DESIGN of FLUID SYSTEMS

STEAM UTILIZATION

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PREFACE

Recognizing the on-going need for education as it relates to the fundamentals of steam including the most efficient use of its heat content, Spirax Sarco has developed the Steam Utilization Course. This handbook represents over 80 years of steam experience in the proper selection, sizing and application of steam traps, pressure and temperature controls, and condensate recovery systems in major industrial plants throughout the world.

The Steam Utilization Course can be used in conjunction with "Design of Fluid Systems-Hook Ups" for a complete and concise knowledge of the use of steam for heat.

For additional information or technical assistance talk directly to a Spirax Sarco Application Engineer toll-free:
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Design of Fluid Systems Steam Utilization

Contents

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Basic steam engineering principles

Introduction

The Spirax Sarco steam course is intended to cover the characteristics and use of steam, as a conveyor of energy to space heating or process heating equipment. The use of steam for power is a specialized subject, already well documented, and is outside the scope of this course.

The course is aimed at those people engaged in the design, operation, maintenance or general care of a steam system. Some moderate knowledge of physics is assumed, but the first part of the course is an attempt to define the basic terminology and principles involved in steam engineering.

What is steam?

Like other substances water can exist in the form of a solid (ice), as a liquid, (water), or as a gas (steam). In this course our attention will largely be concentrated on the liquid and gas phases, and on the change from one phase to the other.

If heat energy is added to water, its temperature rises until a value is reached at which the water can no longer exist as a liquid. We call this the "saturation" point and with any further addition of energy, some of the water will boil off as steam. This evaporation requires relatively large amounts of energy, and while it is being added, the water and the steam released are both at the same temperature.

Equally, if we can encourage the steam to release the energy that was added to evaporate it, then the steam will condense and water at the same temperature will be formed.

Why use steam?

Steam has been used as a conveyor of energy since the Industrial Revolution. After its first use for cooking foodstuffs, it has continued to be a flexible and versatile tool for industry wherever heating is needed.

It is produced by the evaporation of water which is a relatively inexpensive and plentiful commodity in most parts of the world. Its temperature can be adjusted very accurately by the control of its pressure, using simple valves; it carries relatively large amounts of energy in a small mass, and when it is encouraged to condense back to water, high rates of energy flow (into the material being heated) are obtained, so that the heat using equipment does not have to be unduly large.

The formation of steam

Perhaps the best way of explaining the formation of steam is by considering an imaginary, idealized, experiment (see Fig. 1). Suppose we took a cylinder with its bottom end closed, and surrounded it with insulation which was 100% efficient so that there was no heat loss from it. If we poured into the cylinder 1lb of water at the temperature of melting ice, 32°F, we could use this as a datum point and say that for our purposes its heat content, or enthalpy, was zero. Any addition of heat to the water would raise its temperature, until this reached 212°F (the cylinder being open at the top so that only atmospheric pressure is applied to the water). With any further addition of enthalpy, the water cannot exist as a liquid and some of it will boil off as steam.

The total enthalpy held by each pound of liquid water at the boiling temperature is called the sensible heat of water and is shown by the symbol " hf".

The extra heat which has to be added to each pound of water to turn it into steam is called the latent heat of evaporation shown by the symbol "hf_g ".

The total heat in each pound of steam clearly is the sum of these two. It is called the total heat of steam and can be shown by:- $hf + hf_g = hg$.

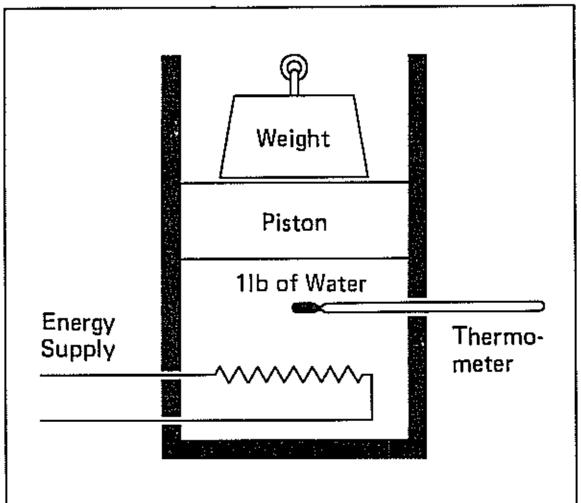


Fig. 1 Steam formation experiment

When the whole of the latent heat of evaporation has been added to the pound of water in our cylinder, then all the water will exist as steam at atmospheric pressure. Its volume will be very much more than the volume of liquid water, by a factor of over 1,650 times. Clearly the molecules of water in the liquid condition are held together much more closely than are the molecules of steam. The process of evaporation can be thought of as one of adding sufficient energy to each molecule that it can break the bonds holding it to its neighbors so that it can leave the liquid in the cylinder and move freely in the gas phase.

Now it is to be expected that if the pressure above the liquid were increased, the molecules would find it more difficult to leave. We would have to give them more energy before they could break the bonds and move into the gas phase, which means that the temperature of the water would increase to over 212°F before boiling occurred. This is, indeed, exactly what is found in practice. If our imaginary cylinder were fitted with a frictionless piston, and a weight placed on top of the piston so as to apply pressure to the water, then the temperature of the water could be increased above the normal 212°F before any evaporation commenced. However, at any given pressure there is a corresponding temperature above which water cannot exist as a liquid, and any heat above the 'sensible heat' will evaporate some of the liquid.

Equally, if the pressure of the water is lowered below the normal atmospheric pressure, then it is easier for the molecules to break free. They require a lower energy level, so the temperature at which boiling occurs, and the corresponding sensible heats are reduced. Each school child learns the difficulty of boiling eggs at the top of a mountain where the air pressure is lowl

Fortunately for all of us, Engineers and Physicists have already carefully measured and recorded the temperatures and energy amounts. Their results appear in the "Steam Tables" which we will look at later.

Terminology and units

Enthalpy

This is the term given for the total energy, due to both the pressure and temperature, of a fluid or vapor (such as water or steam) at any given time and condition.

The basic unit of measurement for all types of energy is the British Thermal Unit (BTU)

Specific Enthalpy

Is the enthalpy (total energy) of a unit mass (1 lb). The units generally used are BTU/lb.

Specific Heat Capacity

A measure of the ability of a substance to absorb heat. It is the amount of energy (BTU's) required to raise 1lb by 1°F. Thus specific heat capacity is expressed in BTU/lb°F

The specific heat capacity of water is 1 BTU/lb°F. This simply means that an increase in enthalpy of 1 BTU will raise the temperature of 1 lb of water by 1°F.

Absolute Pressure & Gauge Pressure

The theoretical pressureless state of a perfect vacuum is "absolute zero". Absolute pressure is, therefore, the pressure above absolute zero. For instance, the pressure exerted by the atmosphere is 14.7 psi abs. at sea level.

Gauge pressure is the pressure shown on a standard pressure gauge fitted to a steam system. Since gauge pressure is the pressure above atmospheric pressure, the zero on the dial of such a gauge is equivalent to approx. 14.7 psi abs.

So a pressure of 45 psi abs. would be made up of 30.3 psi gauge pressure (psig) plus 14.7 psi absolute atmospheric pressure.

Pressures below zero gauge are often expressed in inches of mercury.

Heat and Heat Transfer

Heat is a form of energy and as such is part of the enthalpy of a liquid or gas.

Heat transfer is the flow of enthalpy from matter at a high temperature to matter at a lower temperature, when they are brought together.

Sensible Heat (Enthalpy of Saturated Water)
Let us assume that water is available for feeding to a boiler at atmospheric pressure, at a temperature of 50°F, and that the water will begin to boil at 212°F. 1 BTU will be required to raise each lb of water through 1°F. Therefore for each lb of water in the boiler, the increase in enthalpy is (212 - 50) x 1 = 162 BTU in raising the temperature from 50°F to 212°F. If the boiler holds 22000 lb mass (2638 galls) the increase in enthalpy to bring it up to boiling point is 162 BTU/lb x 22000 lb = 3,564,000 BTU.

It must be remembered this figure is not the sensible heat, but merely the increase in sensible heat required to raise the temperature from 50°F to 212°F. The datum point of the steam tables is water at 32°F, which is assumed to have a heat content of zero for our purposes. (The absolute heat content clearly would be considerable, if measured from absolute zero at minus 459°F). The sensible heat of water at 212°F is then (212 - 32) x 1 = 180 BTU.

Latent Heat (Enthalpy of Evaporation)
Suppose for the moment that any steam which is formed in the boiler can be discharged freely into the atmosphere. When the water has reached 212°F heat transfer between the furnace and water continues but there is no further increase in temperature. The additional heat is used in evaporating the water and converting it into steam.

The heat input which produces a change of state from liquid to gas without a change of temperature is called the "latent heat of evaporation". This latent heat is the difference between the sensible heat of water and the total heat of dry saturated steam.

Total Heat of Steam (Enthalpy of Saturated Steam)
We have established that the steam generated in our boiler contains heat which is described in two ways — sensible and latent. The sum of these is known as the "total heat of steam".

In every one lb mass of steam at 212°F and at atmospheric pressure, the sensible heat is 180 BTU/lb, the latent heat is 970 BTU/lb with the total heat being 1150 BTU/lb. These figures are taken from the steam tables which we will look at in some more detail, later on.

Of course, the proportion of sensible and latent heats remain constant at a given pressure, whatever quantity of steam is involved. For instance, if we were considering a mass of 100 lb of steam rather than 1 lb, each of the figures in the paragraph above would be multiplied by 100.

Density of saturated water and hydraulic pressure.
Note from the above that steam at atmospheric pressure, with a volume of 26.8 $ft.^3$ per lb., takes up some 1672 times the volume of the pound of water with which we started. Of course, the density of water itself changes a little with temperature. At 212 °F, saturated water has a specific density of about 59.8 $lb./ft.^3$ The heated water is a little less dense than is cooler water, nominally taken as 62.4 $lb./ft.^3$ at 60 °F ambient temperature.

Multiplying the specific volume of saturated liquid (inverse of its density) by 1728 $in^3/ft.^3$, we find that a column of water 28.9 in. high will exert a pressure at its base of 1 $lb/in.^2$ This is the theoretical height to which condensate can be elevated by each psi of steam pressure. This also defines the hydraulic pressure at the trap inlet that can be used on modulating service to size a float trap for minimum differential pressure.

Steam pressure

We have already mentioned the term "atmospheric pressure". This is simply the pressure exerted on all things, in all directions, by the earth's atmosphere.

The pressure exerted by the atmosphere, when water is boiling at 212°F, happens to be 14.7 psi.

Now let us look again at the imaginary cylinder with the frictionless piston which we mentioned earlier. If water is heated up in the cylinder until steam is generated, the steam will build up below the piston until the pressure of the steam and water is sufficient to balance the weighted piston. Any more steam being released from the water will then push the piston up the cylinder, the pressure remaining constant. If we were able to pump some more water into the cylinder we could maintain the water level, while at the same time releasing steam which would move the piston even further along the cylinder. Indeed, we could perhaps connect a pipe to the cylinder and carry the steam under pressure to some equipment in which it could condense, still under pressure, and then arrange for the condensed water to be taken to the pump for feeding back into the cylinder.

We have already said that if the cylinder, or boiler, is operated at a pressure above atmospheric pressure, then the temperature of the saturated water and of the steam is greater than 212°F. If the pressure were 150 psi absolute, the saturated water temperature would be 358°F. In order to reach this higher temperature, the water must be given a greater quantity of "sensible heat".

On the other hand, we find that the latent heat needed to convert the saturated water into steam, is lowered as the pressure increases. At high pressure, the molecules of steam are more tightly packed, and the extra energy needed for them to break free from the liquid water (where they already have a high energy level) is lowered in quantity.

At very high pressures indeed, above about 3207 psi the energy level of the molecules of steam is just the same as that of the molecules of water, and the latent heat becomes zero!

Steam Volume

If 1 lb (mass) of water (which is 0.12 gall by volume) is all converted into steam, the result will be exactly 1 lb (mass) of steam.

However, the volume occupied by a given mass depends upon its pressure. At atmospheric pressure 1 lb of steam occupies nearly 26.8 cubic feet (ft^3). At a pressure of 150 psi abs, that same 1 lb of steam will only occupy 3.02 ft^3. The volume of 1 lb of steam at any given pressure is termed its **Specific Volume** (symbol Vg).

The volume occupied by a unit mass of steam decreases as its pressure rises. This is shown in graph form in Fig. 2.

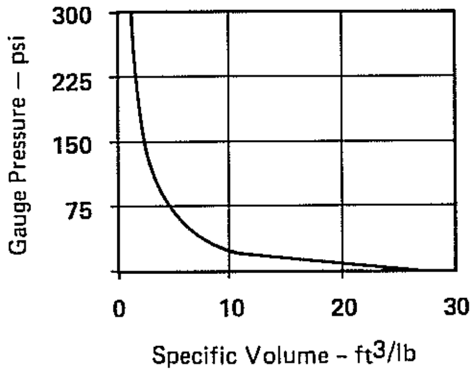


Fig. 2 Dry Saturated Steam — Pressure/ Specific Volume

Steam quality

Dry Steam and Wet Steam

It must be explained that the Steam Tables show the properties of what is usually known as "dry saturated steam". This is steam which has been completely evaporated, so that it contains no droplets of liquid water.

In practice, steam often carries tiny droplets of water with it and cannot be described as dry saturated steam. Nevertheless, we find that it is usually important that the steam used for process or heating is as dry as possible. We shall see later how this is achieved, by the proper use of steam "separators" and steam "traps".

Steam quality is described by its "dryness fraction" — the proportion of completely dry steam present in the steam being considered. The steam becomes "wet" if water droplets in suspension are present in the steam space, carrying no latent heat. For example, the specific enthalpy of steam at 100 psi with a dryness fraction of 0.95 can be calculated as follows —

Each lb of wet steam will contain the full amount of sensible heat, but as only 0.95 lb of dry steam is present with 0.05 lb of water, there will only be 0.95 of the latent heat. Thus, the specific enthalpy of the steam will be:

$$h_g = hf + (0.95 \times hf_g)$$

$$= 309 + (0.95 \times 881.6)$$

$$= 1146.5 \text{ BTU/lb}$$

This figure represents a reduction of 44.1 BTU/lb from the total heat of steam at 100 psi gauge shown in the Steam Tables. Clearly, the "wet steam" has a heat content substantially lower than that of dry saturated steam at the same pressure.

The small droplets of water in wet steam have weight but occupy negligible space. The volume of wet steam is, therefore, less than that of dry saturated steam.

Volume of wet steam =
Volume of dry saturated steam x
Dryness fraction (Vg)

As an aside, it is the water droplets in suspension which make wet steam visible. Steam as such is a transparent gas but the droplets of water give it a white cloudy appearance due to the fact that they reflect light.

Superheated Steam

As long as water is present, the temperature of saturated steam will correspond to the figure indicated for that pressure in the Steam Tables. However, if heat transfer continues after all the water has been evaporated, the steam temperature will again rise. The steam is then called "superheated", and this "superheated steam" will be at a temperature above that of saturated steam at the corresponding pressure.

Saturated steam will condense very readily on any surface which is at a lower temperature, so that it gives up the latent heat which, as we have seen, is the greater proportion of its energy content. On the other hand, when superheated steam gives up some of its enthalpy, it does so by virtue of a fall in temperature. No condensation will occur until the saturation temperature has been reached, and it is found that the rate at which we can get energy to flow from superheated steam is often less than we can achieve with saturated steam, even though the superheated steam is at a higher temperature. Superheated steam because of its other properties, is the natural first choice for power steam requirements, while saturated steam is ideal for process and heating applications.

Steam generation

Before moving on to consider the practical side of steam usage, let us make sure the theoretical aspects of generation are clear in our minds.

The chemical energy which is contained in coal, gas or other boiler fuel is converted into heat energy when the fuel is burned. This heat energy is transmitted through the wall of the boiler furnace to the water. The temperature of the water is raised by this addition of heat energy until saturation point is reached — it boils.

The heat energy which has been added and which has had the effect of raising the temperature of the water is known as the **Sensible Heat** (symbol hf). At the point of boiling, the water is termed **Saturated Water.**

The sensible heat of water at 32°F is usually taken as zero. The specific heat capacity of water is 1.0 BTU/lb°F. Therefore raising the temperature of 1 lb of water from 32°F to 212°F (atmospheric boiling point) will require a sensible heat of

(212 - 32) x 1 = 180 BTU

If the boiler holds 2000 lb mass (240 galls) then the sensible heat is

2000 x 1 x 180 = 360,000 BTU

But if the water in our boiler was already at 50°F, the increase in enthalpy to bring it to saturation point becomes

2000 x 1 x (212 - 50) = 324,000 BTU

It must be remembered that this figure is not the total sensible heat. It is the **increase** in sensible heat required to raise the water from 50°F to 212°F.

The water at 50°F already has some heat content or enthalpy (for the purists, this is termed the 'enthalpy of undercooled water'). The total enthalpy remains at 360,000 BTU, the sensible heat at 212°F, for our boiler holding 2000 lb.

But the example provides a useful first lesson in fuel economy. The higher the initial temperature of the water in the boiler the less heat input needed to bring it to saturation point and, therefore, the less the amount of fuel it is necessary to burn.

The water in our boiler is now at saturation (boiling) point at 212°F. Heat transfer is still taking place between the furnace walls and the water. The additional enthalpy produced by this heat transfer does not increase the temperature of the water. It evaporates the water which changes its state into steam; The heat which produces this change of state without change of temperature is known at the latent heat (symbol hf_g).

Thus the steam generated in our boiler has two portions of heat. These are the sensible heat and the latent heat. Adding these together, we arrive at the total heat of steam (symbol h_g).

Thus $hf + hf_g = h_g$

The simple examples we have looked at to illustrate the basic points, all occurred at atmospheric pressure.

But consider our boiler as a closed vessel. As more steam is generated it is compressed and exerts a pressure on everything surrounding it. This includes exerting a pressure on the surface of the water.

As the pressure on the surface of the water increases so the temperature of saturated water increases. While at atmospheric pressure the temperature of saturated water is 212°F, at a pressure of 150 psi abs. the temperature of saturated water rises to 358°F.

Fig. 3 shows the total heat of steam at atmospheric pressure. Compare it with Fig. 4 which shows the changed total heat of steam at the higher pressure of 150 psi abs.

The total heat of each lb of saturated steam in Fig. 4 has increased, but only slightly (by 44.3 BTU). The sensible heat has **Increased** a great deal (by 150.4 BTU) whereas the latent heat has **Decreased** (by 106.1 BTU).

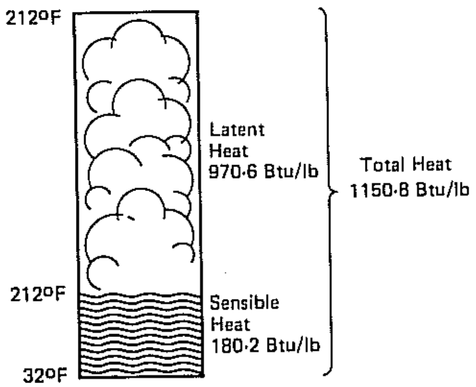


Fig. 3 Total Heat content of steam at atmospheric pressure

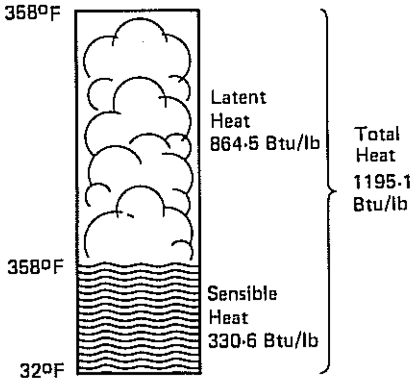


Fig. 4 Total Heat content of steam at 150 psi abs pressure

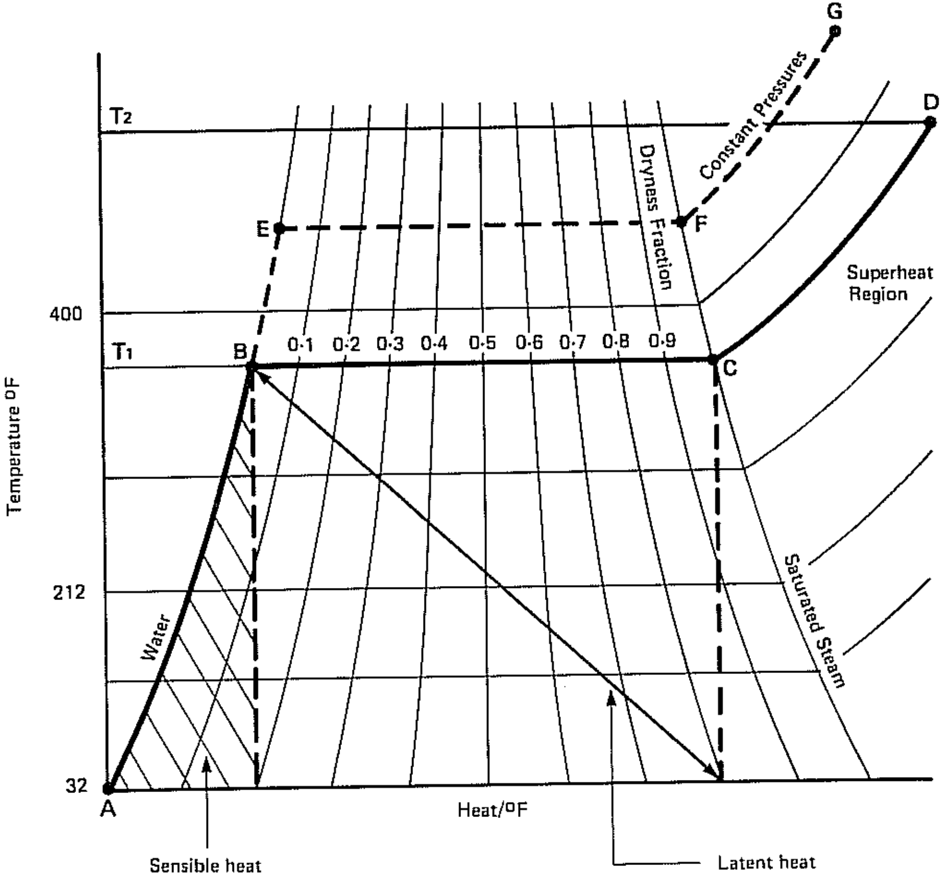


Fig. 5 Temperature — Heat/°F Graph

The basic rules that arise from this are:-

i) When Steam Pressure Increases:-
   Total heat increases slightly.
   Sensible heat increases.
   Latent heat decreases.

ii) When Steam Pressure Decreases:-
   Total heat decreases slightly.
   Sensible heat decreases.
   Latent heat increases.

Thus, the lower the steam pressure the greater the latent heat. The significance of this statement will become apparent later when we consider the Condensation of Steam.

The graph (Fig. 5) shows the change of state from water to steam and the effect of adding heat to either phase. The vertical axis shows temperature. The horizontal axis is actually heat divided by the temperature at which the heat is added. The use of this rather artificial factor means that the area below the lines on the graph represents heat or enthalpy. This makes it easy to show on the diagram the information which otherwise has to be given in the steam tables.

At point A on the graph, water at 32°F is taken to have a heat content of 0. As heat is added, the temperature rises along the line AB. Point B is the saturation (boiling) point T_1, corresponding to the pressure in the system. From point B to point C, latent heat is added at constant temperature T_1. Any further addition of heat beyond point C will then increase the temperature of the steam, for example to T_2 at point D. The part of the graph to the right of the line on which C and D lie, represents superheated steam. T_2 is the temperature of the superheated steam and $T_2 - T_1$ is the amount of superheat added. Increasing the pressure on the water and steam results in a curve like AEFG.

Condensation of steam

As soon as steam leaves the boiler, it begins to give up some of its heat to any surface at a lower temperature. In doing so, some of the steam condenses into water at the same temperature. The process is the exact reverse of the change from water to steam which takes place in the boiler when heat is added. It is the latent heat which is given up by the steam when it condenses.

Let us consider exactly what happens when steam is put to work in process or heating systems. Fig. 6 shows a coil heated vessel which might be found in any steam using system. The vessel is filled with the product to be heated, and steam is admitted to the coil. The steam then gives up its latent heat to the metal wall of the coil, which transfers it to the product. Now water is formed as the steam condenses, and runs down to the bottom of the coil. This "condensate", as it is properly known, must be drained away.

If the steam in the coil condenses at a faster rate than the condensate is able to drain away, the bottom of the coil will begin to fill with water as shown in Fig. 7. We call this waterlogging. Initially, the temperature of the condensate will be the same as the temperature of the steam which has condensed. This fact may tempt us to allow waterlogging to occur without further consideration. A little thought will show that this may greatly reduce the effectiveness of the coil.

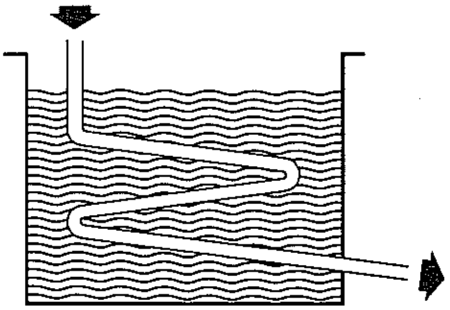


Fig. 6 Coil Heated Vessel

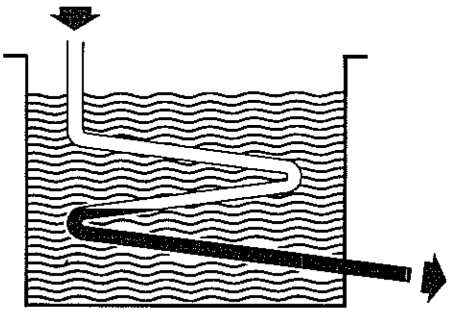


Fig. 7 Coil Heated Vessel — Coil partially waterlogged

Although the temperature of the steam and that of the freshly formed condensate will be the same, the temperature of the condensate must fall if it gives up any of its enthalpy to the coil wall and then to the product. This will reduce the temperature difference between the condensed water and the coil wall, and the rate of heat flow will decrease. Further it will be seen shortly that the co-efficient of heat transfer between water and the coil wall is itself lower than that between condensing steam and the coil. The combination of these two effects means that the rate of heat flow from that part of the coil which contains condensate is much less than from the part which is filled with steam.

While the sensible heat in the condensate is usable energy, maximum output is obtained if the water is removed from the coil as quickly as possible, making room for more steam. Ways of making use of the energy left in the condensate will be discussed later.

The heating surface

The surface of the heating coil is known as the "heat transfer surface area". In order to achieve maximum heat transfer from the steam to the product efficient use must be made of every square foot of that heating surface.

It is clear that if part of the heating surface is covered up, the area through which heat transfer can take place from the steam to the product will be reduced accordingly. This is exactly what happens if the condensate is allowed to collect in the bottom of the steam space. Part of the heating surface will be covered by water and it will not be possible to obtain as much heat transfer from the steam to the product over a given period as would be the case when using the whole of the heat transfer surface area.

The surface area (normally obtained in ft^2) available for heat flow is one of three main factors controlling the total amount of enthalpy transferred from the steam to the product. The fahrenheit temperature difference between the steam and the product is a second factor, and the total heat flow is usually taken as being in direct proportion to this temperature difference. The third factor controlling the total of the heat flow is the "co-efficient of heat transfer" or 'U' factor. This depends upon the resistance of the various films opposing the flow of energy, and is normally given in $BTU/ft^2 {}^\circ F$. Combining these three factors, we have the basic heat transfer formula, $Q = UA\Delta T$.

Barriers to effective heat transfer

Figs. 6 and 7 show only steam and condensate in contact with the heating surface of a coil. It would appear from the drawings that the metal wall is the only obstacle preventing direct heat transfer from the steam to the product. However Fig. 8 is a rather more realistic representation of such a heating surface. Films of air, water and scale, cling to the metal wall and all act as barriers to efficient heat transfer.

On the product side of the wall is a stagnant film of product and perhaps also a layer of baked-on product or rust. The heat flow is very greatly reduced by the resistance of these films. Regular cleaning is the obvious answer for the layer of solid scale or dirt, while agitating the product in some way will reduce the thickness of the stagnant liquid film.

On the heat supply side of the wall, there may again be a layer made up of rust and dirt from the pipework and perhaps of scale from the impurities carried over from the boiler in any water droplets. Again this effect can be minimized by regular cleaning, while the rate at which the layer builds up will be reduced by careful attention to the operation of the boiler and to the removal from the steam supply of any droplets or carryover moisture.

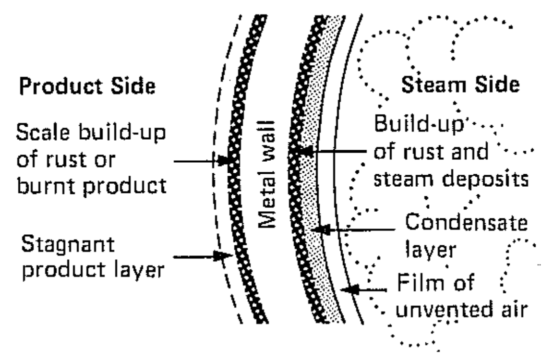


Fig. 8 Resistant Films

It is worth examing the effect of films on the 'U' factor in some more detail.

The films of air and condensate shown in Fig. 8 require especially close attention.

We know that when steam comes into contact with the cooler heat transfer surface, it gives up its latent heat and condenses. The condensation may produce droplets of water, or a complete film may be formed immediately. Even if dropwise condensation takes place, the drops will very often run together and form a film, and as the film thickens, the water begins to run down the wall. It is a fact that water has a surprisingly high resistance to heat transfer. Even a very thin film of water provides a significant obstruction. A film of water only 1/100" in thickness offers the same resistance to heat transfer as a ½" thick wall of iron or a 5" wall of copper. These figures underline still further the importance which must be attached to providing a steam supply which is as dry as possible, and of ensuring rapid removal of the condensate from the steam space.

The air film has an even more drastic effect on heat transfer. It is for this reason that the most effective lagging materials are made up of a mass of minute air cells, enclosed by non-conducting fibers. It is generally accepted that a layer of air only 0.04" thick can offer the same resistance to the flow of heat as a layer of water 1" thick, a layer of iron 4.3 ft thick or a layer of copper 43 ft thick. Full attention will be given to the removal of air from steam systems later in the course.

The steam circuit

The steam generated in the boiler must be conveyed through pipework to the places where its heat energy is required. In the first place, there will be one or more main pipes or "steam mains" from the boiler in the general direction of the steam using plant.

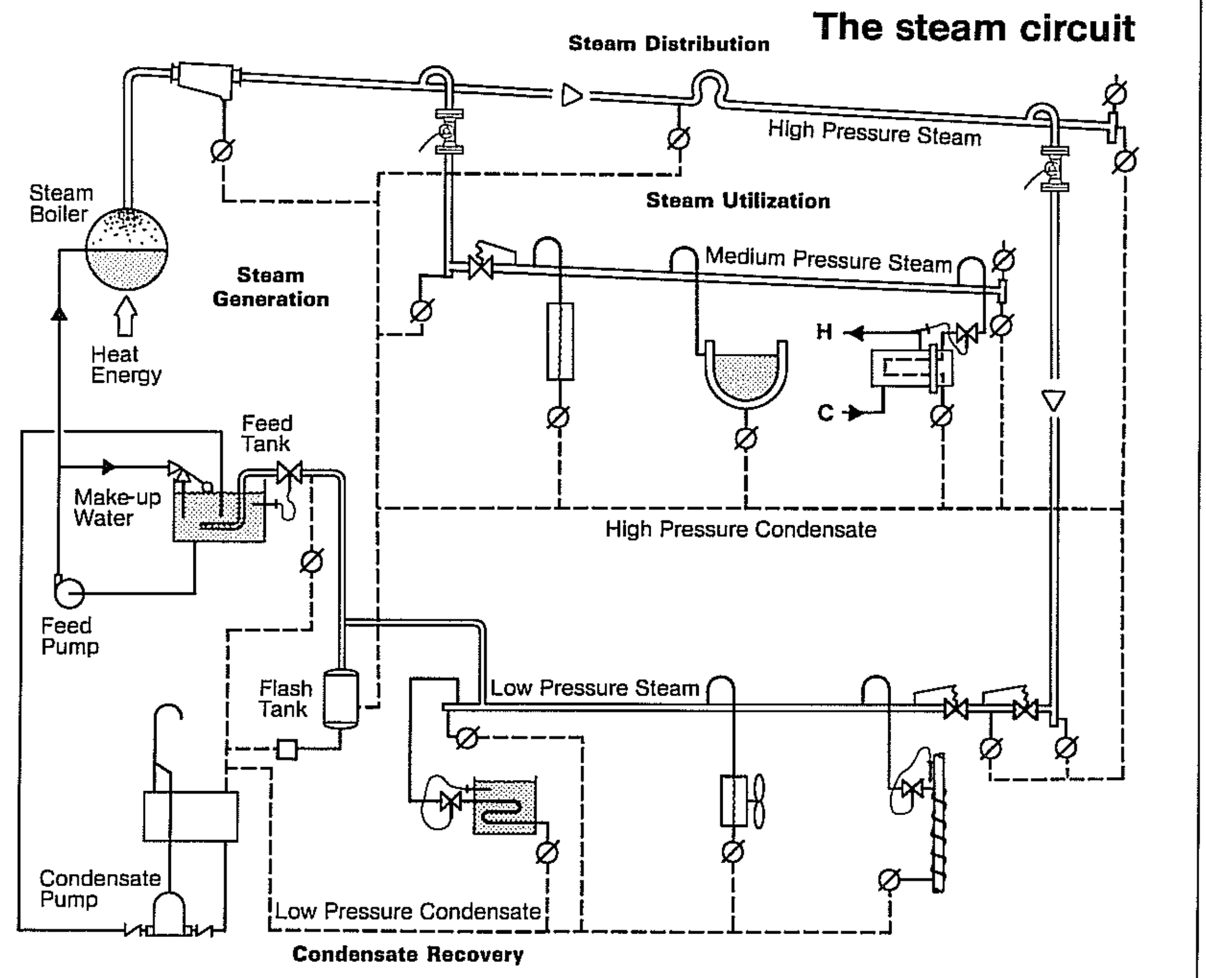


Fig. 9 Typical Steam Circuit

Smaller branch pipes then carry steam to the individual pieces of equipment.

