Armstrong

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A GUIDE TO CONDENSATE DRAINAGE OF SPACE HEATING EQUIPMENT

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1.0 INTRODUCTION

Steam is used all over the world as an efficient, dependable heat source. One of its most common applications is warming air that has been drawn from outside, to provide comfort. This application is called space heating.

There are numerous types of space heaters. They range from single rows of pipes to multiple rows of finned tubes. There are door heaters, make-up air pre-heaters and re-heaters that are part of large air handling systems, and small, self-contained systems called unit heaters that incorporate a fan package. Any of these space heating systems can be configured for vertical or horizontal air flow.

When compared to high temperature water (HTW), another popular heat source, steam has a number of advantages. One of the most important is that steam flows where it is needed, virtually on its own, by following the pressure drop. The constant flow HTW systems must be designed and operated carefully at all times in order to achieve proper operation. Weight is another factor, as considerably more support is needed for piping bearing water than steam. Other advantages of steam systems include shorter cool-down cycles, and often, lower pressure operation for a given temperature.

In general, steam is preferred as a heating medium because it is inexpensive to generate, easy to transport, and readily controllable. Steam temperature may be raised or lowered by changing the pressure. Steam pressure can be adjusted in turn, by a control valve, operated remotely by the signal from a thermostat or similar temperature sensitive device. The very nature of space heating systems, however, as well as their operating environments, require special consideration be paid to their design.

Steam systems which are designed to have the pressure varied (or modulated) as a part of their normal operation are called modulating systems. Space heating equipment is most often placed in a low pressure, modulating steam system. As with any steam heat exchanger, condensate is created when heat is transferred from the steam to the air passing across the coil. What makes space heating systems a special challenge is the fact that the pressure inside the coil can fall below atmospheric, even when condensing steam at a fairly high rate. With greater pressure pushing on the condensate from outside the coil than from within, it cannot drain. The result is a flooded coil.

In space heating systems, if the condensate is allowed to collect when the incoming air temperature is sufficiently low, the water freezes. In severe cases, coils and piping can be ruptured. Even in warmer weather when freezing can't occur, flooding is still likely to cause two other problems, water hammer and corrosion.

In space heating systems then, it is essential to prevent a vacuum from forming, causing the coil to flood, and precipitating freezing, water hammer, or corrosion.

2.0 **HOW THE VACUUM IS FORMED**

It is common for a vacuum to form within the coil of a properly designed and operating space heating system if it is not specifically prevented. This is due to the fact that low steam pressures are supplied to the coil, and they are intentionally raised and lowered to provide needed changes in temperature. Since the coil is a closed chamber, it can maintain pressures less than 0 psig if that is what is required to achieve the necessary temperature rise though the system.

Heat exchange is still taking place, forming condensate, but now there is no pressure to push the condensate through the trap. This problem is compounded if the condensate load is significant when the vacuum occurs. On a **15** psig steam coil, the load is in fact more than 75%. Take for example, a steam/air coil being used to heat make-up air.

The design outside air temperature is -10 degrees F. A constant outlet air temperature of 70 degrees F is required. The system is designed for 15 psig full pressure, and is operating at full load. In order to determine the steam pressure at 75% load we need to determine steam temperature. We can calculate this by applying two heat transfer equations to both the full load and the 75% load conditions.

2.1 THE HEAT TRANSFER FORMULAS

1) $Q = UA \, \Delta T \text{ coil}$

where Q = Heat transfer quantity
U = Material coefficient
A = Coil surface area
ΔT coil = Temperature difference between inside and ouside of coil

and

2) $Q = \text{CFM} \; 1.08 \, \Delta T \text{ air}$

where Q = Heat gain rate of the air
CFM = Air volume
1.08 = Air density / specific heat factor
ΔT air = Air temperature rise across coil

For our 15 psig make up air heater, the material coefficient (U), the coil surface area (A), the air volume (CFM), and the air density/specific heat factor (1.08) are constant. This means that the heat transfer rates (Q) are proportional to the temperature differences (Δ **T 's).** We can assign values to these (Δ T 's) at design conditions.

2.2 FULL LOAD CALCULATIONS

To find the temperature difference between (△ T coil) the inside and outside of the coil, subtract the average air temperature.

1) Average air temperature = 30°F (half way from -10” F to 70° F)
Steam temperature @ 15 psig = 250°F
Temperature difference △ T coil = 250” F - 30°F
= 220°F

To find the temperature rise (△**T** air) across the coil, subtract the entering air temperature from the discharge air temperature.

