ENGINEERING LETTER | 25

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INDUSTRIAL STEAM HEATING SYSTEMS

INTRODUCTION

Reduced to its barest elements, a steam heating system consists of a boiler to convert water to steam, piping to conduct the steam to where it is to be used, a coil or other surface for condensing the steam and transferring the latent heat from the steam to the air, a trap to prevent the steam from passing through the coil before it is condensed, and return piping to bring the condensate back to the boiler. The purpose of this Engineering Letter is to provide a basic overview of the major elements found in typical industrial steam heating systems.

SYSTEM COMPONENTS

Boilers

While the boiler and its attachments are major factors in the steam heating system, it is not the intent of this Letter to do more than point out that boilers are generally divided into "Low Pressure" and "High Pressure" designs. Low pressure boilers, running up to 15 psig, are generally used for space heating with unit heaters, make-up air units, heating and ventilating units, etc. There is no benefit in raising the steam pressure or temperature much beyond the minimum needed to boil water and to provide the pressure necessary to drive the steam through the piping system. Higher pressures not only require more expensive piping and fittings but the added danger involved in higher pressures and temperatures has given rise to municipal and insurance codes requiring additional safety features, licensed operators, etc.

High pressure boilers generate more than 15 psig. High-pressure systems are used either to provide adequate pressure for long runs of steam piping or to develop higher temperatures for process systems. The air passing across a steam coil cannot be heated any higher than the steam temperature. At 5 psig the steam temperature is 227°F. At 200 psig it is 388°F. There is little difference between the amount of total heat at 5 psig and at 200 psig but the fact that the heat is released at a higher temperature gives the capability of producing substantially higher final air temperatures.

Piping

Piping is addressed on page 3.

Steam Coils

The steam coil is the part of the system designed to condense the steam and transfer the latent heat to the airstream. If all coils are 100% efficient, then what differentiates a good steam coil from a poor one? Here are some important factors:

1. The metal or metals of which a steam coil is manufactured are relatively unimportant insofar as heating capacities are concerned but may be extremely important in determining the life of the coil. Coils have been successfully made from almost every conceivable metal. Copper tubes have long been a favorite because of copper's supposed corrosion resistance and ease of soldering, brazing, and forming. However, other tubes, particularly steel, are quite adaptable to the manufacture of steam coils. Conventional copper or steel tube coils are usually adequate for commercial heating installations.

2. Industrial heating and process applications demand the most rugged possible coil construction. The most practical coil is one using heavy-gauge, welded-steel tubes with an oval-shaped cross-section. The resultant strength is several times that of light-gauge copper or steel tubing. A round tube will split when filled with water and frozen, as so often happens when the condensate return system fails for one reason or another. An oval tube deforms slightly, increasing its cross-sectional area, but rupture normally will not occur if the oval tube is made of heavy-gauge, high-strength steel.

3. Condensate is water and it runs downhill. The condensate drains from the coil's tubes by gravity. Good coil installation produces an almost uniform pressure through the coil. The steam pressure cannot and does not force the condensate through the tubes. For high heating capacities, the tubes should be vertical. This allows quick drainage and clearing of the tubes. In addition to reducing the possibility of freezing, the washing action brought about by the quick drainage also reduces the boundary layer of water in the tubes and improves heat transfer.

An advantage of vertical-tube coils, often overlooked, is their lack of susceptibility to water hammer. Water is virtually incompressible. When driven through a pipe or coil tube at the velocity of steam, it "hammers" the turns in the pipe or the end of the coil tube. Vertical drainage eliminates water hammer in vertical-tube coils. Horizontal-tube coils are destroyed by repeated water hammer. Typically, water hammer results in a fairly uniform bulge, or rounding, at the end of the steam coil tube. When the bulge finally ruptures it is frequently mistaken for failure due to freezing. The visual distinction between the results of the two kinds of failures is that water hammer gives a symmetrical bulge at the end of the tube, where freezing gives a non-symmetrical distortion.

4. Lack of maintenance, particularly in industrial plants, can cause deterioration of the coil and of its capacity. Coils with thin copper tubes and thin aluminum or copper fins are physically weak. Normal industrial cleaning methods can be too rough. Cleaning aluminum or copper fins with an air hose is almost certain to deform the fins and result in a loss of heating capacity. Welded-steel tubes with steel fins bonded to them and reinforced with hot-dipped galvanizing offer the physical strength to withstand scrubbing or high-pressure air-hose cleaning.

