ANSI/FCI 87-1-2017

AMERICAN NATIONAL STANDARD

CLASSIFICATION AND OPERATING PRINCIPLES OF STEAM TRAPS

Fluid Controls Institute, Inc.

Sponsor:

Fluid Controls Institute, Inc.
1300 Sumner Ave
Cleveland, Ohio 44115-2851

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Classification and Operating Principles of Steam Traps

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Foreword

For many years, steam trap manufacturers and users have recognized the need to establish standards for determining capacities of industrial steam traps. Many factors affect steam trap capacity and this has led to some confusion in the past. The FCI Steam Trap Section has developed a series of standards that serve as the authoritative source for reference regarding the capabilities of steam traps.

Since steam traps are for the purpose of venting air and discharging condensate, many principles of operation are employed. This has led to some confusion in determining trap capacities. However, since all steam traps are governed by basic flow principles which will affect the amount of condensate through an orifice, a set of standards is very practical.

In order to have a comprehensive standard, we have developed this standard, which describes the various types of steam traps, their principles of operation, and factors that affect their performance. This information enables a user to compare the relative capacities of traps of different types and different manufacturers.

The Steam Trap Section of the Fluid Controls Institute began work on these standards many years ago. The final results represent the labors and the accumulated years of experience of many individuals in arriving at what we feel is a very complete and correct set of standards. At the same time, we as a committee realize that there are always opportunities to expand and to improve, and we invite comments for consideration.

FCI recognizes the need to periodically review and update this standard. Suggestions for improvement should be forwarded to the Fluid Controls Institute, Inc., 1300 Sumner Avenue, Cleveland, Ohio, 44115-2851. All constructive suggestions for expansion and revision of this standard are welcome.

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AMERICAN NATIONAL STANDARD

Classification and Operating Principles of Steam Traps

1.0 SCOPE

This standard is for the purpose of establishing and illustrating various classifications of Steam Traps in accordance with their basic principles of operation. This standard does not attempt to define details of conception or construction.

2.0 DEFINITIONS

2.1 Steam trap – An integral, self actuated valve which automatically vents air in the steam system and drains condensate from a steam containing enclosure while remaining tight to live steam. Most steam traps will also pass non-condensible gases while remaining tight to live steam.

Note: Some designs will allow a minimal steam flow at a controlled or adjusted rate using a separate secondary orifice.

2.2 Production tests - Tests carried out by the manufacturer to confirm that the steam trap functions correctly. These tests may be witnessed by the purchaser or his representative. In this case, these tests are referred to as witness tests.

2.3 Performance characteristics - Carried out to determine the operational characteristics of a particular design of steam trap.

3.0 OPERATING PRINCIPLES

3.1 Factors Affecting Condensate Flow Through a Steam Trap

One of the most common components to all steam traps is the discharge orifice. In some trap types, the valve seat and the discharge orifice are the same; in others, the discharge orifice may be smaller than the valve seat.

3.2 In considering steam trap capacities, therefore, it is important to explain what happens when fluid flows through an orifice.

While in steam trapping we are concerned with the discharge of cold water, air and other gases, condensate and air mixtures, and hot (flashing) condensate, the main function of the trap is to discharge condensate, usually in the flashing state.

The water discharge capacity of an orifice depends on the following factors:

1. The area and shape of the orifice and the coefficient of discharge C_D
2. Lift of valve from orifice
3. The pressure drop across the orifice
4. Density of the water
5. The temperature of the water.
6. The physical changes that take place when water flows through the orifice.

3.2.1 Orifice Area and Shape

Theoretically, the flow of cold water through a round, sharp-edged orifice in pounds per hour discharge is very nearly

$$Q_1 = 19{,}046 \times \text{area (in}^2\text{)} \times \sqrt{\text{pressure drop}}\ \text{(psi)}$$

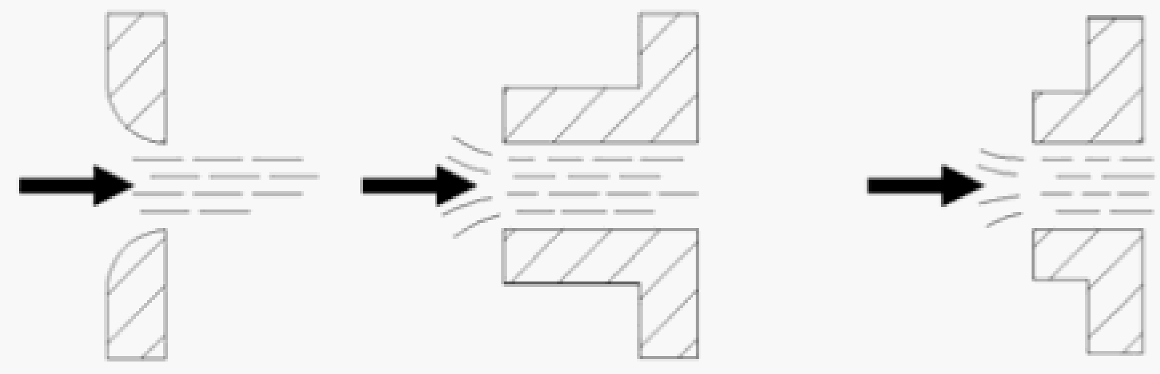
In other words, at 1 psi drop, a hole with an area of 1 in^2 will pass 19,046 lbs/hr of cold water; at 4 psi drop the same 1 in^2 hole will pass 38,092 lbs/hr.

- or -

$$\text{Kg/hr} = 5060 \times \text{area (cm}^2\text{)} \times \sqrt{\text{pressure drop (bar)}}$$

In other words, at 0.07 bar drop, a hole with an area of 6.45 cm^2 will pass 8,635 Kg/hr of cold water; at 0.28 bar drop, 17,270 Kg/hr.

In practice, however, the orifice creates friction, which reduces the flow. For example, the orifices shown in these sketches would pass 98%, 73%, and 52% (coefficient of discharge C_D) of the theoretical flow, based on their flow entrance geometry.



98% **73%** **52%**

Figure 1

3.2.2 Valve Lift

The formula in paragraph 3.2.1 assumes a full open orifice. In a steam trap this is not necessarily true. The fact that, in some stream traps, the valve does not lift fully to the equivalent free area of the orifice does not imply poor design. It, however, makes comparison of steam trap capacities on orifice diameter alone unreliable.

3.2.3 Pressure Before and After the Orifice (Pressure Drop)

The theoretical flow in 3.2.1 is based on the difference in pressure immediately before and immediately after the orifice, which is also called pressure drop.