When the boiler crown valve is opened (slowly of course) steam immediately rushes from the boiler into and along the main. The pipework is cold initially and so heat transfer takes place from the steam. The air surrounding the pipes is also cooler than the steam, so the system as it warms up will begin to radiate heat to the air. This heat loss to the atmosphere causes more steam to condense.

However large or small the quantity of heat lost from the steam main, it can only be supplied by the condensation of some of the steam. The water falls towards the bottom of the pipe and also is carried along by the steam flow to low points in the main.

When a valve on a piece of steam using equipment is opened, steam from the distribution system enters the equipment and agains comes into contact with surface cooler than itself. The steam then gives up its latent heat and it condenses, just as we saw in our earlier example of the coil-heated vessel.

There is now a continuous flow of steam coming out of the boiler. To keep up the supply, more and more steam must be generated. In order to do this, fuel is fed to the furnace and more water is pumped into the boiler to make up for water which has been evaporated to provide steam.

We know that the sensible heat of water increases by 1 BTU/lb with each 1°F increase in temperature. If we put into the boiler water which is already hot instead of feeding it with cold water, then a smaller amount of sensible heat will have to be added to bring the water to boiling point. Obviously this would result in a substantial reduction in the amount of fuel required for steam generation.

The condensate formed in both the steam distribution pipework and in the process equipment is a ready made supply of usable hot boiler feed water. Although it is important to remove this condensate from the steam space, it is far too valuable a commodity to be wastefully discharged. The basic steam circuit should be completed, as shown in Fig. 9, by returning all condensate to the boiler feed tank. We will consider the best practical means of condensate removal and return in the following three parts of the course.

Steam tables

We have already seen that a relationship exists between steam pressure and saturation temperature: that sensible, latent and total heats vary and interact with pressure and that the volume changes with changes in pressure.

Fortunately steam tables exist which list the properties of steam at varying pressures. These are the results of actual tests carried out on steam and serve as a handy reference.

The information given in the seven columns of the table is as follows:–

Column 1
gives the steam pressure as registered on a normal gauge in psi. Pressure below atmosphere are given in inches of mercury. Atmospheric pressure is zero on the gauge.

Column 2
is the steam pressure in psi absolute. This means that the starting point is 14.7 psi below atmospheric pressure.

Column 3
shows the temperature in °F of steam at the pressure indicated in columns 1 and 2. This is also the temperature of saturated (boiling) water at the same pressure.

Column 4
is the sensible heat (hf) at the specified pressure. These figures represent the number of BTU's of sensible heat in every 1lb of steam. They are also the number of BTU's in every 1lb of saturated water at the same pressures.

Column 5
gives the latent heat of evaporation (hf_g) at the various pressures. The figures are the number of BTU's of latent heat in every 1lb of steam.

Column 6
shows the total heat of steam (h_g) at the specified pressure. The figures are the total number of BTU's of total heat of steam in every 1lb of the steam. The figure is the sum of columns 4 and 5 (for each given pressure) since $hf + hf_g = h_g$.

Column 7
is the specific volume of steam (Vg) at the various pressures. This is the space occupied by 1lb of steam in ft^3.

PROPERTIES OF SATURATED STEAM

			Heat Content			
Gauge Pressure In. Hg. Vac.	Absolute Pressure psia	Temperature °F	Sensible (h_f) BTU/lb	Latent (h_{fg}) BTU/lb	Total (h_g) BTU/lb	Specific Volume Steam (V_g) ft^3/lb
27.96	1	101.7	69.5	1,032.9	1,102.4	333.0
25.91	2	126.1	93.9	1,019.7	1,113.6	173.5
23.87	3	141.5	109.3	1,011.3	1,120.6	118.6
21.83	4	153.0	120.8	1,004.9	1,125.7	90.52
19.79	5	162.3	130.1	999.7	1,129.8	73.42
17.75	6	170.1	137.8	995.4	1,133.2	61.89
15.70	7	176.9	144.6	991.5	1,136.1	53.57
13.66	8	182.9	150.7	987.9	1,138.6	47.26
11.62	9	188.3	156.2	984.7	1,140.9	42.32
9.58	10	193.2	161.1	981.9	1,143.0	38.37
7.54	11	197.8	165.7	979.2	1,144.9	35.09
5.49	12	202.0	169.9	976.7	1,146.6	32.35
3.45	13	205.9	173.9	974.3	1,148.2	30.01
1.41	14	209.6	177.6	972.2	1,149.8	28.00
Gauge Press. psig						
0	14.7	212.0	180.2	970.6	1,150.8	26.80
1	15.7	215.4	183.6	968.4	1,152.0	25.20
2	16.7	218.5	186.8	966.4	1,153.2	23.80
3	17.7	221.5	189.8	964.5	1,154.3	22.50
4	18.7	224.5	192.7	962.6	1,155.3	21.40
5	19.7	227.4	195.5	960.8	1,156.3	20.40
6	20.7	230.0	198.1	959.2	1,157.3	19.40
7	21.7	232.4	200.6	957.6	1,158.2	18.60
8	22.7	234.8	203.1	956.0	1,159.1	17.90
9	23.7	237.1	205.5	954.5	1,160.0	17.20
10	24.7	239.4	207.9	952.9	1,160.8	16.50
11	25.7	241.6	210.1	951.5	1,161.6	15.90
12	26.7	243.7	212.3	950.1	1,162.3	15.30
13	27.7	245.8	214.4	948.6	1,163.0	14.80
14	28.7	247.9	216.4	947.3	1,163.7	14.30
15	29.7	249.8	218.4	946.0	1,164.4	13.90
16	30.7	251.7	220.3	944.8	1,165.1	13.40
17	31.7	253.6	222.2	943.5	1,165.7	13.00
18	32.7	255.4	224.0	942.4	1,166.4	12.70
19	33.7	257.2	225.8	941.2	1,167.0	12.30
20	34.7	258.8	227.5	940.1	1,167.6	12.00
22	36.7	262.3	230.9	937.8	1,168.7	11.40
24	38.7	265.3	234.2	935.8	1,170.0	10.80
26	40.7	268.3	237.3	933.5	1,170.8	10.30
28	42.7	271.4	240.2	931.6	1,171.8	9.87
30	44.7	274.0	243.0	929.7	1,172.7	9.46
32	46.7	276.7	245.9	927.6	1,173.5	9.08
34	48.7	279.4	248.5	925.8	1,174.3	8.73
36	50.7	281.9	251.1	924.0	1,175.1	8.40
38	52.7	284.4	253.7	922.1	1,175.8	8.11
40	54.7	286.7	256.1	920.4	1,176.5	7.83
42	56.7	289.0	258.5	918.6	1,177.1	7.57
44	58.7	291.3	260.8	917.0	1,177.8	7.33
46	60.7	293.5	263.0	915.4	1,178.4	7.10
48	62.7	295.6	265.2	913.8	1,179.0	6.89
50	64.7	297.7	267.4	912.2	1,179.6	6.68

PROPERTIES OF SATURATED STEAM

Gauge Pressure psig	Absolute Pressure psia	Temperature ^{o}F	Heat Content			Specific Volume Steam (V_g) ft^3/lb
			Sensible (hf) BTU/lb	Latent (hf_g) BTU/lb	Total (h_g) BTU/lb	
52	66.7	299.7	269.4	910.7	1,180.1	6.50
54	68.7	301.7	271.5	909.2	1,180.7	6.32
56	70.7	303.6	273.5	907.8	1,181.3	6.16
58	72.7	305.5	275.3	906.5	1,181.8	6.00
60	74.7	307.4	277.1	905.3	1,182.4	5.84
62	76.7	309.2	279.0	904.0	1,183.0	5.70
64	78.7	310.9	280.9	902.6	1,183.5	5.56
66	80.7	312.7	282.8	901.2	1,184.0	5.43
68	82.7	314.3	284.5	900.0	1,184.5	5.31
70	84.7	316.0	286.2	898.8	1,185.0	5.19
72	86.7	317.7	288.0	897.5	1,185.5	5.08
74	88.7	319.3	289.4	896.5	1,185.9	4.97
76	90.7	320.9	291.2	895.1	1,186.3	4.87
78	92.7	322.4	292.9	893.9	1,186.8	4.77
80	94.7	323.9	294.5	892.7	1,187.2	4.67
82	96.7	325.5	296.1	891.5	1,187.6	4.58
84	98.7	326.9	297.6	890.3	1,187.9	4.49
86	100.7	328.4	299.1	889.2	1,188.3	4.41
88	102.7	329.9	300.6	888.1	1,188.7	4.33
90	104.7	331.2	302.1	887.0	1,189.1	4.25
92	106.7	332.6	303.5	885.8	1,189.3	4.17
94	108.7	333.9	304.9	884.8	1,189.7	4.10
96	110.7	335.3	306.3	883.7	1,190.0	4.03
98	112.7	336.6	307.7	882.6	1,190.3	3.96
100	114.7	337.9	309.0	881.6	1,190.6	3.90
102	116.7	339.2	310.3	880.6	1,190.9	3.83
104	118.7	340.5	311.6	879.6	1,191.2	3.77
106	120.7	341.7	313.0	878.5	1,191.5	3.71
108	122.7	343.0	314.3	877.5	1,191.8	3.65
110	124.7	344.2	315.5	876.5	1,192.0	3.60
112	126.7	345.4	316.8	875.5	1,192.3	3.54
114	128.7	346.5	318.0	874.5	1,192.5	3.49
116	130.7	347.7	319.3	873.5	1,192.8	3.44
118	132.7	348.9	320.5	872.5	1,193.0	3.39
120	134.7	350.1	321.8	871.5	1,193.3	3.34
125	139.7	352.8	324.7	869.3	1,194.0	3.23
130	144.7	355.6	327.6	866.9	1,194.5	3.12
135	149.7	358.3	330.6	864.5	1,195.1	3.02
140	154.7	360.9	333.2	862.5	1,195.7	2.93
145	159.7	363.5	335.9	860.3	1,196.2	2.84
150	164.7	365.9	338.6	858.0	1,196.6	2.76
155	169.7	368.3	341.1	856.0	1,197.1	2.68
160	174.7	370.7	343.6	853.9	1,197.5	2.61
165	179.7	372.9	346.1	851.8	1,197.9	2.54
170	184.7	375.2	348.5	849.8	1,198.3	2.48
175	189.7	377.5	350.9	847.9	1,198.8	2.41
180	194.7	379.6	353.2	845.9	1,199.1	2.35
185	199.7	381.6	355.4	844.1	1,199.5	2.30
190	204.7	383.7	357.6	842.2	1,199.8	2.24
195	209.7	385.7	359.9	840.2	1,200.1	2.18
200	214.7	387.7	362.0	838.4	1,200.4	2.14
210	224.7	391.7	366.2	834.8	1,201.0	2.04
220	234.7	395.5	370.3	831.2	1,201.5	1.96

PROPERTIES OF SATURATED STEAM

Gauge Pressure psig	Absolute Pressure psia	Temperature °F	Heat Content			Specific Volume Steam (V_g) ft^3/lb
			Sensible (h_f) BTU/lb	Latent (h_{fg}) BTU/lb	Total (h_g) BTU/lb	
230	244.7	399.1	374.2	827.8	1,202.0	1.88
240	254.7	402.7	378.0	824.5	1,202.5	1.81
250	264.7	406.1	381.7	821.2	1,202.9	1.74
260	274.7	409.3	385.3	817.9	1,203.2	1.68
270	284.7	412.5	388.8	814.8	1,203.6	1.62
280	294.7	415.8	392.3	811.6	1,203.9	1.57
290	304.7	418.8	395.7	808.5	1,204.2	1.52
300	314.7	421.7	398.9	805.5	1,204.4	1.47
310	324.7	424.7	402.1	802.6	1,204.7	1.43
320	334.7	427.5	405.2	799.7	1,204.9	1.39
330	344.7	430.3	408.3	796.7	1,205.0	1.35
340	354.7	433.0	411.3	793.8	1,205.1	1.31
350	364.7	435.7	414.3	791.0	1,205.3	1.27
360	374.7	438.3	417.2	788.2	1,205.4	1.24
370	384.7	440.8	420.0	785.4	1,205.4	1.21
380	394.7	443.3	422.8	782.7	1,205.5	1.18
390	404.7	445.7	425.6	779.9	1,205.5	1.15
400	414.7	448.1	428.2	777.4	1,205.6	1.12
420	434.7	452.8	433.4	772.2	1,205.6	1.07
440	454.7	457.3	438.5	767.1	1,205.6	1.02
460	474.7	461.7	443.4	762.1	1,205.5	0.98
480	494.7	465.9	448.3	757.1	1,205.4	0.94
500	514.7	470.0	453.0	752.3	1,205.3	0.902
520	534.7	474.0	457.6	747.5	1,205.1	0.868
540	554.7	477.8	462.0	742.8	1,204.8	0.835
560	574.7	481.6	466.4	738.1	1,204.5	0.805
580	594.7	485.2	470.7	733.5	1,204.2	0.776
600	614.7	488.8	474.8	729.1	1,203.9	0.750
620	634.7	492.3	479.0	724.5	1,203.5	0.726
640	654.7	495.7	483.0	720.1	1,203.1	0.703
660	674.7	499.0	486.9	715.8	1,202.7	0.681
680	694.7	502.2	490.7	711.5	1,202.2	0.660
700	714.7	505.4	494.4	707.4	1,201.8	0.641
720	734.7	508.5	498.2	703.1	1,201.3	0.623
740	754.7	511.5	501.9	698.9	1,200.8	0.605
760	774.7	514.5	505.5	694.7	1,200.2	0.588
780	794.7	517.5	509.0	690.7	1,199.7	0.572
800	814.7	520.3	512.5	686.6	1,199.1	0.557

Questions

1. Dry saturated steam at 120 psig is used in a piece of equipment and the condensate runs to waste at a temperature 10°F below steam temperature. How much of the total heat is lost and what is the percentage of the total heat which is being wasted?

2. Why is it thought more efficient to use steam for heating at 30 psig rather than steam at 150 psig.

3. If 100 gallons of water is to be heated from 60°F to 190°F, how many BTU's are needed and how is the added energy described?

Notes

Steam traps and the removal of condensate

Condensate removal

Part 1 concluded with a broad outline of what constitutes an efficient heat circuit. This must now be examined in greater detail. Let us return to the point when steam first enters the system from the boiler and encounters the cold surfaces of the distribution pipework and process equipment. The temperature difference between the steam and metal walls will be greater during this initial warm up period than at any other time. We know that the highest rate of heat transfer will occur when the temperature difference is greatest and it is for this reason that steam consumption is at a peak during start up.

As the steam system warms up, the gradual decrease in temperature difference brings about a corresponding decrease in the rate of steam condensation, until a fairly stable condition is reached. The two extremes of variable condensate formation are generally known as the "start-up load" and a "running load". Frequent reference will be made to these terms as we consider the most efficient methods of condensate removal.

If an adequately sized hole is provided at the bottom of a piece of process equipment, any condensate which is formed will be free to drain away. The problem is that steam will also be allowed to escape — a waste of energy which cannot be tolerated under any circumstances. Clearly there is a need for some means of discharging condensate without letting out any steam.

Manually Operated Valves

One way in which we could try to control condensate removal would be to fit a drain cock or valve of the type illustrated in Fig. 10. It would appear that the valve simply needs to be opened to release condensate and closed to prevent any loss of steam. The problem with such a device lies in the difficulty of catering to any variation in the condensate load. Unless the valve is continuously adjusted to keep in step with the rate of condensation, either steam loss or waterlogging is bound to occur. Even if we could afford to employ a full time valve operator, total accuracy of adjustment could not be guaranteed.

An alternative way of using this type of valve is to maintain one permanent setting with the valve just cracked open off its seat. Unfortunately, this arrangement is even less satisfactory than our previous suggestion. The slow condensate discharge rate on start-up will result in waterlogging and, worse still, a considerable amount of steam could be wasted under normal running conditions. It is clear that this does not provide a viable solution to our condensate removal needs.

One other type of manual valve that can be considered is the drilled plug cock shown in Fig. 11. The larger hole is used for the heavy condensate load during start-up, while the smaller hole should be sufficient to cope with the reduced running load. The cock has to be turned by hand and it is impossible to gauge exactly when the change from one hole to the other should be made. Even if the plug could have a dozen different sized holes and an experienced operator, there would still be occasions when none of the holes matched the rate of condensation.

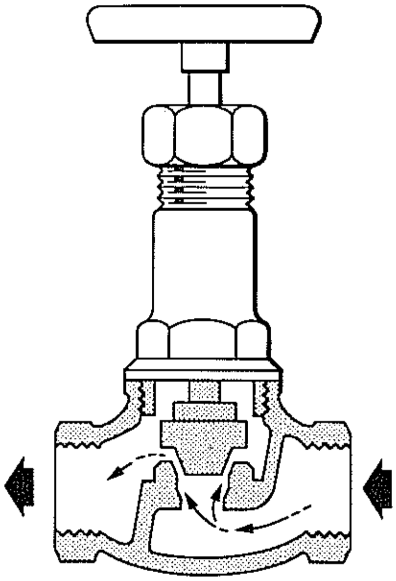


Fig. 10 Valve

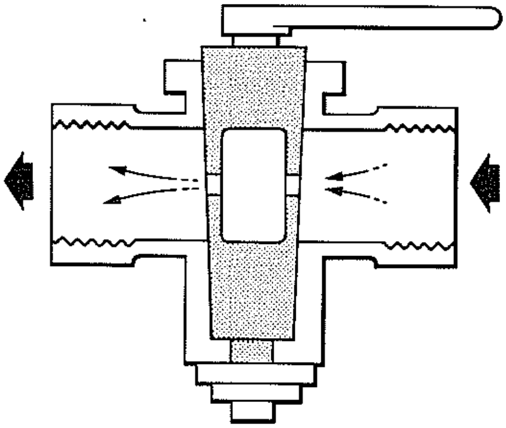


Fig. 11 Drilled Plug Cock

Automatic Valves

We have established that the use of a hand operated valve, plug cock or cracked valve as a means of discharging condensate is crude, inefficient and wasteful. Not one of these options can cope effectively with variable rates of condensation without either waterlogging the steam space or passing steam.

The only answer to this problem is to use an automatic valve which is somehow able to sense the difference between steam and condensate and react accordingly. An automatic valve of this type is known as a "steam trap" and its function is to discharge condensate without allowing live steam to escape. All steam traps are designed to do just that, but they don't all do it in the same manner.

If the conditions in every item of steam using equipment were the same, it would be reasonable to use one type of steam trap for all applications. In practice, however, a steam trap which is ideal for draining say a steaming oven, could never be used successfully on a heater battery. It is considerations such as these that account for the many different steam trap types which are currently available.

Steam Trap Applications

It has already been mentioned that there is no such thing as a "universal" steam trap which is suitable for all applications. For this reason, we must familiarize ourselves with each of the main steam trap groups and learn how best to take advantage of the merits of each type.

It is a much neglected fact that the efficiency of any piece of steam using equipment is ultimately dependent upon the efficiency of its condensate drainage arrangements. In times of ever escalating fuel costs, it is essential that we seek to achieve maximum output with minimum fuel consumption. Bad steam trapping practice cannot be tolerated.

Reference was made to the detrimental effect of air in steam system in Part 1. It can also cause problems with the steam traps themselves. When steam is shut off, air will be drawn in to take up all the space formerly occupied by steam. Since this air has to be removed from the system on start-up, it is a considerable bonus if the steam traps have a good air venting capability. While this is the case with certain traps, other types are actually prone to "air binding" – a condition in which the trap remains closed when it should be opening to release condensate. It is for this reason that frequent reference will be made to air, as well as to condensate, during our detailed examination of the main steam trap groups.

Flash Steam

One further subject must be considered albeit briefly at this stage, before we look in detail at the various types of trap.

We know that the sensible heat of freshly formed condensate at steam pressure and temperature can be obtained from the steam tables. For example, at a pressure of 100 psi gauge, condensate will contain 309 BTU/lb at a temperature of 338°F. If this condensate is discharged to atmosphere, it can only exist as water at 212°F containing 180 BTU/lb of sensible heat.

The surplus heat content of 309 – 180 = 129 BTU/lb will boil off a proportion of the water, producing a quantity of steam at atmospheric pressure. This process is described as "flashing", and the low pressure steam which is produced is usually known as "flash steam".

The downstream pressure need not be as low as atmospheric pressure. For instance a flash tank may be used to try to utilize this valuable low pressure steam. This will be discussed in detail later on in the course.

We can generalize and calculate the amount of flash steam formed as follows:

$$\text{Flash Steam produced} = \frac{\text{Sensible heat at higher pressure} - \text{Sensible heat at lower pressure}}{\text{Latent heat at lower pressure}}$$

In the example given above

$$\text{Flash Steam} = \frac{309 - 180}{971} = 0.133 \text{ lb/lb Steam}$$

If the trap were discharging 1000 lb/hr of condensate at 100 psi gauge to atmosphere, the amount of flash steam generated would be 1000 x 0.133 = 133 lb/hr.

Steam trap groups

There are three main steam trap groups:-

Thermostatic Group
This group identifies steam and condensate by the temperature difference which operates a thermostatic, valve-carrying element. Condensate must cool below steam temperature before it can be released.

Mechanical Group
Traps of this group operate mechanically, sensing the difference in density between steam and condensate. The movement of a "float" or a "bucket" operates the valve.

Thermodynamic Group
This group works on the difference in kinetic energy or velocity between steam and condensate flowing through the trap. The most widely used types are thermodynamic disc models. In these traps the valve consists of a simple disc which closes to high velocity steam but opens to lower velocity condensate. Some other, miscellaneous types include "impulse" or piston traps, labyrinth traps, and even the rudimentary orifice plate.

We will look in more detail at each of these groups!

Thermostatic group

Balanced Pressure Type
A typical balanced pressure thermostatic steam trap is shown in section in Fig. 12. The thermostatic element marked "A" is made up of a corrugated metal bellows which will expand and contract if pulled or pushed at the sealed ends. A valve "B" on the bottom of the element is free to enter the valve seat "C" if the element moves downwards. The top of the element is firmly fixed so that any expansion or contraction must take place at the free end "B";

The element is filled with an alcohol mixture which has a boiling point lower than that of water.

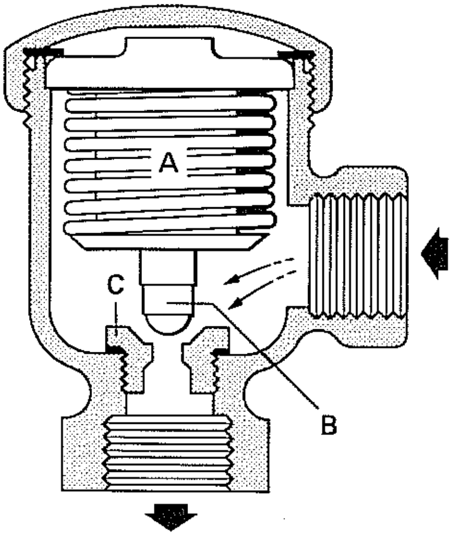


Fig. 12 Balanced Pressure Thermostatic Trap

When steam is turned on, air will be pushed out through the wide open valve "B". Cooler condensate will follow the air and be discharged in the same way. As the condensate gradually warms up, heat transfer will take place to the alcohol mixture inside the element. Before the condensate reaches steam temperature, the mixture reaches its boiling point. As soon as it boils, vapor is given off, increasing the pressure inside the element. This pressure exceeds the pressure in the trap body and so the element expands, forcing the valve "B" on to its seat "C". The trap is now closed and the steam which is following the condensate cannot escape.

Eventually the condensate in the trap body cools down, allowing the alcohol mixture inside the element to cool and condense. This relieves the pressure holding the valve shut and the element is free to contract and open the valve. Condensate is then discharged through the open valve and the complete cycle is repeated.

The working steam pressure does not affect the operation of the trap. It is the difference in temperature between the steam and condensate which sets up the difference between the pressure inside and outside the element which operates the trap. (See Fig. 13).

As we already know, steam temperature increases with steam pressure and the balanced pressure trap is able to automatically adjust itself to any variation in pressure. The higher the steam pressure, the higher the pressure in the element which causes the trap to close.

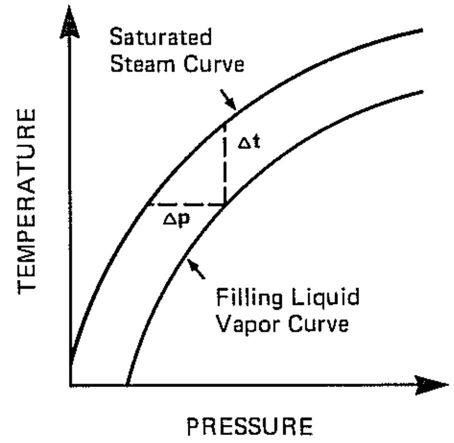


Fig. 13

A single valve seat size is suitable for any pressure within the working limits of a trap of this type.

Advantages of the Balanced Pressure Type

Thermostatic balanced pressure traps are small, light and have a large capacity for their size. The valve is fully open on start up allowing air to be discharged freely and giving maximum condensate removal when the load is greatest. This type of trap is unlikely to freeze when working in an exposed position (unless there is a rise in the condensate pipe after the trap which would allow water to run back and then flood the trap when steam is off).

The balanced pressure trap automatically adjusts itself to variations of steam pressure up to the maximum pressure for which it is suitable.

Trap maintenance is easy. The element and valve seat are detachable and can be replaced in a few minutes without removing the trap body from the line.

Disadvantages of the Balanced Pressure Type

The flexible element in this type of trap may be susceptible to damage by waterhammer or corrosive condensate, depending upon its construction. The type used to operate each trap determines its limitations. The welded stainless steel elements introduced in recent years are better able to tolerate such conditions than those of corrugated bronze. A typical stainless steel element is shown in Fig. 14.

An element that is solidly filled with liquid is even better able to withstand waterhammer without distorting. One such element uses a spin-filling technique to ensure that no air remains inside. This, along with other features including a condensate heat sink to prevent overexpansion, allows the element to operate at pressures to 600 psig.

Unfortunately the majority of balanced pressure traps cannot be used on superheated steam. The excess temperature creates a pressure in the thermostatic element which is not balanced by the pressure surrounding it. This results in irreparable damage to the element. However, a new encapsulated element has recently been developed which is able to cope with superheat conditions. The capsule, shown in Fig. 15 and 16 is comprised of a pair of fully nesting diaphragms in place of the traditional flexible tubing. The trap operates in exactly the same way as other balanced pressure models.

In common with all thermostatic traps, the balanced pressure type does not open until the condensate temperature has dropped

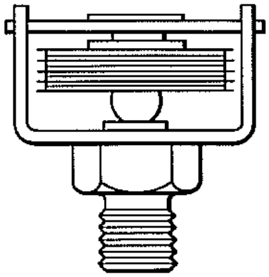


Fig. 14 Stainless Steel Element

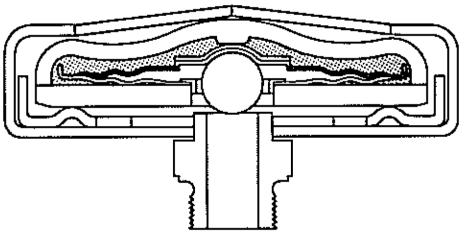


Fig. 15 Open Balanced Pressure Capsule

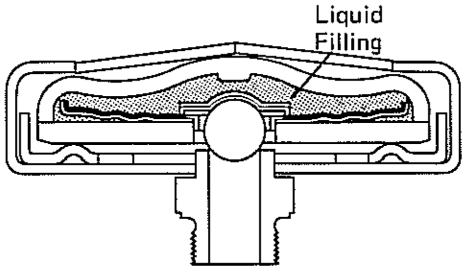


Fig. 16 Closed Balanced Pressure Capsule

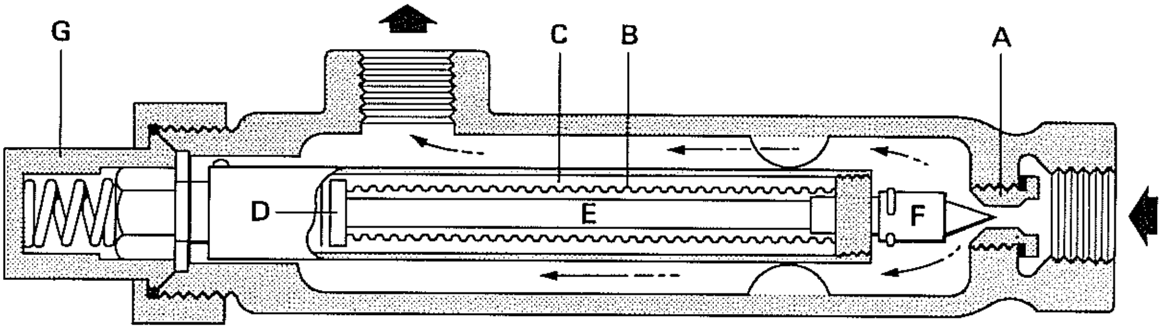


Fig. 17 Liquid Expansion Thermostatic Trap

by a set number of degrees below steam temperature, (the exact temperature drop is determined by the alcohol mixture used in the element). This is clearly a disadvantage if the trap is wrongly chosen for an application in which no waterlogging of the steam space can be tolerated.

Liquid Expansion Thermostatic Type

A well tried and tested liquid expansion trap is shown in section in Fig. 17. The trap is operated by the expansion and contraction of a liquid filled thermostat which responds to the temperature difference between steam and condensate.

When steam is turned on, air and condensate are expelled through the open valve 'A'. The thermostatic element 'B' is filled with oil 'C' which is in contact with a free moving piston, 'D'. On the end of the piston rod 'E' is fixed a valve 'F'. As the temperature of the condensate passing through the trap increases, heat is transmitted to the oil 'C' causing it to expand. This expansion acts on the piston, 'D' and the valve 'F' is pushed nearer and nearer to its seat, steadily reducing the flow of condensate. The trap is normally set to close off completely before steam reaches it.

If condensate is forming at a steady rate, the valve will take up a position to pass just this amount. If the quantity of condensate increases, it will back-up in the pipe before the valve and cool off. This cooler condensate passing through the trap will cause the oil to contract and the valve will be forced back, allowing the greater volume of condensate to be discharged. On the other hand, if the quantity of condensate coming to the trap decreases, it will be higher in temperature due to its closer proximity to the steam. This greater temperature will cause the oil to expand and the valve opening will be reduced accordingly.

These traps can be adjusted by the nut, 'G' so that the valve will be pushed against the seat after a certain amount of oil expansion has taken place. This means that the traps can be set to close off at a certain temperature (within the pressure range of the trap), to suit the requirements of the equipment being drained. Normally this discharge temperature setting will be 212°F or lower.

Advantages of the Liquid Expansion Type

Liquid Expansion Traps can be adjusted to discharge at very low temperatures, if so desired. This feature can effectively reduce steam consumption on applications where controlled water-logging of the steam space can be tolerated.

Like the Balanced Pressure Trap, the liquid Expansion Trap is fully open when cold giving good air discharge and maximum condensate capacity on start-up loads. An exposed trap cannot freeze unless there is a rise in the discharge line to keep the trap flooded.

This type of trap can be used on superheated steam and is able to withstand vibration and water hammer conditions.

Disadvantages of the Liquid Expansion Type

If the steam pressure at the trap is subject to wide and rapid variation, the element will not respond to the changes as quickly as that of a Balanced Pressure Trap.

The flexible tubing of the element can be destroyed by corrosive condensate.

Since the Liquid Expansion Trap discharges condensate at a temperature of 212°F or below, it should never be used on applications which demand immediate removal of condensate from the steam space.

Bimetal Type

Valve movement in this type is obtained from the bending of a composite strip of two metals which expand by a different amount

Fig. 18 Bimetallic Strip

when heated up. If thin strips or discs of two suitable metals are bonded together and then their temperature is raised, they will assume a curved shape such as in Fig. 18. The metal which expands most is sited on the outside of the curve. The original shape is regained when the strip cools down.

Fig. 19 shows a simple steam trap using a single bimetal strip. One end of the strip is fixed to the trap body, while the other end is connected to the valve. Air and condensate pass freely through the open valve until the bimetal strip approaches steam temperature. The free end will then bend downwards and close the valve. The trap will remain shut until the body is filled with condensate which has cooled sufficiently to allow the strip to straighten and open the valve.

There are two important points to be noted about this simple bimetallic trap. First of all, the bending of the bimetal takes place at a certain fixed temperature, so that the trap tries to open and close at one particular temperature even though the steam pressure (and therefore temperature) in the equipment, is likely to vary quite widely during normal operations.

Secondly, when the valve in Fig. 19 is on its seat, steam pressure in the body of the trap is trying to hold it in the closed position against the pull of the bimetal. Although the strip is free to bend downwards to close the valve when it is expanded by heat transfer from the steam, it has much more trouble in straightening out again as it tries to pull the valve open against full steam pressure. This means that the condensate must cool considerably before the valve can open to release it and while it is cooling, more condensate is collecting in the plant and causing waterlogging.

