CONTROLLING STEAM HEATERS

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INTRODUCTION. Steam Heaters are simply heat exchangers in which one of the media is steam being condensed while the other is a process fluid being heated. In doing this, there is a phase change which puts special demands on the process control system. It is difficult to generalize about the various options for control. Special system requirements often put unexpected constraints on the process. Even the orientation of the exchanger can have peculiar and unexpected results.

A SIMPLE STEAM SPACE HEATER. Figure 4-1 shows a steam heater such as those used to heat a warehouse. This simple example demonstrates many of the characteristics of steam heaters of all sizes and applications. Steam enters the heater at the top. As the moving air draws away the heat, the steam condenses. The condensate flows down the tubes, through the steam trap, and into the condensate drain header.

The function of the steam trap, TCV, is to prevent steam from blowing through into the condensate system. It is the one essential part of any steam heater and will receive further attention later. For now it is sufficient to say only that it passes condensate and blocks steam.

This system tends to be rather self-regulating. The moving air rises to some temperature approaching that of the steam and draws away as much heat as it can. Colder air will draw more heat, and warm air will draw less. The steam trap is essentially a level controller with a set point of zero.

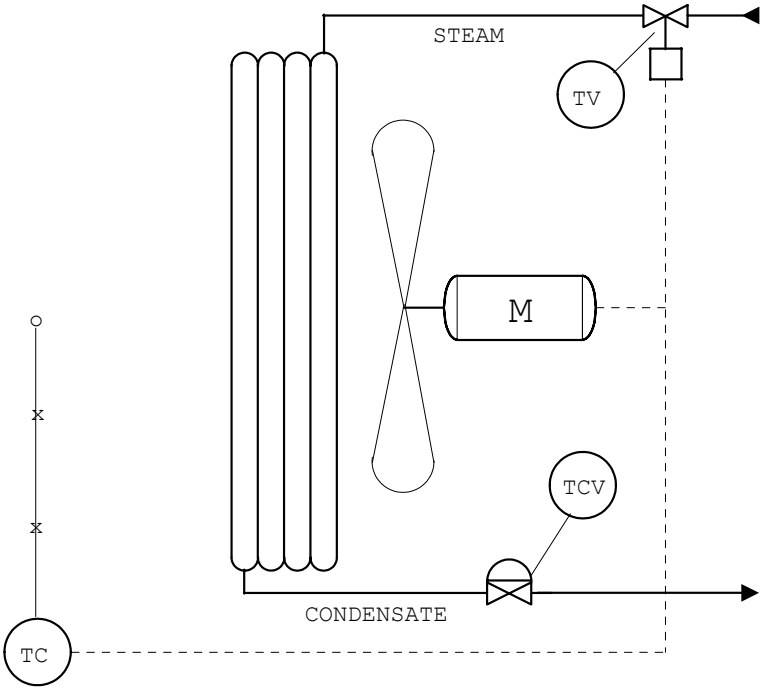

Fig. 4-1. A Steam Heater

This arrangement can be compared to a shell and tube exchanger where the room itself is the shell and the air is the process stream. The fan draws some of the air through the heater and then blends it with the remaining air in the room. The first level of control complexity is to add a thermostatic switch to control the fan. As with any exchanger on bypass control, the sensing element must be placed at a point where the two stream has mixed sufficiently to provide an representative temperature (not directly in front of the fan, as the drawing shows). When the

temperature in the room reaches the setpoint, the fan will stop and the air immediately around the tubes will rise to the steam temperature. The heat withdrawn will be reduced until only a small amount of steam is condensed.

If it were practical to stop all air circulation and to fully insulate the heater so that no heat is transferred out of it, steam condensation would cease and no condensate would flow through the steam trap. This is not practical, so on a hot day any amount of steam that still is condensed by air convection is a complete waste. Furthermore it adds to the heat in the room. Thus the next level of complexity is to block the steam to the heater. When this is done, the steam already in the heater condenses, the temperature drops to room temperature and the pressure drops to the corresponding vapour pressure. Condensate will not flow through the trap once the pressure drops below that of the condensate header. Because of the higher density of water, a given volume of steam condenses to a much smaller volume of condensate. The final equilibrium is reached with a pressure of about 2.8 kPa_{abs} (0.4 psia), essentially full vacuum, and with the tubes about 0.15% full of water. (The steam supply in this example is assumed to be at 170 kPa_{ga} (25 psig), fully saturated.)