In a steam trap, the body and the mechanism of the trap offer resistance to flow, and the pipe connections on the discharge cause similar interference. So, in practice, the pressures at the orifice proper are rarely, if ever, known and are variable, with a corresponding effect on discharge capacity.

3.2.4 Density of Water

The density of water as compared to steam is another factor to consider. At typical atmospheric conditions, the density of water is 62.3 lbs/ft^3 and for steam it is .037 lbs/ft^3. Therefore, 1 lb of steam at typical atmospheric conditions occupies a volume of approximately 1700 times that of water.

3.2.5 Temperature and Phase Changes Relative to Discharge Capacity

Discharge capacity of condensate through a steam trap is most seriously affected by the physical changes that take place.

When discharging to atmospheric pressure, the physical state of water normally does not change as it flows through an orifice or a trap, provided the temperature is below 212°F at the inlet. Condensate above 212°F at the inlet, when reaching atmospheric pressure, cannot retain all of its heat and some of the heat causes “flash” steam to be generated. The result is a considerable increase in the specific volume and a corresponding reduction in the density of the mixture of steam and water flowing through the orifice.

The theoretical effect of "flash" steam generation can be seen in Table 1, showing the volume of 1 lb. of condensate following release to atmosphere from various upstream pressures and temperatures.

From Table 1, it can be seen that atmospherically discharged saturated condensate at 250°F flashes and expands to 86 times its original volume at the inlet. At 300°F it expands to 140 times, and at 350°F it expands to 216 times its volume at the inlet. This considerable expansion of the condensate and flash steam mixture seriously interferes with the flow of condensate and reduces the discharge capacity. The impact of this reduction can be seen by comparing the theoretical flow of water through a one square inch area at various temperatures and at a pressure differential of 100 psi. (See Table 2).

These figures clearly demonstrate how specific steam trap discharge capacity figures can be misunderstood unless the pressure and temperature of the condensate at the trap inlet and trap outlet are known.

TABLE 1
VOLUME CHANGE OF 1 LB. OF CONDENSATE FOLLOWING FLOW THROUGH ORIFICE AT DIFFERENT INLET PRESSURES AND TEMPERATURES

Upstream – Inlet			Downstream – Outlet			Expansion in outlet over inlet volume
Pressure (psig)	Temperature (degrees F)	Volume (cu.ft./lb.)	Pressure (psig)	Temperature (degrees F)	Volume (cu.ft./lb.)	
0	60	0.016	0	60	0.016	0 times
0	212	0.0167	0	212	0.0167	0 times
15	250	0.017	0	212	1.48	86 times
52	300	0.0175	0	212	2.46	140 times
120	350	0.018	0	212	3.9	216 times
Example: At 15 psig / 250 degrees F the condensate has a volume of .017 cu.ft./lb. At atmospheric conditions this condensate has a volume of 1.48 cu.ft./lb., an increase of 86 times its volume under pressure.						

TABLE 2
FLOW OF WATER THROUGH ORIFICE OF 1 in^2. AREA AT 100 PSI DIFFERENTIAL PRESSURE

Temp. °F	°F Below Saturation	Flow lb/hr · in^2
Cold Water (60°F)	278	190,460
308	30	107,000
318	20	90,000
328	10	70,000
333	5	47,000

3.2.6 Effect of Steam Trap Operating Principle

A typical steam trap is not just a simple orifice but includes an integral, self-actuated valve operated either by temperature difference, buoyancy, or change of phase. This fact must be taken into consideration when comparing steam trap capacity ratings.

The capacity of all steam traps increases as the condensate temperature is lowered. Not all steam traps will, however, discharge condensate at steam temperature. Some traps, while being capable of operating at steam temperature, have their best condensate discharging characteristics at lower temperatures.

It would, therefore, be impossible to fix an arbitrary standard temperature at which all steam traps should be tested. Thus, each manufacturer determines the best operating temperature range for their product, and the resultant capacity ratings are only meaningful when based on this stated operating temperature. For this reason, manufacturers who use this standard will state operating temperatures for each published trap capacity.

4.0 TYPES OF STEAM TRAPS

4.1 Principles of Operation

While there are many ways in which steam traps may be classified, it is probable that the basic principles of operation most simply satisfy our needs. The principles most commonly used in steam traps are as follows:

Type 1 - THERMOSTATIC (Temperature). A thermostatic element, sensitive to the temperature difference between steam and cooled condensate, operates the valve.

Type 2 - MECHANICAL (Buoyancy). The difference in density of steam and condensate operates a bucket or float controlled valve.

Type 3 - THERMODYNAMIC (Change of Phase). The generation of flash steam (change from liquid to vapor phase) either throttles the discharge or operates a valve to regulate condensate flow.

In the descriptions which follow, the order of presentation has no significance other than to simplify later explanation. This is particularly true in the case of air removal from the steam traps.

4.2 Thermostatic - (Temperature Operated) Traps

This general type of steam trap operates on the difference in the temperatures of the steam and the condensate reaching the trap. It follows that thermostatic traps discharge condensate at below the saturated temperature. It also follows that a mixture of air and gases and steam, which lowers the mixture temperature, will also cause the trap to discharge.