In addition, because the power exerted by a single strip of bimetal on the valve is quite small, a comparatively large mass of bimetal has to be used and this is slow to react to changes in temperature and move the valve one way or the other.

Various attempts have been made to try to overcome these disadvantages of the simple bimetallic trap by using alternative shapes and arrangements of bimetal elements and valves.

Fig. 20 shows one of these in which a double-ported valve is used. The inlet pressure is allowed through a passage to the bottom section of the trap so that equal forces are acting on both sides of the valve. This means that there is no tendancy for the valve to move towards or away from its seat except when the bimetal element expands or contracts due to temperature changes. In order to give sufficient movement to the valve, the bimetal takes the form of a long strip which is bent double several times to reduce the amount of space needed to contain it.

Let us imagine that this trap is connected to a steam space at a pressure of 100 psi gauge and adjusted so that the valve is just closed when steam surrounds the element. When condensate reaches the trap, it collects in the body because it cannot escape through the closed valve. Heat transfer from the trap to the surrounding air causes the condensate and bimetal to gradually cool down and eventually the element will contract and open the valve, allowing the trap to discharge. When steam reaches the trap, the element expands, the valve shuts and the cycle is repeated. However, if a steady amount of condensate is produced, the trap will eventually

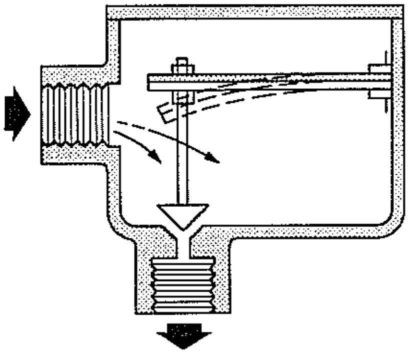


Fig. 19 Simple Bimetallic Trap

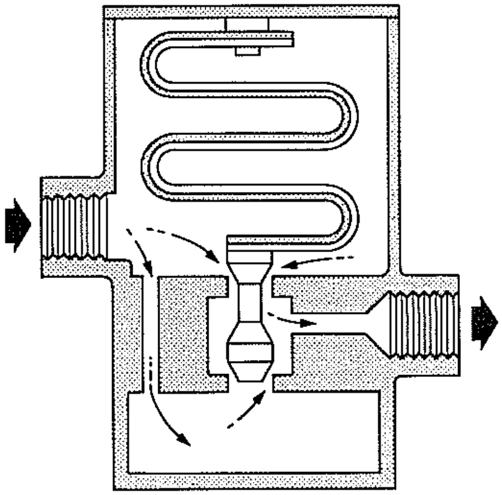


Fig. 20 Double Ported Bimetallic Trap

settle down to give a steady discharge of condensate at a temperature which is below the saturation temperature of steam at 100 psi gauge.

Up to now, the operation of the trap has been satisfactory so long as an adequate cooling leg is provided before the trap to allow the condensate to collect and cool down without water-logging the steam space. This will not be the case if the steam pressure in the system starts to fluctuate.

If the pressure drops, the steam temperature is reduced accordingly and it cannot expand the bimetal enough to seat the valve. The trap is then free to blow steam. If the pressure rises, the higher temperature causes the element to expand more than at 100 psi gauge. The valve is pushed further into its seat and the condensate must cool down even more than before in order to open the valve. This may well water-log the steam space.

A bimetallic trap of this type needs to be re-adjusted manually if the conditions change much from those for which it is set. A further disadvantage is that the double-ported valve does not give a tight shut-off and steam may blow. It is also sensitive to dirt because of the fairly close clearances needed to prevent steam from blowing.

Another arrangement that has been tried is where the valve is on the outlet side of the valve orifice instead of the inlet as in Fig. 21. Here the bimetallic element operates the valve by means of a stem that passes through the seat orifice and it is clear that steam pressure is trying to open the valve in contrast to the trap in Fig. 19 where it is trying to close it.

Once again, let us consider the case when steam pressure is 100 psi gauge and the trap is set so that the valve is just closed when steam at this pressure surrounds the element as in Fig. 22. When condensate fills the trap and starts to cool the element, steam pressure helps the bimetal to open the valve by pushing it away from its seat. This means that less cooling is needed to open the valve than in a trap of the type shown in Fig. 19. If the steam pressure increases, the higher temperature will make the bimetal pull the valve harder onto its seat but this effect is opposed by the higher pressure trying to push the valve away from its seat. If the pressure is reduced, the reverse happens and there is less pull from the bi-metal but also less push from the pressure. This arrangement approaches a balanced pressure type of operation, although the adjustment to varying pressures still falls far short of that given by a true balanced pressure trap. Further improve-

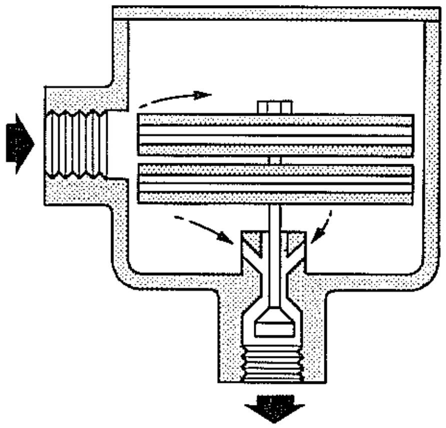


Fig. 21 Bimetallic Trap with valve on the outlet

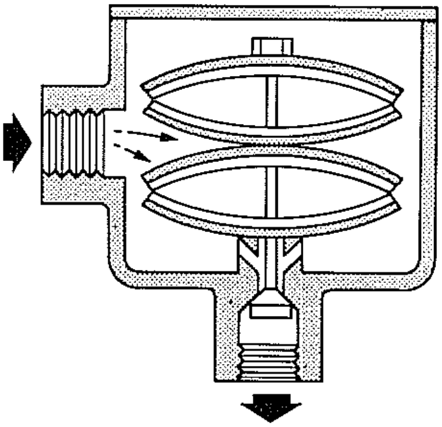


Fig. 22 Valve closed position on bimetal trap with valve on outlet.

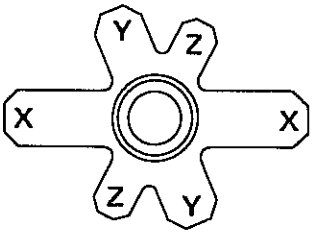


Fig. 23 Cross-shaped bimetal element.

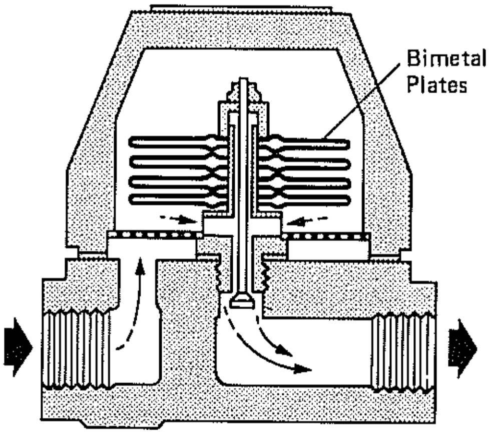


Fig. 24 Thermostatic Trap with Bimetal Plates

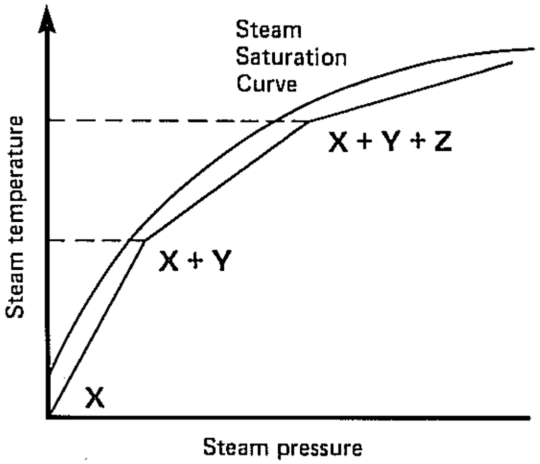


Fig. 25 Action of Bimetal arms

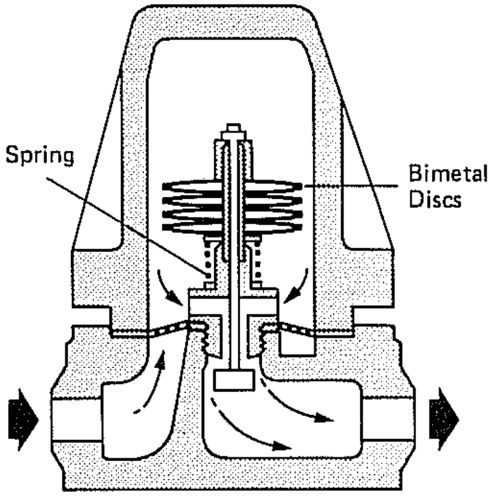


Fig. 26 Thermostatic Trap with Bimetal Discs

ments can be achieved by attention to the design of the bi-metal element itself.

In some cases, the bimetal plates are shaped so as to produce a varying force on the valves as they expand under temperature. An example of this is the element shown in plan view in Fig. 23. A number of these cross-shaped bimetal plates are arranged to work in pairs to operate the valve, as in Fig. 24. The arms are of different lengths and widths and so they come into operation in sequence to produce a force on the valve which increases as higher temperatures cause more of the arms to come into contact with each other. Fig. 25 clearly illustrates how the different pairs of arms are brought into action to close the valve as steam temperature and pressure rises. While the trap cannot follow the steam saturation curve as exactly as a balanced pressure trap, the use of bimetal crosses achieves a more than passable result.

Another arrangement is shown in Fig. 26 where a number of bimetal discs are used in combination with a spring which absorbs some of the movement as the discs deflect. Eventually, the spring cannot be compressed any more and any further movement of the bimetal discs is transmitted directly to the valve.

Advantages of Bimetal Type

Bimetallic traps are usually small in size and yet can have a large condensate discharge capacity. The valve is wide open when the trap is cold, giving a good air venting capability and maximum condensate discharge capacity under start up conditions.

With a suitable body design and free condensate discharge from the outlet, this type of trap will not freeze up when working in an exposed position. The bodies of some bimetallic traps are so designed that they will not come to any harm even if freezing does occur.

Bimetallic traps can be constructed to withstand waterhammer, corrosive condensate, high steam pressures and superheated steam.

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, although the position of the valve may need adjusting.

If the valve is on the downstream side of the seat it will act as a check valve and prevent any reverse flow through the trap.

Condensate is discharged below steam temperature which means that some of the sensible heat can be utilized if waterlogging of the steam space can be tolerated.

Maintenance of this type of trap presents few problems, as the internals can be replaced without removing the trap body from the line.

Disadvantages of the Bimetal Type

Bimetallic traps do not usually respond quickly to changes in load or pressure because the bimetal is relatively slow to react to variations in temperature.

As condensate is discharged below steam temperature, waterlogging of the steam space will occur unless the trap is fitted to the end of a fairly long cooling leg. Bimetallic traps are not generally suitable for fitting to process equipment where immediate condensate removal is vital if maximum output is to be achieved.

If the trap has to discharge against a back pressure the condensate must cool down further than normal before the valve will open. It may be necessary to adjust the trap to meet this condition.

Mechanical group

Loose Float Type

The simplest example of a ball float trap is shown in Fig. 27. When condensate enters the trap through the inlet 'A', the water level rises and the float 'B' is lifted off its stop 'C'. This allows the condensate to pass freely through the valve orifice 'D'. If the flow of condensate diminishes, the water level in the trap falls and the ball begins to cover the outlet 'D'. When all the condensate has been discharged, the ball seals off the orifice, preventing any loss of steam.

The action of the float allows a continuous discharge action to be maintained in step with the amount of condensate reaching the trap.

Advantages of the Loose Float Type

The loose float type of steam trap needs little maintenance, as there are no working parts to go wrong.

Disadvantages of the Loose Float Type

Fig. 27 shows that the outlet 'D' is lower than the inlet 'A'. This provides a water seal which prevents steam from blowing through the trap. The seal also has an adverse effect in that the trap is unable to discharge air from the system through the main orifice. For this reason, a separate hand air cock 'E' has to be fitted.

Another disadvantage with the loose float type is that it can be difficult to obtain a really good seating of the large ball on the small outlet hole.

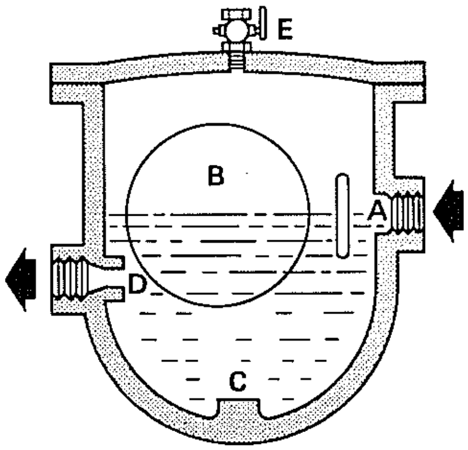


Fig. 27 Loose Float Trap

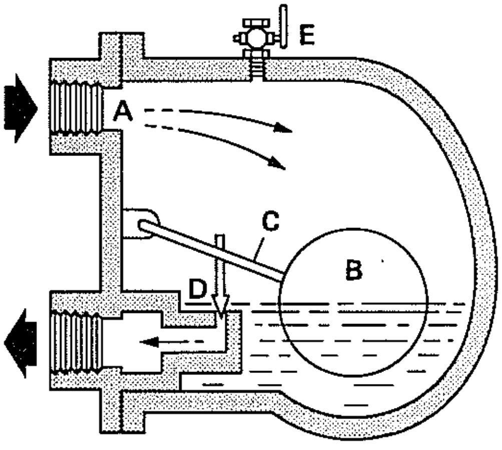


Fig. 28 Simple Float and Lever Trap

Float and Lever Type

Fig. 28 shows a simple float and lever type steam trap. Condensate enters the trap body through the inlet 'A' and the Ball 'B' is lifted as the water level rises. The float arm 'C' connects the ball to the outlet valve 'D' which is gradually opened as condensate raises the ball. The position of the valve varies according to the level of water in the trap body, giving continuous condensate discharge on any load which falls within the maximum capacity of the trap.

If the condensate load diminishes and steam reaches the trap, the float will drop to its lowest position. The valve is held firmly against its seat and no steam can be wasted.

The one major drawback with this trap as it stands is that air cannot be discharged through the main valve on start up. Unless some means is provided for releasing air from the system, condensate will be prevented from flowing into the trap, which then becomes "air-bound".

A manual cock 'E' is sometimes provided on the top of the trap but such a device has the disadvantage of requiring manual operation each time that steam is turned on.

A much better solution is shown in Fig. 29. While the float mechanism remains the same as in our previous example, the manual cock has been replaced by an automatic air venting device 'E'. This is, in fact, a thermostatic element of the type used in the thermostatic

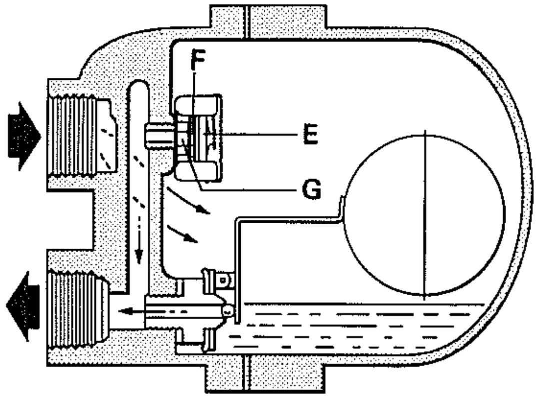


Fig. 29 Float Trap with Thermostatic Air Vent

traps already explained in this folio.

The valve 'F' is wide open when the trap is cold, so that the air is readily discharged on start up. As soon as steam reaches the trap, the element 'E' expands and pushes the valve 'F' into its seat 'G', so that no steam is able to escape. Any air which enters the trap during normal operation will collect at the top. Its cooling effect will cause the thermostatic element to cool and contract, allowing the air to be discharged.

If the condensate rate is very heavy, it is possible for the level in the trap to rise sufficiently for condensate to be discharged through the air vent seat. However, reliance on the air vent to discharge condensate really means that the trap is undersized.

Some ball float operated traps incorporate a steam lock release valve instead of the standard thermostatic air vent. This is simply a needle valve which by-passes the main valve and dissipates steam that would otherwise lock the trap and cause condensate to be held back. The problem of steam locking will be discussed in greater detail later on in the course.

Advantages of the Float and Lever Type

The float and lever trap gives continuous discharge of condensate at steam temperature. This makes it the first choice for applications where the rate of heat transfer is high for the area of heating surface available.

It is able to handle heavy or light condensate loads equally well and it is not adversely affected by wide and sudden fluctuations of pressure.

As long as an automatic air vent is fitted, the trap is able to discharge air freely.

The patterns with a steam lock release valve are the only type of trap suitable for use where steam locking can occur.

Disadvantages of the Float and Lever Type

The ball float, and bellows pattern thermostatic elements are susceptible to damage by waterhammer. The materials of this type of thermostatic element cannot tolerate corrosive condensate and they are not suitable for use on super heated steam, unless modified.

A float trap can be damaged by freezing and the body should be well lagged if it is to be placed in an outdoor location where freezing conditions exist.

One disadvantage which applies to all types of mechanical steam traps is that the size of the discharge orifice is governed by the power of the float and the steam pressure. The power of the float is constant, so as the steam pressure goes up, the size of the permissable discharge orifice goes down. In practice, mechanical traps must have different sizes of valve seats for different pressure ranges. For instance, a typical float trap range will have different valve seat sizes for pressure up to 65 psi, up to 150 psi up to 200 psi and so on.

Open Top Bucket Type

An open top bucket can be used to operate the valve instead of a ball float. This bucket will float in condensate when empty but sink by its own weight when full of condensate. Such a trap is shown in Fig. 30.

Attached to the bottom of the bucket 'A' is a spindle 'B' which carries the valve 'C'. The

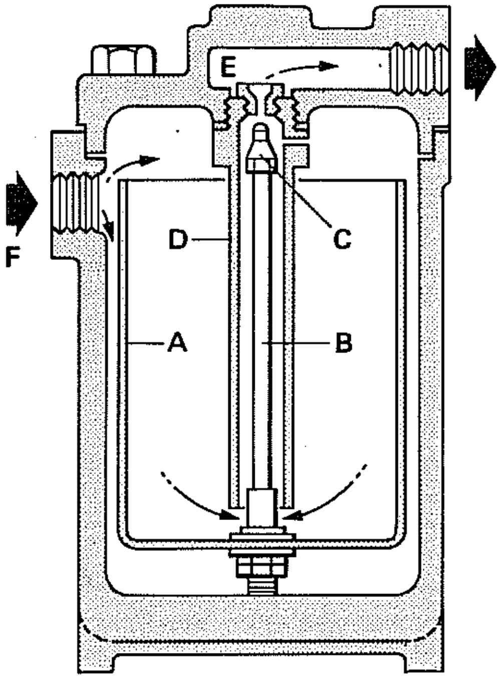


Fig. 30 Open Top Bucket Trap

spindle and valve are inside a tube 'D' which is open at the bottom. At the top end of the top end of the tube is the valve seat 'E'.

When condensate enters at 'F' it first fills the body of the trap outside the bucket. The bucket floats and the valve is pushed up on to its seat. More condensate flowing into the body spills over into the bucket. When it is full enough, the bucket is sufficiently heavy to drop back to the bottom of the trap, drawing the valve away from its seat. The steam pressure on the condensate in the trap forces water out through the central tube and the bucket becomes buoyant once again. The whole action is then repeated. It should be noted from this description that traps of this type have an intermittent blast discharge action.

Advantages of the Open Bucket Type

Open bucket traps are usually robust and can be made for use on high pressure and superheated steam. They can withstand waterhammer and corrosive condensate better than most types of mechanical traps and there is little that can go wrong with the simple mechanism.

Disadvantages of the Open Bucket Type

As the weight of the bucket determines the valve area which can be provided for any given pressure, it also determines the rate at which condensate can be discharged. This mechanical limitation means that open bucket traps tend to be rather large and heavy in relation to their discharge capacity. It is mainly for this reason that this type of trap has fallen into disfavor.

No provision is made for air venting unless either a manual cock or thermostatic air vent is fitted. It is possible to drill a small hole across the top of the discharge tube to release air but an external air vent is recommended if a large quantity of air has to be discharged.

This type of trap is susceptible to damage by freezing and the body must be well lagged if it is placed outdoors.

Inverted Bucket Type

A trap which is more commonly used than the open bucket is the inverted bucket pattern shown in Fig. 31. In this type, the operating force is provided by steam entering an inverted bucket and causing it to float in the condensate with which the trap is filled.

When steam is turned on, the bucket 'A' is at the bottom of the trap and the valve 'B' is wide open. Air is discharged through a small hole 'C' in the top of the bucket. Condensate enters the trap at 'E' and the water level rises both inside and outside the bucket. The bucket remains at the bottom of the trap and the water is able to pass away through the wide open valve 'B'. When steam reaches the trap, it enters the bucket and makes it float upwards, shutting the valve 'B' through a lever arrangement. The steam in the bucket will slowly escape via the small vent hole 'C', collecting at the top of the trap. If it is replaced by more steam, the trap remains closed. If however, further condensate takes its place, the bucket will sink, pulling the valve open. Like the open bucket trap, this type has an intermittent blast discharge action.

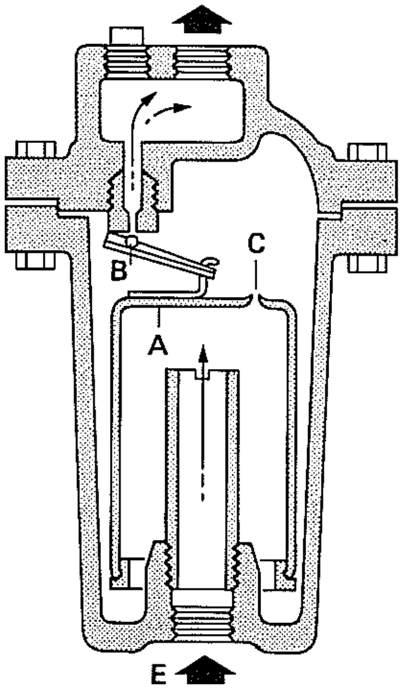


Fig. 31 Inverted Bucket Trap

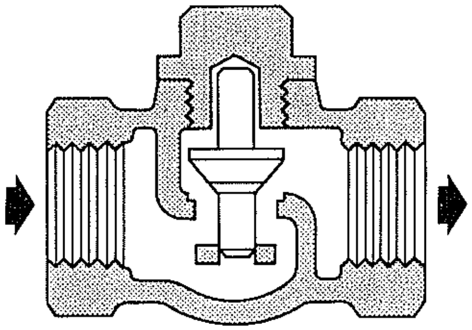


Fig. 32 Check Valve

Advantages of the Inverted Bucket Type

The inverted bucket trap can be made to withstand high pressures and can be used on superheated steam if a check valve is fitted on the inlet. It has a reasonably high degree of tolerance to waterhammer conditions and there is little to go wrong with the simple bucket and lever mechanism.

Disadvantages of the Inverted Bucket Type
The small size of the hole in the top of the bucket means that this type of trap can only discharge air very slowly. The hole cannot be enlarged, as steam would pass through too quickly during normal operation.

There should always be enough water in the trap body to act as a seal around the lip of the bucket. If the trap loses this water seal, steam can blow to waste through the outlet valve. This can happen on applications where there is an abrupt drop in steam pressure, so that some of the condensate in the trap body flashes into steam. The water in the trap is pushed back through the inlet port until the bucket, supported only by froth, sinks to the bottom of the trap. The discharge valve is then pulled open and steam blows out.

Until the rate at which condensate flows towards the trap is greater than the rate at which steam and water flow through the open valve, water cannot collect in the bottom of the trap in sufficient quantity to reform the seal.

If an inverted bucket trap is used on an application where fluctuation of the pressure can be expected, a "check valve" (also known as a "non return valve") should be fitted on the inlet line in front of the trap. This will help to prevent any loss of the water seal in the trap. A simple check valve is shown in Fig. 32. Steam and water are free to flow in the direction indicated, while reverse flow is impossible as the check valve would be forced on to its seat.

The extra temperature of superheated steam is even more likely to cause an inverted bucket trap to lose its water seal. A check valve in front of the trap should be regarded as essential under such conditions. Some manufacturers actually build a check valve into the trap itself.

The inverted bucket trap is likely to suffer damage from freezing if placed outdoors in an exposed position. As with other types of mechanical traps, suitable lagging may be sufficient to overcome this problem if conditions are not too severe.

Thermo-dynamic® group

Thermo-dynamic® Disc Type

The construction of the thermodynamic disc type of steam trap is extremely simple. Fig. 33 shows a typical model which consists of only a body "A", a top cap "B" and a free floating disc "C". This disc is the only moving part of the trap.

An annular groove is machined into the top of the body, which forms the seat face. Two seating lands "D" and "E" are left, as shown in Figs. 34 and 35. The faces of the seat and of the disc are carefully ground flat, so that the disc seats on both rings at the same time. This seals off the inlet "F" from the outlet "G" and is essential if a tight shut off is to be achieved.

On start up, air and cool condensate reach the trap, passing up the inlet orifice "F". The disc "C" is lifted until it is held against the boss "H" in the top cap. Air and condensate flow radially outwards from the center of the disc into the space between the seat rings "D" and "E" and are discharged through the outlet passage "G".

The temperature of the condensate gradually increases and as this passes through the trap inlet some of it flashes into steam. The resulting mixture of flash steam and conden-

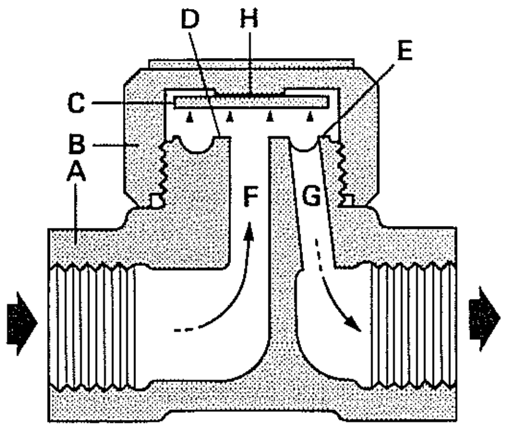


Fig. 33 Typical Thermodynamic Trap

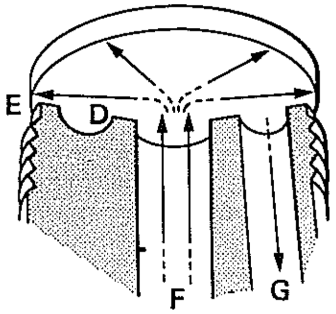


Fig. 34 Thermodynamic Trap Disc

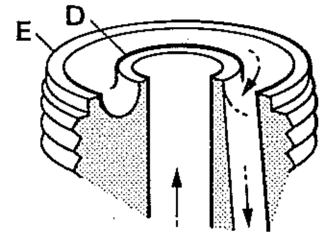


Fig. 35 Thermodynamic Trap Seat

sate flows radially outwards across the under side of the disc and because flash steam has a larger volume than the same weight of condensate, the speed of flow increases steadily as more and more flash steam is formed.

In order to understand what happens next, it is necessary to have a basic grasp of what is known as "Bernoulli's theorem". This simply states that in a moving fluid, the total pressure is the same at all points. This total pressure is the sum of the static and dynamic pressures of a fluid. The static pressure is that which would be measured by a pressure gauge, while the dynamic pressure is that which would be produced by the individual fluid particles if they were to be brought to rest by hitting an obstruction. The dynamic pressure increases as the speed of the particles increases.

If we apply this theorem to the thermodynamic disc trap, we can appreciate that the dynamic pressure of the steam and condensate flowing under the disc will increase as the speed of flow increases. Since the total pressure must remain constant, the static pressure falls as the dynamic pressure rises. This static pressure drop results in the disc being drawn down towards the seat rings.

As the disc is drawn downwards, flash steam passes between the edge of the disc and the top cap and enters the "control chamber", as shown in Fig. 36. The flash steam comes to rest and exerts a static pressure on the whole of the top surface of the disc. This builds up until it is sufficient to overcome the inlet pressure which acts only on a small section in the middle of the disc. When this happens, the disc snaps shut against the seat rings as shown in Fig. 37, preventing further flow through the trap.

The disc remains firmly against its seat until the flash steam above it condenses due to heat transfer from the control chamber to the atmosphere and to the body of the trap. This relieves the pressure acting on the top of the disc, allowing it to be raised again by the inlet pressure. If there is no condensate waiting to be discharged when the trap opens, a small amount of high pressure steam will enter the control chamber and cause the disc to seat very quickly.

A current pattern of a thermodynamic disc steam trap is shown in Fig. 38. This embodies a number of design improvements over earlier versions. The addition of an inbuilt strainer helps to prevent the possibility of dirt particles either blocking the small outlet holes of the trap or preventing the disc from giving a tight shut off.

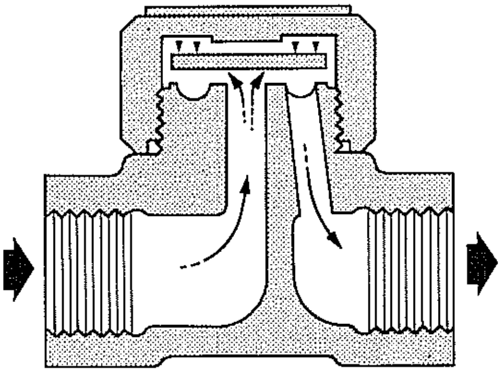


Fig. 36 Closing Action of Thermodynamic Trap

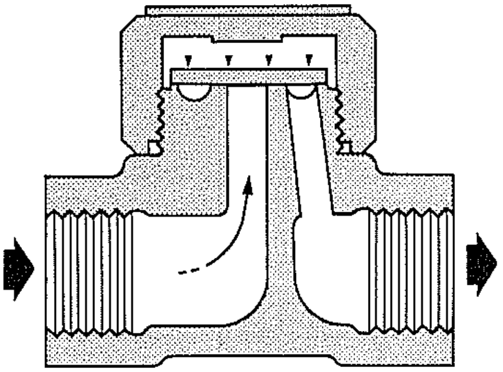


Fig. 37 Thermodynamic Trap in Closed Position

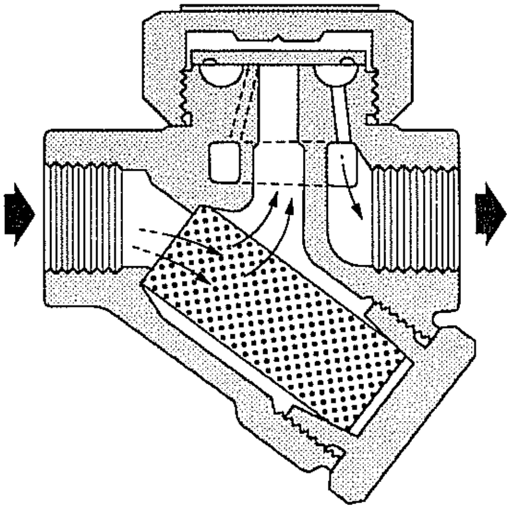


Fig. 38 Thermodynamic Steam Trap

The trap has three outlet passages leading from the annulus between the inner and outer seat rings to the outlet connection. When the trap discharges, there is a symmetrical flow of condensate outwards from the center of the disc. This ensures that the disc remains parallel to its seat during the discharge phase, thus avoiding the problems of uneven disc wear caused by tilting in models with only one or two outlet passages.

Closer examination of a thermodynamic trap disc reveals that one side is plain, while the other has one or more concentric grooves. The trap is normally used with the grooved side facing the seat rings. The grooves break up the smooth flow pattern across the disc, delaying the lowering of the static pressure until the condensate passing through the trap is almost at steam temperature. This helps to ensure that the steam space before the trap is effectively kept clear of condensate.

If the disc is turned over so that the plain side faces the seat rings, the flow pattern is smooth and the trap will shut off when the condensate is still some way below steam temperature. With this arrangement, some condensate will still be left in the process when the trap shuts. The decision as to which way to fit the disc (grooves up or down) therefore depends upon the requirements of the installation in question.

Advantages of the Thermodynamic Disc Type

Thermodynamic disc traps can operate within their whole working range without any adjustment or change of valve size.

They are compact, simple, lightweight and have a large condensate handling capacity for their size.

This type of trap can be used on high pressure and superheated steam and is not damaged by waterhammer or vibration. The all stainless steel construction offers a high degree of resistance to corrosive condensate.

They are not damaged by being frozen and are unlikely to freeze if installed with the disc in a vertical plane and discharging freely to atmosphere. However, operation in this position may result in increased wear of the disc edge.

As the disc is the only moving part, maintenance can easily be carried out without removing the trap from the line.

The disc prevents any return flow of condensate through the trap, cutting out the need for a separate check valve. When failed open, the disc moves rapidly up and down giving off a "clicking" sound. This sound is an audible warning that tells us trap maintenance is required.

Disadvantages of the Thermodynamic Disc Type

Thermodynamic traps will not work positively on very low inlet pressures or high back pressures. In either case, the speed of flow across the underside of the disc is reduced too much for the necessary low pressure to occur. The model shown in Fig. 36 requires a minimum inlet pressure of 3.5 psi gauge and can withstand a maximum back pressure of 80% of the inlet pressure.