Although not precisely related to the subject of this Engineering Letter, it seems worth recording the “Steam Formula”, the equation used to predict coil performance at one steam pressure and entering air temperature from the performance of the same coil at the same standard air velocity but at a different steam pressure and/or entering air temperature:

$$\frac{TR_1}{TR_2} = \frac{ST_1 - EAT_1}{ST_2 - EAT_2}$$, where

TR is air temperature rise through the coil,
ST is steam saturation temperature,
EAT is entering air temperature.

Traps

All steam traps serve the same basic purposes:

1. The trap prevents the higher steam supply pressure from passing directly to the return line. If the supply pressure had ready access to the return piping, the whole system would be at the same pressure and there would be reduced steam flow.

2. The steam must not be allowed to pass through the trap until it has condensed in the coil. The whole purpose of the steam heating system is to condense the steam in the coil, and nowhere else.

3. When a steam heating system is started up, the system is filled with air. The water used to produce steam contains dissolved air, which is released when the water is heated. It may also contain nascent oxygen and noncondensable gases which can form CO_2 and which, if not released immediately from the coil, will inhibit heat transfer and may attack the tube walls. The air and gases must be allowed to pass through the coil and out of the trap. On high-pressure steam systems, the trap may not have enough air-venting capacity. Refer to note 3 on condensate piping later on in this Letter.

All traps are rated on the basis of constant steam and condensate flow at a differential in pressure across the trap. In practice, constant flow rates are seldom encountered. Temperature control variations are the principal cause of uneven flow rates. All steam traps should be sized to handle three times the anticipated maximum condensate rate to ensure condensate removal under surge-load conditions and cold startups.

Condensate will not flow from one side of a trap’s orifice to the other without a pressure differential.

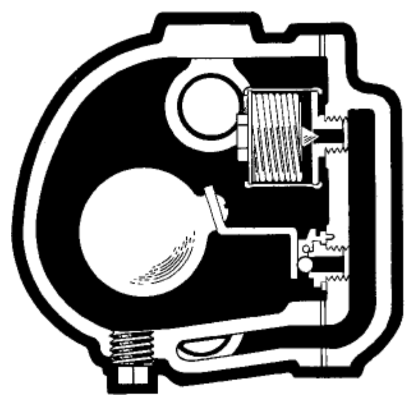
For systems with non-modulating types of steam control, the trap must at least be below the coil to ensure that the water level in the trap is below the coil.

For systems with modulating types of steam control, the trap should be at least twelve inches below the coil to ensure the trap of a water head when the modulating valve has throttled down to 0 psig at the coil. Therefore, for modulating systems, the trap should be sized to handle the maximum condensate load at the pressure available in the water leg only. For a twelve-inch leg, this would be .43 psi.

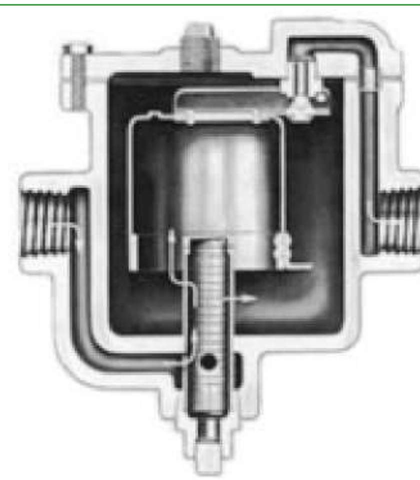
The two types of traps of most interest for industrial heating and process work are described below:

The Float and Thermostatic Trap shown in Figure 1 is the closest thing to a general-purpose trap for industrial heating and process work. F and T traps function well over broad ranges of pressure and steam volume. They are especially suitable for low to medium pressures up to about 20 psig. However, they should not be used on systems involving steam that is superheated more than a few degrees. In operation, air is vented through the thermostatic element on systems with under 20 psi steam pressure at the coil. Condensate raises the float, opening the lower port.

The Inverted Bucket Trap of Figure 2 should, generally, take the place of the F and T trap for both high pressure steam and for superheated steam systems. There are other types of traps, but they should not be used as condensate traps on heating and ventilating systems.



Float and Thermostatic Trap (Courtesy of Sarco Co.)
Figure 1



Inverted Bucket Trap (Courtesy of Sarco Co.)
Figure 2

PIPING

The key to successful steam piping requires that these two principles be kept in mind:

A. Steam is a gas and can flow in any direction, but condensate, a liquid, flows downhill.

C. Both steam and condensate cause friction when they flow. As with air flowing in ducts, consideration must be given to velocity, pipe size, and pressure drop.