4.2.1 Metal Expansion Traps

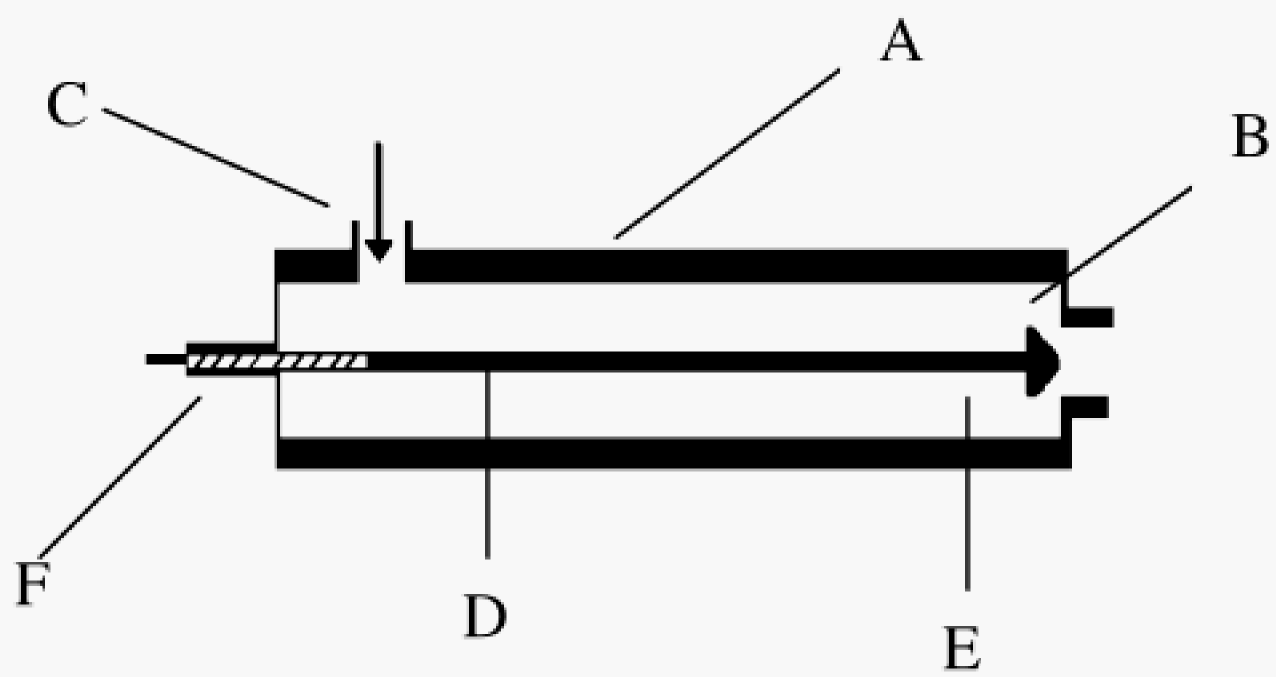


Figure 2

A. Construction

Tube A has at its outlet a valve seat B and an inlet connection C for condensate. The metal rod D has a markedly greater coefficient of expansion than A, so that changes in temperature of fluid in the tube A causes the rod to expand or contract and so move the valve, plug E, to or from the orifice. The rod is threaded at F, allowing the adjustment position of the rod to suit operating conditions.

B. Operation

When cold, the rod D is contracted and the valve wide open. Air, forced out as steam enters the heating surface, flows through the orifice. Condensate follows and heats the rod D which expands, closing the valve. By adjustment of F, the trap can be set to discharge condensate at a predetermined temperature. Collection of air or gases in the tube A reduces the temperature as does condensate, opening the valve. Discharge may be continuous and variable, or intermittent according to condensate temperature and load conditions.

4.2.2 Bi-Metal Traps

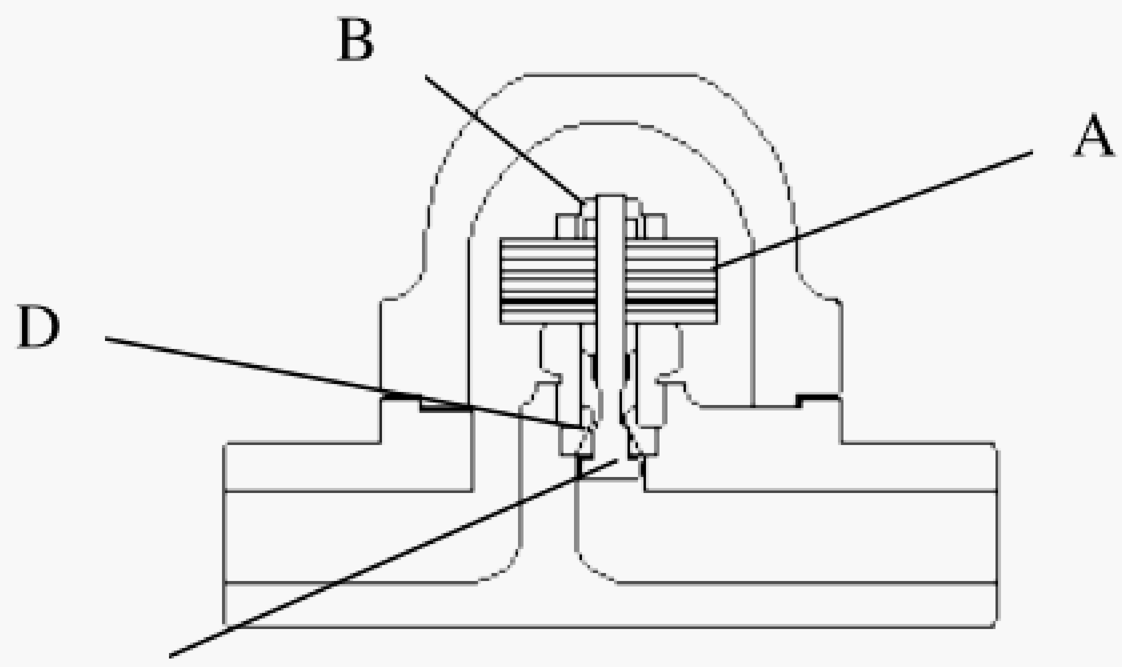


Figure 3

A. Construction

The thermostatic element portion (schematically shown as A) of a bi-metal trap can be:

1. a series of bi-metal discs or strips, stacked; or
2. a single bi-metal strip specially shaped.
3. a combination of the above

Bi-metal is two metals having different coefficients of expansion that are bonded, fused or formed together. The difference in unequal expansion and contraction of these two metals upon heating and cooling causes the disc or shape to change providing movement that can open or close a steam trap valve seat.

These bi-metal(s) are secured at one end, B, and free to deflect at the other end which is connected to a valve, C, that can seat against line pressure.

B. Operation

Like all thermostatic traps, the bi-metal traps are wide open when cold and initial air flows out on start-up followed by condensate. Increasing temperature causes unequal expansion of the bi-metal element and the valve, C, moves towards seat, D, closing the orifice when a predetermined design temperature is reached in the trap body.

Condensate discharge is primarily modulating but the trap may operate intermittently, depending on temperature and load conditions.