They can discharge a lot of air on start up if the inlet pressure builds up slowly. However, rapid pressure build up will cause high speed air to shut the trap in the same way as steam and it will "air bind". In this case a separate thermostatic air vent may have to be fitted in parallel with the trap.

If the trap is exposed to very low ambient temperatures, the flash steam in the control chamber will obviously condense more rapidly than normal. This will cause the disc to open and shut much too frequently, causing excessive wear and reduced trap life. Fortunately, the simple expedient of fitting an insulating cover or "insulcap" over the top cap, is sufficient to keep the frequency of operation to an acceptable level.

The operation of the disc tends to be rather noisy and this factor may prohibit the use of a thermodynamic trap in some locations.

Miscellaneous Thermodynamic Types

Impulse Type

A typical impulse trap is shown in Fig. 39. The main valve "A" is part of a hollow cylinder which carries a thin piston disc "B". The cylinder is free to move up and down within a tapered guide "C". When the plant is shut down, the valve "A" is resting on its seat "D".

When steam is turned on, air and then cold condensate reach the trap and the pressure under the piston "B" lifts the main valve and the trap discharges. Some of the condensate passes up the gap between the piston and its guide "D" into the chamber above the valve and then through the orifice

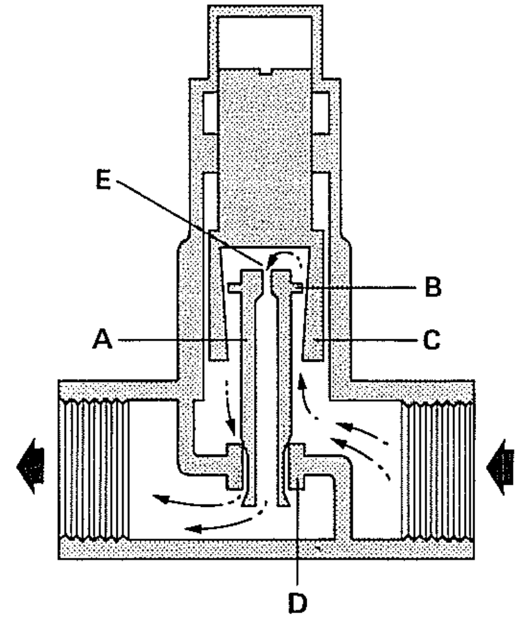


Fig. 39 Impulse Trap

"E" to the outlet. The water pressure drops as it flows through the gap so that the pressure above the piston is less than that below it and the valve is held open.

As the condensate nears steam temperature, some of it flashes into steam as it passes through the gap between "B" and "C". This flash steam collects in the chamber above the valve and trys to escape through the orifice "E". As the flash steam has a considerably greater volume than the same mass of condensate, it takes longer to pass through "E" and starts to build up a higher pressure in the chamber, eventually forcing the piston down the guide cylinder. The rate of flow is reduced because of the taper on the guide cylinder and the trap settles down to discharge condensate at the required rate.

If steam reaches the trap, it builds up an even greater pressure above the piston and the main valve is closed. However, the trap cannot give a dead shut off because there is no provision for sealing off the orifice "E".

Advantages of the Impulse Type

Impulse traps have a substantial condensate handling capacity for their relatively small size.

They will work over a wide range of steam pressures without any change in valve size and can be used on high pressure and superheated steam.

Impulse traps have a good air venting capability and cannot "air bind".

Disadvantages of the Impulse Type

Impulse traps cannot give a dead shut off and will blow steam on very light loads.

They are easily affected by any dirt which enters the trap body due to the extremely small clearance between the piston and cylinder.

The traps can pulsate on light load causing noise, waterhammer and even mechanical damage to the valve itself.

They will not work against a back pressure which exceeds 40% of the inlet pressure.

Labyrinth Type

A simple form of labyrinth trap is shown in Fig. 40. Condensate enters at "A" and encounters a number of adjustable baffles 'B' which increase in diameter towards the outlet end of the trap. As it flows past each of these restrictions, the condensate gradually loses pressure. This results in some of the condensate flashing into steam in each of the chambers formed by the baffles. The flow of condensate is thus slowed down, preventing live steam from escaping.

The baffle plates can be pushed in or out by adjusting the spindle "C". If the clearance between the baffles and the trap body is wide, both hot condensate and steam can pass. If the clearance is very small, only comparatively cool condensate will be discharged.

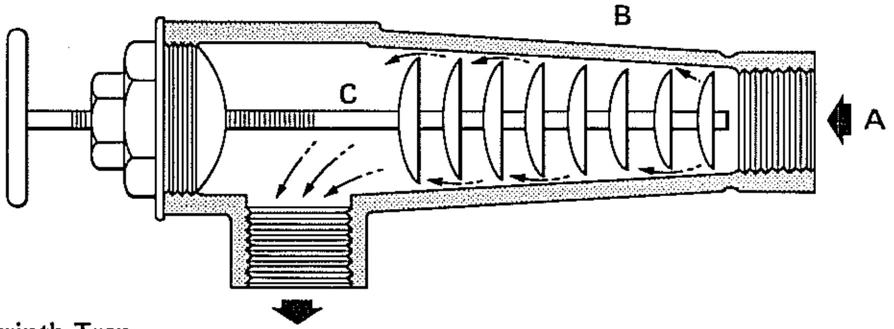


Fig. 40 Labyrinth Trap

Advantages of the Labyrinth Type
This type of trap is comparatively small in size for its condensate handling capacity and there can be no mechanical failure since there are no working parts.

Disadvantages of the Labyrinth Type
The labyrinth trap needs to be adjusted manually whenever there is a significant variation in either steam pressure or condensate load. If the setting is not exactly right for the prevailing conditions, steam waste or waterlogging of the steam space will occur.

Orifice Plate
The orifice plate is simply a development of the drilled plug cock discussed earlier in this folio. It consists of a fixed hole which is sized to pass the condensate load of the piece of equipment being drained.

Advantages of the Orifice Plate
This device requires little or no maintenance since there are no working parts. They are extremely small for their condensate handling capacity and radiation losses are virtually eliminated.

Disadvantages of the Orifice Plate
The main disadvantages of the orifice plate lie in the fixed, small size of the hole. Air can only be discharged very slowly from the system on start up and the hole can easily become blocked by dirt particles.

If no condensate reaches the orifice plate, steam will be wasted through the constantly open hole. The orifice will gradually be enlarged by erosion, increasing the potential steam loss accordingly.

As peak condensate loads are often three to four times higher than the normal running load, it is likely that the fixed hole of the orifice plate will cause waterlogging of the steam space under such conditions.

Questions

4. Of the types described in the course, which steam trap is LEAST likely to be affected by severe vibration? And why?

5. A piece of steam heated equipment has a high rate of heat transfer for the amount of heat transfer surface area available (such as a heater battery). Which type of steam trap is the best to use?

6. Another piece of steam heated apparatus has sudden changes of pressure and fluctuating condensate loads. Which is likely to be the best type of trap to use, and which type of trap would be an unwise choice?

7. On some industrial equipment, the process cycle involves very violent changes in the steam demand. On peak demand there can be a temporary drop in supply pressure but it is not thought worthwhile enlarging the supply main since the pressure recovers quickly. The quality of the steam is good, and the main is adequately drained at several points between the boiler and point of usage, through inverted bucket traps.

   Trouble is experienced with a trap nearest to the steam using equipment resulting in a continuous steam blow after the equipment has been in operation for a little time each day. What is a likely cause of this trouble and how can it be overcome?

8. Is a bimetallic thermostatic steam trap suitable for draining a unit heater? Put down reasons for thinking "Yes" or "No".

Notes

Correct steam trapping

The drain point

The benefits of selecting the most appropriate type of steam trap for a particular application will be wasted if condensate cannot easily find its way to the trap. For this reason, careful consideration should always be given to the size and situation of the drain point itself.

Let us consider what will happen to condensate in a steam main at shut down, when all flow ceases. Obviously it will run in the direction of any fall in the pipework and collect at the lower points in the system. Steam traps should, clearly, be fitted to these low points.

However the amount of condensate formed in a large steam main under start up conditions is sufficient to require the provision of drain points at all natural low points and at intervals of 150 ft. for automatic startup, to no more than 300 ft. for supervised startup.

In normal operation, steam may flow along the main at speeds of up to 90 miles per hour, dragging condensate along with it. Fig. 41 shows a ½" drain pipe connected from the bottom of a main to a steam trap. Although the ½" pipe has sufficient capacity, it is unlikely to catch much of the condensate moving along the main at high speed. Such an arrangement will be ineffective.

One solution to this problem is shown in Fig. 42. A full size 'T' piece is fitted in the main which acts as a natural collecting pocket. All the condensate will drop into the pocket and make its way through the ½" pipe to the trap. This collecting pocket is just as important to the trapping installation as the steam trap itself.

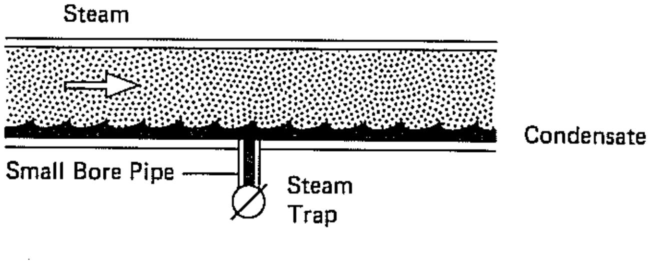


Fig. 41 Incorrect Drain Point

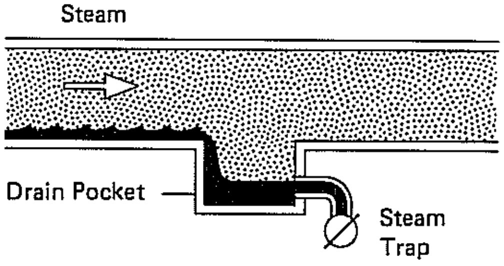


Fig. 42 Correct Drain Point

Steam separators

Modern packaged steam boilers have a high duty for their size and lack any reserve capacity to cope with overload conditions. Incorrect chemical feedwater treatment and periods of peak load can cause serious priming and carryover of boiler water into the steam mains. In Part 1, we found that "wet steam" contains less latent heat than "dry saturated steam" at the same pressure and will reduce the efficiency of process or heating equipment accordingly. For this reason, steps must be taken to maximize the dryness fraction of the steam generated.

Although the drain point shown in Fig. 42 will deal with any condensate which forms on the pipe wall, it cannot remove moisture droplets entrained in the steam itself. The most simple solution to this problem is to fit a steam separator, a typical model being shown in Fig. 43. A series of baffles force the steam to change direction several times as it flows through the body of the separator. Dry steam is able to pass through without any difficulty but the heavier water droplets impinge on the baffles and run down to the drain point below. A suitable steam trap then removes the separated water, along with any condensate running along the wall of the main.

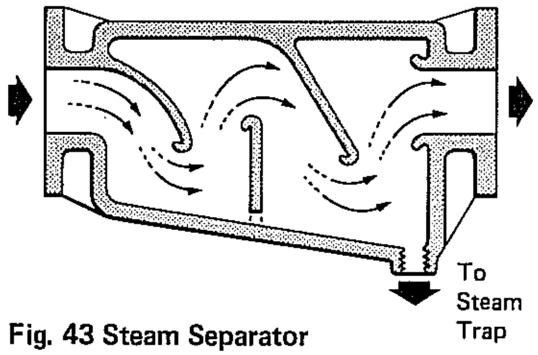


Fig. 43 Steam Separator

The most common source of wet steam

is boiler carryover and for this reason, a separator should be fitted immediately after the boiler crown valve. It is also advisable to install separators before any pieces of steam using equipment which demand a good quality supply of dry steam.

Pipe scale and dirt

When new piping is installed, it is common for fragments of casting sand, packing, jointing, chips, solder, and even nuts and bolts to be left inside. In the case of older steam pipework, there will be rust and in hard water districts, a carbonate deposit. From time to time, pieces will break loose and pass along the pipe with the steam. This would not matter if the pieces had a free passage to the condensate drain. In practice, however, the dirt will come to rest in a steam trap, jamming the valve open and causing the trap to blow steam.

The trap itself may suffer permanent damage through wire-drawing — the cutting action of high velocity steam and water passing through the partly opened valve. Once wire-drawing has occured, the valve will never give a tight shut off, even if the dirt is removed. It used to be common practice to fit a dirt pocket in front of steam traps, as shown in Fig. 44. Although a dirt pocket will collect some dirt, the speed of the condensate rushing into the trap when it is discharging will carry pieces of dirt across the top of the pocket and into the trap. If the pocket is not emptied regularly, it will soon fill up and then all the dirt in the system will go straight to the trap. Such an arrangement clearly leaves a lot to be desired.

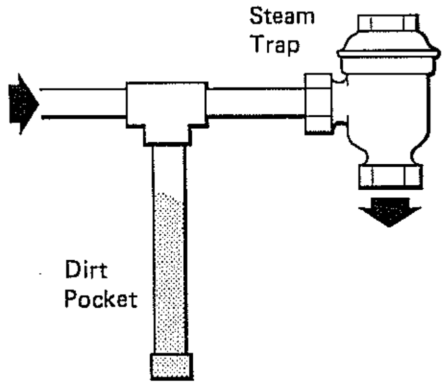


Fig. 44 Dirt Pocket

Current practice is to fit a simple pipeline strainer prior to every steam trap, meter, reducing valve and regulating valve. Fig. 45 shows a typical strainer in section. Steam flows from the inlet "A", through the perforated screen "B" to the outlet "C". While steam and water will pass readily through the screen, the progress of any kind of dirt will be arrested. The cap "D", can be removed, allowing the screen to be withdrawn and cleaned at regular intervals.

Some traps contained an integral 'secondary' strainer such as shown in Fig. 46. This inexpensive addition to the trap provides extra protection from contaminants.

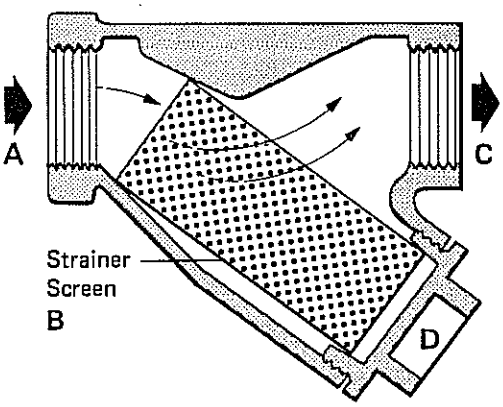


Fig. 45 Typical Strainer

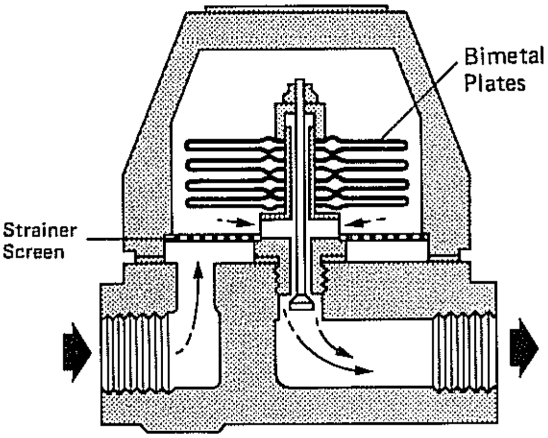


Fig. 46 Trap Strainer Unit

Air in steam systems

Effect of Air on Steam Temperature

In a mixture of gases, each of them exerts a partial pressure. The sum of the partial pressures of these separate gases makes up the total pressure of the mixture. The amount of partial pressure exerted by each gas separately depends upon the proportion of it which is present in the mixture. This phenomenon was first explained by Dalton.

As an example, let us imagine a mixture of ⅔ steam and ⅓ air, with a total pressure of 45 psi absolute. The steam exerts a partial pressure of ⅔ of 45 psi absolute (30 psi absolute) and the air exerts a pressure of ⅓ of 45 psi absolute (15 psi absolute).

The heat available for transfer to the mixture must all come from the steam because the air does not contribute any at all. The problem is that instead of the steam having the apparent pressure of 45 psi absolute, it only has a pressure of 30 psi absolute. Reference to the steam tables shows that the temperature of saturated steam at 45 psi absolute is 274.5°F, but at 30 psi absolute the temperature is only 250.3°F. Although the pressure reading would correspond to a temperature of 274.5°F, the temperature of the steam/air mixture is in fact 24.2°F less.

This means that if the gauge on a piece of steam heated equipment shows just under 30 psi (45 psi absolute) and the "steam" is really a mixture of ⅔ steam and ⅓ air, the temperature will be 24.2°F less than might be expected from the pressure reading.

Effects of Air on Heat Transfer

When a piece of steam heated equipment is started up, the steam space is full of air. As steam enters the unit, it will drive the air before it towards either the drain point or the part of the steam space furthest from the inlet. Some of it will also be carried on to the heat transfer surface where it will be left behind as a film when the steam condenses. This film of air is a significant barrier to efficient heat transfer from the steam to the heating surfaces of the unit. As we mentioned earlier, a layer of air only 0.04" thick can offer the same resistance to the flow of heat as a layer of water 1" thick.

Not all of the air which is drawn towards the drain points will be immediately discharged by the steam traps. Even though the traps may be of the type that can readily handle the air, the shape and size of the equipment may prevent a good deal of the air reaching the traps. Any air which remains will collect in one or more pockets in the unit and also form the insulating film to which we have just referred.

In some cases, air can temporarily isolate a steam trap from condensate which needs to be discharged, simply because the trap is unable to release air quickly. A large volume of air may need to be handled in such a short time that it can form a compressed column in the condensate pipe leading to the trap. Temporary air binding then occurs and the trap cannot function.

Do Air and Steam Separate or Mix?

In addition to the air already present in the unit when steam is turned on, air continues to enter the apparatus with the steam and mixes with it. When the steam condenses, the air remains and is deposited on the condensing surfaces. As steam flows naturally towards the point furthest from the steam inlet, it is reasonable to expect a relatively large collection of air at that extremity.

However, when steam is flowing along a pipe or through the steam space of a heater of any kind, any turbulence will lead to mixing of the steam and any air which is also present. So, steam and air in motion tend to mix, but under the more static conditions present in larger closed vessels, condensation of the steam will leave behind air which may tend to fall towards the bottom of the space. Air is heavier than steam under the same conditions of temperature and pressure, and so a mixture of air and steam is heavier than pure steam.

The question behind the question is — "where should the air vents be fitted?", of course. From what has just been said, the ends of the steam lines should be vented, so that air is not pushed from the supply lines into the unit being served. On the equipment itself, the "remote point" should be sought. This is the point furthest from the steam entry, along the path the steam follows as it fills the vessel. Where there is a choice of options, air venting low down on the steam space may be advantageous, especially where the steam trap does not have a large venting capacity.

Air Removal

Figs. 47 and 48 show how altering the position of the steam inlet on an item of equipment influences its air venting requirements. The steam spaces in both figures are identical except that in Fig. 47 steam comes in at the top and in Fig. 48 at the bottom. In both cases, condensate falls by gravity to the

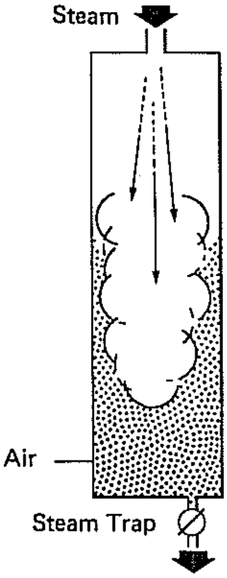


Fig. 47 Steam/Air Flow

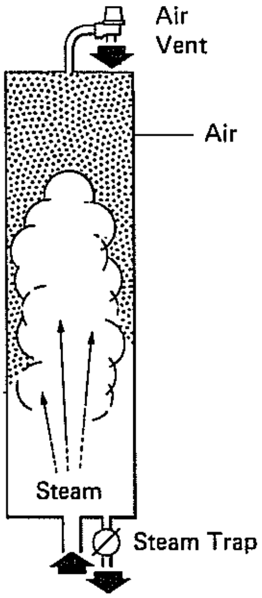


Fig. 48 Steam/Air Flow needing separate Air Vent

bottom where it is removed via a suitable drain point and steam trap.

Let us consider Fig. 47 first. Steam coming in at the top will push the air in front of it towards the bottom of the steam space where it will be discharged by the trap, assuming that it has good air venting qualities. In this case, no further provision need be made for air venting.

If we now look at Fig. 48 the situation is quite different. Again the incoming steam will push the air in front of it but this time it will finish up at the top of the steam space. Unless we make some provision for discharging it, the air will collect in a pocket and cause a cool spot on the heating surface. The turbulence of the steam will result in some of the air mixing with it and being carried to other parts of the heating surface where it will be deposited as a resistant film, considerably reducing output. It is essential that some form of air vent is fitted to the top of the steam space to discharge this air quickly before it has time to mix with the steam to an appreciable extent.

The use of manual cocks for this purpose embodies all the disadvantages of manually operated condensate removal valves and it is far better to use an automatic air vent. This may be of the balanced pressure type but liquid expansion and bimetal air vents are also used, where there is superheat or

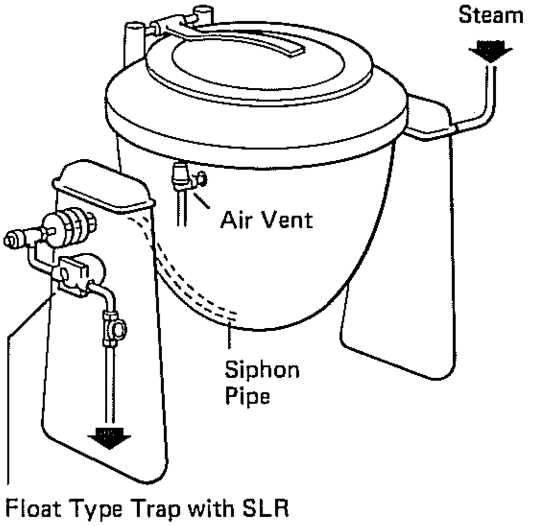


Fig. 49 Air Venting Tilting Pan

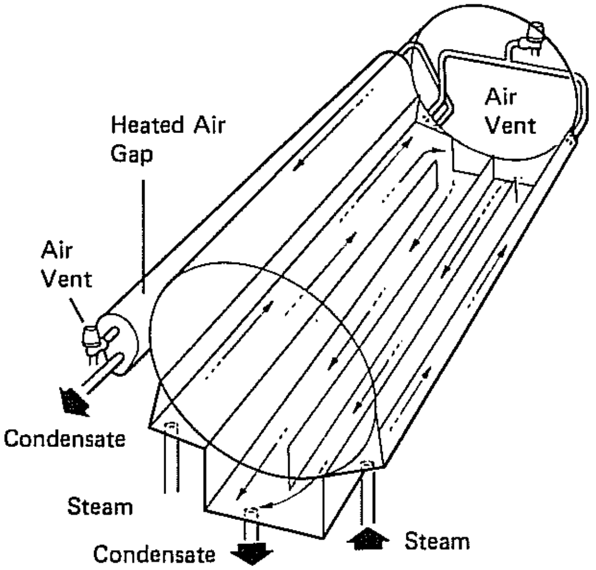


Fig. 50 Air Venting Laundry Ironer

waterhammer.

The valve of a thermostatic air vent will be wide open when the equipment is started up from cold and a large quantity of air must be discharged quickly. It will shut off before steam temperature is reached but if air collects during the normal running of the apparatus it will open periodically in response to the drop in temperature.

Practical examples of air venting are shown by the tilting pan in Fig. 49 and by Fig. 50, which is a sketch of the bed of a laundry ironer. Both pieces of equipment have steam spaces of such a shape and size that the dynamic effect of the steam flowing in through the inlet determines where the air will collect and therefore where the air vent must be fitted.

Steam trap selection

It can be claimed that the majority of steam trap types will "work" on any application (provided that the operating conditions fall within the pressure range and condensate discharge capacity of the trap). However, we do not just want steam traps which "work" moderately well. We must aim to achieve maximum output and efficiency from all steam using equipment. This means selecting the best trap to suit each particular job.

The following list contains a number of important questions which should be considered when choosing a steam trap:—

A. Must condensate be discharged immediately as it forms?

B. Is the condensate return line higher than the steam heated unit?

C. Are there waterhammer conditions in the steam supply line?

D. Is there vibration or excessive movement in the equipment?

E. Does the condensate contain corrosive substances?

F. Will the trap be in an exposed position.

G. Is the steam supply superheated?

H. Is air likely to be present in any quantity?

I. Is steam locking a possibility?

J. Is the installation made up of several steam heated units?

We will now run through this list in more detail.

A. Waterlogging

With most steam heated equipment it is desirable, and very frequently essential, to discharge condensate as soon as it forms in the steam space. Although the sensible heat in the condensate is usable heat, a much greater rate of heat transfer will be obtained if only steam is in contact with the heat transfer surface. The reasons for this were made clear in our example of the coil heated vessel in Part 1.

Steam traps of the mechanical type should always be chosen for applications which require rapid condensate removal. Thermostatic type traps cannot release condensate until it has cooled a set number of degrees below steam temperature, resulting in waterlogging of the steam space. There are however, a number of occasions when such waterlogging may be perfectly acceptable and even desirable.

As an example, let us consider the difference in the trapping requirements of a steam radiator and a unit heater. While the steam space of the radiator is great compared with its heating surface, the steam capacity of the unit heater is small compared with its heat output. The radiator can make good use of the sensible heat in condensate before it is discharged but the unit heater cannot. For this reason, the radiator should be fitted with a thermostatic trap that will hold back condensate until its temperature has dropped a predetermined amount below that of the steam. On the other hand, the unit heater must be fitted with a trap that will discharge condensate immediately as it forms. The slightest waterlogging in this case would reduce heat output and cause the heater to blow cool air. Condensate held back in the unit heater will also promote corrosion and unnecessarily reduce the life of the heater tubes.

The extent to which waterlogging of a steam space can be tolerated is clearly a significant factor in steam trap selection. The wrong choice of trap is at the root of many instances of poor plant performance.

B. Lifting Condensate

The rate at which a steam trap can discharge condensate depends on the size of the valve orifice and the "differential pressure" – the difference in pressure between the inlet and outlet of the trap.

If a steam trap discharges to atmosphere, the differential pressure across the trap will be the same as the upstream steam pressure. The same will be true if the trap discharges into a return line at a lower level which allows the condensate to gravitate back to the boiler feed tank (unless an undersized return system itself creates some back pressure). Unfortunately, such an arrangement is often ruled out because either the boiler feed tank is higher than the traps or the return main has to run at high level to clear obstructions. In these cases, the condensate must be lifted either directly by steam pressure in the apparatus or by a pump. In this section we are particularly concerned with the problems which may arise from lifting condensate by the steam pressure at the trap inlet.

For every 1 psi of steam pressure at the trap, condensate can be lifted to a height of approximately 2.3 ft. In order to lift the condensate, the trap must be of the type in which the body is subjected to full steam pressure. All Spirax Sarco traps and most others in current use are of this type.

There are disadvantages to lifting condensate in this way. In the first place, the necessary steam pressure may not always be available at the trap inlet. If, for example, the normal operating pressure is 25 psi it is theoretically possible to lift the condensate 57.5 ft. However, on start up from cold, the steam pressure may for a time drop to, or even below, zero. Until this pressure builds up, condensate cannot be removed from the apparatus and will collect in the steam space. This will result in a greatly extended heat up period. The condensate will also prevent any air from escaping through the steam trap which makes the problem even worse.

If the equipment is temperature controlled, the very action of the control may reduce the steam pressure below the point at which it can successfully lift condensate to an overhead return line. Once again the steam space will waterlog until the control valve opens, resulting in poor temperature control and the possibility of waterhammer as the steam rushes into the waterlogged steam space. Additionally if the steam space is a coil, considerable erosion and corrosion may take place.

It must be remembered that certain types of steam trap are limited as to the amount of "back pressure" against which they will operate satisfactorily. This is particularly true of the thermodynamic type of steam trap, while bimetallic traps may need resetting if they have to discharge against the back pressure imposed by lifting condensate.

The trap can be fitted either at the bottom or the top of the rising pipe, depending on the needs of the particular installation.

Trap at the Bottom of the Lift

It is always preferable to fit a steam trap below the actual drain point of the unit being drained. Fig. 51 shows the best arrangement for lifting condensate direct from the trap.

The trap is at the bottom of the lift and close to the unit being drained. It is preceded by a strainer and followed by a check valve. The check valve is fitted to prevent condensate running back down the rising leg into the steam space during shut down. It is always advisable to connect the rising pipe to the top of the condensate main.

Trap at the Top of the Lift

There are occasions when it is not possible to fit the trap at the bottom of the lift due to the layout of the system. Fig. 52 shows a vat of liquid, such as a plating solution, heated by a steam coil. This drops down one side of the vat near the steam inlet valve, runs flat across the bottom and then up and over the top before reaching the trap. The end of the coil cannot be taken through the side of the vat because this would involve adding another connection which might leak corrosive liquid. Steam condenses when it is admitted to the coil and condensate collects in the bottom. At the same time, steam can pass over the top of this condensate and up the rising pipe to the trap, which must then shut. The trap cannot open until all the steam in the rising pipe has condensed. However, steam will continue to enter the riser until sufficient condensate has collected in the bottom of the coil to prevent this. When the trap does eventually open, the condensate level drops and again allows steam to reach the trap. The whole process is then repeated with the result that the steam coil is never clear of condensate and its heating efficiency is always low.

This situation can be improved greatly by the arrangement shown in Fig. 53. Instead of lying flat, the coil slopes gradually in the direction of steam flow and a loop is formed before the coil rises up to the top of the vat. A small bore pipe is inserted into the larger bore coil, with a steam tight joint between the two, and the end is pushed right down into the bottom of the loop. The trap is connected to the other end of the small bore pipe.

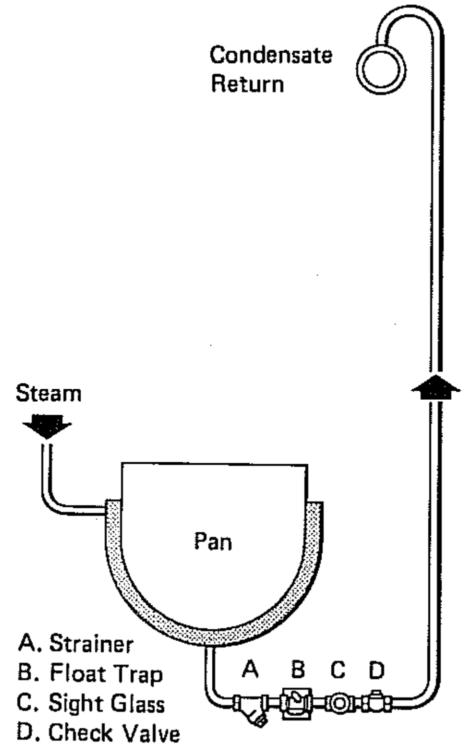


Fig. 51 Trap at bottom of lift

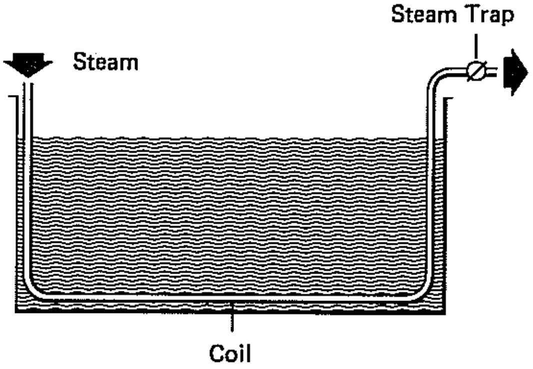


Fig. 52 Trap at top of lift — incorrect

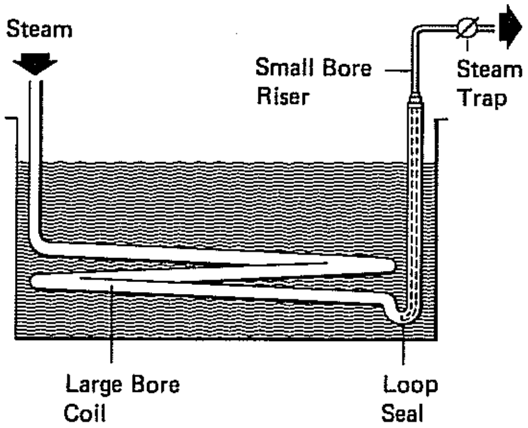


Fig. 53 Trap at top lift — correct

When steam is turned on, the first condensate to be formed flows down into the loop, sealing off the end of the small bore pipe and preventing steam from reaching the trap. The small diameter of the pipe stops steam from bubbling up through the condensate which it could do if the pipe was larger.

Most types of traps can be fitted at the top of the rising pipe, provided that the installation comprises a loop seal as described. However, if an inverted bucket trap is used, a check valve should be fitted at the inlet to prevent the water seal in the trap from being lost down the rising pipe.