The simple system described above, minus the fan, is used for many non-process heating applications such as steam tracing or open tank heating.

STEAM TRAPS. As steam condenses, the resulting water drains downward. A steam trap is placed at the low point of the system. It is a valve that opens to allow the water to drain out into the condensate system but closes when all the water has been drained and steam tries to pass through. There are numerous varieties of steam traps operating on various principles. A detailed discussion of various types can be found in the article *Steam Traps, Key to Process Heating*[1] by Haas.

CONTROLLING A PROCESS HEATER. The parameter of interest in any process heater is the temperature of the process stream at some particular point in the process. There are essentially only three means of control:

- Bypass a fraction of the process stream around the exchanger and blend it with the fraction that has passed through.
- Vary the effective surface area of heat exchange. This is accomplished by restricting the outlet and partially flooding the exchanger with condensate.
- Vary the temperature of the heating medium. This is accomplished by throttling the steam and dropping the pressure of the steam in the exchanger.

Each of these is discussed in turn below.

BYPASS CONTROL. Bypass control on a steam heater is similar to bypass control on any other type of heat exchanger[2]. The only difference is the addition of a steam trap at the outlet of the steam side where the condensate exits at the bottom of the exchanger. Simple steam traps do not come in large sizes, so a more explicit way of separating condensate from steam may be needed. A condensate receiver is a vessel placed below the heat exchanger to receive the condensate that drains from the bottom. A level controller is used to control the outlet valve. The entire arrangement is simply a steam trap on a large scale. The only additional component is the

equalizing line from the receiver. This is needed so that steam or air in the receiver does not block the inflow of condensate. It may not be needed if the line into the receiver is large and free draining. The full story is shown in Figure 4-2.

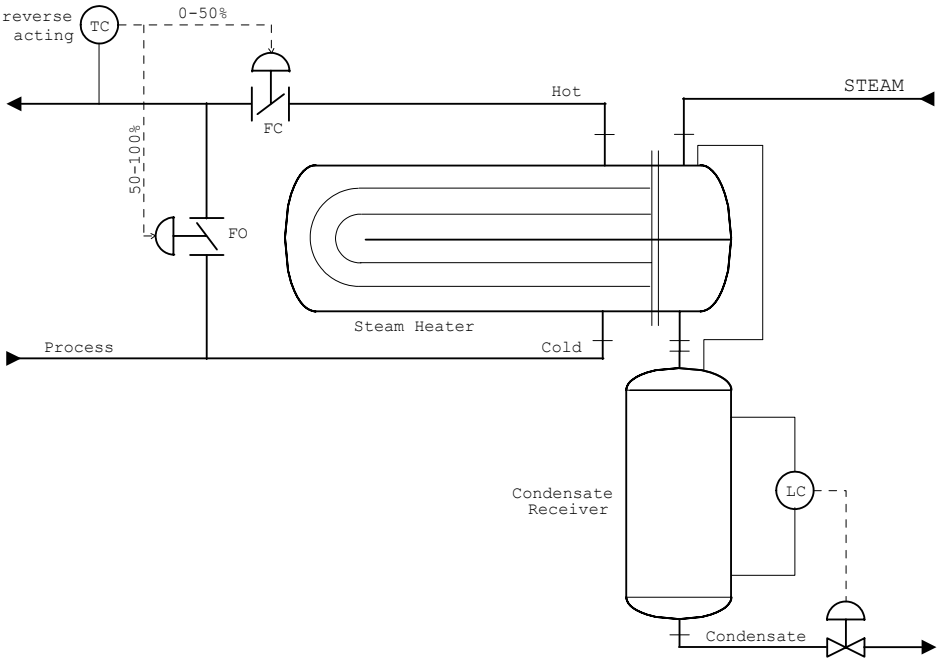

Fig. 4-2. A Steam Heater with a Process Bypass

There are many situations where bypass control cannot be used. Note that the process fluid that passes through the exchanger will experience the full temperature of the steam. If the fluid is liable to coking, polymerization or other damage at the maximum steam temperature, some other form of control must be employed. Over done and half-baked do not average out!