4.2.3 Liquid Expansion Traps

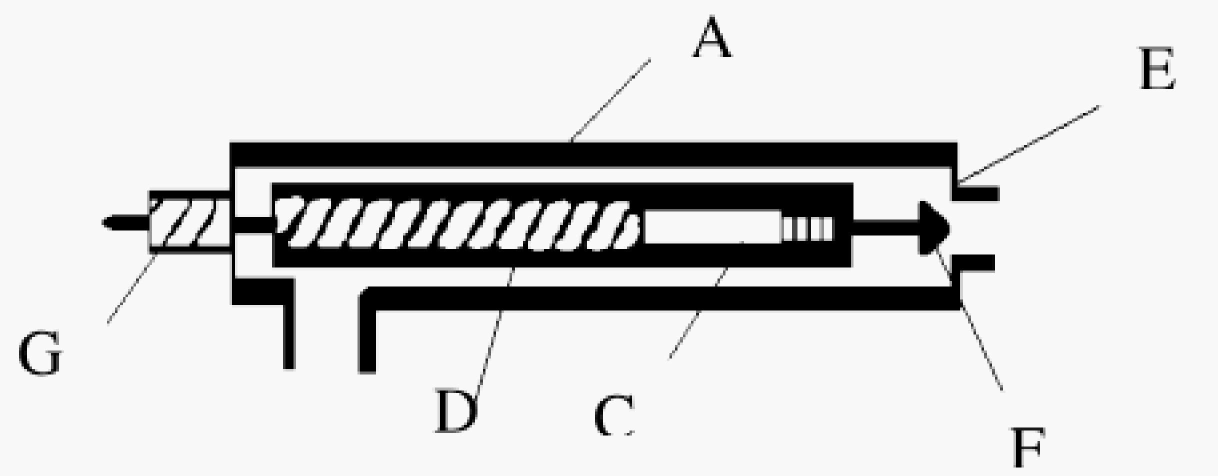


Figure 4

A. Construction

The body A has an outlet valve seat E and thermostatic element D which is filled with a liquid which expands under heat. The expansion of the filling is transmitted by the packless gland C to the valve rod and valve F. Adjustment is provided at G.

B. Operation

Air and cool condensate flow freely through the open valve on start-up. As the condensate temperature increases, the liquid in the thermostatic element expands, forcing the valve toward the seat, throttling the condensate flow. Change of the condensate temperature by varying load changes the valve position to release condensate at the predetermined temperature for which the trap is adjusted.

Condensate discharge is continuous and varies according to temperature and load. These traps are usually set to discharge at below 200°F.

4.2.4 Balanced Pressure Flexible Structure Traps

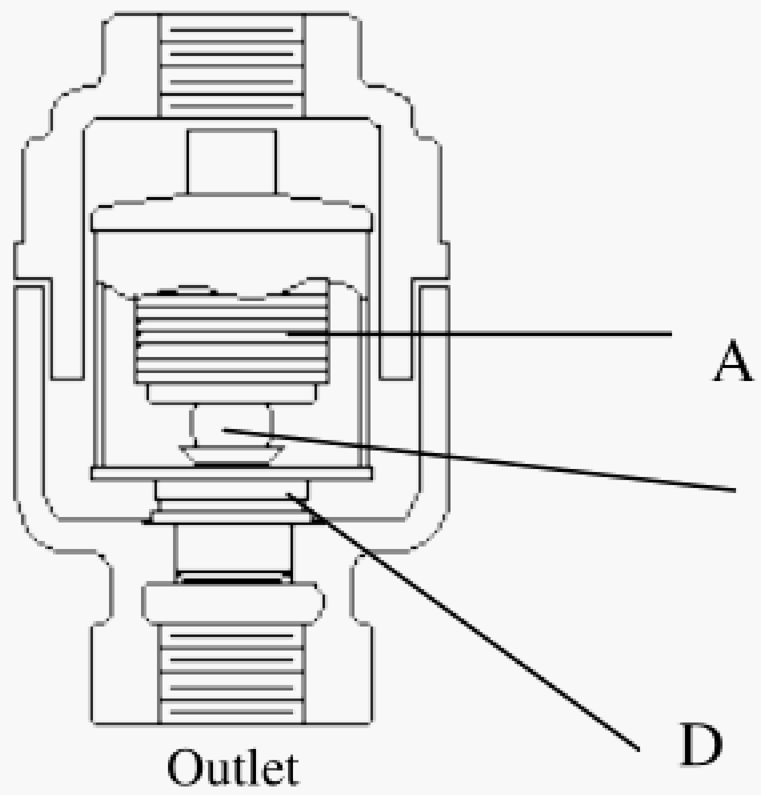


Figure 5

A. Construction

Thermostatic element A is a bellows or diaphragm structure to allow expansion and contraction. Fixed at the top, expansion carries the valve C to the seat D. The element may contain water, a mixture of water and a volatile fluid, or volatile fluids either under vacuum or at atmospheric pressure.

B. Operation

When cool, the vacuum inside the bellows or diaphragm structure contracts the element, opening the orifice. Heat generates vapor pressure inside the bellows or diaphragm structure which expands the element to close the orifice.

No adjustment is provided, the discharge temperature being pre-set by the filling medium at some temperature below saturation at the steam pressure.

Operation is generally intermittent but may be continuous on light, steady load, and pressure.

4.3 Mechanical (Buoyancy) - Float & Bucket Traps

This type of steam trap, often referred to as a mechanical trap, consists of a float or bucket which is actuated by a liquid. The buoyancy of the float or bucket in a liquid causes the valve to open or close, depending on whether or not the liquid is present.