C. Waterhammer

As soon as steam leaves the boiler, condensation takes place in the pipework due to heat losses. This is particularly heavy during start up when the sytem is cold. Fig. 54 shows how droplets of condensate can build up along a length of steam pipework, eventually forming a solid slug carried along at high

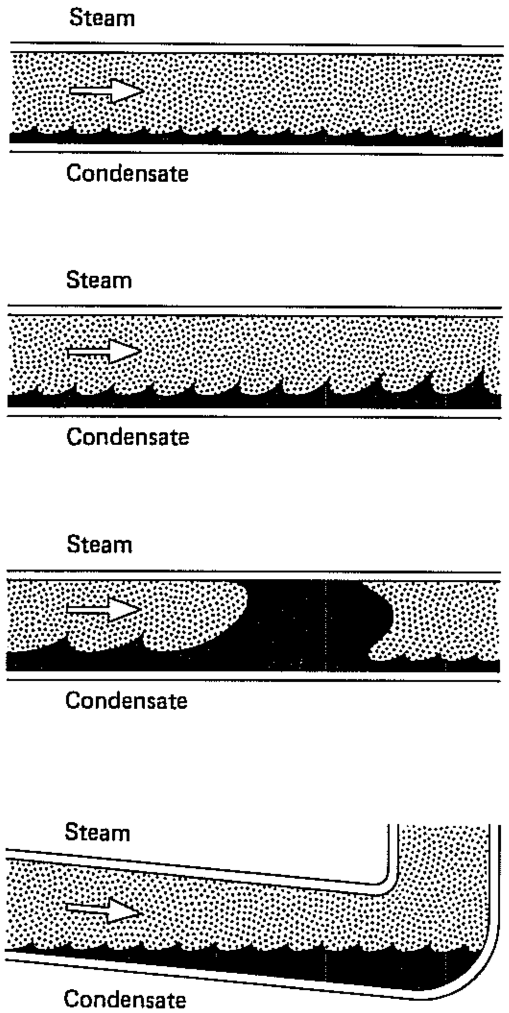


Fig. 54 Steam/Water in pipe

velocity.

When this slug encounters an obstacle such as a change in the direction of the pipe, it will be brought to an abrupt halt. The kinetic energy of the high velocity condensate is suddenly converted into pressure energy which has to be absorbed by the pipework. If the velocity is very high or the weight of condensate great, the amount of energy given up may be sufficient to rupture the fittings. Even if the velocity and weight are small, the noise created in the system by the impact can be a severe nuisance.

The incidence of waterhammer will be encouraged if pockets of condensate are allowed to build up in low points of the steam system. Common sources of trouble are sags in the pipework and the incorrect use of concentric reducers, as shown in Fig. 55. The correctly installed eccentric reducer in Fig. 56, will not allow condensate to collect. Even a strainer fitted as in Fig. 57 is a potential source of waterhammer. It is far better to fit strainers on their sides in steam lines and so prevent the formation of a pocket of condensate which can be picked up by fast moving steam.

In order to minimize the possibility of waterhammer, steam lines should be arranged with a gradual fall in the direction of flow and drain points installed at regular intervals and at all low points. Check valves should be fitted after any traps which would otherwise allow condensate to run back into the steam line or equipment during shut down. When steam is first turned on, the isolation valves should be opened slowly so that any condensate lying in the system will be able to flow gently towards, and through the drain traps before it is picked up by high velocity steam.

Waterhammer can occur in submerged steam heating coils commonly found in tanks and vats. Although the coils do not have the long uninterrupted lengths of steam mains or space heating pipes, incoming steam can be condensed very rapidly. This results in a comparatively large weight of water being carried forward by steam which has a fairly high velocity due to the heavy condensation rate. It is important that the coil falls continuously along its length and is fitted with a loop seal and small bore riser, if condensate is lifted to the trap.

If condensate has to be lifted after the steam trap, difficulties arise when there is insufficient pressure available at the trap inlet. The equipment will then waterlog and waterhammer may occur when the steam pressure builds up again. This is particularly the case with equipment fitted with automatic tem-

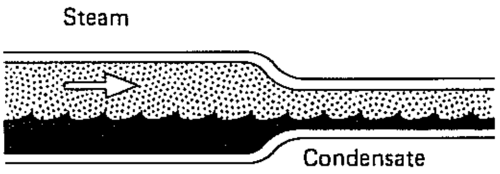


Fig. 55 Incorrect Use of Concentric Reducer

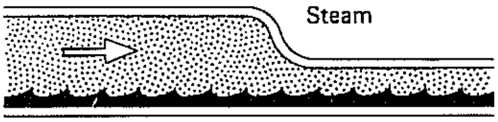


Fig. 56 Correct Use of Eccentric Reducer

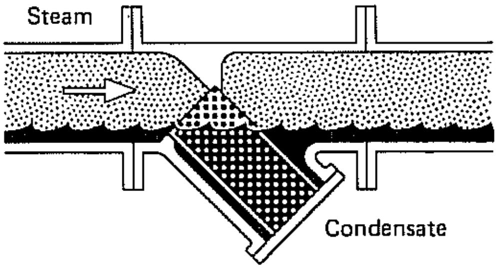


Fig. 57 Strainer forming a low point

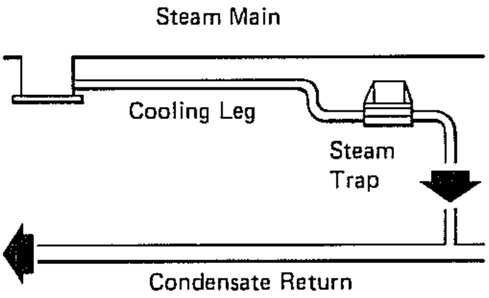


Fig. 58 Discharging into a flooded return

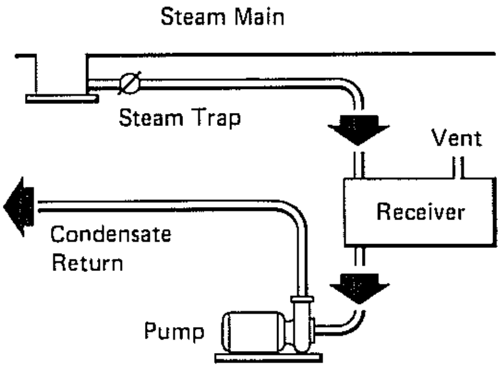


Fig. 59 Trap discharge into pump receiver

perature controls. The best arrangement in such cases is to drain the condensate by gravity to a vented receiver and use a pump to lift to a higher level.

It is advisable to fit fairly robust steam traps such as the thermodynamic or bucket types wherever there is a risk of waterhammer.

Waterhammer can also occur in the condensate return system. This is particularly evident when steam traps discharge condensate at or near saturation temperature into a condensate return main that is completely flooded. The flash steam formed as the condensate passes through the orifice of the trap has to force its way into the flooded main and violent waterhammer can occur. A compromise solution is to use a steam trap which will hold back condensate until it has cooled well below steam temperature, thereby minimizing the flash steam released (Fig. 58). An adequate drain pocket and cooling leg are essential for this arrangement, otherwise the equipment or steam main will waterlog. The practice of discharging condensate into a flooded return line should really be avoided wherever possible. Fig. 59 illustrates the only sure way of avoiding trouble.

D. Vibration

Most heating and process equipment is not subjected to excessive vibration or movement and this factor rarely influences which type of steam trap should be used. However, this is not the case with a number of applications such as reciprocating steam engines and pumps, steam hammers and other steam equipment found on board shipping vessels.

Undoubtedly, the best trap to use under these conditions is the thermodynamic disc type.The only moving part is the stainless steel disc which is quite unaffected by even the severest vibration. If the movement is not too excessive, liquid expansion thermostatic traps can also be used. This type requires a cooling leg of unlagged pipe between itself and the drain point. This allows the condensate to collect outside the steam space and cool down before it is discharged through the trap.

On board ship, there are other complicating conditions. Vibration is nearly always accompanied by waterhammer because of the impossibility of arranging an ideal layout in the cramped space available. In addition, the pitching and rolling of a ship may also affect the operation of a float or bucket. Again the thermodynamic disc trap is best able to cope with such severe conditions and it is for this reason that it is so widely used in the marine world.

E. Corrosive Condensate

Water is seldom pure enough to be used for boiler feed water without some form of treatment. It is likely to contain both dissolved solids (which can precipitate as scale on the heat transfer surface in the boiler) and gases such as oxygen and carbon dioxide. These gases can be carried by the steam to the heating surfaces where they will remain when the steam condenses. As the concentration of the gases increases, they will start to dissolve in the condensate, making it corrosive. If the boiler should prime, both boiler water and solid impurities will be carried over into the steam using equipment and subsequently in the condensate.

The production of satisfactory conditions in the boiler itself is not the only concern of proper feed water treatment. It should also control the condition of the condensate so that the pipes and fittings which make up the condensate return system are not attacked.

Correct feed water treatment is essential for modern packaged boilers which are very highly rated for their size. Severe priming is likely to occur unless the boiler water is in exactly the right condition. Expert advice should be sought whenever it is suspected that the condensate is corrosive due to the condition of the feed water.

Further sources of corrosion include the kind of process where steam and condensate are brought into contact with the substance being heated. For example, during the process of vulcanizing a certain amount of sulphuric acid can be formed, which quickly causes corrosion of certain parts of steam traps and other fittings.

In certain processes, it is necessary to inject live steam directly into liquids which are of a corrosive nature. When the main stop valve is shut, any steam left in the supply pipes will condense and for a short time a partial vacuum will form as the volume of the condensate is much less than that of the steam. As a result, liquid will be drawn into the piping and may reach steam supply lines to other process equipment, When steam is turned on again, the corrosive liquid will be pushed through the equipment to the steam traps, damaging any parts of these which are susceptible to corrosion.

A similar problem can occur in tanks where corrosive mixtures are heated by means of steam pipe coils fitted with steam traps. When steam is turned off, a partial vacuum will form in the coil and any slight leak in the latter will allow corrosive liquid to be drawn into the system. Again, corrosion damage is likely to occur.

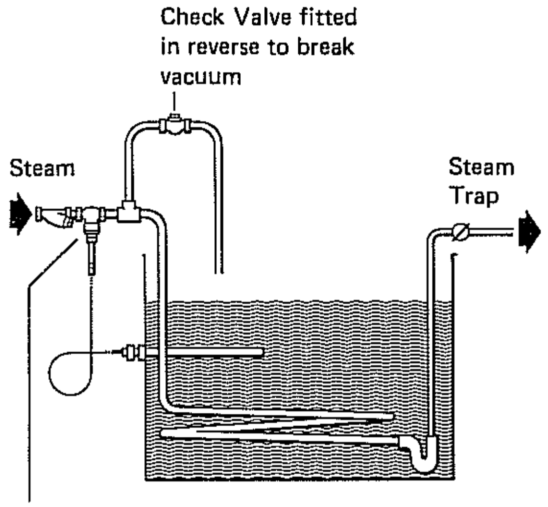


Fig. 60 Check valve fitted as a vacuum breaker

The simplest way of preventing the formation of this vacuum is to fit a check valve in reverse to a branch in the steam supply line, as shown in Fig. 60. Fitted in this way, the check valve will be closed when steam pressure is present, preventing any loss of steam. When the supply valve is closed and the steam left in the system condenses, atmospheric pressure will open the check valve and prevent the formation of a vacuum.

Some types of steam trap are made from materials which will resist certain types of corrosion for a long time. However, the installation of such traps is rarely the complete answer to the problem because of the effect of the corrosion on other fittings in the system. It is always better to eliminate the cause of the corrosion at its source.

Corrosion can occur rapidly in systems that are used intermittently and are left standing undrained. Condensate collecting at various points in the system can set up severe corrosion in the presence of air. A common example of this is a space heating system which is not used during the summer months. Wherever possible, such systems should be completely drained when they are shut down.

Oxygen and carbon dioxide are probably responsible for the majority of cases of corrosion in steam systems. Although relatively harmless as gases, severe problems can occur if they are allowed to dissolve. The rate at which the gases will dissolve increases as the temperature of the condensate drops. For this reason, systems which are well air vented and have condensate removed at steam temperature are least likely to suffer. It may be undesirable to allow air vents to discharge into the condensate return system as this will only aggravate corrosion problems downstream of the traps.

F. Freeze Up

Steam pipes running outdoors can freeze up in winter when steam is shut off and some kinds of steam traps used on these outside lines will suffer in the same way. Freeze damaged traps are by no means uncommon.

The possibility of such trouble can be guarded against in several ways. Traps of the thermodynamic disc type are perhaps the best solution as they are quite unharmed by freezing. Alternatively, a trap which is open when cold will not be damaged provided that all the water in the system is free to drain away on shut down. It is possible to lag most types of steam traps although there are some which should not be insulated. Even so, this may not prevent damage if the cold spell is prolonged and steam is shut off all the time. In some cases it may be possible to trace the traps as a protection against freezing.

G. Superheat

When considering the effect of superheated steam on steam traps, there are two important points to bear in mind:—

Firstly, superheat temperatures can be very high and secondly the steam temperature does not bear any relation to its pressure.

The first point follows from the fact that superheated steam is nearly always generated so that it can be used in a turbine or engine to produce power. For this purpose, the greater the amount of superheat the better and this high superheat is usually associated with a high steam pressure. Superheated steam is rarely encountered in process and heating applications since these can usually be served more effectively with saturated steam. However, the steam may sometimes be superheated slightly so that it can be distributed around a large site without heat losses causing it to become wet before it reaches the process.

Contrary to what might be expected, steam traps are required to drain superheated steam lines. On start up, the system will be cold and this will cause the steam not only to give up superheat but also to condense. Energy losses from the heated systems will then have to be met, by the steam giving up some or all of its superheat, and then condensing unless superheat temperatures and steam flow rates are high.

Steam traps used on superheated steam must be constructed of materials that will stand up to the temperature as well as the pressure. Thermodynamic and inverted bucket traps are commonly used, as are bimetallic traps. With inverted bucket traps, there is always the danger that the water seal around the open end of the bucket will be evaporated by the superheat. This can be prevented by fitting a check valve close to the inlet of the trap. Inverted bucket traps for high pressures and temperatures often have a suitable built-in check valve.

The fact that the temperature of superheated steam does not bear any relation to its pressure means that the majority of balanced pressure thermostatic traps cannot be used on superheated lines. Most thermostatic bellows have no means of withstanding temperatures above that of saturated steam at any given pressure.

H. Air Binding

Air will always fill steam using equipment during periods of shut down and air and incondensible gases will be carried along with the steam when the system is operating. We have already seen that the presence of air will aggravate corrosion problems and that it can also have a seriously detrimental effect on equipment output. One further problem which must be overcome is the tendency of certain types of steam trap to "air bind".

When steam is turned on, all the air which has filled the system during shut down must be removed as quickly as possible. The incoming steam pushes the air to the steam traps where it should be discharged. Special arrangement must be made if the trap in question does not have a good air venting capability.

All traps of the thermostatic type are fully open when cold and allow air to be discharged freely both on start up and whenever air builds up in front of the trap during normal operation. The practice of fitting an inbuilt thermostatic vent in float traps ensures that this pattern can cope with air in the same way.

Although inverted bucket traps cannot air bind completely, they will only release air very slowly due to the necessarily small size of the vent hole in the bucket. It should be stressed that the pressure available to push the air out of the bucket is due only to the difference between the water level in the bucket and the water level on the outside of the bucket, as shown in Fig. 61.

There is one way to get over this difficulty. Sometimes inverted bucket traps are fitted with a simple internal bimetal air vent in the bucket itself. When open, this gives an increased air discharge orifice to speed up the discharge of air from the bucket on start up. However, since the trap is always full of water, the temperature difference available to operate this type of air vent does not permit it to have much power and functional troubles are common. In addition, because this air vent is a simple bimetal strip, it is only effective on start up and is completely closed, incapable of discharging any air during normal operation when temperatures are above 190°F. Finally, the air still has to find its way through the main valve seat.

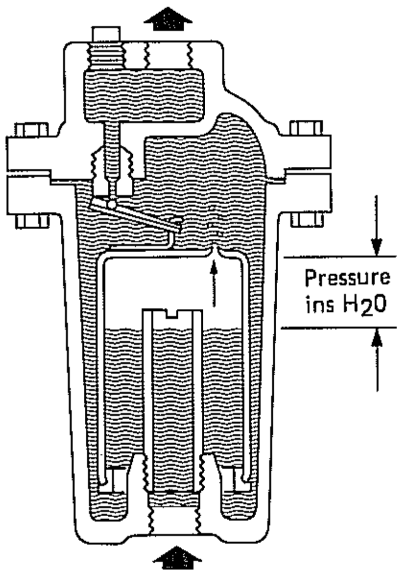


Fig. 61 Air Release in a Bucket Trap

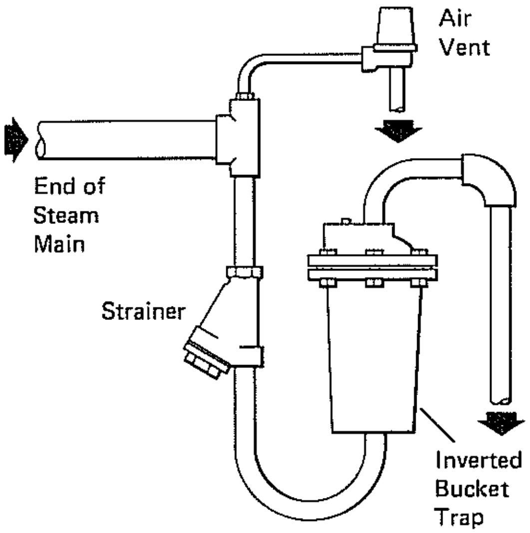


Fig. 62 Air Vent fitted around a Bucket Trap

A better way to speed up the air venting of an inverted bucket trap is to fit a separate thermostatic air vent above the trap, on the lines of Fig. 62. The construction and operation of a suitable thermostatic air vent can be identical to that of a thermostatic steam trap.

Thermodynamic traps are capable of discharging air on start up provided that the inlet pressure does not build up too rapidly. However, if the air is forced through the trap at high velocity, the dynamic effect will cause the disc to seat and the trap will air bind. If this becomes a problem, it may be necessary to fit a separate thermostatic air vent in parallel with the trap.

I. Steam Locking

Steam locking is a common cause of much inefficient operation of steam heated equipment and yet is widely ignored. The basic problem is illustrated by the simple arrangement in Fig. 63. A steam heated unit is drained by a balanced pressure thermostatic trap which is correctly sized and in good working order. The unit to which the trap is connected is working at a steam pressure of approximately 45 psi gauge and there is a run of some 15ft of 1" pipe from the drain outlet 'A' to the trap 'B'.

When steam is turned on, everything is cold and the trap is wide open. Air and condensate from the unit are forced by steam pressure to the trap and discharged. Steam follows and causes the trap to close, leaving the pipe from 'A' to 'B' full of steam.

Let us imagine for a moment that the pipe from 'A' to 'B' was full of air instead of steam. Obviously it would be air locked. Although the working pressure is 45 psi gauge, the difference in pressure between the drain point of the unit and the trap is small. The difference is due to only a matter of inches in level, as can be seen from Fig. 63. Any condensate in the unit must flow to the trap by gravity, so that air in the connecting pipe would be difficult to displace.

Precisely the same sort of thing happens when steam fills the pipe from 'A' to 'B'. Until the steam condenses, it acts in a similar way to the air. Instead of an air lock, there is a steam lock.

One way of preventing steam locking would be to fit a very large diameter pipe from the drainage point 'A' to the trap 'B'. However, it would be necessary to make the connection into the steam unit the same size as the pipe itself, otherwise the throttling effect of the small connection would cause steam locking at this point. Such a large diameter pipe would also be wasteful and cumbersome and would not really prove a

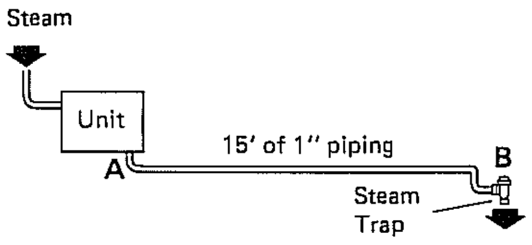


Fig. 63 Steam Locking

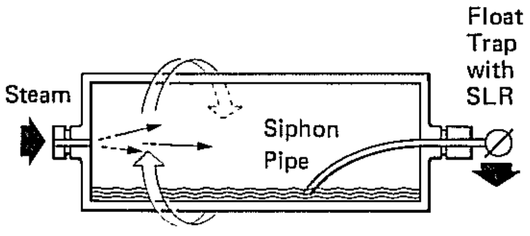


Fig. 64 Drying Cylinder

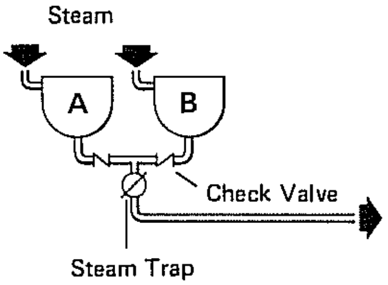


Fig. 65 Group Trapping

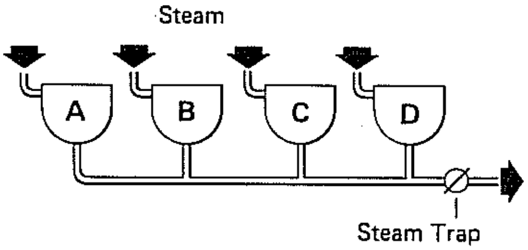


Fig. 66 Incorrect Group Trapping

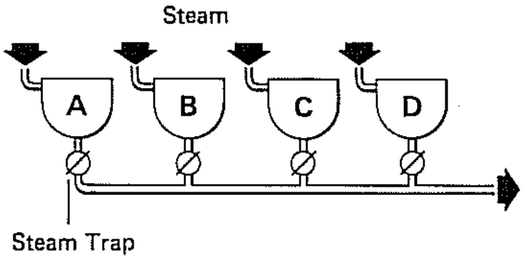


Fig. 67 Correct Individual Trapping

feasible solution to the problem. The best idea is to fit the trap as close as possible to the unit being drained.

If a balanced pressure thermostatic trap is used, the best place for it will be some 3 to 5ft away from the drain outlet, depending on the make of trap. This shorter length of piping will reduce the effect of steam locking. If a thermostatic trap was fitted any closer to the drain outlet, the condensate would take longer to cool off and waterlogging of the unit would result before the trap could open.

Where a mechanical type trap is used, it should always be installed close to the drain outlet. If this is not possible, it will be necessary to use a trap with a special steam lock release valve which allows the locked steam to bleed away, avoiding any back up of condensate in the unit being drained.

The drying cylinder in Fig. 64 is one case where it is impossible to install the trap close to the drain point. The cylinder rotates on trunnion bearings and the condensate has to be lifted up the siphon pipe and out through one of the trunnions before it can reach the trap. The siphon pipe is surrounded by steam so that heat loss from any steam locked in the pipe is very slow. The only solution is to use a float trap with an inbuilt steam lock release valve.

One other important example of steam locking occurs when the trap has to be installed at the top of a lift after the drain point. The solution to this problem, using a small bore rising pipe, has already been explained in our section on lifting condensate.

J. Group Trapping

Let us consider the arrangement shown in Fig. 65. Two adjoining pieces of steam heated equipment 'A' and 'B' are working at steam pressures of 5 psi gauge and 100 psi gauge respectively. The condensate drain of each piece of equipment is connected to a common drain point which is fitted with a steam trap in good working order.

The higher pressure in equipment 'B' ensures that any condensate formed will quickly reach the trap and be discharged. Steam will follow and the trap will close. The lower pressure in equipment 'A', cannot discharge condensate against the 100 psi gauge pressure of 'B' and the steam space will waterlog.

This may seem all too obvious and it is unlikely that anyone would try to adopt such an arrangement. However, it is extremely common to find a number of units working at the same steam pressure which are drained by a single trap. This practice of "group trapping" of units working on the same steam supply pressure can have the same effect as the group trapping of units working at dissimilar pressures.

The loss of pressure when steam is flowing along steam mains or into steam heated vessels is proportionate to the velocity of the steam. If in a number of steam units, the steam consumption of one is greater than that of another, the velocity of the steam into the vessel will be greater and therefore the pressure loss will be greater. This means that the actual pressure at the drainage point of that unit will be less than the pressure at the drainage points of the other vessels. We know that when the drainage points of different units at different pressures are connected to one trap, the vessel having the higher pressure will cause condensate to be held back longer in the others. Exactly the same thing will occur in the case under consideration. The unit that has the greatest load and needs to discharge its condensate most freely will waterlog because steam from the higher pressure units on lighter loads will reach the trap first.

Even when the units are working on similar loads, the connecting pipes from the drainage points to the trap will be of different lengths. Reference to Fig. 66 clearly shows that condensate from unit 'D' is likely to reach the trap first, causing it to close before all the condensate from units 'A' and 'B' and 'C' has been discharged.

Even if the units have similar loads, it does not follow that their steam requirements will be exactly the same at any given moment. The demand for steam of a unit on start up from cold is obviously greater than that of a similar unit which is hot. This is particularly important in terms of batteries of equipment (such as boiling pans) on batch process, rather than continuous working.

The original reason for group trapping was that there used to be only one kind of steam trap. It was a very large fore-runner of the present day bucket trap and cost a great deal of money. Now that compact, efficient steam traps are available at reasonable cost, there is no excuse for failing to achieve the correct individual trapping arrangement shown in Fig. 67.

Steam trap sizing

The benefits of selecting the best type of steam trap for a given application will be wasted if the trap is not sized correctly. It is bad practice to choose a ¾" trap simply because it has to go on a ¾" drain pipe.

In order to size a steam trap, we obviously need to know the quantity of condensate to be handled in a given time. The makers of most standard kinds of steam equipment usually supply reliable figures on the condensation rates of their equipment. If such information is not available, it has to be acquired either by calculation or practical measurement of the condensate produced. A test procedure which will give reasonably accurate results is set out at the end of this section.

Reference has already been made to "start up loads" and "running loads" in this course. We know that steam will condense most rapidly on start up when the system is cold. It is for this reason that it is common practice to size using a safety factor. The trap selected should be able to handle twice the normal running load, or as much as 3-4 times following an automatic temperature control. An undersized trap will cause waterlogging of the steam space when it can be least afforded.

In Fig. 68 , the actual condensate rate of equipment working on a continuous process is shown in graph form. When the equipment is started up at 8:00 a.m., there is a peak load of 250 lb of condensate an hour; by 8:30 a.m., the equipment is up to its normal maximum working temperature and the condensation rate has fallen to 150 lb/hour. At 1:30 p.m., after the lunch break, there is another peak load of 200 lb/hour. This is slightly less than at 8:00 a.m., because the equipment is still warm. By 2:15 p.m., the light running load of condensate has been restored. A steam trap sized on twice the normal running load will clearly be suitable for this application.

The second graph, Fig. 69, shows what happens in equipment working on a batch process. At 8:00 a.m., when the equipment is first started up, the condensation rate peaks at 200 lb an hour. During the course of the day there are no less than 26 peaks in the rate of condensation, rather than the steady running load seen in Fig. 68. Although a steam trap sized on twice the average running condensation rate will be more than adequate, we must remember that some types of steam trap may handle heavy loads of condensate very well but tend to waste steam on light loads. For example, the bimetal type of trap is unable to respond rapidly when the steam pressure fluctuates. The ball float type trap is generally most suitable for those conditions where steam pressure and/or condensate load are subject to wide and frequent fluctuation.

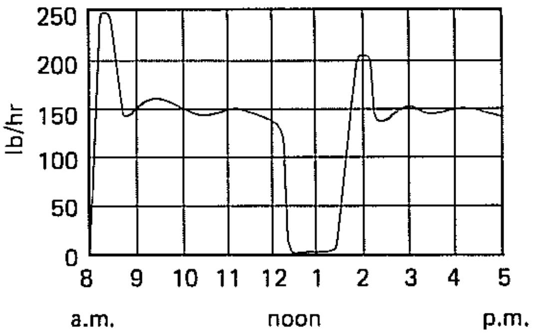


Fig. 68 Condensate Rate on Continuous Process

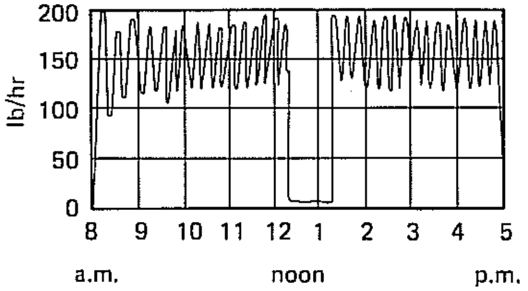


Fig. 69 Condensate Rate on Batch Process

Steam pressure and trap capacity

We know that for a steam trap to operate, there must be a higher pressure at its inlet than there is at its outlet. The actual amount of condensate which the trap can discharge is governed by the following three factors:—

1. **The differential pressure**
2. **The size of the trap discharge orifice**
3. **The temperature of the condensate**

We must now examine these factors in more detail.

1. Differential Pressure

The maximum amount of condensate the trap will discharge will increase as the differential pressure (the difference in pressure between the inlet and outlet of the trap) increases. In other words, the capacity of a trap discharging to atmosphere with steam at 75 psi will be greater than that of the same trap with steam at 30 psi. The capacity does not, however, increase in proportion to the pressure.

It is not safe to assume that the pressure at which steam is supplied to a piece of equipment will be the pressure on the inlet to its steam trap. Pressure losses often mean that the steam pressure at the trap will be considerably less than the steam supply pressure.

If a steam trap is discharging condensate to atmosphere, the outlet pressure will be atmospheric and therefore the differential pressure will be the same as the gauge pressure at the trap inlet. However if the trap discharges into a main which is under pressure, the differential pressure will be reduced by an amount which can be determined by subtracting the outlet pressure from the trap inlet pressure. The quantity of condensate which the trap is capable of passing in a given time will be reduced accordingly.

2. Size of Discharge Orifice

The size of the discharge orifice not only helps to determine the capacity of the trap but also often fixes the maximum pressure at which the trap will operate.

Reference to Part 2 reveals that the vast majority of the traps described have the valve on the pressure side (the inlet side) of the valve seat. The only notable exception to this arrangement occurs in some of the bimetal traps where the valve is at the outlet side of the valve seat.

In the case of the traps with the valve on the pressure side of the valve seat, the valve when closed, will be held on its seat by the steam pressure. According to the type of trap in question, the thermostatic element, ball float or bucket must have enough force to pull the valve away from its seat against this pressure. In any given trap (with the exception of the slide valve type), the force is a fixed amount.

Force required = pressure x area.

The maximum pressure at which the valve of the trap can open is the pressure (psi) at which this operation force (pounds force) is just greater than the valve seat area (square inches) multiplied by the pressure (psi) in the trap

In the case of traps with the valve at the outlet side of the valve seat the situation is different. In this type, the steam pressure tends to open the valve, so the maximum pressure at which the trap can close is when

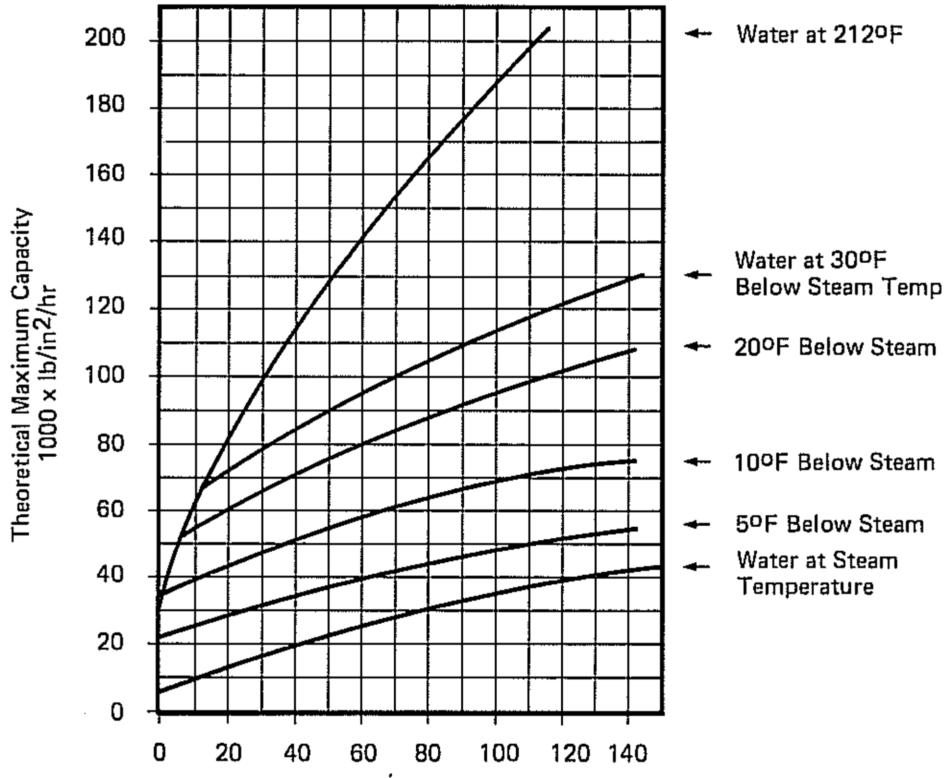


Fig. 70 Hot Water Discharge Rates

the operating force is just greater than the steam pressure multiplied by the valve seat area.

3. The Temperature of the Condensate

The capacity of a trap should never be based on the amount of cold water the trap will pass at any given differential pressure.

Condensate in a steam trap is usually at a temperature above atmospheric boiling point. When the condensate is passing through the valve seat of the trap, its pressure is quickly reduced and a certain amount of flash steam is generated. This flash steam tends to choke the discharge orifice, reducing its effective area. As the condensate temperature rises, the amount of flash steam generated will increase and the discharge capacity of the trap will decrease. The extent to which condensate temperature affects trap discharge capacity is shown in Fig. 70.

Steam consumption by measurement

From time to time it is necessary to find out the steam consumption of a piece of equipment by practical measurement of the condensate rate. Fig. 71 shows a suitable method of arranging equipment to measure the rate at which condensate is produced by a steam jacketed production pan. The following points should be noted before starting any tests.

1. Never rely on only one test. Always carry out at least three and average the results unless one set of figures is very different from the others. In this case, carry out a further test.

2. At the start of each test the pan should be filled to the same level and the contents should be at the same temperature.