If the process fluid is being boiled, as in a reboiler on a distillation column, the bypass simply will not work at all. Consider a reboiler where the exchanger shell is half full of liquid. The bypass line will also be half full. Vapour from the exchanger will exit at the top but nothing will pass through the bypass line. There is another problem with the arrangement shown in Figure 4-2, if it is to be applied to a reboiler. The temperature at the exit bears no relation to the total quantity of liquid being boiled. If the set point is slightly below the boiling point, only enough boiling to heat the outlet pipe will occur. If the setpoint is even slightly above the boiling point, the controller will open the valve wide. To put the set point *exactly* at the boiling point is meaningless; *exactly* does not exist in the real world.

LEVEL CONTROL. The total heat transfer rate (heat flux) can be controlled by throttling the condensate leaving the bottom of the exchanger. This causes it to blank off more of the tube surface, reducing the heat transfer area. Figure 4-3 shows a typical arrangement. Orientation is important to the success of this method. In the diagram, the exchanger is placed vertically and has the steam on the shell side. The exchanger can then act as its own condensate receiver.

Figure 4-3 shows one simple arrangement. Note that the steam **must** be in the shell. If the steam were in the tubes, the condensate would have to be blown upwards out of the tubes. The resulting water hammer would be totally unacceptable. Secondly, there must be no baffle down the middle of the exchanger. If there were, the level could not equalize on the two sides. The side opposite the steam inlet would fill to the top with condensate and effectively blank off half the exchanger. In any case, the condensate must flow out of the bottom.

The temperature controller is shown working directly on the condensate valve. The valve must be fail-closed to prevent steam from blowing into the condensate header during an air failure. The controller must be reverse acting so that a rise in the outlet temperature will cause the controller to close the valve. This raises the condensate level and blanks off some of the tube surface. Reduced tube surface area exposed to steam reduces the heat flux in direct proportion.

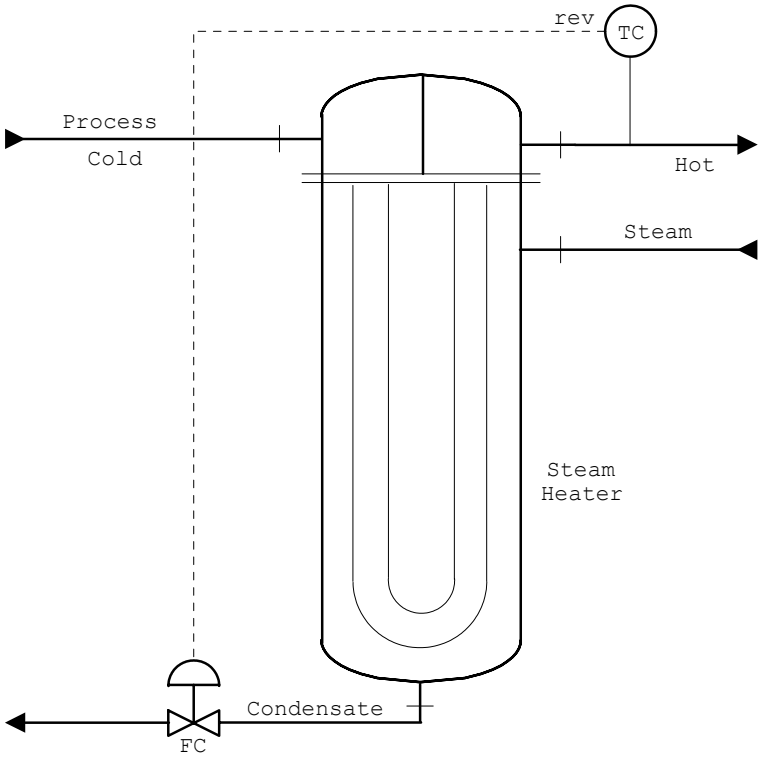

Fig. 4-3. A Steam Heater with Direct Level Control

This arrangement works quite well but it has several characteristics that must be kept in mind. The first of these is the transient response. The controller reacts to a sudden increase in process flow by opening the valve. This rapidly dumps condensate so that the exchanger can fill with fresh steam. If the process flow abruptly drops, the response is not so rapid. A valve cannot work backwards; it can stop the flow but it can never cause it to reverse direction. Until the process has absorbed sufficient heat to fill the exchanger with condensate, the heat flux will not go down. An extreme case is when the flow stops entirely. The temperature of fluid remaining in the tubes will rise to that of the steam and will not cool down until enough heat has been lost through the insulation to condense enough water to fill the exchanger. This may take some time. An exchanger being controlled by controlling condensate level is a little like a car with excellent acceleration but bad brakes. (We seem to have quite a few of these in our town.)