Bringing the steam to the coil is not nearly so difficult nor troublesome as getting the condensate from the coil back to the boiler. Because "steam" is the working element in the system and condensate is, after all, only ordinary water, we tend to concentrate our attention on the steam piping and ignore the condensate piping. We should do just the opposite. Although the following discussion treats steam piping first, it is the return piping that demands most careful attention.

Referring to Figures 3 (Low Pressure) and 4 (High Pressure) the elements of a good steam-piping system are:

A. Steam mains must be sized based on the steam pressure, how much of the pressure may be used to overcome friction drop, and the length of the longest run. (System designers accustomed to air-duct design will recognize the basic similarity.) A nomograph for sizing steam pipes is contained on page 8.

Pipe expands when heated. The increase is .00008 in./ft.°F. A 100-foot long main for 50 psig steam would expand .00008(100) (298-70) = 1.82". Piping must be installed so the expansion may take place without placing stress on the pipe or the equipment to which it is connected. Some of the methods employed to accommodate expansion are metal bellows expansion joints, expansion loops (Figure 5), swing connections (Figure 6), and pipe-support brackets employing rollers.

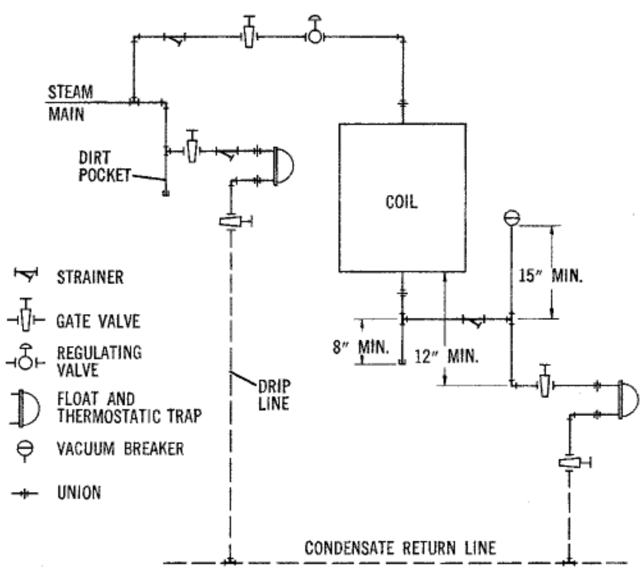


Figure 3 - Low Pressure 0-15 lbs.
Typical connections - multiple-coil arrangements require each coil to be connected as shown.

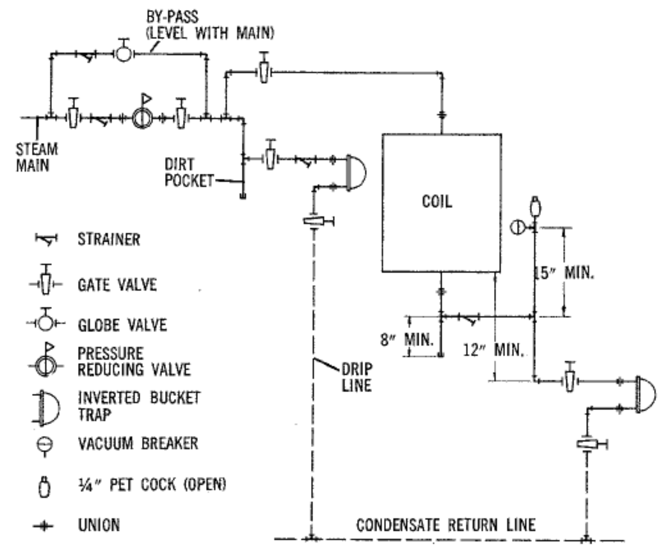


Figure 4 - High Pressure 15 or more lbs.
Typical connections - multiple coil arrangements require each coil to be connected as shown, except for the pressure reducing valve and by-pass line which is used only once ahead of a system.