3. The points at which the test finishes is usually determined by the temperature of the pan contents but in some cases the operator will decide the finishing point from his judgement of the consistency of the product. Each test should finish up the same temperature or product consistency.

4. So that only condensate formed during the test period is collected, the pan must be completely empty when the test starts. The steam supply should also be drained as close to the stop valve as possible, so that condensate from the main does not run into the jacket and upset the readings.

5. Flash steam should be condensed in the water in the tank, otherwise an estimate will have to be made of the amount of flash lost and this may not be very accurate. For this reason, the tank or drum should be large enough to hold plenty of cold water at the start of the test. If this is not possible, several tanks must be used and the hose changed from one to another when a significant amount of flash steam starts to escape. Each drum will have to be weighed before and after use.

6. The weight of the tank should be noted every one or two minutes throughout the test, so that the variation in steam consumption as the pan heats up can be calculated.

7. If possible, the steam temperature should be the same throughout all the tests. If it varies greatly, the pressure gauge must be read at regular intervals so that some allowance can be made when the results are calculated.

The test should be carried out as follows:-

A. Fill the pan with the carefully weighed or measured ingredients of the batch and record the temperature.

B. Weigh the half filled tank of cold water.

C. Put the open end of the flexible hose from the trap outlet well below the surface of the water in the tank.

D. Open the drain cock at the bottom of the pan jacket and turn on steam for a few seconds only to clear out any condensate in the jacket and steam supply. Close the steam valve and drain cock.

E. Turn on steam fully and note the time.

F. Record the steam pressure and the weight of the tank at intervals during the test, also recording the actual time at which each reading is taken.

G. At the end of the test, as determined by the temperature of the pan contents or its consistency, turn off steam and record the time.

H. Let all the condensate drain from the flexible hose into the tank. It may be necessary to lower the end into a bucket at floor level to catch the last drops. Add this to the water in the tank.

I. When the steam pressure in the pan has fallen to zero, open the bottom drain, collect any condensate that runs out and add this to the water in the tank.

J. Weigh the tank and its contents.

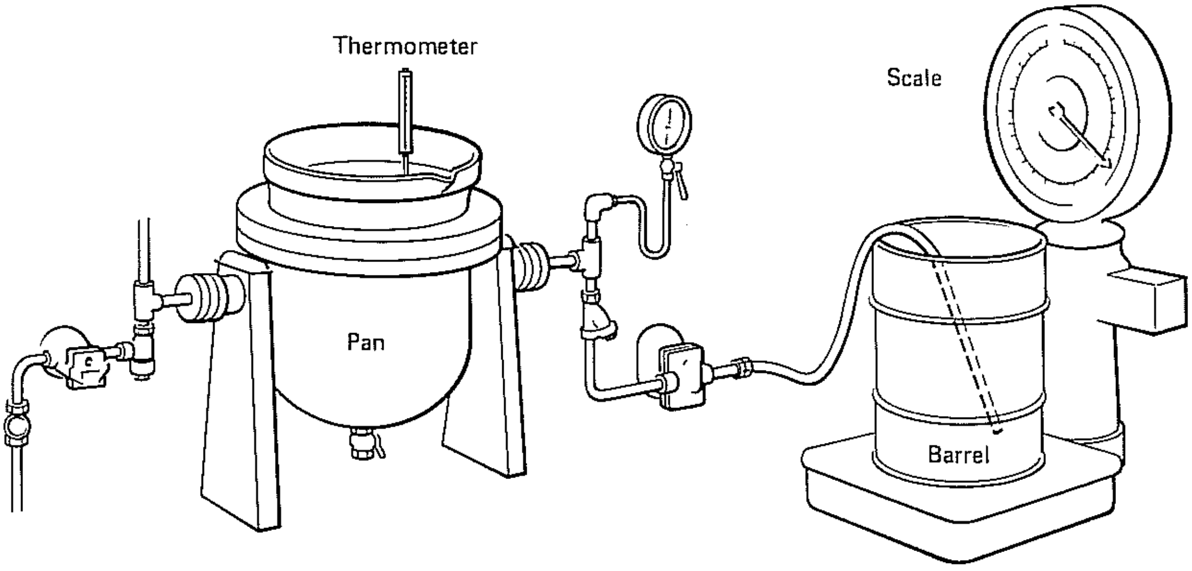


Fig. 71 Equipment for Measurement of Steam Consumption

The difference in weight of the tank and its contents at the start and finish of the test indicates how much steam has been condensed in the test period, so that the average consumption rate over the period can be calculated.

It is possible to work out the steam consumption at invervals during the test from the intermediate readings and so obtain the maximum and minimum consumptions.

Questions

9. A piece of steam heated equipment operates at 200 psi gauge with a running load 1000 lb per hour. The equipment is drained through a trap discharging condensate at steam temperature, direct to atmosphere. What will be the temperature of the condensate on discharge from the trap, how much flash steam will be lost per hour, and at what pressure?

10. List the items which are normally fitted before and after a steam trap in a sound installation.

11. Condensate from a jacketed pan working at 15 psi gauge is discharged at an average rate of 330 lb/hr, through a ball float steam trap. The trap was sized to pass 330 lb/hr of condensate at a differential pressure of 15 psi. The jacket is fitted with an automatic air vent. The condensate is lifted directly from the trap up a vertical pipe 20 ft high. Leaking traps elsewhere in the system are setting up a back pressure of 3 psi gauge in the condensate return. The output of the pan is slowing down. What is the probable cause of the trouble and what other snags are present?

12. Is a balanced pressure thermostatic trap suitable where there are superheat conditions? If not, give the reasons.

13. Does steam locking of a steam trap increase the steam consumption? If it does, give the reasons and an example.

14. The pressure gauge on the inlet to a steam heated drying cylinder shows 15 psi, (say 30 psi absolute). In the cylinder there is air as well as steam and the thermometer shows the temperature of the mixture to be 235°F. What are the proportions of air and steam making up the mixture? How much of the pressure is due to the steam and how much due to the air which is present?

Notes

Practical energy conservation in steam systems

Introduction

The need for optimum efficiency increases with every rise in the cost of fuel. Steam and condensate systems must be carefully designed and maintained to ensure that unnecessary energy wastage is kept at a minimum. For this reason, the final part of the course is concerned chiefly with practical aspects of energy conservation in steam systems.

Boiler efficiency

Boilers and the associated firing equipment should be designed for efficient operation. They should also be properly sized. A boiler which has to cope with a peak load above its maximum continuous rating will operate at reduced efficiency. Pressure may drop and the resultant priming and carry-over will mean that the boiler is incapable of doing its job of providing good quality steam at the right pressure and at the right time.

If a boiler has to work at a small percentage of its rating, then radiation losses become significant and, again, there is a drop in overall efficiency. Clearly, it is not easy to match boilers to what is normally a variable steam load. Two or more boilers are more flexible than a single unit which explains the common arrangement of a large boiler for the winter load with a smaller boiler for the summer load.

The boiler is, however, only part of the installation. It is just as important to have firing equipment which will respond to the load but maintain the correct fuel/air ratio. This is a very wide subject and advice should be sought from the suppliers of boilers and combustion equipment if there are any doubts.

The major losses in any boiler are represented by the hot gases discharged at the chimney. If combustion is good, there will be only a small amount of excess air. The exhaust gases will contain a relatively large percentage of carbon dioxide and only a small amount of oxygen. At the same time, if the boiler is not being pushed and the heating surfaces are clean, a high percentage of heat will be extracted and the exhaust gas temperatures will be low.

If combustion is poor, with a lot of excess air, then the increased weight of the exhaust gases will carry a lot of heat up the chimney. The exhaust gases will contain a reduced percentage of carbon dioxide or increased amounts of oxygen. Again, if the burning rate is high or the heating surfaces are dirty, it will not be possible to extract such a high percentage of heat and exhaust gas temperatures will rise.

Measurements of carbon dioxide or oxygen in flue gases, together with temperature, enable the flue gas losses to be calculated and is the normal method of monitoring boiler efficiency. This should be done correctly and frequently under all conditions of boiler load. Larger installations will usually justify continuous measurement.

The job of the boiler is to supply good quality dry steam at the correct pressure. There may be little point in achieving high combustion efficiency if the end result is a steam supply containing a good deal of water and water treatment compounds.

Boilers are usually designed to operate at relatively high pressures. This means that small steam bubbles will be released at the water surfaces giving good quality dry steam. If the pressure is allowed to fall, for whatever reason, then the bubble size will be increased, resulting in turbulence, priming and carry-over. For this reason, boilers must be operated at the correct pressure.

The boiler feed tank is the heart of any steam system. It provides a reservoir of returned condensate and fresh make-up water with which the boiler feed pump can replenish the boilers.

The feed tank must be properly sized and allowance made for fluctuations and possible interruptions in supply; it is normal to hold enough water to provide one hours steam at maximum rating. However, there should be enough free space to cope with the relatively massive return at start-up. Significant quantities of condensate can be lost if this is not provided.

In some cases, the temperature of the feed water is limited by the ability of the feed pumps to handle it. The problem is cavitation which can usually be avoided by increasing the filling head over the pump. Where it is not practical to lift the feed tank, a high level service tank can be incorporated to give the required head.

Since the feed tank is hot, steps must be taken to minimize heat losses. The greatest losses will take place from the water surface and some form of cover or lid is therefore essential. An alternative is to cover the surface with a floating blanket of plastic balls. Apart from saving heat, tests have shown that this kind of blanket has a marked effect in reducing the absorption of oxygen and carbon dioxide by the water. Lagging the tank will provide additional savings and will often help to keep boiler house temperatures down.

A detailed consideration of how best to collect and return condensate to the boiler house will be given later.

Steam metering

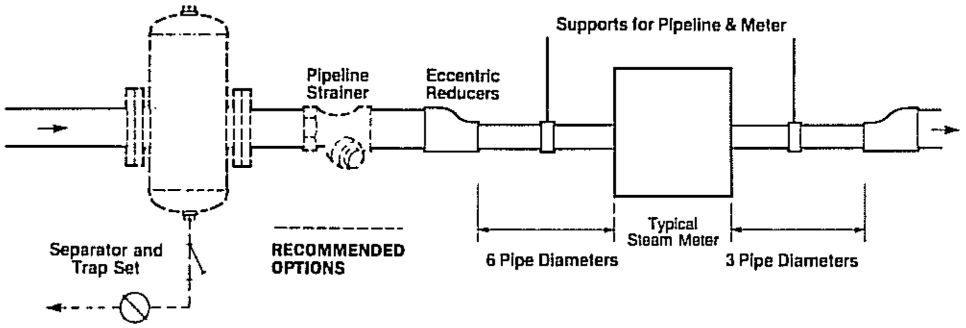
Difficulties in energy management of steam arises from the fact that it is often a totally unmeasured service. Metering starting in the boiler house, is essential if savings are to be made.

Although fuel consumption is fairly easy to monitor, measurement of steam is rather more difficult. A steam meter must compensate for quality as well as pressure and temperature. Performance of different types of meters when used on steam will vary and the measurement may not always be accurate. Most meters depend on a measurement of volume. Since volume depends on pressure, measurements should be taken at the pressure appropriate to the meter or else corrections specific to steam have to be applied. Readings taken under fluctuating pressure conditions are inaccurate unless the meter can automatically compensate.

Steam metering should be done down-stream of a good quality reducing valve which maintains a constant pressure. Readings should be interpreted using the meter factor and meter calibration should be checked from time to time.

Although steam metering is most often carried out in the boiler house, it is also important to determine:

1.) Custody transfer. To measure steam usage and thus determine steam cost.
    a.) Centrally at the boiler house.
    b.) At all major steam using areas.
2.) Equipment efficiency. Identifying major steam users, when loaded to capacity or idle; also peak load times, and plant deterioration and cleaning requirements.
3.) Process control. Meters indicate that the correct steam requirement and quantity is supplied to a process, when bypass lines are opened; and when valves and steam traps need attention.
4.) Energy efficiency. Compare the efficiency of one process area with another; monitor the results of plant improvements and steam saving programs.



Typical Steam Metering Station

Reducing heat losses

Insulation

All potential sources of heat loss in a steam system should be insulated or lagged. An uncovered 300 ft run of 2" NB pipe carrying steam at 150 psig will lose approximately 200 lb/hr of steam through heat losses, under ambient conditions of 60°F. Flanges and valves should also receive attention as the heat loss from a single pair of flanges is equivalent to that from a 1 ft length of plain pipe. With current fuel prices, a lagging efficiency not less than 80% should be regarded as essential.

Lagging of steam pipework is not simply a means of conserving fuel. It reduces the heat losses which produce condensate inside the line. This water is picked up by the steam, and the apparatus gets a low quality supply.

Even good insulation needs protection to maintain it in an efficient condition. Most types of insulation make use of the poor rate of heat transfer through air. The materials used are composed of millions of microscopic air cells which form an effective barrier to escaping heat. However, if these air cells become waterlogged or crushed, they will lose their ability to insulate and then become useless. For this reason, it is essential to protect insulation once it has been fitted and it is particularly important to waterproof any insulation on lines which run out of doors.

While on the subject of reducing heat losses by insulating it is as well to remember that another source of unnecessary heat loss is redundant piping. When a piece of process equipment is removed, all too often the line serving it is plugged off in such a way that it remains fully charged with steam. This can be very wasteful and should be avoided by removing all redundant pipework.

Intermittent Operation of Steam Using Equipment

In order to keep distribution losses to a minimum, it is advisable to divide the various processes fed by a steam system into sections which can be individually isolated when not in use. The most obvious example of this is to split heating and process equipment into two separate systems. This ensures that the entire steam supply network feeding heating equipment, can be completely isolated during the summer months.

This arrangement can be extended to take in sections of process equipment which may only need steam at certain times of the day. Isolation of such areas can produce considerable fuel savings through elimination of the unnecessary radiation losses which would otherwise take place. Although such isolation can be achieved by use of manual valves, it is preferable to use pressure reducing valves and temperature controls fitted with an overriding solenoid valve which can be shut down by the signal from a time switch. See Fig. 72.

In some cases, it is possible to carry a policy of intermittent shutdown right back to the boiler itself. Many oil or gas fired packaged boilers are fully automatic and can be switched off at night and on again in the morning by a time switch. However, this may well result in problems during start-up with expansion, boiler stress, carryover and very slow pressure build-up through the system. Condensation rates in the mains will be high and if they are not completely drained by gravity, there is a serious danger of waterhammer. Given these potential hazards, it is especially important with either complete or zonal shutdown to ensure removal of all condensate from low points in the system. The use of liquid expansion type steam traps, by-passing the normal drain traps and discharging downwards, can be a great help on these applications.

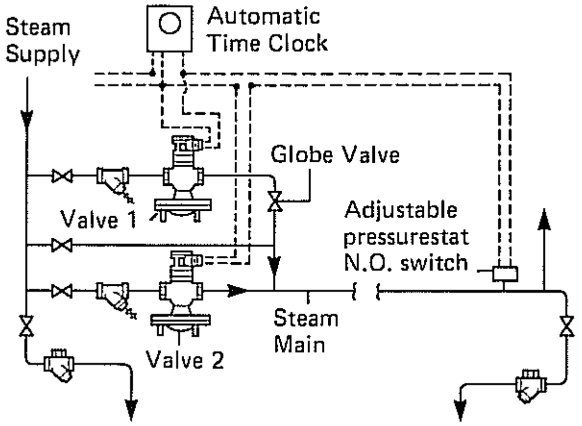


Fig. 72 Automatic Start-up

Operation

Valve number 1 is sized to provide enough steam to warm up the main. It is opened by the timeclock first pressurizing the main. The globe valve downstream should be adjusted to carry out this pressurization gradually, preventing waterhammer from occuring. When the steam main pressure is satisfied the N.O. pressurestat opens valve number 2 for normal operation.

Pressure reduction

Every piece of steam using equipment has a maximum safe working pressure. If this is lower than the main steam supply pressure, a reducing valve has to be fitted. This is not, however, the only occasion when a pressure reducing valve can be used to advantage.

Most steam boilers are designed to work at relatively high pressures and should not be run at lower pressures, since carryover of water is liable to occur. For this reason, it is best to generate at high pressure and fit reducing valves before any equipment requiring steam at a lower pressure. Such an arrangement has the added advantage that small bore distribution pipes can be used, due to the relatively small volume occupied by steam at high pressure.

Since the temperature of saturated steam is determined by its pressure, control of pressure is a simple but effective method of accurate temperature control. This fact is used to good effect on applications such as sterilizers and control of surface temperatures on contact dryers. Reducing steam pressure will also cut down the loss of flash steam from open vents at condensate collecting tanks.

Most pressure reducing valves currently available can be divided into 2 main groups:-

Direct Acting Valves

The direct acting valve shown diagrammatically in Fig. 73 is the simplest design of reducing valve. Reduced pressure downstream of the valve acts on the underside of the diaphragm 'A', opposing the pressure applied by the control spring 'B'. This determines the opening of the main valve 'C' and hence the flow through the reducing valve.

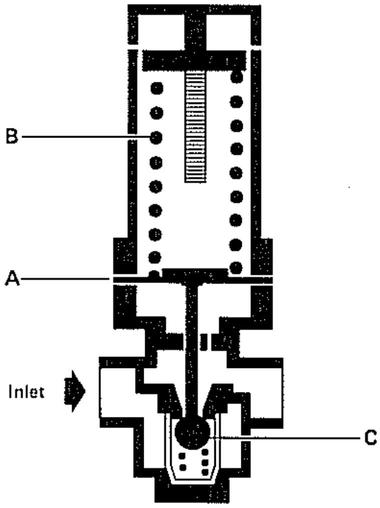


Fig. 73 Direct Acting Reducing Valve

In order to move the valve from the open to the closed position, there must be a build up of pressure under the diaphragm. This results in an inevitable variation of the downstream pressure. It will be highest when the valve is closed, or nearly closed, and will "droop" as the load increases.

Outlet pressure acting on the underside of the diaphragm tends to close the valve as does inlet pressure acting on the underside of the main valve itself. The control spring must be capable of overcoming the effects of both the reduced and inlet pressures when the downstream pressure is set. Any variation in the inlet pressure will alter the force it produces on the main valve and so affect the downstream pressure.

This type of valve has two main drawbacks in that it allows some fluctuation of the downstream pressure and has a relatively low capacity for its size. It is nevertheless perfectly adequate for a whole range of simple applications where accurate control is not essential and where the steam flow is fairly small and reasonably constant.

Pilot Operated Valves

Where accurate control of pressure or large capacity if required, a pilot operated reducing valve should be used. Such a valve is shown diagrammatically in Fig. 74.

Reduced pressure acts on the underside of the pilot diaphragm 'C', either through the pressure control pipe 'F' or the drilling 'I', so balancing the load produced on the top of the pilot diaphragm by the pressure adjustment spring 'B'.

When the reduced pressure falls, the spring force overcomes the pressure acting below the pilot diaphragm and opens the pilot valve 'E', admitting steam through the pipe 'D' to the underside of the main diaphragm 'K'. In turn, this opens the main valve 'H' against its return spring 'G' and allows more steam to pass until the reduced pressure returns to the correct value.

Any further rise in reduced pressure will act on the pilot diaphragm to close the pilot valve. Fluid from below the main diaphragm will then flow into the valve outlet through the pipe 'L' and the orifice 'J' as the return spring moves the main valve towards its seat, throttling the flow.

The pilot valve will settle down to an opening which is just sufficient to balance the flow through the orifice 'J' and maintain

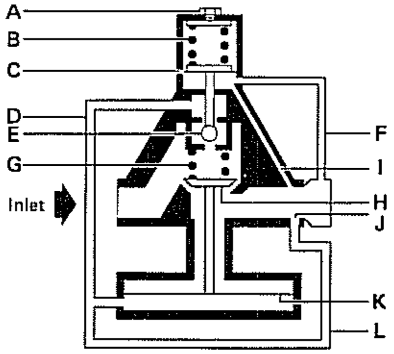


Fig. 74 Pilot Operated Reducing Valve

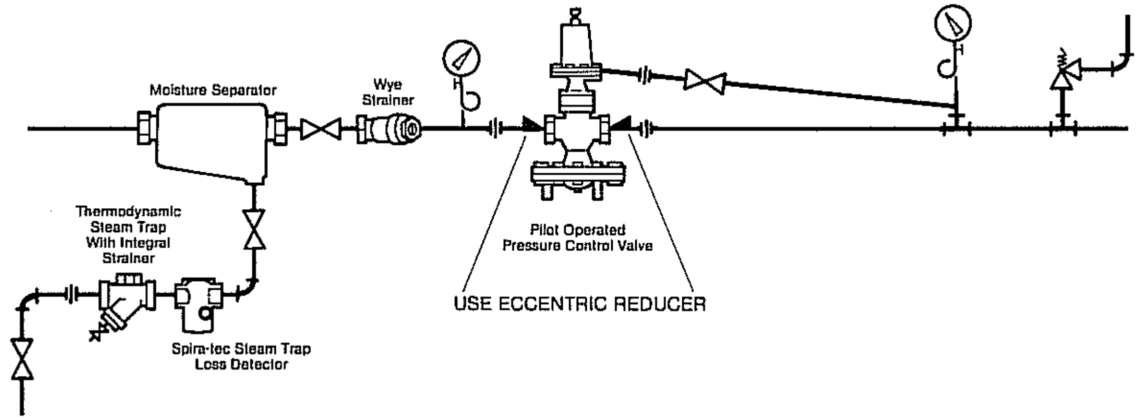


Fig. 75 Pressure Reducing Valve Station

the necessary pressure under the diaphragm to keep the main valve in the required position for the prevailing upstream and downstream pressure and load conditions. Any variation in pressure or load will be sensed immediately by the pilot diaphragm, which will act to adjust the position of the main valve.

The reduced pressure is set by the hand wheel 'A' which alters the compression of the adjustment spring 'B'.

The pilot operated design offers a number of advantages over the direct acting valve. Only a very small amount of steam has to flow through the pilot valve to pressurize the main diaphragm chamber and fully open the main valve. Thus, only very small changes in downstream pressure are necessary to produce large changes in flow. The droop of the pilot operated valve is therefore small.

Although any rise in upstream pressure will apply an increased closing force on the main valve, this is offset by the force of the upstream pressure acting on the main diaphragm. The result is a valve which gives close control of downstream pressure regardless of variations on the upstream sides.

In some valves, the main diaphragm is replaced by a piston. This can be advantageous in bigger valves which would require very large size main diaphragms. However, problems with the piston sticking in its cylinder are common particularly in smaller valves.

Selection & Installation

The first essential is to select the best type of valve for a given application and this follows logically from the descriptions already given. Small loads where accurate control is not vital should be met by using the simple direct acting valves. In all other cases, the pilot operated valve is the best choice, particularly if there are periods of no demand when the downstream pressure must not be allowed to rise.

Oversizing should be avoided with all types of control valve and this is equally true of reducing valves. A valve head working close to its seat when passing steam can suffer wire-drawing or erosion. In addition, any small movement of the oversized head will produce a relatively large change in the flow through the valve orifice.

A smaller, correctly sized reducing valve will be less prone to wear and will give more accurate control. Where it is necessary to make big reductions in pressure or to cope with wide fluctuations in load, it may be preferable to use two or more valves in series or in parallel.

Although reliability and accuracy depend on correct selection and sizing, they also depend on correct installation. Fig. 75 shows an ideal arrangement for the installation of a pilot operated reducing valve. Since the majority of reducing valve problems are caused by the presence of moisture or dirt, a steam separator and strainer with fine mesh screen are fitted before the valve. The strainer is fitted on its side to prevent the body filling with water and to ensure that the full area of the screen is effective. All upstream and downstream pipework and fittings must be adequately sized to ensure that the only appreciable pressure drop occurs across the reducing valve itself. If the isolating valves are the same size as the reducing valve, it is essential that they are of the full flow type. This is not quite so important if the isolating valves are sized to match the larger upstream and downstream pipework.

If the downstream pipework or connected plant is incapable of withstanding the full upstream pressure, then a safety valve should be fitted on the downstream side. This safety valve should be set at or below the maximum pressure which the downstream side will withstand and it must be a size capable of handling all the steam which could pass through the reducing valve at that set pressure when failed fully open.

The use of flash steam

When hot condensate under pressure is released to a lower pressure, its temperature must drop very quickly to the boiling point for the lower pressure as shown in the steam tables. The surplus heat is utilized by the condensate as latent heat causing some of it to re-evaporate into steam.

The quantity of "flash steam" available from each pound of condensate can be calculated, as in our example in Part 2, or read off the simple table shown in Fig. 76. For example, if one pound of condensate at 200 psi gauge is discharged to atmosphere (zero psi gauge) 0.186 pounds of flash steam will be released. With condensate at 100 psi gauge, the amount of flash will drop to only 0.133 pounds. This figure will be reduced further to 0.088 pounds if the condensate at 100 psi gauge is discharged into a back pressure of 20 psi gauge.

These examples clearly show that the amount of flash released depends upon the difference between the pressures upstream and downstream of the trap. The higher the initial pressure and the lower the flash recovery pressure, the greater will be the quantity of flash steam produced. It must be noted that Fig. 76 is based on the assumption that the trap is discharging condensate immediately as it is formed. A reduced amount of flash steam will be available if the trap is of a type which holds back condensate until it has cooled below steam temperature.

Before discussing ways of recovering flash steam, there are two important practical points which should be noted:—

Firstly, one pound of steam has a volume of 26.8 cubic feet at atmospheric pressure. This means that if a trap discharges 100 pounds/hour of condensate from 100 psi gauge to atmosphere, the weight of flash steam released will be 13.3 pounds/hour, having a volume of 356.4 cubic feet. This will appear to be a very large quantity of steam and may well lead to the erroneous conclusion that the trap is passing live steam. Secondly, as flash steam pressure builds up, it imposes a back pressure on the steam traps. This pressure must be kept low enough to ensure that condensate is not held back in the high pressure equipment.

The actual formation of flash steam takes place within and downstream of the steam trap orifice where the pressure drop occurs. From this point onwards, the condensate return system must be capable of carrying this flash steam as well as condensate. High back pressure is a problem in many condensate return systems because inadequate allowance has been made for flash steam at the pipe sizing stage.

If the flash steam is to be recovered and utilized, it obviously has to be separated from the condensate. This is best achieved by passing the mixture of flash steam and condensate through what is known as a "flash tank" or "flash vessel". A suitable arrangement is shown in Fig. 77. The diameter of the vessel is such that a considerable drop in velocity takes place, allowing the condensate

Steam Pressure psig	Atmosphere	Flash Tank Pressure-psig									
	0	2	5	10	15	20	30	40	60	80	100
5	1.7	1.0	0								
10	2.9	2.2	1.4	0							
15	4.0	3.2	2.4	1.1	0						
20	4.9	4.2	3.4	2.1	1.1	0					
30	6.5	5.8	5.0	3.8	2.6	1.7	0				
40	7.8	7.1	6.4	5.1	4.0	3.1	1.3	0			
60	10.0	9.3	8.6	7.3	6.3	5.4	3.6	2.2	0		
80	11.7	11.1	10.3	9.0	8.1	7.1	5.5	4.0	1.9	0	
100	13.3	12.6	11.8	10.6	9.7	8.8	7.0	5.7	3.5	1.7	0
125	14.8	14.2	13.4	12.2	11.3	10.3	8.6	7.4	5.2	3.4	1.8
160	16.8	16.2	15.4	14.1	13.2	12.4	10.6	9.5	7.4	5.6	4.0
200	18.6	18.0	17.3	16.1	15.2	14.3	12.8	11.5	9.3	7.5	5.9
250	20.6	20.0	19.3	18.1	17.2	16.3	14.7	13.6	11.2	9.8	8.2
300	22.7	21.8	21.1	19.9	19.0	18.2	16.7	15.4	13.4	11.8	10.1
350	24.0	23.3	22.6	21.6	20.5	19.8	18.3	17.2	15.1	13.5	11.9
400	25.3	24.7	24.0	22.9	22.0	21.1	19.7	18.5	16.5	15.0	13.4

Fig. 76 Percent flash steam produced when high temperature condensate is discharged to atmosphere or into a flash tank controlled at various pressures.

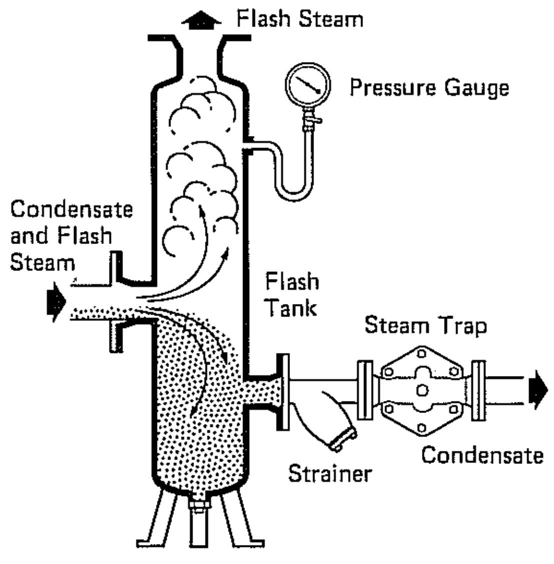


Fig. 77 Flash Tank

to fall to the bottom of the vessel where it is drained out. Adequate height above the inlet allows flash steam to be taken off at the top without picking up any droplets of water which may rise into the steam space by splashing. A ball float type steam trap is used to ensure prompt drainage of the condensate.

A number of basic requirements must be fulfilled if flash steam recovery is to be a viable proposition:—

1. The first essential is obviously a supply of condensate at a reasonably high pressure. The traps supplying this condensate must be able to accept the back pressure which will be created by the operating pressure of the flash steam system.

2. The second requirement is a suitable user for the low pressure/flash steam. The demand for flash steam should preferably be greater than the available supply and should be in step in terms of time.
   If flash steam from process equipment is used to augment steam for heating purposes, savings will be achieved for much of the year but the system will be ineffective in the summer when heating is not required. It is obviously preferable to use the flash steam on the equipment providing the high pressure condensate, so that supply and demand are in step.

3. Flash steam should be utilized as close to its source as possible. Piping low pressure steam may involve relatively large pipework and high radiation losses and it is possible that installation costs may outweigh the advantages of flash steam recovery if long runs are involved.

A typical flash recovery system is shown in Fig. 78. The flash steam is used in a pre-heat section added to a multi-bank heater battery. The low temperature of the air meeting this section means that the flash steam can usually be condensed very readily. The pressure in the flash tank and pre-heater will find its own level but, it may not ever reach atmospheric pressure unless the pre-heat battery happens to be tightly sized.

The example in Fig. 78 clearly fulfills the basic requirements of having a flash steam supply which is in step with the demand. Only when the heater batteries are called upon to supply heat does flash steam become available and it can then be condensed in the first battery which is essentially a pre-heater.

This simple arrangement ensures that the high pressure traps are not subjected to any

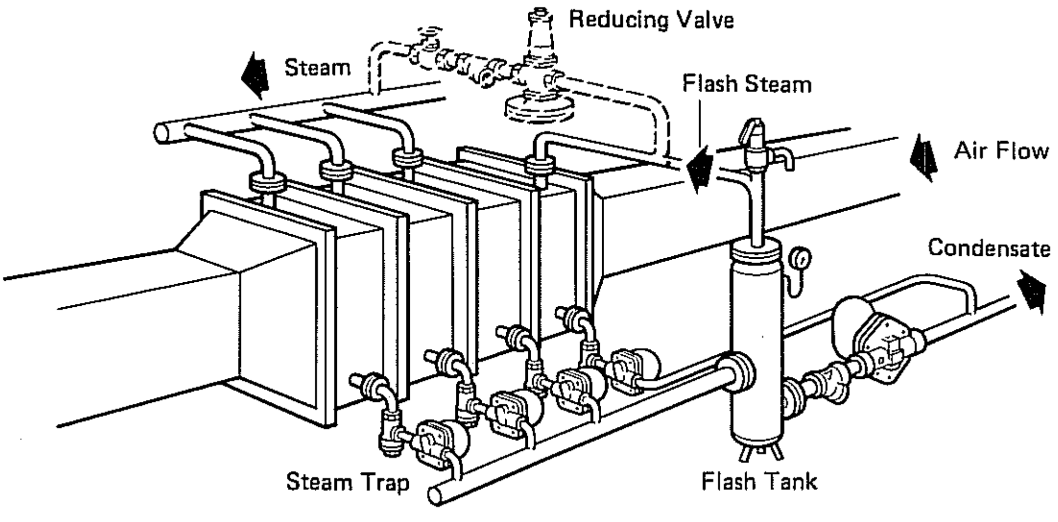


Fig. 78 Typical Flash Recovery System

back pressure on start up. However, the flash steam battery is not fully utilized and there can be problems in draining the flash vessel due to the lack of differential pressure across the trap. For this reason, it is advisable to fit a pressure reducing valve as shown in broken print in Fig. 78. This meets any deficiency in the supply of flash steam and effectively controls the flash steam pressure. It ensures that there is a useful contribution from the flash steam battery even when there is little or no flash steam available and provides a reasonable differential across the trap on the flash tank at all times. The only problem is that the high pressure traps have to start up against a small back pressure and so it may be advisable to shut off the make up steam supply until the main batteries are up to pressure.

Similar arrangements can be made for large areas heated by unit heaters or radiant panels. It is possible to separate 10 to 15% of the heaters and supply them with flash steam generated from condensate collected from the remaining heaters. Supply and demand are again in step, as the peak heat requirement from all the units occurs at the same time.

The output of any equipment supplied with low pressure flash steam will be less than that of equipment supplied with high pressure steam, due to the difference in steam temperature. However, this can normally be accepted and, in any case, a small increase in the heating surface will always compensate.