4.3.1 Upright Bucket Traps

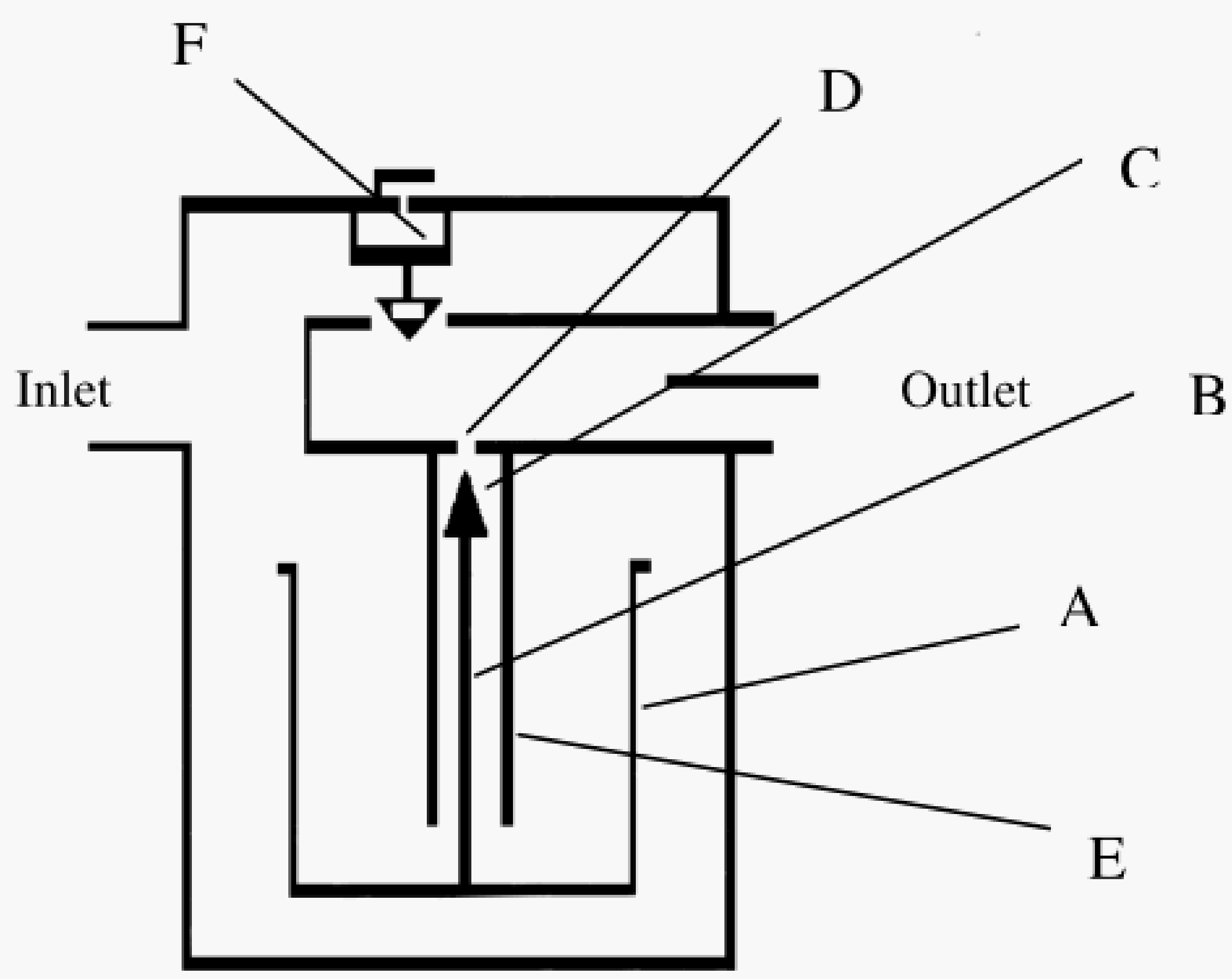


Figure 6

A. Construction

An open bucket A carries the valve rod B and valve C seating on seat D. The rod B passes through the discharge tube E. Venting device F is either automatic or manual. To provide automatic air venting, refer to Paragraph 4.3.2.

B. Operation

The air vent F, which may be a hand valve or a bi-metal or balanced pressure thermostatic vent, releases air from the body and condensate follows. The bucket A floats in the condensate, closing valve C. Condensate from the bucket is forced up the discharge tube until, with the bucket again floating, the valve is closed.

Operation is intermittent and condensate is discharged at the temperature at which it reaches the trap, no subcooling being necessary.

4.3.2 Combination Upright Bucket and Thermostatic Traps

An open bucket trap, as above, except provided with an auxiliary air venting device (F in 4.3.1A).

4.3.3 Inverted Bucket Traps

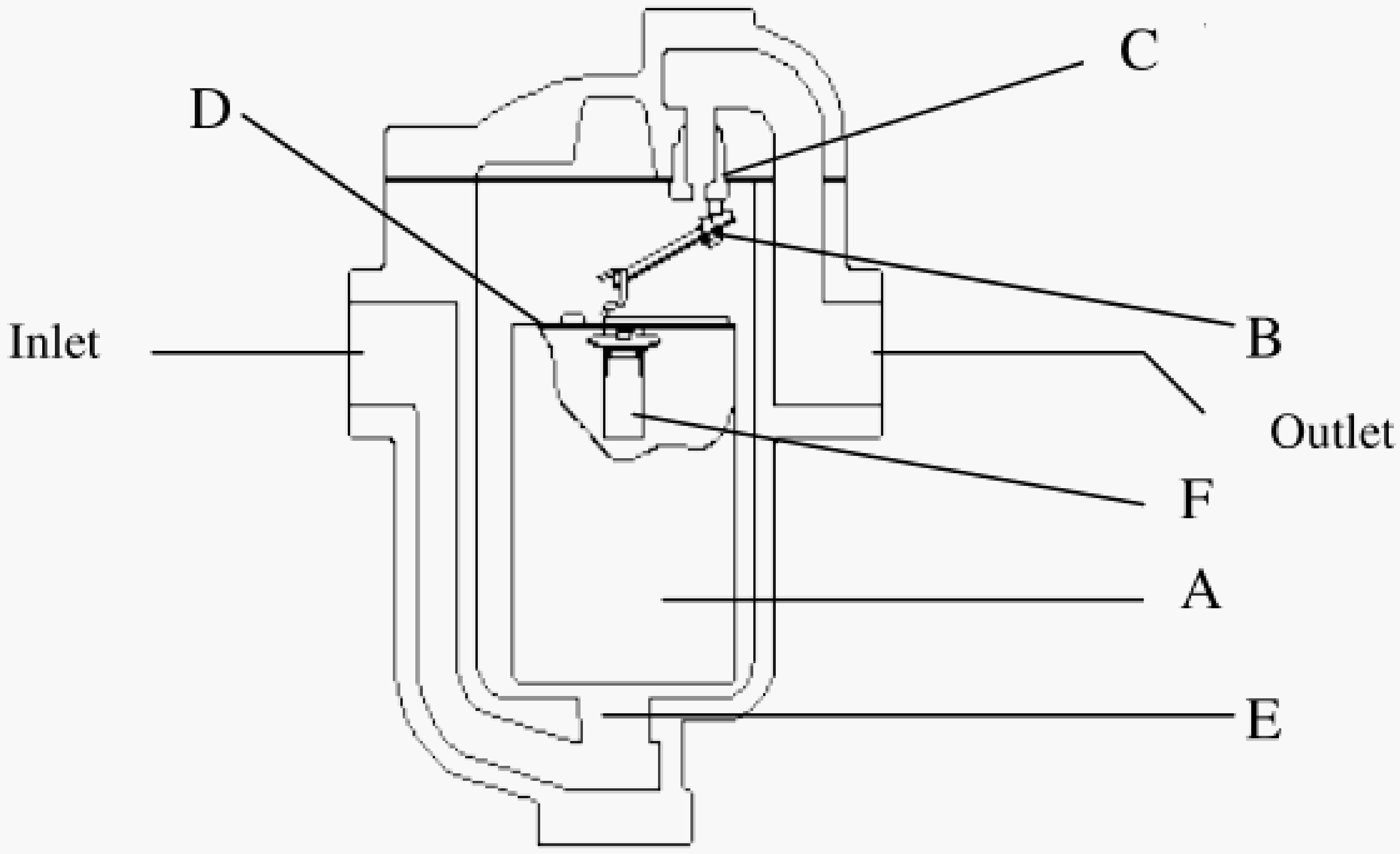


Figure 7

A. Construction

The valve B seating on C is connected to the inverted open bucket A in such a way that, as the bucket rises, the valve is closed and, as it falls, the valve is opened. A small opening D is provided on top of the bucket for air venting and for operation of the trap. Condensate enters the trap at E. An automatic device may be provided to facilitate air venting.

