamber will be fast hence it will operate too frequently. Therefore, thermodynamic steam traps are less energy efficient. This types of steam traps are used because of simple design and low capital cost. But as the cost of energy/coal is increasing day by day, such loss of energy is unwarranted therefore designers are now selecting steam traps which are robust as well as energy efficient.

Case study:

For calculating heat loss due to improper functioning of steam trap in typical power plant (3 X 500 MW capacities) auxiliary steam consumption has been monitored and observed that actual steam consumption is much higher than the design value. The design steam flow as indicated in Table 2 (Ref. APRDS sizing calculation and VAM data sheet) should be 9.9 T/hr. However the actual auxiliary steam flow as per control desk reading is 21.8 T/hr. Therefore there is a loss of 11.9 Ton auxiliary steam per hour. The entire steam loss may not be due to improper functioning of steam trap but a substantial amount of steam is being lost due to frequent opening of thermodynamic steam trap installed in the line. Further it has been observed that many thermodynamic steam traps never closes properly due to seat damage.

SN	Auxiliaries	Estimated Steam Consumption (T/hr)
1	BFPT gland sealing	0.3
2	Fuel oil heating	2
3	Fuel oil tracing (PH, boiler area & trestle)	3.1
4	Drain oil tank heating	0.5
5	AC plant	4
	Total Estimated (Design) Steam Consumption	9.9

Table 2 Design Steam flow calculation

Auxiliary steam parameter and enthalpy has been indicated in Table 3. Heat/ energy loss calculation and saving if this loss of auxiliary steam can be avoided is indicated in Table 4. It is observed that due to proper selection and maintenance of steam trap and auxiliary steam system coal up to 75 Ton per day can be saved. Further, one lacs ton of DM (Demineralized) water costing Rs 20 Lacs can also be saved per year by stopping leakage of auxiliary steam through steam trap. Total saving per year basis worked out to be Rs 8.05 Crore.

Operating Pressure	Operating Temp	Aux Steam Flow	Design Steam flow	Leakage	Enthalpy of Steam	Saturation Temp	Enthalpy of water
kg/sqcm(g)	Deg C	T/Hr	T/Hr	T/Hr	KJ/kg	Deg C	at 30 Deg C
10.8	290.0	21.8	9.9	**11.9**	**3028.6**	182.4	125.7

Table 3 Auxiliary steam parameter and enthalpy

Sl. No.	Description	Unit	Value
1	Heat Loss due to steam leakage	KW	9563.22
2	Heat loss per day	kJ	826262568.4
3	Calorific value of coal	Kcal/kg	3100
4	Boiler efficiency	%	85
5	Coal saved per day	Ton	74.95
6	Coal saving per year	Ton	27355.1
7	Landing cost of Coal	Rs/ Ton	2865
8	Saving per year	Rs (Crore)	7.837242303
9	Saving of DM water per Year	Ton	103893.6
10	Cost of DM water	Rs/Ton	20
11	Saving of DM water per Year	Rs (Lacs)	20.77872
12	Total Saving	**Rs (Crore)**	**8.05**

Table 4 Heat/Energy loss and saving Calculation.

Replacement cost of steam traps

The existing thermodynamic steam traps can be replaced with inverted bucket steam traps for main header auxiliary steam line which is robust in design and has excellent energy conservation property. For steam tracing line bimetallic type steam trap may be preferred as it has excellent heat recovery property. The replacement cost of steam traps is worked out to be Rs 31,20,000/- (Refer Table 4). Further Installation of these 232 no of steam traps may cost Rs 3 lacs. Therefore, the total replacement cost will be around Rs 34 lacs. In terms of payback period it is worked out to be 15 days only. Even if leakage through stem traps are one ton per hour the payback period will be six months only.

SN	Area/ location	**Size (NB)**	Total no of traps installed	Per unit cost (Rs)	Cost (Rs)
1	Auxiliary stem system header, Steam traps on drains of Aux steam to FOPH header	25	112	15,000	16,80,000
2	Steam Trap on steam tracer line	15	120	12,000	14,40,000
			232	**Total cost (Rs)**	**31,20,000**

Table 5 Replacement cost of steam traps (supply)

Conclusion:

In this study working principle of different types of Steam traps has been discussed. It is concluded that thermodynamic type steam traps are uneconomical and has short reliable service life. In view of raising price of fuel and concern of environment these inefficient steam traps may be replaced with robust and economical steam traps like inverted bucket and bimetallic type thermostatic steam traps.

The payback period of replacement of existing thermodynamic steam traps by inverted bucket and bimetallic type thermostatic steam traps is only 15 days. Even if leakage through steam traps are one ton per hour the payback period will be six months only. Therefore, it is prudent to go for a replacement program of existing non performing steam by efficient steam traps. Hundreds of Crores of Rupees can be saved by implementing steam trap replacement and maintenance program across NTPC older units.

In view of their importance as steam savers and to monitor plant efficiency, the steam traps require considerably more care than is given. Periodic maintenance schedule to repair and replace defective traps should be implemented.