There are occasions when it is possible to make use of flash steam without having to install a flash tank. In some cases, it is worth considering an arrangement along the lines of Fig. 79. A hot water storage cylinder is fitted with a secondary coil near the bottom where the cold feed water comes in. The condensate from the steam filled primary coil is passed through this secondary coil immediately after the trap and any flash steam present will be condensed, giving up its heat to the water. This ensures that use is made of the flash steam rather than simply allowing it to escape through the vent of a condensate receiver.

A useful extension of this idea for heating systems is the packaged heat exchanger shown in Fig. 80. Condensate and flash steam are discharged through the steam trap from the top unit which is a normal steam to water heat

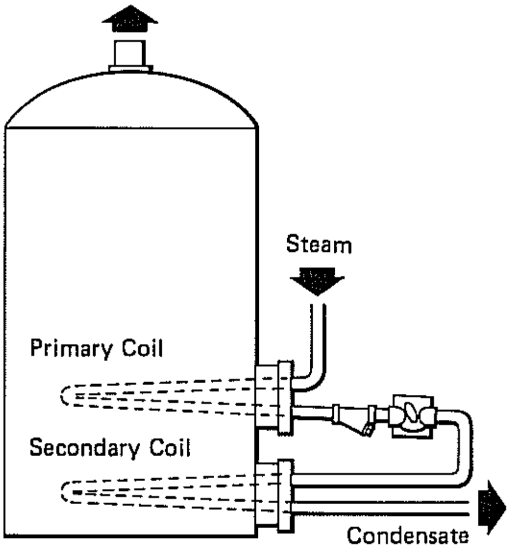


Fig. 79 Secondary Flash Steam Coil

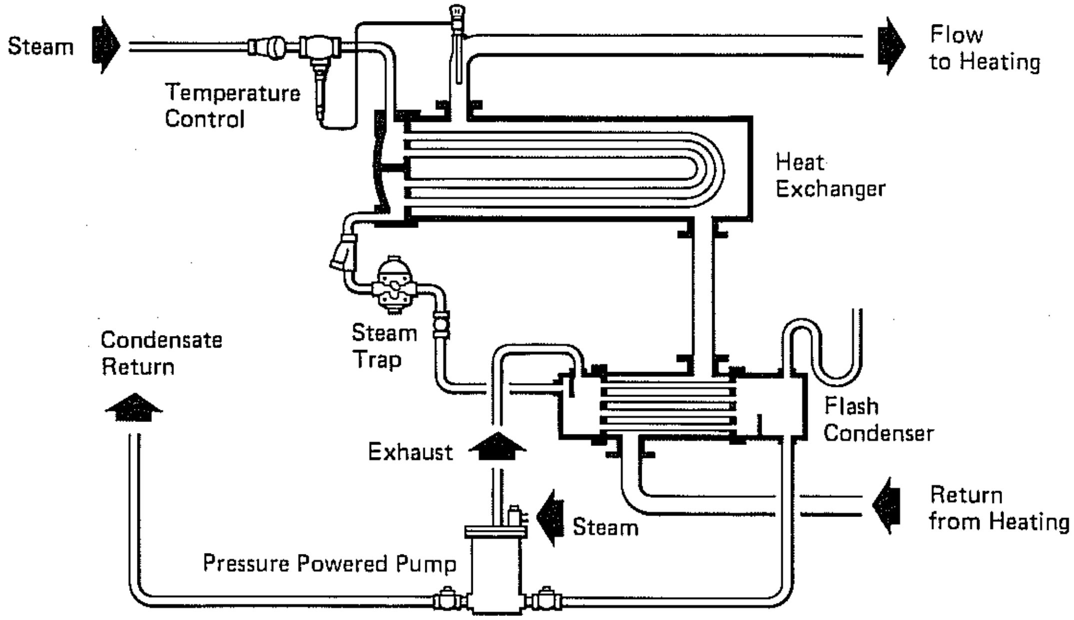


Fig. 80 Packaged Heat Exchanger and Flash Condenser Unit

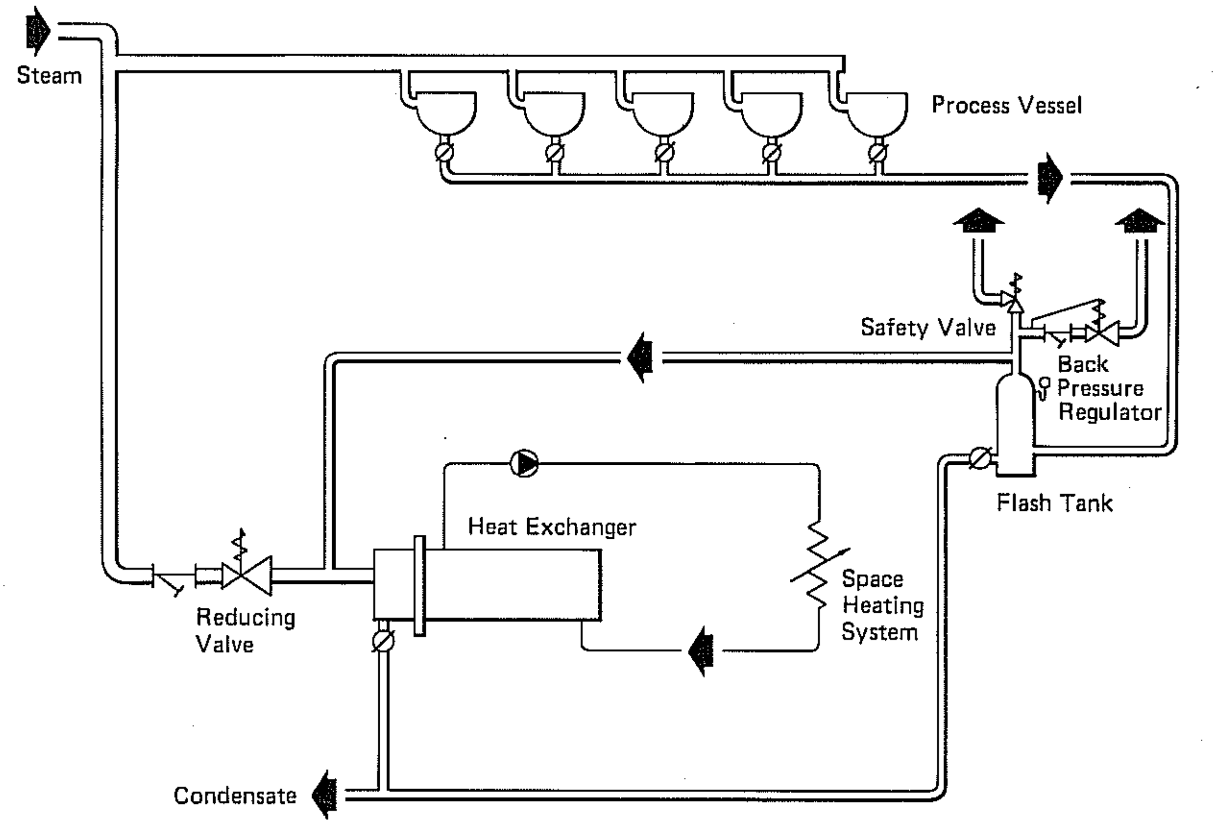


Fig. 81 Flash Steam Recovery

exchanger. They are then separated in the flash condenser below and both give up useful heat to the return water from the heating system before it reaches the main heat exchanger. The unit is completed by a pump which returns the condensate to the boiler feed tank.

Fig. 81 shows a system where condensate from a process system is used to provide flash steam to augment the steam supply to a space heating system. This may be perfectly satisfactory for much of the year but flash steam will be blown to waste in the summer when heating is not required. To prevent undue wear of the safety valve internals, a back pressure regulator is sometimes fitted. This is a case where supply and demand are not in step. The arrangement is not ideal but the savings to be made during the winter may well justify the cost of the installation. Rather than allow the system to vent steam for long periods, it is better to by-pass the flash tank in summer and return the condensate direct to the feed tank or a condensate receiver if another suitable use for the flash steam cannot be found.

Continuous boiler blowdown is another possible source of valuable flash steam which should not be neglected. In many modern boiler plants the heat exchange rate is high and both the water and steam capacities are low. It is imperative to keep the solids content within limits if the boiler is to operate satisfactorily. For this reason, a system of continuous blowdown is used, whereby water is discharged from the boiler continuously during the whole of the time it is in operation and controlled at a rate equivalent to some 5 to 10% of the total boiler evaporation.

As the blowdown water from a boiler contains a high percentage of solids, one of the most practical ways of making use of its heat content is to recover flash steam. The flash tank must be generously sized to ensure that no solids are carried over with the low pressure steam. The most common use for flash steam recovered from continuous blowdown is to pre-heat the boiler feed water.

Condensate return

The importance of effective condensate removal from steam spaces has been stressed throughout this course. If maximum system efficiency is to be achieved, then the best type of steam trap must be fitted in the most suitable position for the application in question. Having considered how best to utilize any flash steam which may be available, we must now decide what to do with the condensate which remains.

There are a number of reasons why condensate should not be allowed to run to drain. The most important consideration is the valuable heat which it contains even after flash steam has been recovered. It is possible to use condensate as hot process water but the best arrangement is to return it to the boiler house, where it can be used as boiler feed water without further treatment, saving fuel, raw water and the chemicals needed for boiler feed treatment. This threefold saving will be even greater in the cases where effluent charges have to be paid for the discharge of valuable hot condensate down the drain.

The financial benefits of using hot condensate as boiler feed water are illustrated by the following example shown below:—

Fig. 82 shows the formation of steam at 150 psi gauge when the boiler is supplied with cold feed water at 50°F. The shaded portion at the bottom of the diagram represents the relatively small amount of sensible heat available in the feed water. A further 320.6 BTU/lb of heat energy has to be added in the boiler before saturation temperature at 150 psi gauge is reached.

Fig. 83 again shows the formation of steam at 150 psi gauge, but this time the boiler is fed with hot condensate at 160°F. The increased amount of sensible heat contained in the feed water means that the boiler now only has to add 210.6 BTU/lb of heat energy to bring it up to saturation temperature at 150 psi gauge. This represents a saving of 9.2% in the cost of fuel alone.

One reason for not returning condensate is the risk of contamination. Perforated coils in an acid vat or oil tank might allow these harmful substances to reach the boilers where considerable damage would occur.

However, even in cases where contamination is likely, condensate can still be returned to the boiler feed tank if suitable precautions are taken. Filters can be installed which will cope with oily condensate, while the presence of harmful acids can be signalled by suitable detection equipment.

In extreme cases it may be safer to run the condensate to waste, but useful heat can still be extracted by first passing it through a coil in another process vat. Alternatively, it is common practice in plating processes to run the condensate directly into hot rinse tanks. This provides the hot water necessary for final rinsing of articles that have been treated and produces a saving of live steam that would otherwise be needed to heat the water.

Lifting Condensate

Although condensate can be lifted by the steam pressure at the trap outlet, it should really be allowed to flow away by gravity. Such a arrangement is essential if the pressure at the trap outlet is low or the equipment is

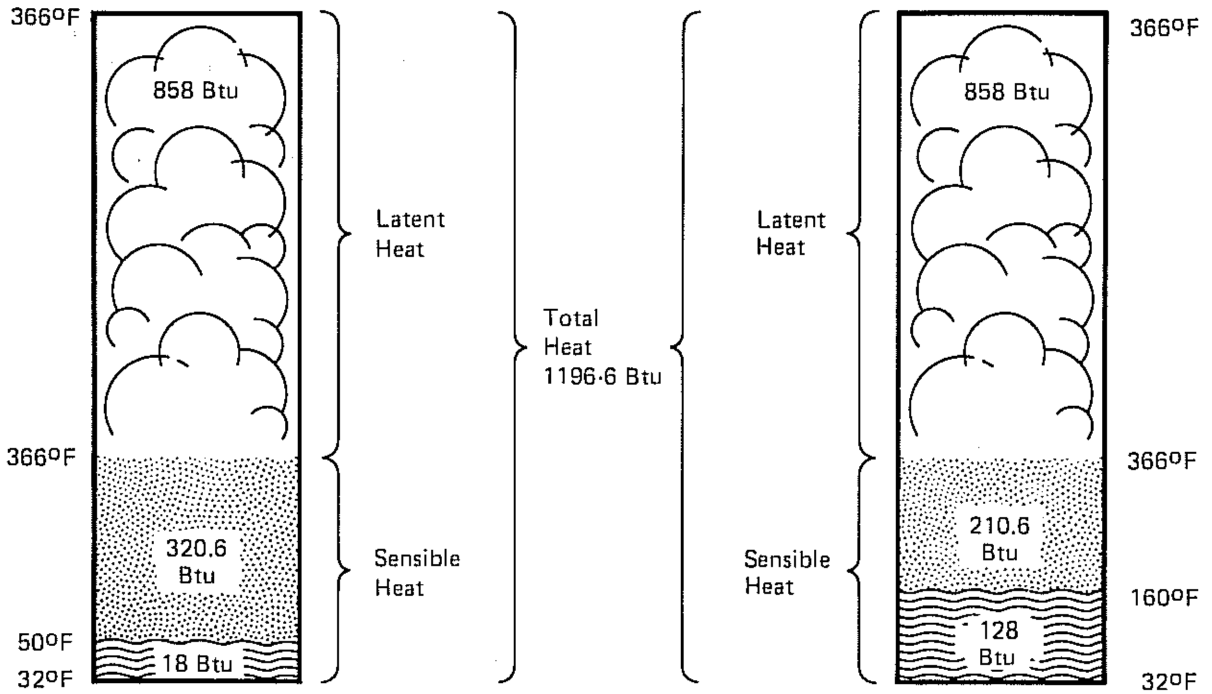


Fig. 82 Formation of Steam at 150 psig — Feed Water 50°F

Fig. 83 Formation of Steam at 150 psig — Feed Water 160°F

Operation

1. In the normal position before start-up the float (C) is at its lowest position with the steam valve (J) closed and exhaust valve (K) open.
2. When liquid flows by gravity through inlet check valve (A) into pump body (B), the float (C) will become buoyant and rise.
3. As the float (C) continues to rise, the mechanism link (E) is engaged which increases the tension in the springs (G). When the float (C) has risen to its maximum position, the energy on the springs is released instantaneously, causing the linkage mechanism (H) to snap upwards over center moving push rod (L) upwards to simultaneously open steam inlet valve (J) and close exhaust valve (K).
4. Steam will now flow through the steam valve (J) and develop a pressure within the body, forcing the liquid out through the discharge check valve (M). The inlet check valve (A) will be closed during the discharge cycle.
5. As the liquid level in the pump body decreases, so does the float's position. Before the float reaches its lowest position, the mechanism link (E) is engaged, increasing the tension in the springs (G). When the float is at its lowest position in the body, the energy in the springs is released instantaneously, causing linkage mechanism (H) to snap over center downward, moving push rod (L) down, causing the steam valve (J) to close and exhaust valve (K) to open simultaneously.
6. Liquid will again flow through inlet check valve (A) to fill pump body and the cycle will be repeated.

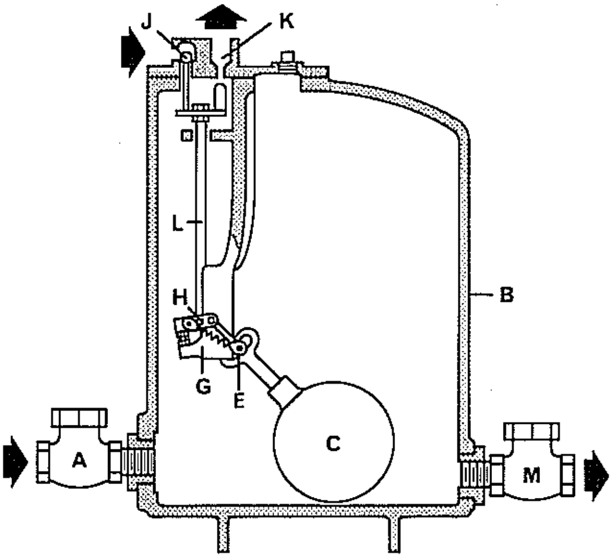


Fig. 84 How the Spirax Sarco Pressure-Powered Pump Operates

temperature controlled. Unfortunately, it is rarely possible to return condensate by gravity back to the boiler feed tank. For this reason, it is usual to run condensate to a collecting point from which it can be pumped back to the boilerhouse.

The operating cycle of a simple automatic pump suitable for condensate return applications can be split up into six distinctive phases, as shown in Fig. 84.

The operating medium of this type of pump can be either steam or compressed air and, in either case, the consumption is very low. Since the pump handles a measured amount of condensate at each stroke, it is relatively easy to calculate the flow rate. By adding a cycle counter to the top cover, the pump can be used as a simple metering device to measure the condensate load of the plant to which the pump is connected.

Fig. 85 shows the recommended installation layout to ensure satisfactory operation of an automatic pump.

The vented receiver is an essential part of

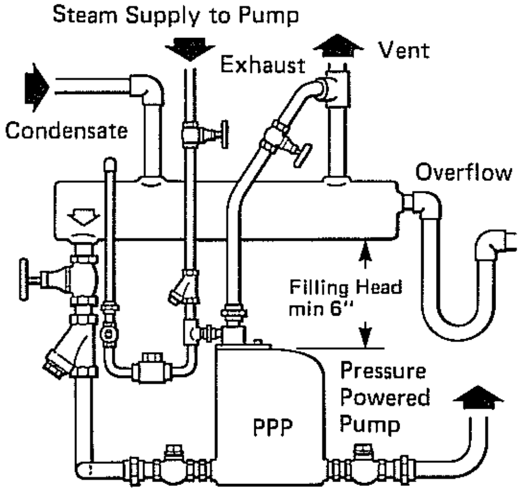


Fig. 85 Automatic Pump Installation Layout

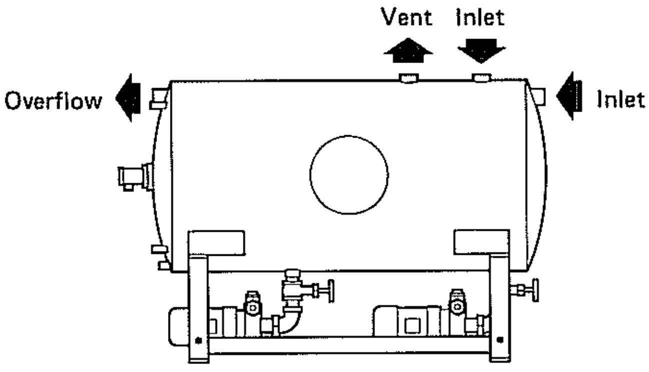


Fig. 86 Electrical Condensate Recovery Unit

the set up and so it must be remembered that any flash steam which has not been separated from the condensate before it reaches the pump receiver will be lost through the vent pipe. One method to preclude virtually any loss is to equalize certain types of pressure powered pumps with the equipment which they drain. Fig. 87 demonstrates a system that returns steam power to the next exchange after it has worked. The heat energy is recovered and pumping costs are nil.

An automatic pump is capable of reasonably high duties, but there are occasions when extremely heavy condensate loads or very long, tortuous return lines preclude the use of even two or more automatic pumps in parallel. The solution to this problem is to revert to an electrically driven pump. Fig. 86 shows a typical electric condensate recovery unit, comprising a vented receiver and duplex pumps which alternate.

Electric pumps are capable of working against a higher resistance then automatic pumps and for this reason, smaller return lines can be used when condensate has to be pumped over a long distance. The reduction in line size will produce a corresponding reduction in heat losses, resulting in condensate reaching the boiler feed tank at a higher temperature.

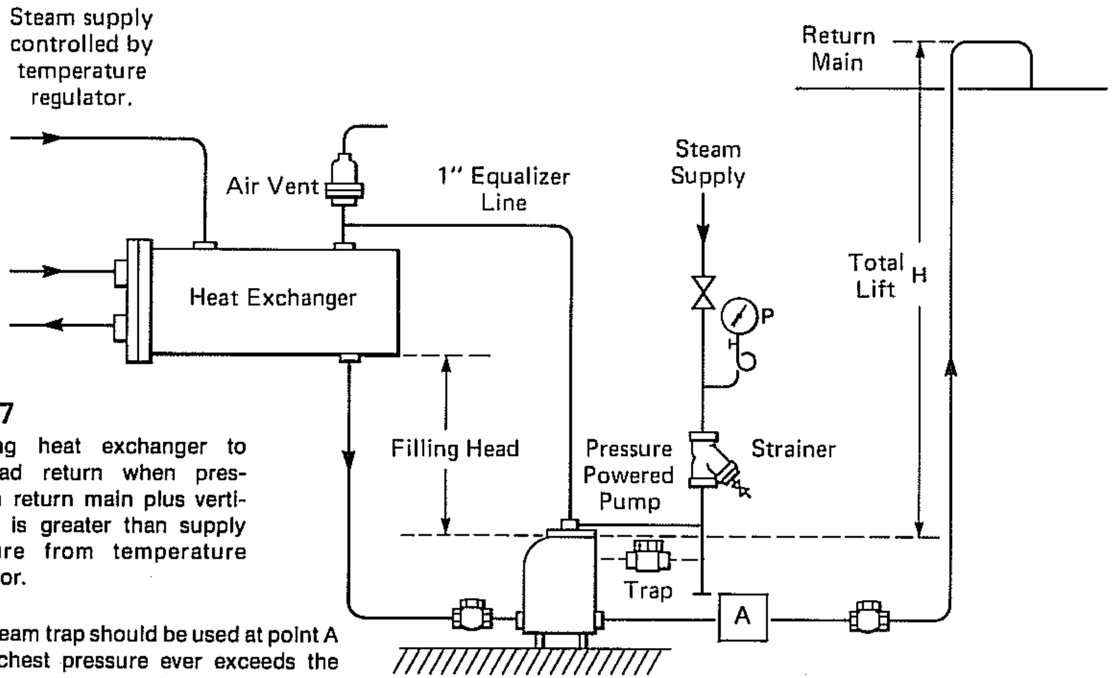


Fig. 87
Draining heat exchanger to overhead return when pressure in return main plus vertical lift is greater than supply pressure from temperature regulator.

A. A steam trap should be used at point A if the chest pressure ever exceeds the back pressure. This combination pump/trap is ideally suited for modulating control applications.

Temperature control

Many types of steam equipment need to be fitted with some form of temperature control. In process work, product quality is often dependent upon accurate temperature control, while heating systems need to be thermostatically controlled in order to maintain optimum comfort conditions. From an energy saving point of view, the ideal temperature is obviously the lowest which can be accepted for any given application, as the following example shows:

Let us imagine that the open-topped, uninsulated tank in Fig. 88 is heated by a coil with steam at 30 psi gauge. No temperature control is fitted and the temperature of the tank contents is approximately 160°F under ambient conditions of relatively still air at 70°F. If the process involved could be carried out with the tank contents at say 125°F the original fuel load could be cut by as much as 54%. We must now consider how best to put this theoretical saving into practice.

In order to lower the temperature of the contents of the tank, the rate at which heat transfer takes place from the coil must be reduced. The simplest way of doing this is

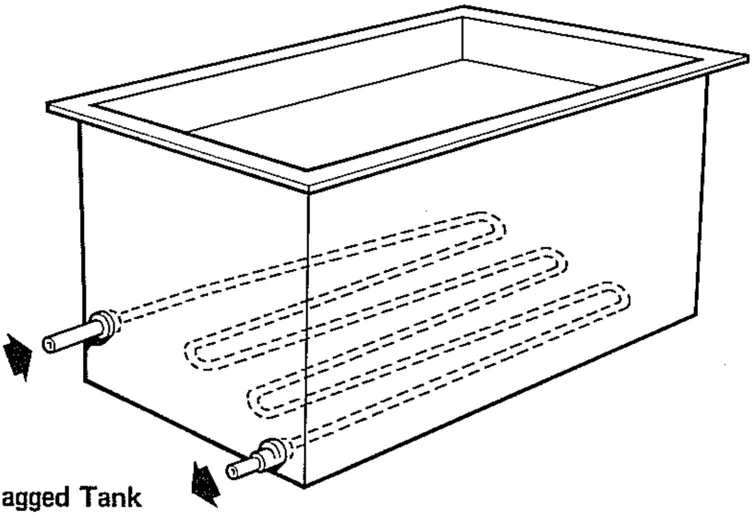


Fig. 88 Open Top Unlagged Tank

to reduce the temperature of the steam in the coil. Clearly, this will lower the difference in temperature between the steam and the solution being heated and reduce the rate of heat transfer, as desired. We know from the steam tables that any reduction in the pressure of saturated steam is accompanied by a drop in temperature. For this reason, a suitable means of controlling steam pressure is the natural solution to the problem of controlling the rate of heat transfer in our coil heated tank.

This can be achieved by using a simple manual valve to throttle the steam flow, in the same way that a gas tap is used to regulate the supply of heat on a domestic cooker. Unfortunately, such an arrangement may call for frequent manual adjustment if the heat requirements of the equipment in question are liable to fluctuate significantly. More accurate control can be obtained by the installation of a pressure reducing valve but the need for manual adjustment still remains. The ideal answer is to fit one of the automatic temperature regulators described below:

Automatic Temperature Control
A suitable arrangement for a simple self-acting temperature regulator on a coil heated tank is shown in Fig. 89A. The immersion sensor is connected via capillary tubing and a valve actuator to a 2-port control valve. The principle of operation of the system is illustrated in Fig. 90. As the temperature of the tank contents increases, the fluid in the sensor expands through capillary tubing into the valve actuator. Here it compresses the bellows of a packless gland, producing linear thrust which pushes the valve towards its seat and throttles the steam flow. When the temperature falls, the fluid contracts and a return spring moves the valve in the opposite

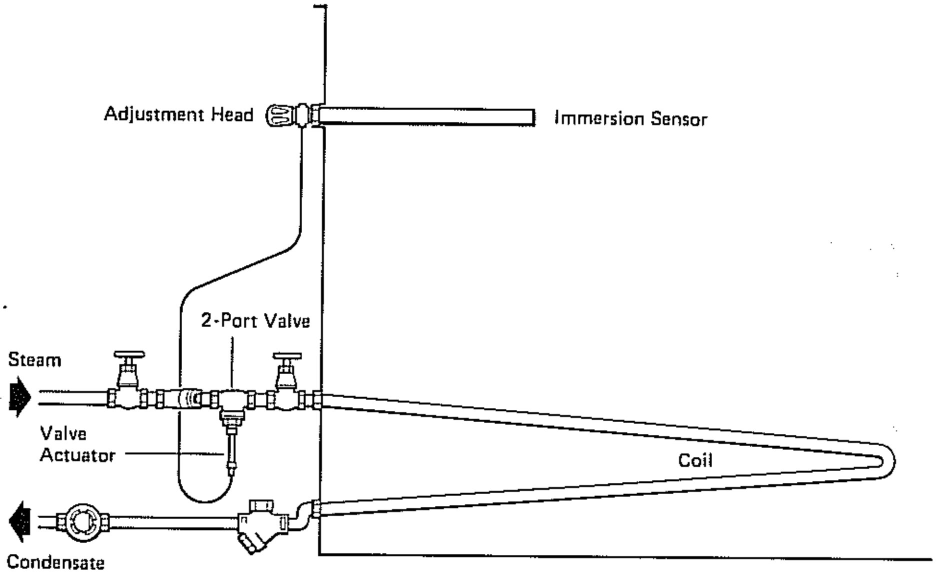


Fig. 89A Temperature Control of Tank Contents direction, increasing the steam flow. The control system is calibrated to control within a given temperature range and can be set to any temperature between the upper and lower limits by means of an adjustment knob.

Similar temperature control is achieved using pilot operated regulators. These regulators can use smaller sensing bulbs than the self acting controls described earlier and their more sensitive response is typically quicker acting.

A pilot operated regulator is shown in Fig. 91. Normal position before start up is with the main valve closed and the pilot valve held open by spring force. Entering steam passes through the pilot valve into the diaphragm chamber and out through the control orifice. As flow through the pilot valve exceeds flow through the orifice, control pressure increases in the diaphragm chamber, which opens the main valve. As the medium being heated approaches the preselected temperature, liquid in the bulb expands through the capillary tubing into the bellows and throttles the pilot valve. Control pressure maintained in the diaphragm chamber positions the main valve to deliver the required steam flow. When heat is not required the main valve closes tight to provide dead end shut off. The temperature setting can be changed by turning the calibrated adjustment dial These types of temperature controls are known as "modulating controls", since the steam supply is gradually increased or decreased in response to variation in the temperature of the medium being heated. This means that the steam pressure in the heating coil can vary from a relatively high pressure when the valve is wide open to practically nothing, or even vacuum conditions, when it is shut. (A vacuum can form as the residual steam in the coil condenses because the closed valve prevents any further steam from entering).

Proportional Control Band

Since these self-acting controls require a change in sensor temperature to effect a response in the amount of valve opening, they provide a set temperature value that is offset in proportion to the load change. Thus Fig. 89B shows that the proportional band of the control describes the amount that the temperature setting "droops" at full load. Both set point accuracy and system stability result when the regulator valve described in Fig. 90 is sized for the range of offset recommended. Main valves and pilots of Fig. 91 types are matched so that typically only a 6°F sensor bulb change results in full opening of the high capacity main valve.

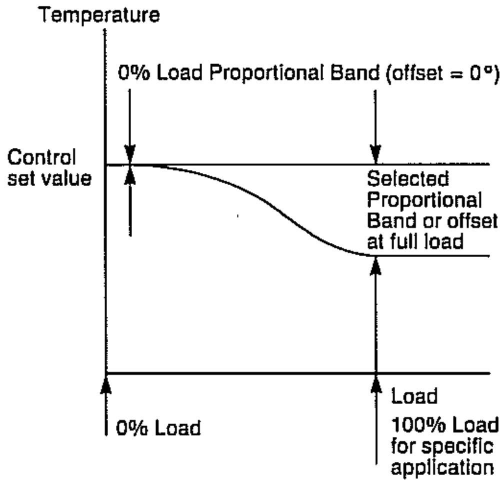


FIG. 89B ACCEPTABLE PROPORTIONAL BANDS FOR COMMON APPLICATIONS

Application	Proportional Band°F
Domestic Hot Water Heat Exchanger	7-14
Central Hot Water	4-7
Space Heating (Coils, Convectors, Radiators, etc.)	2-5
Bulk Storage	4-18
Plating Tanks	4-11

On certain applications such as hot water supply systems, periods of heavy steam demand alternate with periods of no demand. In such cases, it is possible to use the "on/off" type of temperature regulator. Here the control thermostat closes off the steam valve completely when the control temperature is reached and consequently the steam pressure in the primary side rapidly drops to zero. As soon as hot water is drawn off, cold make-up water enters and is sensed by the control system thermostat which opens the steam valve fully, giving a rapid build up of steam pressure in the primary side.

This section is essentially a brief introduction to the subject of temperature control, rather than a comprehensive coverage of the many types of control currently available for use on steam plant. In place of self-acting control systems, it is possible to govern valve movement by means of an external electrical or pneumatic source of power. Similarly, the opening characteristics of the valve itself

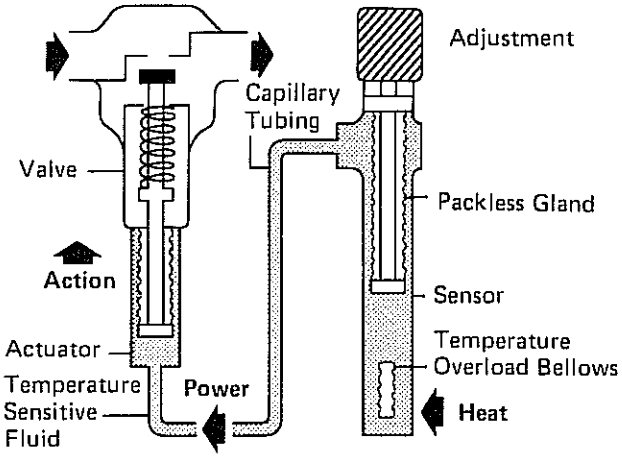


Fig. 90 Operating principle — Self Acting Control

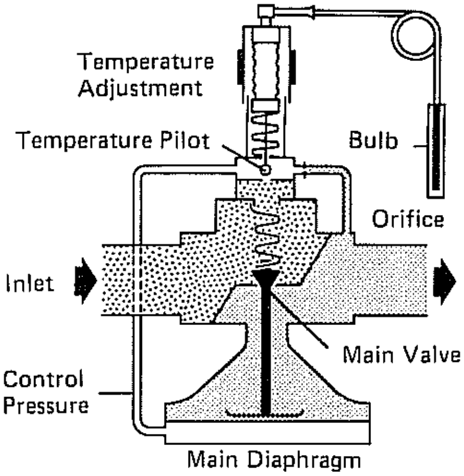


Fig. 91 Operating Principle — Pilot Operated Control

can fall anywhere between the fully modulating and on/off patterns described. However, the basic principles remain the same.

We must now consider how the installation of temperature control can affect the steam trap which is trying to drain condensate from the steam space.

If, for example, we attempt to lift condensate directly from the trap, then there will come a time when the control valve has reduced the steam pressure at the trap below that needed to overcome the lift. The flow of condensate will cease and the steam space will waterlog until the pressure builds up again. Even if this periodical waterlogging is acceptable, there is likely to be severe waterhammer when the control valve opens to allow steam into the waterlogged steam space. Waterhammer can also occur with on/off controls when the steam valve suddenly opens wide and allows high velocity steam into the equipment.