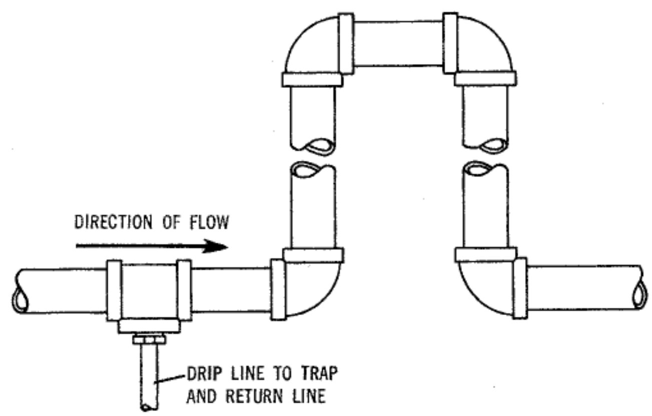


Figure 5 -Typical Steam Piping Expansion Loop

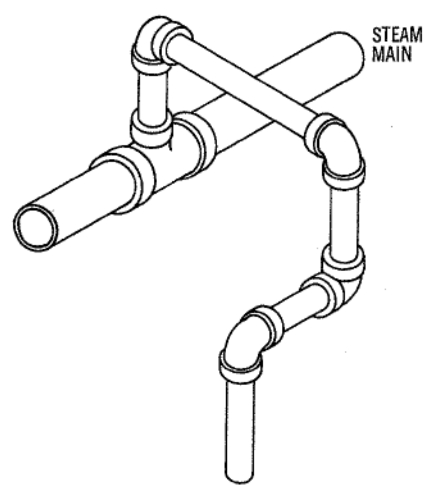


Figure 6 -Typical Swing Connection

Some steam condenses in the steam mains. The amount may be minimized by insulating the pipes and by using superheat, but all steam supply piping should provide for condensate drainage.

Vertical-steam pipes cause no particular problem if the steam if flowing down, but long up-flowing steam lines can be troublesome. Water hammer can be avoided by installing a short horizontal swing connection and drip leg every 20 to 40 feet.

The condensate that forms in the steam pipe is passed through a trap to the return (condensate) line. (Sometimes the connection and trap are called the *drip leg* and *drip trap.)* See Figure 7.

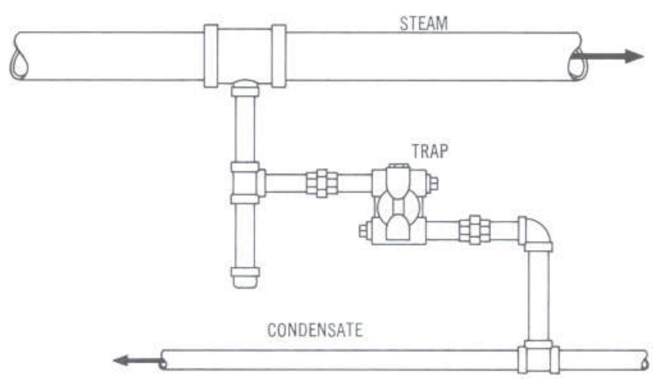


Figure 7 -Drip Leg and Trap Systems Use Swing Connections

The purpose of good drainage and drip lines is to avoid water hammer. Steam traveling at high velocity has the capability of scooping up condensate and driving it, in slugs, against a pipe turn, valve, coil, etc. The hammering effect can be violent enough to burst pipes. The only prevention of water hammer is to keep the steam lines "dry", i.e., clear them of condensate at frequent intervals.

B. Steam supply to the coils should consist of these components:

1. A drip line and trap should parallel the coils unless the coils are located quite close to a drip line on the main. The steam supply should rise above the drip line, as it approaches the coil, for best drainage.

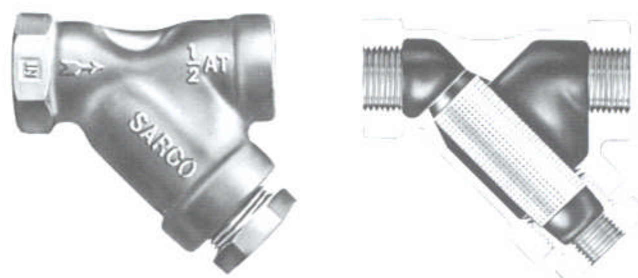
2. Swing connections, see Figures 3, 4, and 6, from the main to the branch and from the branch to the coils.

3. A strainer to keep foreign matter out of the valves, coils, and traps. See Figure 8.

4. A shutoff valve for possible maintenance use.

5. A pressure-control valve.

6. A union. By putting unions and shutoff valves on both sides of coils and traps, an individual coil or trap may be removed without shutting down the entire system.



Steam or Condensate Strainers (Courtesy of Sarco Co.)
Figure 8

C. Condensate (return) piping should include:

1. A stub pipe or "dirt pocket", at least 8" long, directly below the coil. This is simply a settling spot for dirt and scale, and should be periodically emptied.

2. The strainer, Figure 8, with the dirt pocket, keeps extraneous matter from the mechanism of the trap. Boilers, pipes, and coils are apt to contain small particles of scale, weld-spatter or thread-turnings. The strainer in the condensate line is intended primarily to pick up dirt, pipe dope, etc., that find their way into the system during installation. The element should be removed from the condensate strainer assembly after the system is fully in operation. It should not be replaced. The strainer on the supply side of the coil is adequate for the entire system. Since "high pressure" steam implies high velocity and rapid scouring of dirt from pipes, especially when the system is new, it may be best to use strainers that are available with accessory blow-down valves for frequent and quick cleaning.