The above example also illustrates a problem common to all heat exchanger controls: What happens when the flow stops entirely? If the temperature element is located some distance downstream of the heater, the section of line in which it is located gradually cools off and the controller asks for more heat. Eventually steam will blow out the bottom and into the condensate system. Interlocks may be required to prevent this.

A second controls problem occurs during situations of extreme turndown. Consider the following scenario: Plant feed is taken from tankage and heated to approximately 25°C (77°F). The plant is located in a far northern location so the heater is sized large enough to provide sufficient heat even on the coldest days. In the summer the situation is quite different. Little or no heat is required and the exchanger fills with condensate nearly to the top. Once the level rises above the steam inlet, severe hammering occurs as the condensate backs up into the steam line and the steam blows through it into the space at the top where some condensation is still occurring. Persistent gasket leaks are one result. The operators try to remedy this by partially closing the manual block valve at

the steam inlet. This does not help as it is the low rate of condensation that controls the steam flow. Eventually the hammering stops when the manual bypass on the condensate valve is opened. At this point the operators are convinced that the condensate valve is undersized since opening the bypass "cured" the problem. They do not observe that the process is being overheated and that the control valve is actually tightly closed.

The actual source of the difficulty is that it is not possible to blank off the entire heat exchange surface without raising the level above the steam inlet. A short-term fix may be to inject air or other appropriate non-condensable into the shell. The proper solution is to use a horizontal exchanger. The steam will then enter at the top. Once the condensate has risen above the highest tubes, heat transfer stops and the condensate rises no further.

IMPROVED LEVEL CONTROL. There are essentially three forms of disturbance that can affect a steam heater:

- The process load can change as a result of changes in either the flow rate or the feed temperature. A change in the setpoint of the temperature controller is equivalent to a change in load.
- The steam pressure and temperature can change.
- The condensate back pressure can change.

If the condensate valve starts out in manual with a fixed position, the system response to an increase in load will be an increase in condensation followed by rise in level. The end result will be a lower outlet temperature. Since neither the steam nor the condensate pressure change in this example, the flow through the valve is constant. Therefore the heat flux is constant. The same heat flux into a greater process load results in a lower temperature. If the valve is placed under automatic temperature control, it will be opened and a new equilibrium established at a somewhat lower level and the appropriate higher heat flux, after the initial drop in temperature.