2) Entering air temperature = **-10° F**
Discharge air temperature = **70°F**
Temperature rise △ T air = 70° F- (-10” F)
= 80°F

2.3 75% LOAD CALCULATIONS

Since the heat transfer rates are proportional to the temperature differences (AT ‘s), to analyze and compute the steam temperature at 75% load we must determine the values of the temperature differences (△ T ‘s).

1) △ T coil @ 75% load = △ T coil x .75
= 220° F x .75
= 165” F
2) AT air@ 75% load = △ Tair x .75
= 80° F x .75
= 60°F

Since 70° F (T leave) is held constant by the temperature controller, we can solve for T enter:

Tair = T leave-T enter
T enter = T leave - △**T** air
= 70° F-60°F
= 10° F

Note that this air is still sub freezing. If the coil does not drain properly, it can freeze.

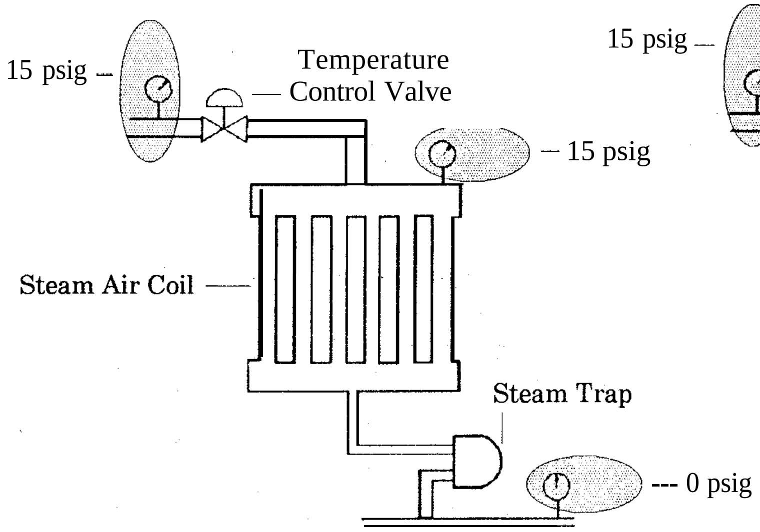
The average air temperature can now be calculated:

Average air temperature (T outside) = 40° F (halfway from 10° F to 70° F)

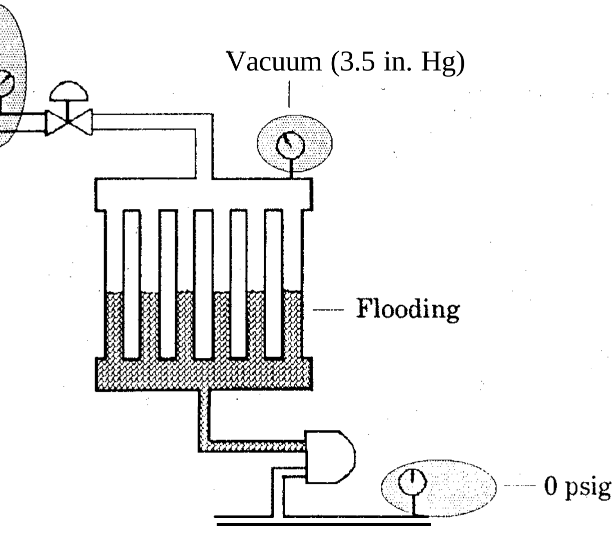
Returning to our first formula, we can solve for the inside temperature of the coil, which is the steam temperature at 75% of full load. Based on the temperature difference from the inside to the outside of the coil, which we know, and the average air temperature (T outside), we can calculate the steam temperature (**T** inside).

△ T coil = T inside - T outside
T inside = A T coil t T outside
= 165°F + 40° F
= 205” F

Looking up 205 degree F steam temperature on a steam table we find it relates to a pressure of -1.5 psig or 3 inches of mercury. We can conclude, therefore, that a significant amount of condensate is forming (75% of the full load), and yet the system is in a vacuum and unable to drain.



FULL LOAD CONDITIONS



75% LOAD CONDITIONS

3.0 COIL PROBLEMS INDUCED BY FLOODING

Without a positive differential pressure, the coil cannot drain, even if there is no trap and the outlet of the coil is open directly to atmosphere. As more and more steam condenses, the water level rises. This flooding not only cuts down the amount of coil area where heat transfer can take place, decreasing heater efficiency, but may lead to problems that can eventually ruin equipment.

The most dramatic of these problems is the freezing of condensate inside the coil, piping, and related equipment when the incoming air temperature is sufficiently low.