When a modulating control is used, the trap should be capable of giving continuous condensate discharge over a wide range of pressures. If maximum output is required from the unit the trap used must be able to discharge condensate and air freely and must not be of a type which is prone to steam locking. A thermostatic trap is not suitable because its fixed discharge temperature may cause condensate to be held back just when the control valve is wide open and the equipment is calling for maximum heat transfer.

The traps which give a heavy blast discharge, such as a large bucket traps, may upset the accurate temperature control of certain units because of the sudden change in pressure in the steam space which occurs when they open. This effect is most likely to be noticeable in equipment where the steam space has a high output in relation to its volume.

The most suitable type of trap for temperature controlled applications is the continuous discharge ball float trap with built in air vent (or steam lock release, if necessary). The trap will discharge condensate steadily as it is formed without upsetting pressure conditions in the steam space. It will not steam lock or air lock or attempt to control the discharge temperature of the condensate.

If waterhammer is likely to occur, the combined float and thermostatic trap is liable to become damaged and should not therefore be used. Another good choice is the inverted bucket trap which is more able to withstand the rigorous conditions. Wherever possible, both waterhammer and waterlogging should be prevented by allowing the discharge from the steam trap to run away by gravity. If the condensate has to be lifted, this should be carried out by a suitable pump rather than by the fluctuating pressure available at the trap outlet.

Elimination of steam leaks

Clearly there is little point in spending time and money in creating a highly efficient steam system and then failing to maintain it at this same high level. However, all too often leaking joints and valves are accepted as a normal feature of both steam and condensate services.

Even a 1/8" diameter hole can discharge

as much as 65 lb/hr of steam at 150 psig which represents a waste of approximately 30 tons of coal, 4800 galls of oil or 7500 therms of gas in an 8,400 hour working year.

Elimination of the visible leaks already mentioned is obviously reasonably straightforward. It is the invisible steam leaks through faulty steam trap that present a far more taxing problem.

Detection of Leaking Steam Traps

We know that the basic function of a steam trap is to discharge condensate but prevent any loss of live steam. If the trap happens to be discharging to atmosphere in a place where it can readily be observed, it should be possible to tell whether or not it is functioning correctly. Even under such conditions, however, the intermittent discharge pattern of say a thermodynamic disc type trap will present a very different picture to the continuous discharge of a ball float trap. The release of clouds of flash steam only serves to further confuse the uninitiated observer.

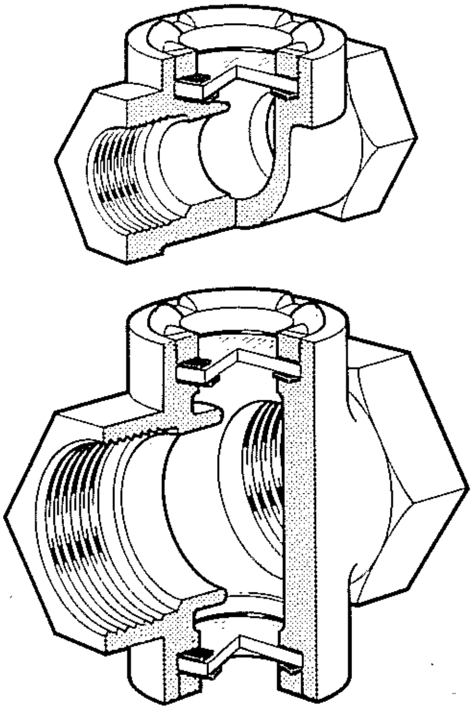


Fig. 92 Sight Glasses

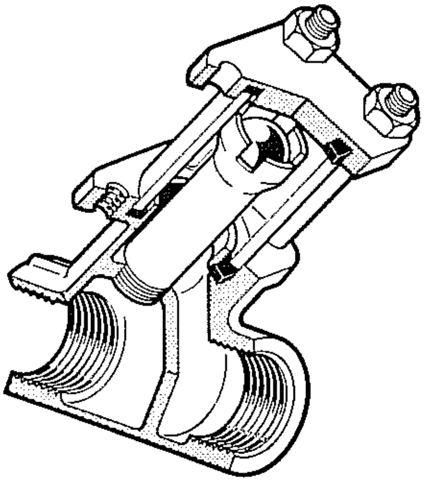


Fig. 93 Sight Check Unit

The problem is even greater when the trap is discharging into a condensate return line. The first indication that live steam is escaping through a number of steam traps in the system is often the release of excessive quantities of flash steam from the vent of a condensate receiver, or boiling of the boiler feedtank. While this serves to show that a problem exists, it does not help to pinpoint which traps are at fault.

A long standing method of checking the discharge from a steam trap is to fit what is known as a "sight glass" on the downstream side. Single window and double window sight glasses are shown in Fig. 92. With a sight glass at the outlet side of a steam trap, it is possible to see whether or not the trap is discharging condensate. It may also be possible to obtain some indication as to whether the trap is passing live steam. Unfortunately, the sight glass does not offer a truly clear-cut means of deciding exactly what the trap is discharging.

The "sight check" shown in Fig. 93 offers a number of improvements over the basic sight glass. As well as acting as a non return valve, regular lifting and closing of the ball check generally indicates that the trap is operating satisfactorily. The window of the sight check is also less susceptible to the build-up of opaque deposits which so often render the standard sight glass completely useless. If sight glasses or sight checks are fitted after a trap with a blast discharge action, they should be at least 3ft away from the trap outlet so that erosion of the glass is minimized.

A second, established, "method" of checking for steam leaks involves measurements of the temperature at, or close to, the steam trap. Pyrometers, temperature sensitive crayons, paint, band-aids and thermocouples all have their advocates, as does the simple expedient of spitting on the trap! Unfortunately these methods are of limited use, since the temperatures of condensate and flash steam on the downstream side of the correctly working trap will normally be around 212°F. This is exactly the same as the temperature of condensate and live steam on the downstream side of a defective

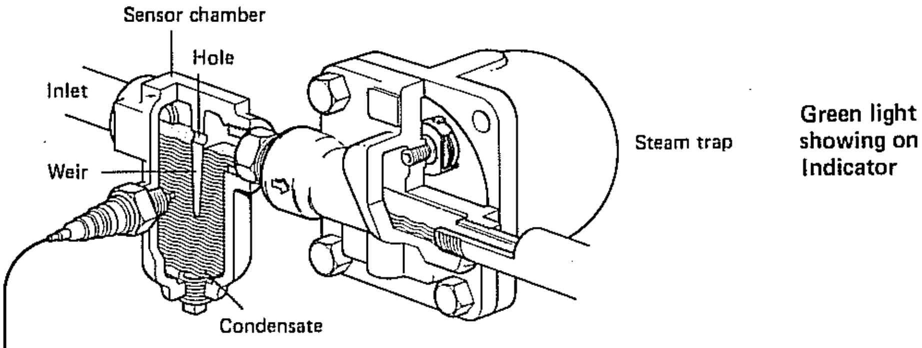


Fig. 94 Steam Trap Checking Device (Trap Working Correctly)

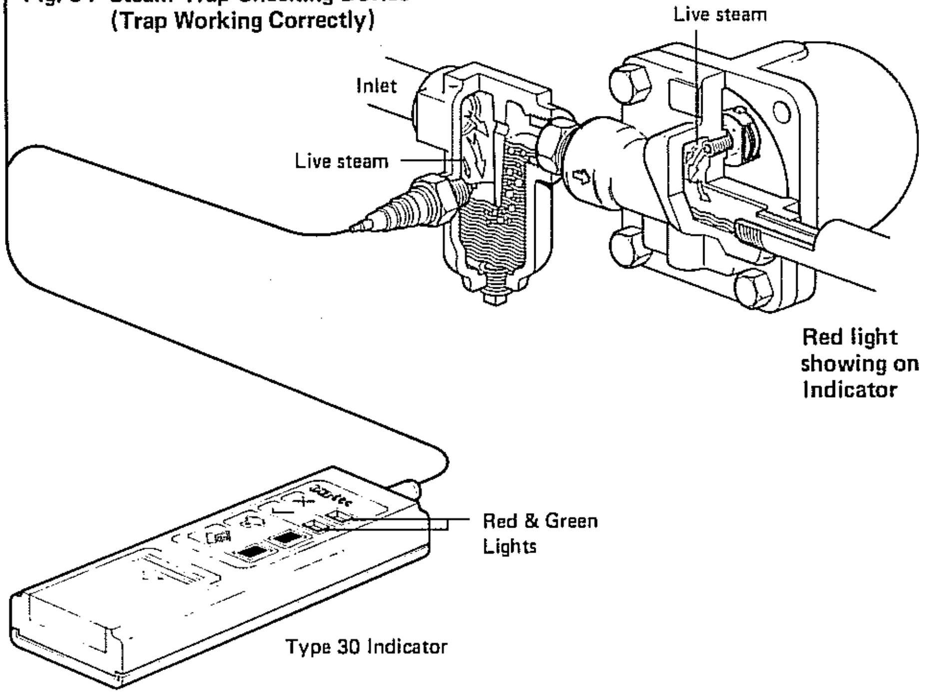


Fig 95 Steam Trap Checking Device (Trap Passing Steam)

trap. The only exception would appear to be the case of thermostatic traps which normally discharge below steam saturation temperatures. In theory, it is possible to detect a leaking trap of this type by measuring the rise in trap temperature which takes it closer to saturation. In practice, however, surface temperature measurements are subject to so many incidental errors, generally giving low temperature readings, that it is normally impossible to tell exactly what is happening.

A rather more reliable indication is given by the sound made by a steam trap. In this case, the ultrasonic leak detector is the modern equivalent of a screwdriver handle used as a make-shift stethoscope. This method is ideal for steam traps with a distinct signal, such as the regular click given by some thermodynamic traps. Defects can be detected by the untrained ear using the crudest "equipment".

Unfortunately there are many traps with no distinctive signal. Condensate and flash steam immediately downstream of the trap orifice can sound very similar to condensate and live steam at the orifice. Both sounds will be affected by the mass flow and also pressure. A further problem is provided by the way in which the sound of adjacent traps can be transmitted through the pipework. The ultrasonic leak detector can be used, but it needs careful tuning to match or suit trap conditions. A trained and experienced operator is essential.

A more recent development uses the electrical conductivity of condensate. This involves the fitting of a chamber containing an inverted weir upstream of the steam trap as shown in Fig. 94. With the trap working normally, condensate flows under this weir and out through the trap. The small hole at the top equalizes the pressure on each side. A sensor fitted on the upstream side detects the presence of condensate. By plugging in a portable indicator it is possible to check whether the electrical circuit is complete — a visual signal indicating that the steam trap is working.

If the trap becomes defective and blows a significant amount of live steam, the equilibrium on either side of the weir is disturbed. The sensor is no longer surrounded by conductive condensate, as shown in Fig. 95, and the broken circuit indicates that the trap has failed. The chief advantage of this method is the very positive signal which can be interpreted without resorting to experience or personal judgement. It is possible to wire-up a number of sensor chambers to one remote test point. This can be useful in the case of traps at high level or in ducts which would otherwise be fairly inaccessible.

It is, or course, possible for steam traps to fail in the closed position, resulting in water-logging of the steam space. In critical process work, this situation may be even worse than to have a trap which is wasting live steam. The failure of a trap in the closed position will soon be made apparent by the resulting reduction in equipment output.

By-passes Around Steam Traps

The habitual use of a by-pass around a steam trap can result in a significant waste of steam. Although a by-pass can be a very useful emergency device, it should never be regarded as a normal means of discharging condensate or air. Some trapping points still incorporate by-passes due to the misguided belief that they are essential to cope with start-up conditions. The operator may also be tempted to leave the by-passes cracked open during normal running. A valve used in this way will rapidly become wire-drawn and incapable of giving a tight shut-off. Once this has occurred, steam loss is inevitable. Steam traps are fully automatic devices which should be properly sized so that by-passes are unnecessary.

The use of by-passes round steam traps can also aggravate peak load problems. The needless loss of steam through open by-passes increases the demand on the boilers and intensifies all the troubles associated with peak load conditions.

The fact that some types of steam trap are subject to air-binding, or are unable to discharge properly the air which reaches them from the equipment is one reason why by-passes are fitted round the traps. Other reasons are to prevent steam-locking or to help traps which have inadequate discharge capacity during peak periods of condensation. If the trap needs help because it is air-binding the answer is not a by-pass but a trap which does not air-bind. If the trap needs help because it is steam-locking, it should be re-positioned or replaced by a trap fitted with automatic steam-lock release. If the trap needs help in coping with heavy start-up loads, the answer may be one of those already given, or alternatively, that the trap is under-sized and needs replacing by a trap with adequate discharge capacity.

It is common practice to fit a ½" by-pass round a ½" trap, a ¾" by-pass round a ¾" trap and so on. Even if the by-pass has to cope with a full condensate load in an emergency, the by-pass should be sized to match the trap orifice rather than the inlet and outlet connections. This will help to reduce unnecessary steam wastage on those occasions when use of the by-pass is essential.

Where by-passes have been installed to permit trap maintenance it is better to remove these and install unions on the trap line for quick removal and replacement with a spare unit.

Maintenance

In order to ensure that reducing valves, temperature controls, steam traps etc. give long and trouble-free service, it is essential to carry out a suitable program of planned maintenance. In general, this will mean regular cleaning of strainer screens and replacement of any internals which are beginning to show signs of wear. It is always advisable to hold a stock of spares recommended by the relevant manufacturer and a number of standby valves and traps which are on hand for use in an emergency.

Most steam system maintenance may have to be carried out during an annual shut down but it is usually easier to spread the work evenly over the course of the whole year. Most items will only need attention once every twelve months, although strainer screens may need more frequent cleaning, especially in the case of newly installed systems.

In conclusion, it may be useful to list some of the causes of problems commonly experienced with the various patterns of steam trap which are available.

Steam trap fault finding

THERMODYNAMIC DISC TRAP

Symptom — Trap Blows Steam

The trap will probably give a continuous series of abrupt discharges. Check for dirt (including the strainer) and wipe the disc and seat. If no better, it is probable that the seat faces and disc have become worn. The extent of this wear is evident by the amount of shiny surface that replaces the normal crosshatching of machining. This can be dealt with by:

a. returning the trap to the factory for repair.

b. lapping the seat faces and disc in accordance with the maker's instructions.

c. fitting a new seat unit and disc if the trap is of the type with a seat.

If records show that thermodynamic traps on one particular installation suffer repeatedly from rapid wear, suspect either an oversized trap, under-sized associated pipework or excessive back pressure.

Symptom — Trap Will Not Pass Condensate

While the traps discharge orifices may be plugged shut with dirt, this symptom is most likely due to air binding, particularly if it occurs regularly during start-up. Look at the air venting arrangements of the steam using equipment in general. In extreme cases it may be necessary to fit an air vent in parallel with the trap or to use, for example, a float trap with a built-in air vent instead of a thermodynamic trap.

BALANCED PRESSURE THERMOSTATIC TRAP

Symptom — Trap Blows Steam

Isolate the trap and allow it to cool before inspecting for dirt. If the seat is wire-drawn, replace all the internals including the thermostatic element. The original has probably been strained by the continuous steam blow.

If the valve and seat seem to be in good order then check the element. It should not be possible to compress it when cool; any flabbiness indicates failure. Flattening of the convolutions indicates waterhammer damage. If the waterhammer cannot be eradicated at its source a more robust type of trap must be fitted.

Symptom — Trap Will Not Pass Condensate

The element may be over-extended due to excessive internal pressure making it impossible for the valve to lift off its seat. An over-expanded element could be caused by super heat, or perhaps by someone opening the trap while the element was still very hot, so that the liquid fill boiled as the pressure in the body was released.

LIQUID EXPANSION THERMOSTATIC TRAP

Symptom — Trap Blows Steam

Check for dirt or wear on the valve and seat. If wear has occured, change the complete set of internals. It must be remembered that this type of trap is not self-adjusting to changes in pressure. If it has been set to close at a high pressure, it may not close off at a lower pressure. Try adjusting the trap to a cooler setting, making sure that it does not then water-log excessively. If it does not appear to react to temperature, a complete new set of internals should be fitted.

Symptom — Trap Will Not Pass Condensate

Check that it has not been adjusted to too cold a setting.

BIMETAL THERMOSTATIC TRAP

Symptom — Trap Blows Steam

Check as usual for dirt and wear on the valve. A bimetal trap has only limited power to close by virtue of its method of operation and the valve may be held off its seat by an accumulation of quite soft deposit.

This type of trap is usually supplied pre-set. Check that any locking device on the manual adjustment is still secure. If this seems suspect, see if the trap will respond to adjustment. If cleaning has no effect, a complete new set of internals should be fitted.

Symptom — Trap Will Not Pass Condensate

Bimetal traps have the valve on the downstream side of the valve orifice which means that they tend to fail in the open position. Failure to pass cold condensate indicates either gross mis-adjustment or complete blockage of the valve orifice or built-in-strainer.

FLOAT TRAPS

Symptom — Trap Blows Steam

Check the trap for dirt fouling either the main valve or the air vent valve. If a steam-lock release is fitted check that it is not opened too far (one quarter of a full turn is normally more than sufficient).

Make sure that the valve mechanism has not been knocked out of line either by rough handling or waterhammer, preventing the valve from seating. Check that the ball float is free to fall without fouling the casing which would cause the mechanism to "hang-up".

The air vent should be tested in the same way as the element of a balanced pressure trap.

The internals of a float trap should always be replaced in a complete set as supplied by the manufacturer.

Symptom — Trap Will Not Pass Condensate
Check that the maximum operating pressure marked on the trap is not lower than the actual pressure to which the trap is subjected. If it is, the valve cannot open and a valve and seat assembly with the correct pressure rating must be fitted. Make sure that this has sufficient capacity to handle the maximum load.

A leaking or damaged ball float is almost certainly the result of waterhammer damage and the problem should be tackled at its source.

Check that the air vent or steam-lock release (whichever is fitted) is working correctly.

INVERTED BUCKET TRAP

Symptom — Trap Blows Steam
Check for loss of water-seal. Isolate the trap, wait for condensate to accumulate and start up again. If this cures the trouble, try to discover the cause of water-seal loss. This could be due to superheat, sudden pressure fluctuations or to the trap being installed in such a way that the waterseal can run out by gravity.

Try fitting a check valve before the trap.

If the steam blow persists, check for dirt or wear on the valve and linkage. Replace valve and seat complete with lever.

Check bucket. If the bucket and/or lever is distorted, this points to waterhammer. Trace the source of the problem and try to eliminate it.

Symptom — Trap Will Not Pass Condensate
Check that the maximum operating pressure marked on the trap is not lower than the actual pressure to which it is subjected. If it is, the valve cannot open and a valve and seat assembly with the correct pressure rating must be fitted. Make sure that this has sufficient capacity to handle the maximum load.

While checking the internals, ensure that the air vent hole in the bucket is not obstructed, as this could cause air-binding.

Conclusion
It is important to know the type of trap discharge which should be expected when making maintenance checks. The following table sets out the usual discharge characteristics of the most common trap types:

STEAM TRAP FAULT FINDING CHART

TRAP	USUAL DISCHARGE PATTERN
Thermodynamic Disc	Blast action. Tight closure between discharges.
Thermodynamic Piston	Blast action. Continuous leakage through 'bleed' orifice when main valve is closed.
Balanced Pressure Thermostatic	Blast action. Tight closure between discharges.
Liquid Expansion	Continuous dribble discharge on steady, normal or heavy loads.
Bimetal	Continuous dribble discharge varying with the amount of condensate.
Float Traps	Continuous discharge varying with the amount of condensate.
Inverted Bucket	Blast action with tight closure between discharges, except on light loads when there is a tendency to dribble.

Questions

15. A flash tank is supplied by the trap draining an evaporator which works at 150 psi gauge and a steam consumption of 2000 lbs per hour. The flash steam from the vessel is fed to a tank heating coil at a pressure of 5 psi gauge. What is:-

    (a) the quantity of flash steam to be expected?

    (b) the quantity of residual condensate to be discharged from the flash tank.

    (c) the temperature of the condensate leaving the flash tank.

16. What is the main determining factor in deciding on the right place to fit an automatic air vent on a piece of steam heated process equipment?

17. Steam with a dryness fraction of 0.9 at 100 psi gauge passes through a reducing valve to a pressure of 30 psi gauge. What is the dryness fraction of the steam downstream of the valve?

18. What would happen if a float trap designed to operate on pressure up to 65 psi gauge was put on a line carrying steam at 90 psi gauge pressure? And why?

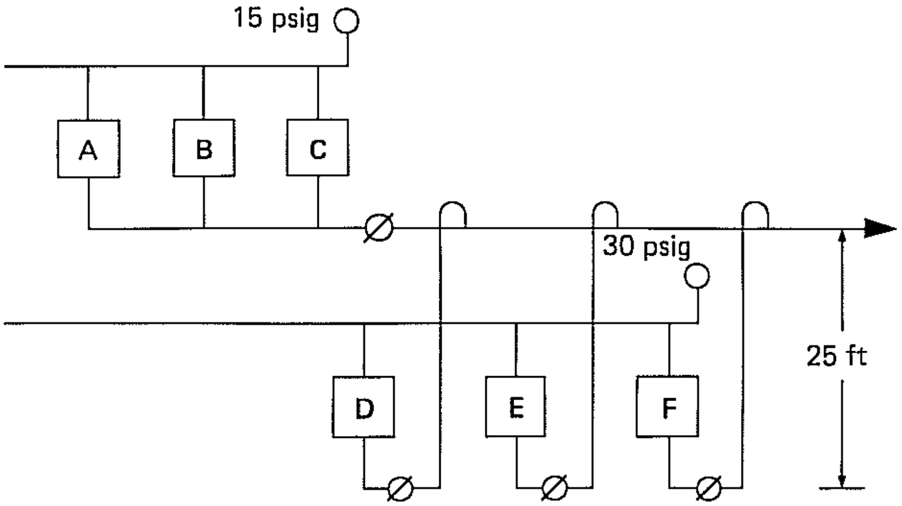
19. Does an inverted bucket trap automatically discharge air and if so, does it do so quickly or slowly? And why?

20. Three vessels, A, B and C are supplied with steam at 15 psi gauge and discharge through a single steam trap.

    The vessels D, E and F are supplied at 30 psi gauge and discharge through their own traps into lines which rise 25 feet to the main return. All the traps are of ample capacity, and there are check valves after the traps draining D, E and F.

    The six vessels start and finish simultaneously, but some of them waterlog even when all are hot.

    Which vessels are most likely to waterlog and why, and how can the trouble be cured?



21. A heat exchanger is supplied with steam at 100 psi, and on the secondary side of the exchanger 30 gallons per minute of water is raised from 160°F to 180°F. What weight of steam is condensed in each second? If the steam supply has a dryness fraction of 0.9, how much condensate must the steam trap handle?

22. The condensate in (21) above, is returned to the boiler feed tank, which is open to atmosphere. Here it would exist at 212°F but make up water at 65°F is added so that the final temperature of the mixture is 140°F. What proportion of make up water is added? The feed water is then heated to 180°F by bubbling in a small amount of steam from the 100 psi steam line. What weight of this steam must be added to each lb of the feed water at 140°F.

23. How much "flash" steam at atmospheric pressure was released from each lb of condensate leaving the heat exchanger steam traps in (21) above? If this steam had been taken off at 5 psi, how much would have been available?

Notes

Answers

1. From the Steam Tables:—

   Total heat of steam at 120 psig = 1193 BTU/lb

   Steam temperature at 120 psig = 350°F

   Condensate temperature 10°F below Steam = 340°F

   Sensible heat of water at 340°F = 311 BTU/lb

   If this condensate is replaced at the boiler feed tank with make up water at 50°F containing 18 BTU/lb, then the energy lost in the condensate is (311 – 18) = 293 BTU/lb

   The percentage is $\frac{293}{1193} \times 100 = 24.56\%$

2. Steam at 30 psi gauge contains latent heat amounting to 929.7 BTU/lb while at 150 psig the value is 858.0 BTU/lb. Thus a given heat load can be supplied by condensing 1.0836 lb of steam at 150 psig for each 1 lb which would be required at 30 psig an increase in steam flow of 8.36%.

   However, the weight of steam used is of no special importance in this context by definition the amount of energy is the same in both cases. What is important is the amount of any losses. If the condensate can be returned to the water feed tank at 212°F the flash steam loss will carry away (338.6 – 180.2) BTU/lb or 158.4 x 1.0836 BTU which is 171.64 BTU if 150 psig steam is used.

   At 30 psig the sensible heat lost by flashing from the condensate is (243 – 180.2) = 62.8 BTU/lb giving a heat loss which is smaller by 108.8 BTU per lb of steam used.

3. Heat added = Weight x Specific Heat x Temperature Rise

   = 100 x 8.34 x 1.0 x (190 – 60)

   = 10842 BTU

   The heat added is Sensible Heat.

4. The traps least likely to be affected by severe vibration are the liquid expansion type and the thermodynamic disc type. Neither of these use any pivoted parts which can wear.

5. Applications like a heater battery where the volume of the steam space is small and the condensation rate high, should drain through a trap which discharges condensate as soon as it forms, since any waterlogging will reduce heat transfer. This means that a mechanical trap is needed, and the choice will be between an inverted bucket trap and a ball float trap.

   The I.B. trap is rather more robust and will better withstand any waterhammer caused by discharging condensate into a pipe which lifts to an overhead return line. The ball float trap can incorporate an inbuilt air vent, and is a better choice if loads and pressure can change quickly.

6. As mentioned in (5) above, the ball float trap is the one which copes best with sudden pressure changes and fluctuating condensate loads. The least suitable pattern is the bimetallic thermostatic type. This responds relatively slowly, especially in those cases where the bimetal is of substantial dimensions.

7. The sudden drop in the supply pressure at the trap furthest from the supply end of the main, where the loads peaks is probably causing a loss of waterseal in this trap.

   At start up each morning, the heavy condensate loads reforms the waterseal. Once the line is working the condensate load is very light, and is insufficient to reform the seal when the normal supply pressure is restored after the peak loading has passed.

   The problem can be overcome by installing a check valve on the inlet side of the trap. High pressure I.B. traps often have an inbuilt check valve, since they are often used on superheated steam applications where the problem also occurs.

8. A bimetallic thermostatic trap is not suitable for draining a unit heater because of its waterlogging characteristic and its inability to respond immediately to variations in steam pressure or load. The use of a steam trap of this pattern would lead to variations in the air-stream temperature, and unless very great care is taken the waterlogging will lead to corrosion of the air heater battery tubes.

9. The Sensible Heat of condensate at 200 psi gauge is 362 BTU/lb. On discharge to the atmosphere, the water can only hold 180.2 BTU/lb and the surplus of (362 – 180.2 = 181.8) will boil off some of the water. The water and steam will both be at atmospheric pressure and at 212°F. Since the latent heat at 212°F is 970.6 BTU/lb the proportion of flash steam is 181.8/970.6 = 0.187 lb/lb and the total flash steam loss is 187 lb/hr.

10. Before the trap – a Strainer (if not built into the trap)
    a conductivity Sensor Chamber

    After the trap – a Sight Glass (if conductivity Chamber has not been fitted)
    a Check Valve
    an Isolating Valve

11. The lift in the return pipe of 20 feet will cause a back pressure of 8.6 psi. With an additional pressure in the return line of 3 psi the total back pressure is 11.6 psi. Since the steam supply is at 15 psi the differential available to push water through the trap is only 3.4 psi. Clearly, the trap is then undersized and the plant will waterlog.

    Further, under start up conditions the condensate load is likely to be something like twice the normal load and the pressure in the steam space is often lower than normal. A trap should be selected which is capable of passing at least 660 lbs/hr with a differential pressure of 3.4 psi.

    Lifting the condensate in this way is not the best way of dealing with the application. Instead, it is better to allow the water to drain freely by gravity to the receiver of a condensate pump which can then lift it to the overhead line. If this is not done, waterlogging at start up is sometimes so severe that water is discharged by the automatic air vent on the jacket.

12. Saturated steam, or condensate at saturation temperature, is at a temperature sufficiently above the boiling point of the filling in the element of a balanced pressure trap that the filling boils and builds up enough pressure to expand the bellows. This closes the valve of the trap and indeed this happens at a temperature of a little below saturation temperature. If the steam around the bellows is at an even higher temperature but at the same pressure, i.e. superheated, then an excess pressure is generated within the bellows, which can become damaged.

    The only balanced pressure traps which can be used when superheat (up to 90°F above saturation temperature) is present are the latest high pressure capsule pattern. In these, the flexible diaphragm is contained within an enclosure strong enough to withstand the overpressure generated.

13. Since steam locking of the traps means that they are not discharging condensate but instead the equipment is being waterlogged, it follows that output is reduced. This means that batch cycle times are lengthened, or continuously operating equipment must use steam at higher pressures and temperatures than would otherwise be needed. In either case the standing heat losses from the equipment are increased, so steam locking does lead to increased steam consumption.

14. The mixture temperature of 235°F is the temperature of steam at 8 psig, or 22.7 psi absolute. Thus, the air must be making up the total pressure of 30 psi absolute by supplying 7.3 psi absolute.

15. Sensible Heat in condensate at 150 psig = 338.6 BTU/lb

    Sensible Heat at 5 psig = 195.5 BTU/lb

    Excess = 143.1 BTU/lb

    Latent heat at 5 psig = 960.8 BTU/lb

    Proportion of Flash Steam $= \frac{143.1}{960.8} = 0.149$

    Quantity of Flash Steam = 0.149 x 2000 = 298 lb/hr

    Quantity of Residual Condensate = 2000 – 298 = 1702 lb/hr

    Temperature of Residual Condensate = 227.4°F

16. The main determining factor is the location of the REMOTE POINT along the path the steam must follow as it flows through the equipment. The steam should push the air before it as it moves towards the remote point (or points), so that the equipment is substantially purged of all air when the air vents close.

17. The Total Heat of the steam is not changed as it passes through the pressure reducing valve. So, on the upstream side of the valve, the steam holds the full amount of Sensible Heat plus 0.9 of the full Latent Heat.

    Thus, Total Heat content at 100 psi = 309.0 + (0.9 x 881.6)

    = 309.0 + 793.4 BTU/lb

    = 1102.4 BTU/lb

At the downstream pressure,

Sensible Heat = 243 BTU/lb

Available Latent Heat = 1102.4 – 243 = 859.4 BTU/lb

Full Latent Heat at 30 psi = 929.7 BTU/lb

Dryness Fraction = $\frac{859.4}{929.7}$ = 0.924

18. The force tending to close the valve in a ball float trap is that provided by the steam pressure over the area of the valve seat, acting on the lever arm. The opening force is the buoyancy of the float acting in the opposite direction at the end of the lever arm. For a ball float and lever arm of given dimensions, the opening force is a fixed value, and of course in a given trap the area of the valve seat is fixed.

    Thus, the trap can only have sufficient opening force to be able to open the valve against a given pressure, which is specified by the makers as a maximum value for each trap. Steam at 90 psi gauge would provide a closing force so high that in a trap designed to operate at pressures of 65 psi or lower, the valve head would be held down on the seat and no condensate could be passed.

19. An I.B. trap will automatically discharge air reaching it, but only at a slow rate. The air must pass through a very small vent hole in the top of the bucket. The differential pressure pushing it through the hole is the difference in water level between the inside and outside of the bucket. Even on the largest traps this is no more than 4" water gauge. It follows that the air discharge rate is severely limited. The vent hole should not be enlarged since if it leaks steam, the bucket loses buoyancy and may fail to float and close the trap discharge valve.

20. Vessels A, B and C are group trapped and any or all of them will waterlog because of this.

    The trouble is easily cured by fitting individual traps to each of the vessels.

21. Heat Load = Weight/hour x Specific Heat x Temperature Rise

    = 30 x 60 x 8.34 x 1.0 x 20

    = 300, 240 BTU/hr

    Steam Condensed = $\frac{\text{Heat Load}}{\text{Latent Heat}}$

    = $\frac{300{,}240}{881.6}$

    = 340.6 lb/hr

    Condensate Load = $\frac{\text{Steam Condensed}}{\text{Dryness Fraction}}$ = $\frac{340.6}{0.9}$

    = 378 lb/hr

22. (a) Each lb of water at the final temperature of 140°F is made up of

X lb of condensate at 212°F and (1 – X) lb of make up at 65°F. By a balance then:–

(X x Specific Heat x [212 – 140]) =
([1 – X] x Spec. Heat x [140 – 65])

$$\begin{aligned} 72\,X &= 75 - 75\,X \\ 147\,X &= 75 \\ X &= 0.51 \end{aligned}$$

and the make up is 0.49 or 49% of the feed water.

(b) Heating this feed water up to 180°F will require:–

Heat Addition = 1 lb x 1.0 BTU/lb°F x (180 – 140)°F

= 40 BTU/lb

The injected steam will give up its Latent Heat and some Sensible Heat in cooling down to 180°F, so:-

Energy available from Steam = 881.6 + (309 – 147.8)

= 1042.8 BTU/lb

Steam Added = 40/1042.8

= 0.0384 lb/lb

23. Sensible Heat of Water Condensed at 100 psi = 309 BTU/lb

Sensible Heat at Atmospheric Pressure = 180.2 BTU/lb

Excess to Evaporate Flash Steam = 128.8 BTU/lb

Latent Heat at Atmospheric Pressure = 970.6 BTU/lb

(a) Flash Steam Loss $= \frac{12.8.}{970.6} = 0.1327$ lb/lb

(b) If flash steam were collected and used at 5 psi pressure,

Sensible Heat at 5 psi = 195.5 BTU/lb

Excess to Evaporate Flash Steam = 113.5 BTU/lb

Latent Heat at 5 psi = 960.8 BTU/lb

Flash Steam Available for Use $= \frac{113.5}{960.8} = 0.118$ lb/lb

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