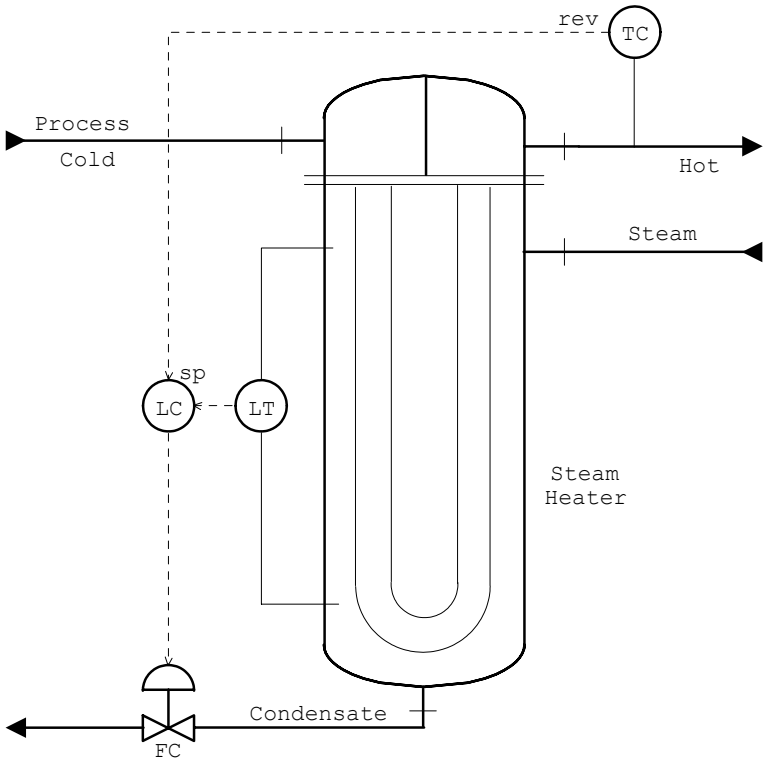

Fig. 4-4. Temperature / Level Cascade Control

The response of manual control to an increase in steam pressure is an increase in heat flux followed by a rise in level. Since the level has no significant bearing on the flow of condensate through the valve, the level will continue to rise until the amount of steam condensed is equal to amount of condensate flowing out through the valve. The final process outlet temperature will be slightly higher than before due to the slightly higher heat content of the higher

pressure steam. If the loop is in automatic, the controller will restrict the condensate flow until the correct operating point is found.

Assuming that the pressure of the steam is not significantly higher than that of the condensate, a rise in condensate header pressure will reduce the flow and cause the level to rise. If the valve is in manual, the outlet temperature will drop until the heat flux corresponds to the reduced condensate flow. If the valve is under temperature control, the controller will open it until the correct level is again achieved. This assumes, of course, that there is sufficient steam pressure to force out all the condensate being produced. The three scenarios played out in the previous paragraphs all result in some transient disturbance to the process temperature. Is there a method by which these transients can be reduced? Cascaded controls come to mind. One common arrangement is to cascade the temperature controller to a level controller, as shown in Figure 4-4. The level controller senses the rise in level resulting from an increase in process load by opening the valve. This provides a correction in the right direction but it is uncertain whether this would be any faster than the response of the temperature controller alone. The temperature/level cascade provides similar limited assistance if the disturbance is due to an increase in steam pressure. A rise in outlet temperature must precede a rise in level. Therefore a temperature controller alone would be faster in eliminating transients.

If the disturbance is caused by a rise in pressure of the condensate header, the first result will be a rise in the liquid level. A level controller would sense this immediately and respond by opening the valve. This would greatly reduce the effect on the process. In conclusion: A temperature/level cascade is helpful if the expected disturbance is caused by the condensate header. It is important to realize that any form of cascading or feed forward must always be addressed at a particular disturbance. **The issue is not whether or not the system works but rather against what type of disturbance it is effective.**