3.1.0 THE MECHANICS OF FREEZING

Most substances expand when heated, and contract when cooled. Water, however, differs in that it expands not only when heated, but also as it begins to freeze.

3.1.1 TEMPERATURE OF MAXIMUM DENSITY

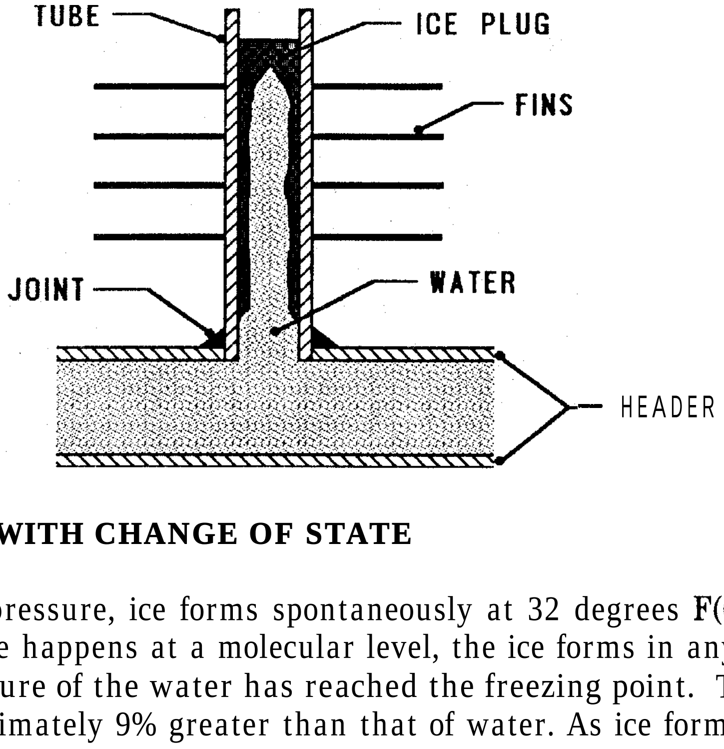
Water is one of the few liquid substances that has a temperature of maximum density (39.2 degrees F). The coefficient of expansion of water is positive above this temperature and negative below it. This causes the water to expand when heated or cooled relative to the temperature of maximum density.

3.1.2 ICE FORMS AT THE AREAS OF GREATEST HEAT EXTRACTION

In an open pool water cools uniformly due to convection until it reaches the temperature of maximum density. Thereafter, colder water tends to stratify at the top. This occurs because the maximum amount of heat extraction takes place in the areas of greatest temperature differential. As the temperature at the surface is lowered, the water there expands and is buoyed up by the denser water beneath it.

The same is true in a closed vessel such as a coil or piping, except the area of greatest temperature differential is near the wall. This results in colder water temperatures along the inside surface of the piping than at the center.

Ice, therefore, will form as a film along the inside surface of coils and pipes, and as a plug at any opening.



3.1.3 EXPANSION WITH CHANGE OF STATE

At atmospheric pressure, ice forms spontaneously at 32 degrees F(0 degrees C). Since change of state happens at a molecular level, the ice forms in any part of the water where the temperature of the water has reached the freezing point. The specific volume of ice is approximately 9% greater than that of water. As ice forms in the low regions of the pipe, it floats to the top, enhancing plug formation. Once the ice has formed a complete film and plugs in a system, the expansion pressurizes the warmer water at the core.

Ice exhibits a normal positive coefficient of expansion, so further cooling of the ice does not increase the pressure in the system (as temperature lowers it becomes marginally less dense).

3.1.4 PRESSURIZING WATER LOWERS THE FREEZING POINT

At atmospheric pressure water changes to ice at 32 degrees F, as we've said. When water is pressurized, however, the freezing point is lowered so the water at the core must achieve a lower temperature in order to freeze. We have also seen that water is maximally dense at 39.2 degrees F and that below that temperature it will expand in volume. Therefore, as the temperature falls the water keeps expanding, further pressurizing the system.

As you can see, the forces at work here are dynamic. The freezing temperature will keep lowering as the pressure goes up until either all the water is frozen, or until the vessel ruptures. In a closed system, the bursting temperature for 2 inch pipe is 23 degrees F and for 3/4 inch pipe it is 12.5 degrees F, assuming iron pipe with a tensile strength of 60,000 lbs./sq. inch. Of course if the vessel ruptures, the pressure returns to one atmosphere and any remaining water immediately freezes. This effect causes most people to believe that it is the ice that ruptures the coil, when in fact it is the water.