B. Operation

In operation, the bottom of the bucket is sealed in condensate. Air is first released by escaping through the vent hole D. Condensate follows, filling the bucket and the body and passing out through C. Steam in the bucket condenses, permitting the bucket to sink and open the discharge orifice, C. Air and some steam also flow upward through D.

Discharge is intermittent and at the temperature at which condensate reaches the trap, no subcooling being necessary.

4.3.4 Combination Inverted Bucket and Thermostatic Traps

An inverted bucket trap, as above, except provided with an auxiliary air venting device.

4.3.5 Float Traps

4.3.5.1 Lever Float Traps

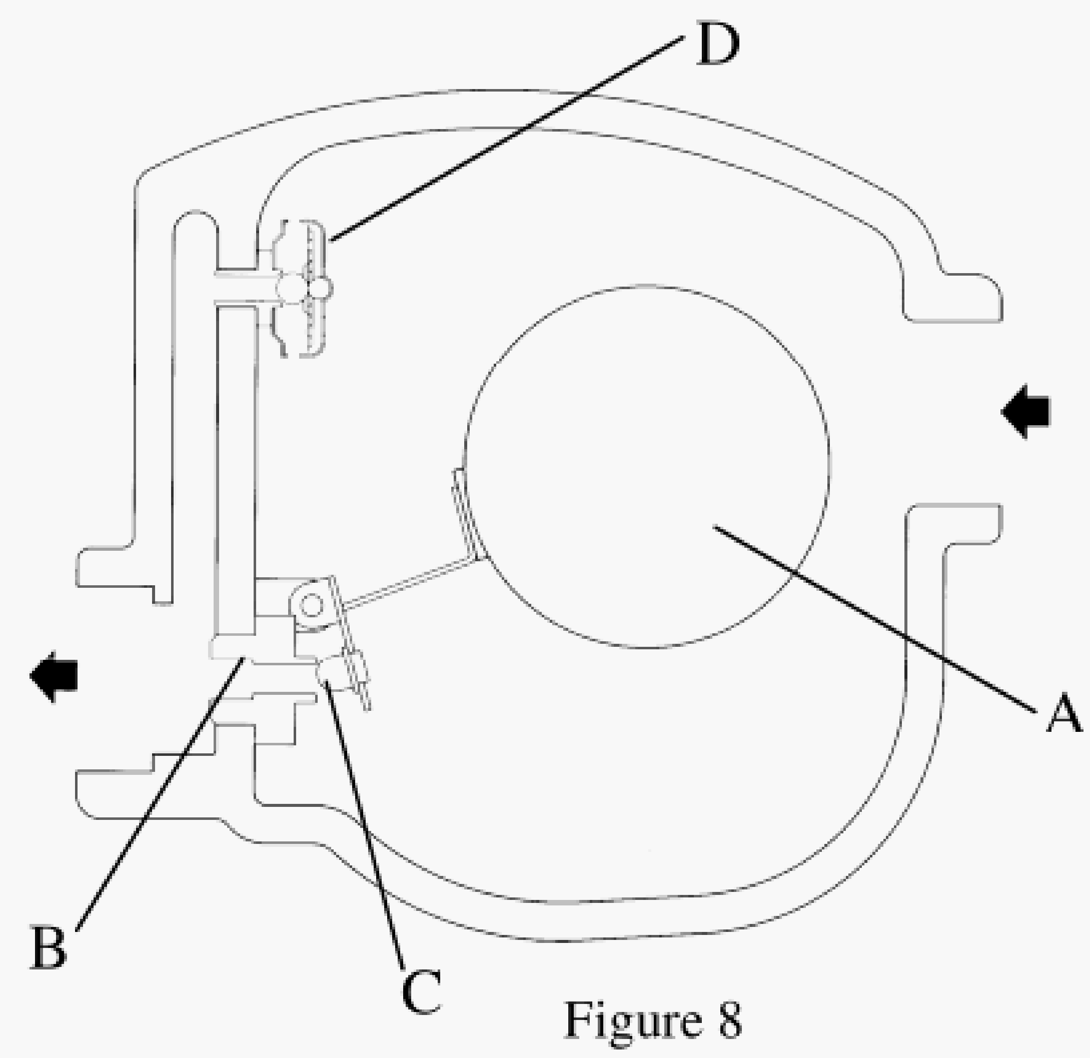


Figure 8

A. Construction

The float A is so connected to valve B seating on seat C that, as the float rises, the valve opens and, as it falls, the valve closes. Valve seat may be a cylindrical sleeve, rotary type.

B. Operation

As condensate enters the body, the float rises, opening the valve. An increase in condensate flow raises the float level and increases the valve opening, while a decrease in flow has the opposite effect.

Condensate discharge is continuous and variable except on no load, when the valve closes.

In the simple float trap, air is vented by a manual cock on the top of the body or automatically by thermostatic element D (see paragraph 4.3.6).