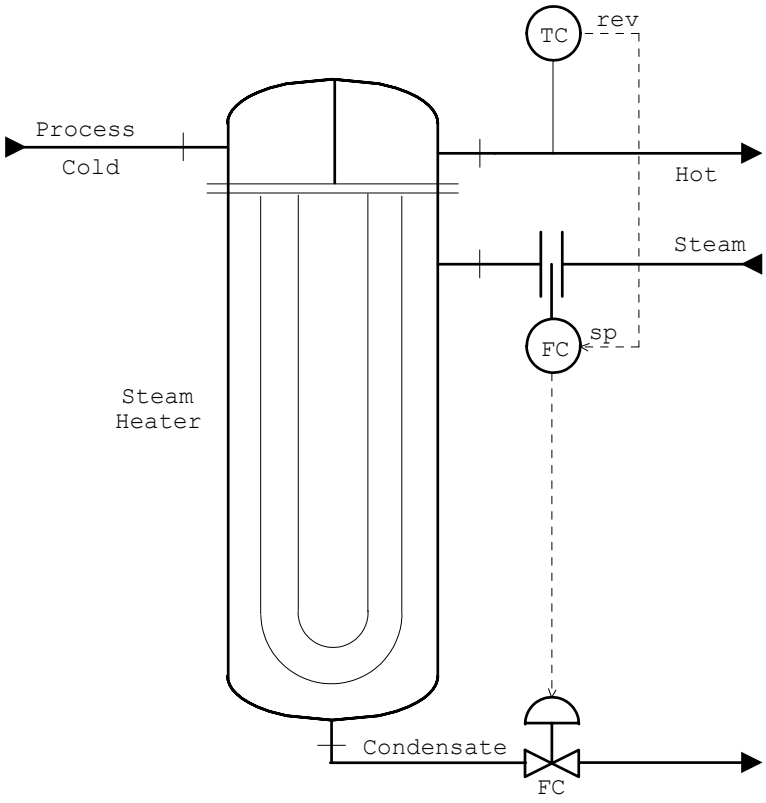

Fig. 4-5. Temperature / Flow Cascade Control

A temperature/flow cascade loop is sometimes employed in an attempt to improve control precision. Steam flow is the measured variable, as shown in Figure 4-5. Unfortunately the configuration has an inverse transient response to load changes. As the load goes up, more steam is condensed causing an increased flow into the exchanger. The flow controller will close the condensate valve at the same time as the level is rising. This causes a further increase in level. Eventually, a new equilibrium is reached but the short-term result is a worsening in response. If the disturbance is in the form of an increase in

steam pressure, the T/F cascade responds correctly and improves the situation. If the disturbance is an increase in condensate header pressure, the flow controller will notice that the steam flow rate drops due to the reduced surface area and act to lower the level. Thus the T/F cascade is effective against steam and condensate disturbances but not against disturbances originating in the process.

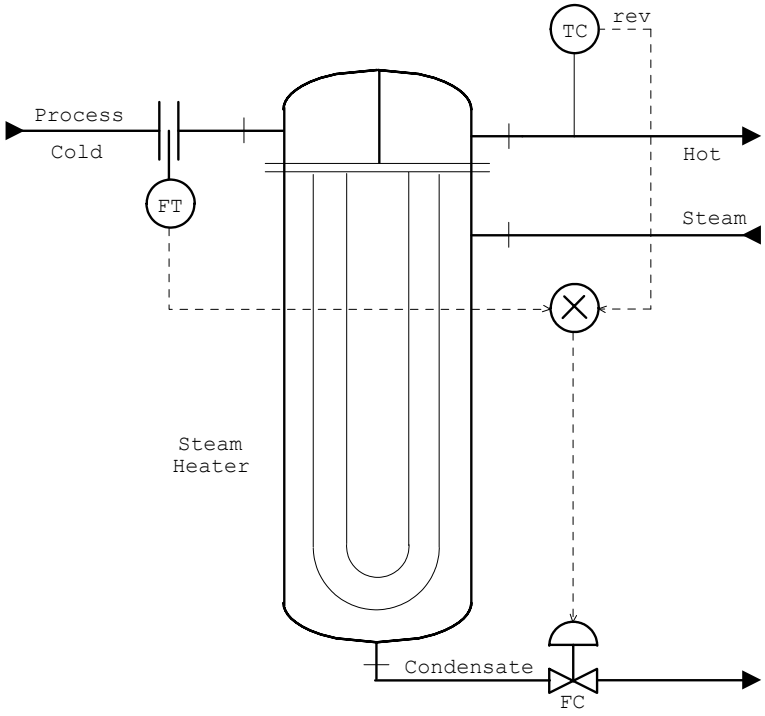

Fig. 4-6. Feed Forward on Flow

The only way to improve response to load changes is through the use of feed forward. This technique measures the disturbance itself and applies a correction before the effect of the disturbance is even felt. If the correction is too early, a transient in the output will be seen that is in the opposite direction of what would otherwise occur. In such cases a signal delay is needed. Every possible disturbance has its own measurement and it is impossible to compensate for all of them. A load disturbance to the heat exchanger could be caused by a change in flow rate, a change in feed temperature or even a change in specific heat. The controls engineer must decide which of these is significant for each particular case. The example in Figure 4-6 shows a system in which it was concluded that process flow is a significant variable. The output of the temperature controller is multiplied by the flow rate to produce the signal that controls the valve. Both signals being multiplied must be linear and in units of percent. A common question is whether to apply the feed forward signal through a multiplier or an adder. In this example it is clear that the steam rate, and therefore the valve position, should be proportional to process flow rate therefore the signal must be multiplied. Note that the installed valve characteristic must be linear for this to work perfectly.