RELATIONSHIP OF **FREEZING** POINT TO PRESSURE FOR WATER

Freezing Point		Pressure	
°C	**°F**	ATM	PSI
0	32	1	0
-5	23	590	8,660
-10	14	1,090	**16,000**
-22	-7.6	2,047	30,000

3.1.5 NON-FREEZE COIL DESIGNS

There is a class of coils called non-freeze coils that are designed to avoid freezing in hostile environments. They are designed in a manner that keeps the first row (that closest to the entering air stream) filled with steam at all times. The non-freeze statement refers, however, to properly installed and drained coils. Once condensate has flooded a coil, no design will keep it from freezing in the presence of frigid air.

3.2.0 WATER HAMMER

Space heating systems have another problem that originates in flooded areas. Water hammer, sometimes called steam hammer, is usually detected by the noise it makes. Unfortunately, the results of water hammer are not limited to annoying noises. Water hammer can acquire the force of a steel sledge, crushing floats and bellows in traps and other equipment, and sometimes bursting coils and related piping.

Water hammer is created when a flooded or partially flooded system receives a shock. There are three separate types of shock known to cause water hammer, and all three can occur in a flooded space heating system.

3.2.1 HYDRAULIC SHOCK

Hydraulic shock can be generated when a valve is closed too rapidly in a flooded line. The valve is most likely to be a check valve, but it can be a control, or any other sort of valve.

Since water is incompressible, the surge from the valve is carried through the water column, accompanied by the characteristic sound of hammering in the pipe. This shock wave takes its toll, expanding the pipe, valves, and fittings along the entire system until it is dissipated.

3.2.2 DIFFERENTIAL SHOCK

Differential shock originates in partially flooded pipes and tubing when there is a bi-phase mixture present. The gas may be steam, flash steam, or air. This becomes a problem because the gas, under pressure, can move at a high velocity relative to the liquid in the system.

As the gas moves over the top of the condensate in the system, it creates waves which eventually rise to the point where they block off a section of the pipe. When this happens, a seal of condensate is formed, with the gas upstream and low pressure downstream. The gas cannot flow through the water seal which, therefore, becomes a piston that is accelerated downstream until it is stopped by a piece of equipment or a turn in the piping.

3.2.3 THERMAL SHOCK

The final type of shock, thermal shock, can also be the hardest to detect. It occurs when steam enters a flooded line and becomes surrounded by relatively cold condensate.

Steam, a gas, is much less dense than water. At atmospheric pressure steam occupies approximately 1,600 times the volume of the same weight of water. When this steam collapses, as it must when cooled by the surrounding condensate, it leaves a void which is immediately filled by water flowing from all directions. The water impacts at the center of the void, sometimes with great force.

Thermal shock is likely to occur in grid-type heat exchange coils that allow steam to fill perimeter tubes from both ends. Waves of condensate can trap bubbles of steam in the center of the tube. The small implosions that occur there tend to chip away at tube walls, and remove oxide layers that would normally prevent future corrosion.

Another source of thermal shock is any heat exchange coil that is not drained promptly at start up when quantities of cold condensate are present. When the control valve opens, thermal shock will occur at the point where the hot steam and cool condensate mix.

The sound of water hammer is a good clue that coil flooding has occurred, and must be prevented.

3.3.0 CORROSION

Corrosion is another problem common to flooded coils. In steam systems, corrosion is generally the product of the reaction between noncondensible gases and condensate, and the metal piping and equipment. The most troublesome gases commonly found are oxygen and carbon dioxide. Although deaerators and water-side chemistry minimize accumulations of these gases, some remain in the system where they pose no great threat until the system floods. Severe corrosion problems can damage or destroy piping and any equipment in the affected system.

3.3.0.1 CORROSIVE GAS SOURCES

Corrosive gases, such as carbon dioxide and oxygen, are introduced into steam systems from three sources. The first is during start up when the coils and piping are full of air which must be removed in order that steam can fill and heat the system. The second is in relieving the vacuum that often forms in modulating systems. This is usually accomplished using a vacuum breaker, a device which draws atmospheric air into the coil.

The third, and most common source of these gases, is the boiler feedwater. Gases are dissolved in the water and chemically tied to it by common salt and mineral content. Feed water treatment usually incorporates the addition of carbonates and bicarbonates which become a source of carbon dioxide and oxygen during the thermal cycle.