3. On high-pressure systems, over 15 psig, it is desirable to provide more air-venting capacity than is incorporated in the trap. This may be done in one of two ways:

a. With an air eliminator, which is a thermostatic vent. This type should be used only if it can be guaranteed to operate at the elevated temperature corresponding to the steam temperature.

b. By means of a petcock left continuously open. The lost steam is far less costly than the damage done to coils by inadequate venting.

Improper venting of high pressure systems is a major cause of coil problems. The high-temperature gases entrained in the steam, if not eliminated, may combine with the condensate to form acids.

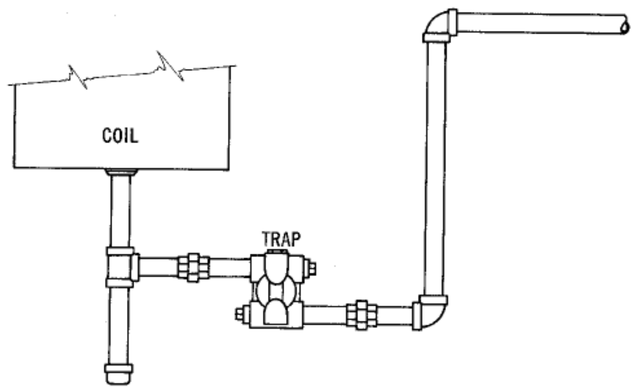


Figure 9 - Overhead Return Line

4. The traps, described in a previous section, must be installed below the coils. Water flows downhill. Overhead return lines (Figure 9) are perhaps the biggest single cause of freezing, water hammer, coil corrosion, and trap failure.

While it is theoretically possible for the steam pressure in the coil to push (lift) water into an overhead return line there are just too many reasons why the pressure may not be available when most needed. Consider, for example, a 25 psi boiler system. Assuming a 5 psi drop through the lines, the remaining 20 psi should be able to raise water 46 feet. (One sea level atmosphere is equal to 14.7 psi. This is, in turn, equivalent to a "head" of 34 feet of water. Stated differently, standard barometric pressure at sea level is 34 feet of water. Since 14.7 psi will "lift" 34 feet of water then 1 psi will lift 2.3 feet and the 20 psi in the example will lift 46 feet.) On this basis a 15-foot "lift" into an overhead line would seem reasonable.

But, on the first cold Monday morning of winter, when the plant heating and process systems were shut down over the weekend, every terminal on the steam system will be at maximum demand. The boiler may develop only 20 psi.

The steam will travel at higher-than-ordinary speeds, and the pressure drop may become 10 psi. The steam coils, normally thought of as having negligible pressure drop, will be temporarily starved for steam. The steam will condense so rapidly in the cold coils that the 10 psi at the coil inlets might drop to 5 psi in the coils. Five psi will lift water 11 1/2 feet, but cannot buck the 15-foot rise. The trap and coil will become waterlogged. Water hammer may be severe in horizontal tube coils. If the coil is handling air below 32°F. the coil will freeze.

Or, consider shutting down the same system at the end of the heating season. As the steam pressure drops, a point is reached where the coil is again waterlogged. A stagnant water level in a coil is an invitation to corrosion.

5. Not shown in Figures 3 or 4, but often advantageous, is an "aquastat" strapped to the return line just beyond the trap. It is set so cold temperature, indicating no condensate flow, shuts off the fan and thereby prevents freezing air from passing over a water-filled coil. It does not prevent the occurrence of water hammer in horizontal tube coils.

6. Where overhead returns are unavoidable, the only good solution is to drop first into a vented reservoir (sometimes called receiver) and use a motor-driven condensate pump to lift the water into the overhead line. This relieves the trap and coil of the dangers of waterlogging.