STEAM CONTROL. A common method of controlling a steam heater is to throttle the steam at the inlet. Since water boils at a lower temperature when the pressure is reduced, the condensate temperature goes down with pressure. It is fairly accurate to assume that the conditions inside the exchanger are isothermal. That is, there is no significant counter-current flow and the maximum temperature to which the process fluid can rise is the temperature of the condensate.

Table 1 gives a number of pertinent parameters for a sample case. The steam header is at 600 kPa_{ga} (87 psig). It is throttled down to 300 kPa_{ga} (44 psig). This corresponds to a drop in condensate temperature from 165°C to 155°C (329 to 311°F). Therefore the process outlet temperature must also drop approximately 10°C (18°F).
Table 1 points out a few other effects of throttling. Firstly, the density of the steam is reduced. This reduces the effective rate of heat transfer. Secondly, throttling saturated steam does not drop its temperature sufficiently to keep it at saturation at the lower pressure. Thus there is a certain

amount of superheat. Superheated steam is less effective in transferring heat than saturated steam because the sensible heat released as it cools to saturation is considerably less

	Header conditions	Exchanger conditions	
Pressure - absolute	700	400	kPa_{abs}
- gauge	600	300	kPa_{ga}
Enthalpy	2764	2764	kJ/kg
Temperature	165	155	°C
Density	3.66	2.10	kg/m^3
Superheat	0	11	°C
Condensate Enthalpy	697	605	kJ/kg
Condensate Temperature	165	144	°C

TABLE 1 - THERMODYNAMIC PROPERTIES

than the latent heat released by condensation. Thirdly, the condensate is released to the header at a lower pressure. This con-densate has a slightly lower enthalpy, therefore there has been a slightly higher amount of heat recovered to the process. It also means that there is less flashing or other disturbance to the condensate header. All these secondary effects, except the last, reduce the efficiency of the heater. The result is to increase the approach temperature of the outlet stream (the difference between the actual outlet and the maximum achievable). This causes a further, minor reduction in outlet temperature.

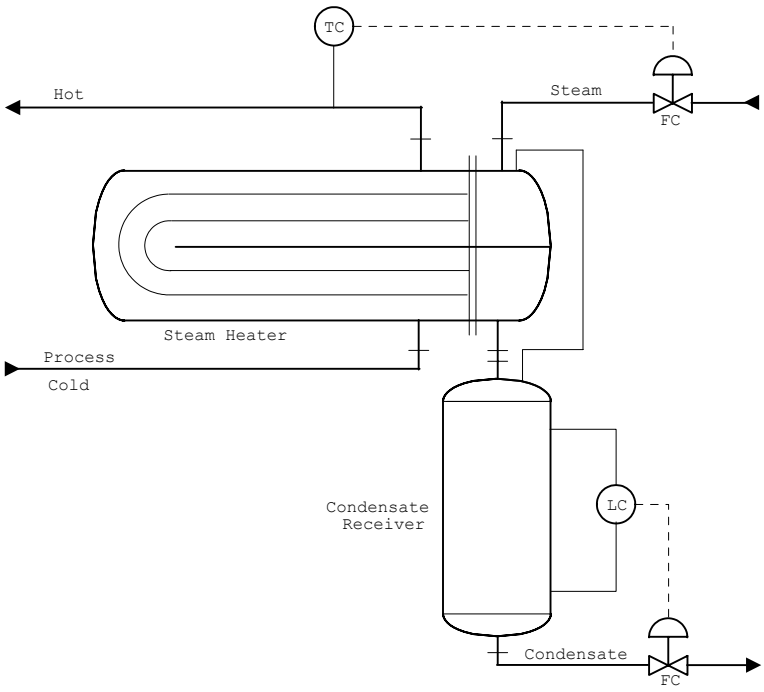

Fig. 4-7. Steam Throttling

Figure 4-7 shows a typical steam heater being controlled by a valve on the steam inlet. The valve on the condensate outlet is still needed to keep steam out of the condensate system. This brings attention to a major problem with steam control in a heater requiring low-pressure steam: After passing through two valves, there may not be enough pressure left to return the condensate to the header. The obvious solution is to raise the steam pressure. This will **not**

help because the purpose of the steam valve is to drop the pressure to a specific value, that corresponding to the desired steam temperature. There are three possible solutions:

1 - The best solution is to reduce the back pressure in the condensate header. This cannot always be done. Perhaps the condensate lines must run in pipe racks that are elevated above the heater. Long return lines may add further to the back pressure.