3.3.0.2 CORROSIVE GAS REMOVAL

Most boiler systems incorporate a deaerator for removing corrosive gases from the feedwater. These devices treat both the returned condensate and the raw make-up water by heating the water and adding chemicals that draw off the gases.

When water is heated, the gases come out of solution and are released as bubbles along the area of greatest heat transfer, where they can be removed long before the water boils. Cooling has the opposite effect, and if the gases are not removed before the liquid cools again, they return to solution.

3.3.0.3 FLOODING AND CORROSION

In the heating coil, we must be concerned about corrosion because the deaeration process is not 100% effective. There is also a likelihood of gas build up in the coil due to start up conditions and opening vacuum breakers.

The gases actually become corrosive only when in solution with the condensate, and then, only if it is a high concentration. In coils, the air is often trapped in pockets. If the system floods, the condensate cools, and the gas goes into solution in a small area, making the solution both highly concentrated and very corrosive.

3.3.1 CARBON DIOXIDE

The usual source of boiler make-up water is common ground water. Among the normal minerals distributed in that water are various carbonates and bicarbonates. Water-side treatment removes a great deal of these minerals by demineralization and distillation, but the remainder are decomposed when the water is heated. The carbonate and hydroxide ions that separate out remain in the boiler water, requiring intermittent boiler blowdown. The other by-product, carbon dioxide CO,, , is released into the steam.

Being a noncondensible gas, the carbon dioxide will accumulate until it is passed from the system by a trap or thermostatic air vent, as long as the system functions properly. If the system is flooded, however, the thermostatic air vent will not be able to vent air because of inadequate pressure differential and the trap discharge is water sealed. The carbon dioxide that is trapped in the system combines with the cooling condensate to form carbonic acid CO, + $H_2O = H_2CO_3$.

Although carbonic is a relatively weak acid and the concentration levels are not particularly high, it can and has caused considerable problems inside steam systems. In the boiler itself, the corrosion by-products of the carbonic acid form an extremely high heat-flow-resistant scale which often causes boiler over heating. Downstream of the boiler, carbonic acid attacks any iron-bearing metals. The result of this type of corrosion is characterized by a gradual thinning of the pipe walls that appears first in the threaded areas, and eventually cause leaks. Piping, steam traps, coils, air vents, and control valves all suffer damage from carbonic acid corrosion. Corrosion effects from carbon dioxide in the system are accelerated when combined with oxygen.

3.3.2 OXYGEN

Oxygen also exists in boiler make-up water. At higher temperatures and pressures, it is released from the water and removed by deaerators. At lower temperatures, however, the oxygen dissolves in the water and it is this solution that causes corrosion damage to steam systems.

Oxygen is another noncondensible gas. It is evacuated from a properly designed system wherever possible by air vents. When the system is flooded, however, air vents and traps cease to function in their normal manner and the oxygen accumulates, dissolving in the cooling condensate. The dissolved oxygen may attack the system in two distinct ways.

The first manner in which dissolved oxygen can attack a steam system is by causing an increase in the condensate alkalinity. When water is run through an iron pipe, the pipe starts to oxidize. Some of the iron will dissolve in the process of oxidizing, or rusting. This coats the pipe with a thin film of hydrogen bubbles, plating the pipe with a protective covering. The other product of this reaction is to turn the water slightly alkaline by forming dissolved ferrous hydroxide. Ferrous hydroxide combines with dissolved oxygen in a system to form insoluble hydrated ferric compounds. These insoluble compounds break down quickly, thereby forming more ferrous hydroxide.

The second manner of attack is against the thin film of hydrogen that forms along the walls of piping and equipment, and serves to prevent further corrosion of the metal surfaces. Dissolved oxygen will combine with this free hydrogen, breaking up the film and forming water, thereby exposing the surface to further corrosion.

Oxidation is characterized by pitting of the surface of iron bearing pipes and equipment. Obviously, the elimination of the protective hydrogen film coating and metal surfaces will accelerate corrosion caused by carbonic acid as well as that caused by oxidation.

4.0 PROPER DESIGN GUIDELINES

There are a number of steps you can take to protect your system against these problems. Freezing, water hammer, and corrosion occur only if the system is allowed to flood in the first place. All of these problems can be prevented if the system is properly designed so that it will not flood. There are concerns other than flooding that affect the performance of space heaters that must be considered when designing a system.

Proper design can be easily achieved by following simple guidelines, once you are acquainted with the general configuration of a steam/air coil system and the role of each of its specific parts.