Despite all of the reasons for not using overhead returns without condensate pumps, such installations are found. In fact, they are so common that they will be discussed here. This is best done by differentiating between those systems that use modulating steam control and those that use non-modulating control.

a. Non-modulating control systems may be calculated as the steam pressure is always great enough to overcome the rise in the return line. It can be argued that there are steam systems that do not involve handling low-temperature air and therefore present no problems of freezing. Such a system might be a process system completely enclosed within a manufacturing plant. However, even in such a system there comes a time when the steam valve is shut off. The condensate that is, at the moment, on the supply side of the trap cannot be discharged from the system (unless fitted with another small trap line that can drain this trapped water into a sewer) and if the water level happens to be such that it settles out across a coil and is allowed to sit there for any length of time, the coil is apt to corrode at the water surface.

b. Modulating systems present a unique situation in that under **most** conditions the only pressure available at the trap is the water leg between the coil and the trap. For example, a coil that will heat from -10°F. to 60°F. with 5 psig (227°F.) steam will heat from -4°F. to 60°F. with 0 psig (212°F.) steam. This not only makes control difficult but aggravates the condensate removal problem. Therefore, a modulating system must be provided with a vacuum-breaker on the **return** side of the coil to ensure that the trap will at least have equal pressure on the upstream and downstream sides - plus the maximum water head over twelve inches that space will allow. (A vacuum-breaker is just a swing check valve installed so it opens into the system.) Obviously overhead returns cannot be tolerated on this type system without the use of a vented reservoir and condensate pump.

c. Due to the difference in volume between water and steam, condensate pipes may be sized at 60% of the diameter of the steam pipe, for gravity-return systems. Pumped systems may be sized at 40% of the steam pipe diameter.

CONTROL METHODS

Control, when referring to steam, means control of the air temperature leaving the coil. Proponents of other heating methods point out that temperature control is difficult with steam. This is a fair criticism. Compare a steam coil to a gas burner, for example. The heat released by the gas burner is a more or less direct function of the amount of gas burned.

Contrast this to a 5 psig steam system. The maximum temperature of the coil, at 5 psig, is 227°F. By throttling the steam pressure down to 0 psig the temperature can be reduced only to 212°F. This difference doesn't allow good control. Attempting to go to a lower temperature necessitates operating at a less than atmospheric pressure and introducing more air into the coil through the vacuum-breaker. This raises the very sort of condensate drainage problems that were discussed in the previous section.

However, there are methods of obtaining satisfactory control.

A. **On-Off.** Two-position control is relatively trouble-free but gives the least desirable type of temperature control. In Unit Heaters it is accomplished by leaving the steam "on" all the time and turning the fan on or off as required by a thermostat. In Make-Up Air and most process and ventilation systems, where constant airflow is desired, the steam is turned full-on or full-off. Before dismissing such systems as too primitive, recognize that most residential heating is done by basically on-off systems. On-off steam systems have one great advantage - full steam pressure is available at all times to operate traps and (despite warnings) overhead return lines, and to minimize the danger of freezing.

B. **Face and Bypass.** By allowing some air to bypass the coils, and thereby remain unheated, and by blending the "face" and "bypass" airstreams it is possible to obtain good temperature control and still maintain full steam pressure on the coils. This is the system best-suited for steam Make-Up Air (See Figure 10). Face and bypass systems may be built-up (plenum) or packaged. Both may have the disadvantages listed below but, generally speaking, built-up systems can be designed to avoid them.

1. The presence of steam in the coils generally precludes the possibility of handling 100% bypass air without a temperature rise of a few degrees.

2. Most packaged units are designed with less bypass area than is desirable for 100% bypass flow. Most manufacturers assume that summer operation will be with the steam off and air flowing through the face. Most customers seem to prefer low unit height to full bypass capability.

3. The two different temperature airstreams force the fan (generally downstream of the coils) to operate with inlet stratification. This damages fan performance.

One important factor often overlooked in the selection or design of face-and-bypass systems is that the damper blades should have their axis of rotation perpendicular to the axis of the coil tubes. Imagine horizontal dampers and horizontal tubes and you can see that in a partly throttled condition, air would be directed towards some tubes and away from others. Using vertical tubes and horizontal dampers gives the best possible combination.

C. **Modulating Valves.** Since the heat comes from the steam, it seems reasonable to control the heat by throttling the incoming steam. By now the reader has been through the previous discussion of the difficulties involved in operating with this sort of control that results in poor drainage. In addition to the danger of freezing, there is the possibility that horizontal coils and long tubes can set up water hammer that will ruin the coil.

D. **Preheat-Reheat.** Two coils in series can be used to give good temperature control and a reasonable measure of freeze protection (See Figure 11). The coils must be accurately sized. The first "preheat" coil is selected to raise the entering air temperature to about 40°F. to 50°F. The second "reheat" coil raises the air to the desired final temperature. The preheat coil is supplied with a snap action on-off steam valve. The reheat coil has a modulating steam valve. Under maximum conditions, with the coldest (design) entering air temperature, both coils will be under maximum pressure. The thermostatic controls are set to throttle the reheat coil until it is fully closed. The preheat coil is sized so that it will not overheat at full pressure.