4.3.5.2 Non-Lever Free Floating Traps

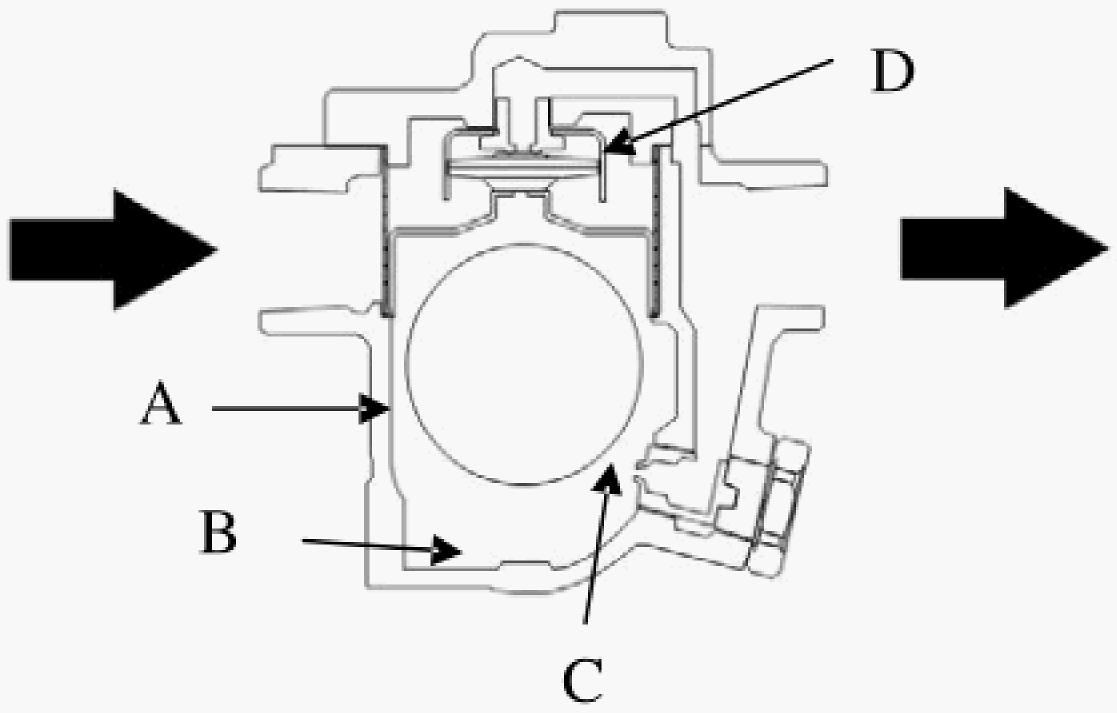


Figure 9

A. Construction

In the Non-Lever Free Floating trap, the surface of the free floating ball A is the valve head that seals against the valve seat C by resting on point B.

B Operation

As condensate enters the trap, the buoyant force rolls the free floating ball A off the seat C allowing flow through the orifice to the discharge. As the level of condensate in the trap rises, the ball continues to roll upward along the top side of the seat C, widening the opening of the discharge orifice to allow more flow. When under heavy load, the ball A completely rises off the seat to provide an unobstructed orifice for maximum flow. The ball then rotates to provide a different location on the ball seating surface when the ball comes back in contact with the seat C as the condensate levels drop.

Condensate discharge is continuous and variable except on no-load, when the valve closes.

Air and non-condensibles are vented automatically by balanced-pressure thermostatic element D, bi-metallic element, or manually with a petcock.

4.3.6 Combination Float & Thermostatic Traps

This is a lever or non-lever float trap as above equipped with an auxiliary air venting device (D in 4.3.5A).

4.4 Thermodynamic (Change Of Phase) Traps

The term "change of phase" refers to the generation of "flash" steam as condensate at a sufficiently high temperature flows from a higher to a lower pressure. This phenomenon is further discussed under "Factors Affecting Condensate Flow Through a Steam Trap," 3.1 and 3.5.

4.4.1 Thermodynamic Piston Traps

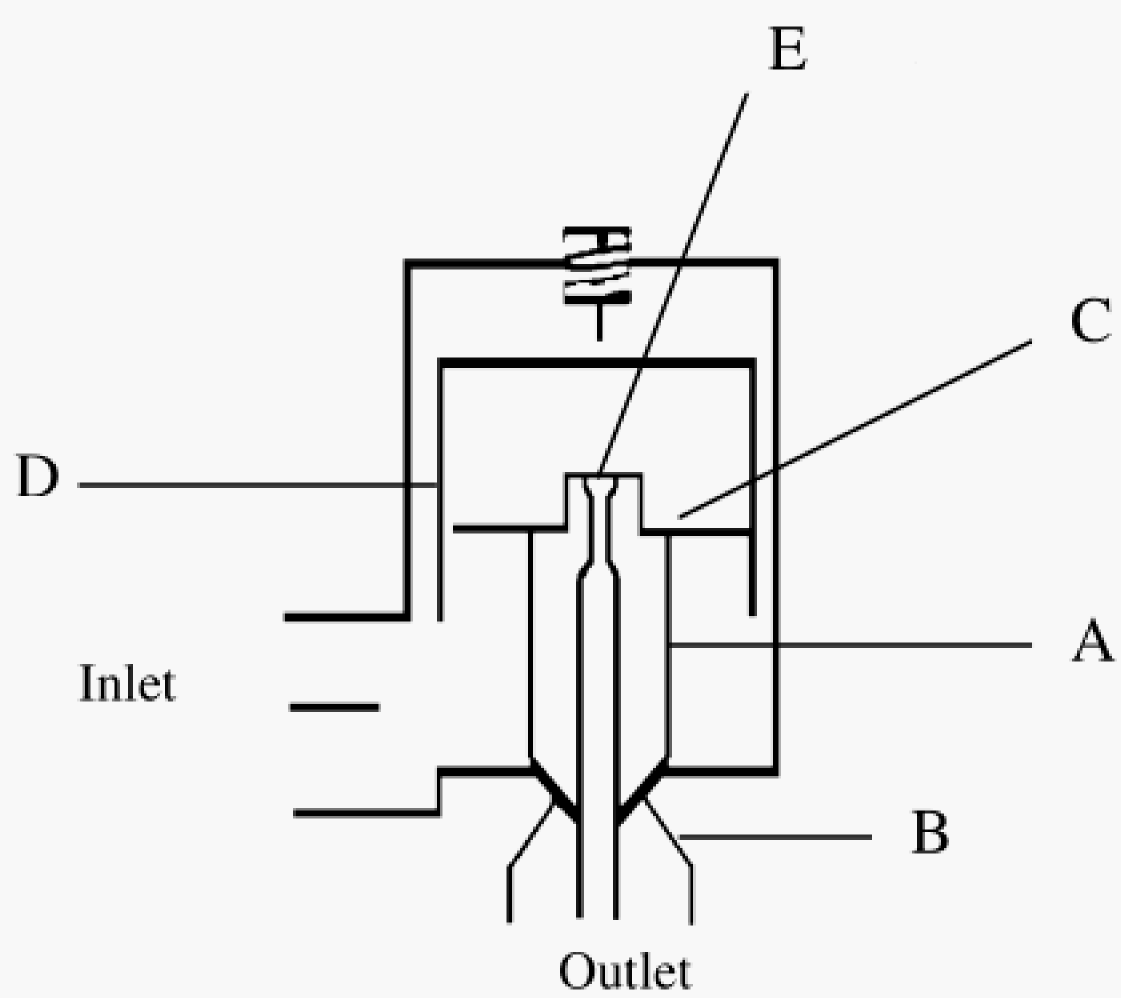


Figure 10

A. Construction

Spindle valve A engages seat B, and the piston disc C at its upper end moves freely in the vertically adjustable cylinder D. The piston disc clearance in cylinder D constitutes one of two control orifices in a series of which E, discharging through the center of the valve, is the second.