4.1.0 PROVIDE CLEAN, DRY STEAM

Steam should be taken from the top of the main in order to assure that it is both clean and dry. The branch should be pitched toward the main 1/2 inch/foot if the runout is less than 10 feet. If the runout exceeds 10 feet, pitch the branch toward the coil at 1/2 inch/l0 feet. A drip leg and trap are required whenever a branch line exceeds 10 feet or wherever the control valve is below the main regardless of branch runout. The drip leg and trap prevent condensate build up ahead of the valve when it is closed.

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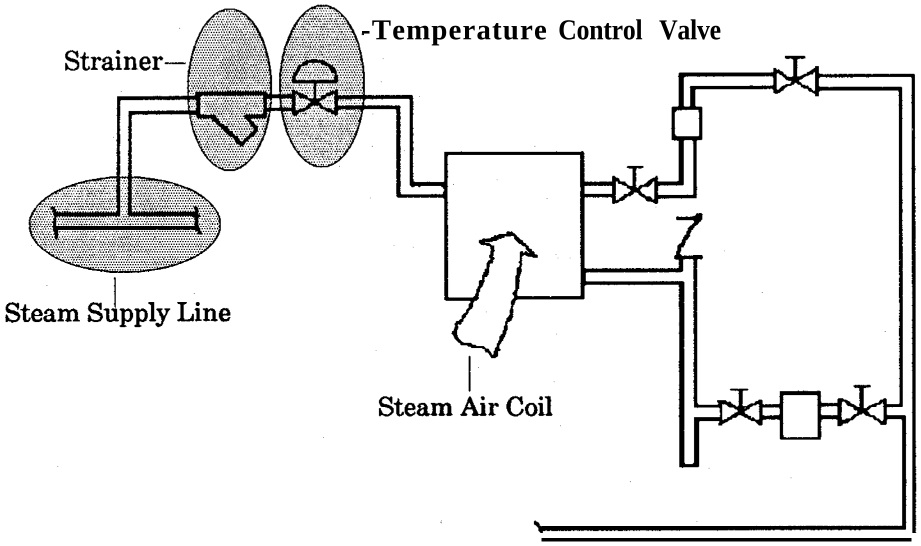
The steam should pass through a strainer to remove any dirt particles from the steam before it reaches the control valve. One variation is to trap the branch with an inverted bucket steam trap connected to the blow-down of the strainer, minimizing strainer cleaning problems. The IB is used because of its excellent dirt handling capabilities. Steam then passes through the externally operated pressure control valve and on to the coil.



4.2.0 REMOVE NONCONDENSIBLE GASES

A thermostatic air vent should be located at the top of the coil above the outlet. Air that is trapped in a coil creates cold spots, reducing efficiency and increasing the likelihood of corrosion. The air vent helps ensure that no air will be trapped inside the coil during start-up.

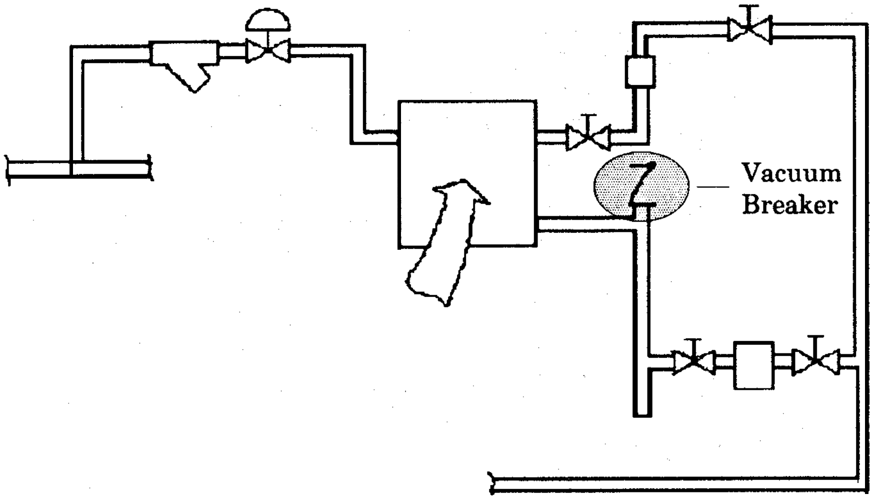
Thermostatic air vents are open when the steam system is cold. When the steam is turned on, air in the system is pushed out ahead of the steam and is evacuated to the condensate return line. When the air has been evacuated, steam reaches the thermostatic element and the surrounding temperature rises sufficiently to close the vent.