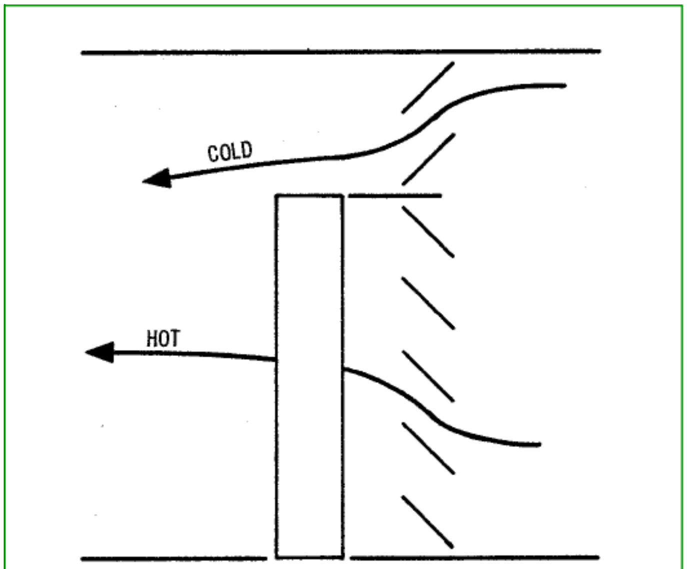


Figure 10 - Face-and-Bypass System

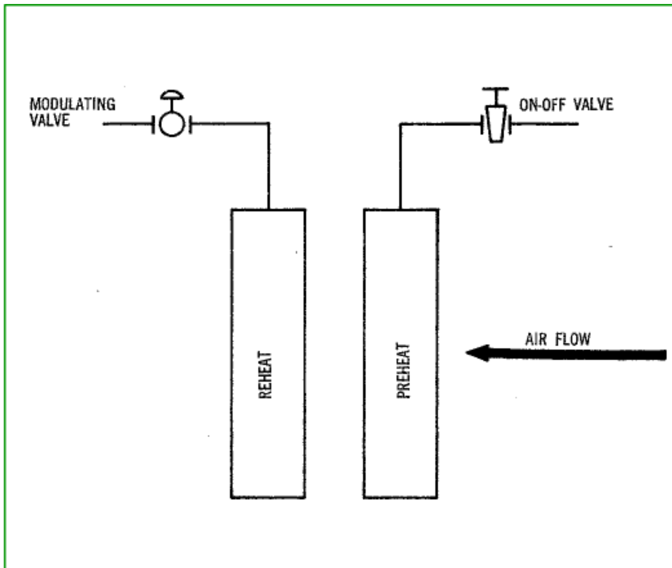


Figure 11 - Preheat - Reheat System

E. **Combinations** can be made of preheat-reheat with face and bypass. Fresh air and recirculating dampers may be used to exercise some control by closing down on fresh air in cold weather. Caution should be used in designing combination systems. Complex control systems are often maintenance headaches. Keep it simple.

F. **High-pressure steam** presents the special problems of superheat and "flashing".

The high temperature of high pressure steam can aggravate the problems of control. One solution is to pass the steam through a pressure-reducing valve before it gets to the coil or temperature control valve. Reducing the pressure reduces the temperature at which the latent heat will be released and makes control easier. However, reducing the pressure does not, in itself, extract any heat from the steam - so the reduced pressure steam is superheated. Reducing saturated 150 psi steam, at 366°F., to 25 psi steam, at 266°F., gives steam with up to 52° of superheat. Since superheated steam is just another gas until it has been cooled to saturation temperature, it is necessary to increase the size of the coil. The added coil face may be thought of as room for the superheated steam to sit and cool to the saturation temperature. Dry superheated steam has a lower film coefficient than does the wet saturated steam. This also adversely affects the overall coefficient of heat transfer. A good rule of thumb is to increase the coil area by 10% for each 100° of superheat.