B. Operation

Air and condensate entering the trap causes valve A to open, allowing discharge through B. As condensate approaches steam temperature, control flow flashing in chamber develops sufficient pressure to close valve A on seat B. As condensate cools, chamber pressure drops and valve reopens. Orifice E design allows a flow of hot condensate which enables the valve to open and remain open on condensate close to steam temperature. Control flow is intended to prevent air or steam binding at operating temperatures.

Note: These traps do not close tight to steam.

4.4.2 Thermodynamic Lever Type

A modification of the above consists of a horizontal lever in which are incorporated the inlet and outlet valves over their respective orifices. Valves open by upward tilting of the lever about a fulcrum point at one end. Clearances between valves and orifices in a closed position provide for control flow which combines with the main discharge flow when the trap opens.

4.4.3 Thermodynamic- Disc Traps

A. Construction

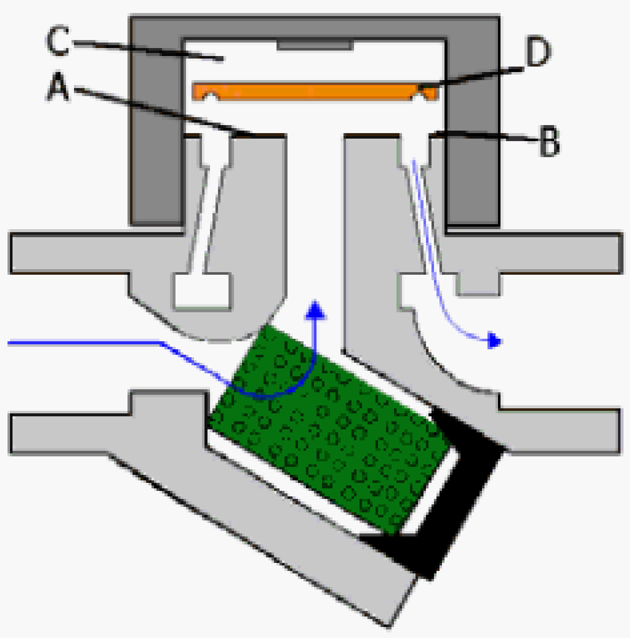


Figure 11

The trap has two valve seats. A on the inlet and B separating the chamber C from the outlet. Valve disc D seats on both A & B simultaneously, closing the inlet and isolating the chamber C.

B. Operation

Thermodynamic Disc Traps are activated by flashed condensate. At system startup, pressure created by the cold condensate pushes the valve disc off the Seating surface. This uncovers the inlet and outlet ports, allowing discharge. Condensate follows and flows radially across the surface of the disc to the outlet. As steam temperature is approached, the flashing condensate increases in specific volume and the velocity on the inlet side of the disc is increased. This increase in velocity causes a lower pressure under the disc than that in the chamber C and the disc is drawn toward the seats. Simultaneously, the radial jet of flashing condensate striking the wall of the chamber C causes build-up of pressure in C and the disc valve is snapped shut. Flash steam that is trapped in C exerts a greater force than the inlet pressure under the disc until the chamber pressure is dissipated by condensation. The cycle is then repeated.

Discharge is intermittent at steam temperature.

5. TESTING

A. Capacity: It is recommended that capacity ratings of steam traps be stated in accordance with ASME PTC 39-2005, *Steam Traps or* ISO 7842: 1988*, Automatic Steam Traps – Determination of Discharge Capacity – Test Methods*, and that the amount of subcooling used to determine the rated capacity shall be stated.

B. Production Testing: FCI 85-1, *Standard for Production Testing for Steam Traps*

C. Pressure Rating: FCI 69-1, *Pressure Rating Standard for Steam Traps*

6. METRIC EQUIVALENT/CONVERSIONS

Table 3 lists the metric equivalents and conversions of the U.S. customary units used in the text of this standard.

TABLE 3

METRIC EQUIVALENT CONVERSIONS

PRESSURE	
PSI (US)	BAR (Metric)
1	.07
4.0	0.28
15.7	1.10
30.0	2.10
67.0	4.7
100.0	7.0
135.0	9.5

SPECIFIC VOLUME	
ft^3/lb (US)	cm^3/Kg (Metric)
0.0160	998
0.0167	1040
0.0170	1060
0.0175	1090
0.0180	1120
1.4800	92,315
2.4600	153,442
3.9000	243,262

AREA	
in^2 (US)	cm^2 (Metric)
1	6.5

WEIGHT	
lb (US)	Kg (Metric)
1	0.4536

MASS VELOCITY	
lb/h/in^2 (US)	Kg/h/cm^2 (Metric)
47,000	21,319
70,000	31,752
90,000	40,824
107,000	48,535
196,000	88,905

TEMPERATURE	
°F (US)	°C (Metric)
60	15.6
200	93.3
212	100.0
250	121.0
278	136.7
300	148.9
308	153.3
318	159.0
328	164.4
333	167.0
350	176.7
TEMPERATURE DROP EQUIVALENTS	
5	2.8
10	5.6
20	11.0
30	16.7

FLOW	
lb/h (US)	Kg/h (Metric)
19,046	8,639.3
38,092	17,278.5

FCI STEAM TRAP SECTION ADDITIONAL STANDARDS

ANSI/FCI 69-1, *Pressure Rating Standard for Steam Traps*

ANSI/FCI 85-1, *Standard for Production Testing for Steam Traps*

FCI 84-1, *Metric Definition of the Valve Flow Coefficient C*

FCI 13-1, *Determining Condensate Loads to Size Steam Traps*

FCI STEAM TRAP SECTION TECHNICAL BULLETINS

Tech Sheet #ST 101 Some Usage Consequences with Orifice Drain Devices

Tech Sheet #ST 102 The Benefits of Steam Tracing vs. Electric Tracing

Tech Sheet #ST 103 Steam: Yesterday, Today and Tomorrow

Tech Sheet #ST 104 Small Drip Legs Cause Big Problems

Tech Sheet #ST 105 Steam Traps: Critical Devices for Optimal Performance of Steam Systems

Tech Sheet #ST 106 Effective Drainage of Condensing Equipment

Tech Sheet #ST 107 Steam Traps: Operating Principles and Types