4.4.0 ELIMINATE THE VACUUM WHERE AND WHEN IT OCCURS

A vacuum breaker should be installed at the coil outlet because vacuums first form at the coil discharge. As we've seen, it is simple under normal conditions to create a vacuum in a coil supplied with modulating steam pressure. A vacuum inside the coil will prevent condensate drainage from the coil to the higher pressure outside of the system even when the trap is wide open.

Vacuum breakers are mechanical devices that open whenever the pressure inside the coil drops below atmospheric. This draws in the outside air breaking the vacuum. They should be piped to atmosphere rather than the return line in order to avoid drawing condensate into the coil from a flooded return line.

For modulating systems below 30 psig, Armstrong recommends an F&T trap with an integral vacuum breaker to simplify piping. The outlet of the trap should be connected to the return line along with the branch drip trap and the thermostatic air vent. It is important that the condensate return line be a true gravity return system, with no back pressure.

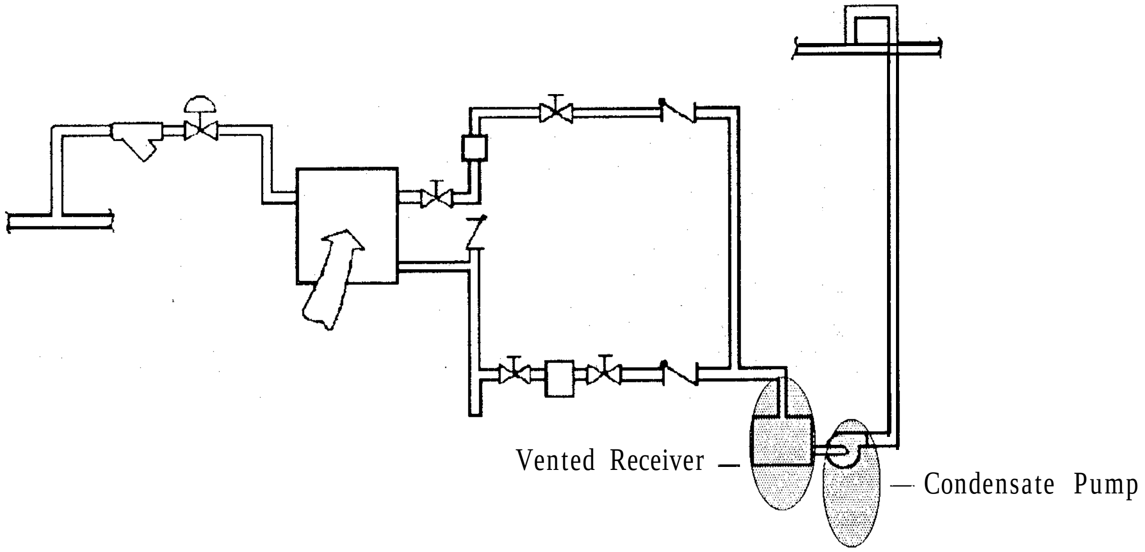


5.0 PRESSURIZED RETURN LINES

In actuality, many steam systems do not have true gravity drain systems. Even if the system was designed with a gravity drain in the first place, years of adding equipment and branches without changing the pipe size of return lines has probably resulted in undersized return lines. Another factor is the scale and corrosion that build up over the years in the lines and tend to decrease the flow area of the returns. Both of these problems create back pressure, which is sure to cause coil flooding if proper precautions are not taken.

Back pressure is guaranteed in any system where the condensate is elevated without pumping. It takes one pound of steam pressure to lift a column of water about 29 inches. Another way to look at this is that when elevating condensate, one (1) pound of back pressure is created for every 29 inches the condensate must be elevated. If the steam pressure modulates below the amount required to elevate the condensate to the return line, the water backs up into the coil.

If it can be avoided, do not elevate the return lines. If elevated return lines are necessary, or if back pressure is present for any reason, install a vented receiver and an auxiliary pump to push the condensate when sufficient steam pressure is unavailable. If pumping is impractical, and you have a system with back pressure, you must take additional precautions to prevent coil flooding.