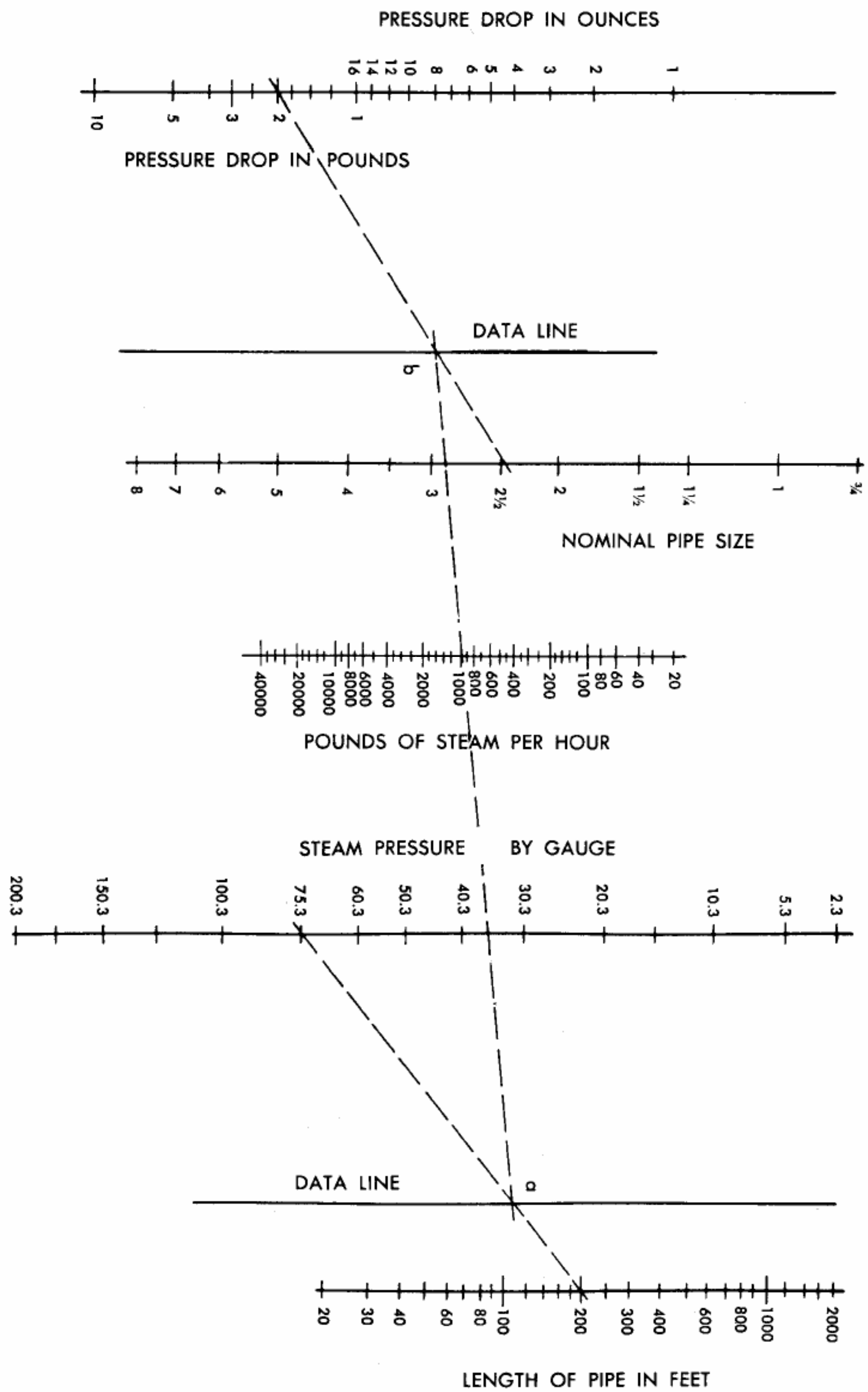
When high pressure steam is used, without pressure reduction, the condensate temperature may be high enough to cause some of the condensate to flash back into steam as it enters the low-pressure condensate line, downstream of the trap. Not all the condensate flashes - just a small part of it, enough to absorb the amount of heat needed to produce a stable mixture of steam and water. The mixture is therefore at a lower temperature than the high-pressure condensate.

G. **Vacuum-steam systems.** One-pipe steam systems and some other variations were, and sometimes still are, used for small space heating installations. They are seldom of much interest in industrial heating or process work.

CONCLUSION

A knowledge of the fundamentals of steam heating is still a necessity in some process applications and building heating systems. The purpose of this Engineering Letter was to provide a basic overview. Engineers and designers of steam-heating systems are encouraged to seek out additional training and resources to build their knowledge base.

STEAM PIPE SIZING NOMOGRAPH



EXAMPLE:

Assume 1000 pounds of steam per hour at 75 pounds steam pressure, to be delivered at a distance of 200 feet, with a permissible pressure drop of 2 pounds.

Dotted line from 75 pounds to 200 feet intersects data line at "a". From this point "a", a line through 1000 pounds intersects data line at "b". Line from 2 pounds pressure drop through "b" gives pipe size required - 21/2 inch.

NOTE:

Above figures are for straight, smooth pipe. It is customary to make 100% allowance in length of pipe for fittings.