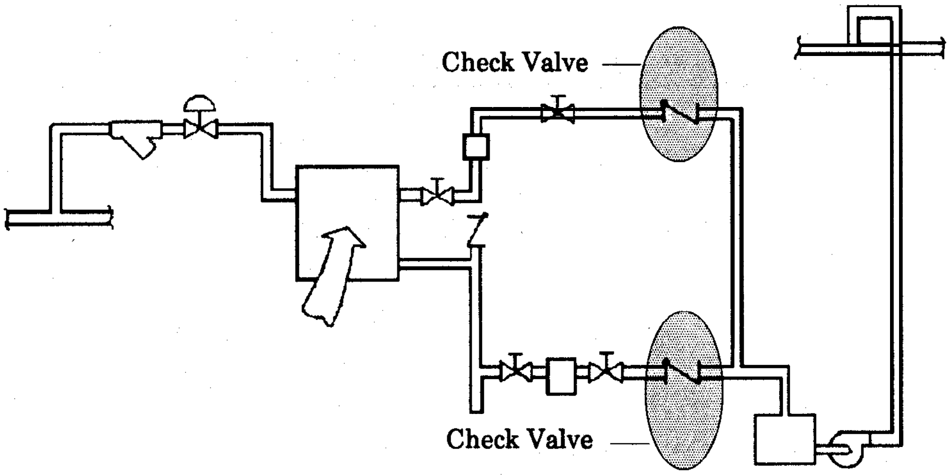
5.1.0 MECHANICS **OF** BACKFLOW

If condensate builds up unabated in the return line, it will backflow through the trap. The F&T trap is a continuous drainer with a thermostatic element. Even if the trap is closed when the differential reverses, the cool condensate will cause the thermostatic element to open, flooding the condensate chamber and opening the float valve.

Without restriction by the trap, the condensate rises in the return line and the coil. The condensate level in the riser and the coil differ only due to the remaining pressure in the coil. Eventually the condensate will reach the level of the air vent. The thermostatic vent opens when it is sufficiently cooled and floods the coil from above.

5.1.1 INSTALL CHECKVALVES

Check valves are mechanical valves that are closed automatically by the reversal of flow. These valves should be located at the discharge of any trap or air vent connected to a pressurized or elevated condensate system. Since check valves are a source of hydraulic shock, it is advisable to use slow closing check valves, or those that close at the instant of flow reversal.



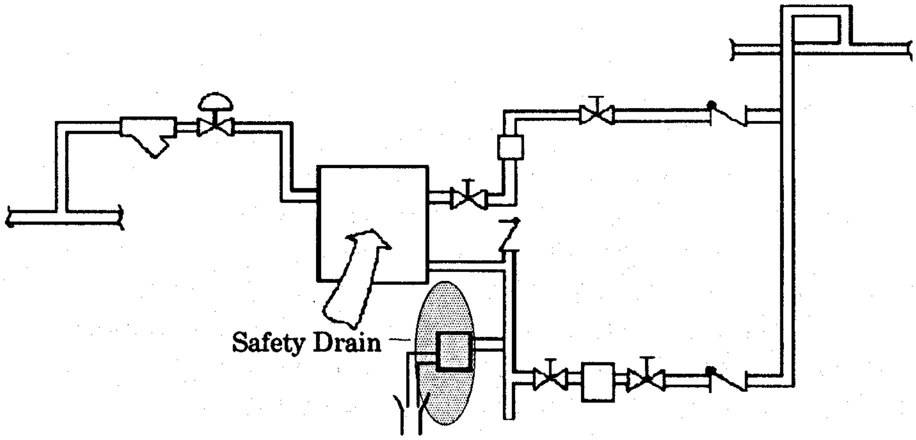
5.2.0 CONDENSING AHEAD OF THE TRAP

Backflow into the system has been eliminated, and the condensate remains in the return riser. Once enough pressure is introduced into the coil to create a sufficient positive differential to raise the condensate, flow reverses again and the check valves open, draining the system.

While the trap is closed, however, the coil is still condensing steam which is rising in the drip leg. If not prevented, this condensate will rise to flood the coil.

5.2.1 INSTALL A SAFETY DRAIN

A safety drain is a second trap that is sized the same as the primary trap. It is located between the coil and the primary trap. This trap discharges to an open drain or to atmosphere. If condensate is unable to drain from the primary trap for any reason, it backs up in the drip leg until it reaches the level of the safety drain which opens, draining the system. In this manner, condensate is prevented from accumulating in the coil.



6.0 SUMMARY

In summary, freezing, water hammer, and corrosion are three common problems in steam/air coil systems. All are the result of system flooding, and can be prevented by proper installation and maintenance. First, provide the system with clean, dry steam. Second, connect a thermostatic air vent at the top of the coil above the outlet. Third, install a vacuum breaker on the discharge side of the coil. Fourth, use a properly sized F&T steam trap to drain the coil. Fifth, return the condensate to the boiler by gravity or with an auxiliary pump if possible. Sixth, if an elevated return is necessary, provide check valves and a safety drain for the system.