2 - Using level control, as explained in previous sections, may be a useful alternative.

3 - When faced with an existing installation in which the steam header pressure has dropped and the condensate header pressure has risen, both because of increasing demand, the only alternative may be to add a condensate return pump. The purpose of this pump is to force low-pressure condensate into a header at a higher pressure. The control valve must, of course, be on the discharge of the pump to prevent flashing or cavitation.

SAFETY. The safety requirements of steam heaters are like those of any other heat exchanger[2]. In particular, relief valves must be provided on both sides as with any pressure vessel[3].

There is one additional hazard associated with steam heaters: Blowing steam into the condensate header. The level control valve or steam trap drops the pressure as the condensate enters the header. If the header is not rated to take the full pressure of the steam, a relief valve must be provided to guard against valve failure. Additional precautions may be warranted. One possibility is an independent low low level switch to block in the valve via a solenoid.

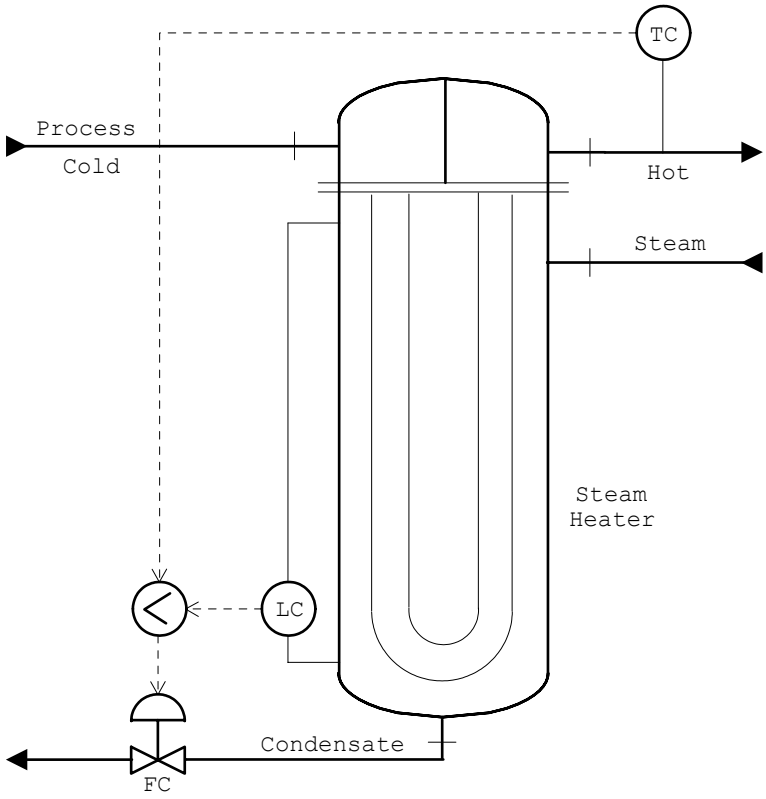

Fig. 4-8. A Steam Heater with a Level Override

A second method, illustrated in Figure 4-8, is a low level override. It consists of a level controller whose output goes to a low selector together with that of the temperature controller. The level setpoint is approximately at the bottom of the tubes. A level below this will cause a direct acting controller to reduce its output. Once the output is less than that of the temperature controller, the level controller has control of the valve and will prevent the level from falling below the bottom of the exchanger. This form of override will work equally well on a condensate receiver vessel and also in conjunction with a T/F cascade or feedforward. It is most likely during a period of maximum production that maximum heat demand is required. In other words, a low level switch is most likely to shut down the heater at precisely the

time when the plant is making the most money. The use a low-level override will prevent this very undesirable occurrence by effectively switching the heater to capacity limit control. That is the heater will run at the limit of its capacity (lowest level) without the risk of a shutdown.

A simple rule helps to remind us whether a high or a low selector is needed. **A valve is always selected so that the lowest value of its input signal corresponds to the safest valve position. Thus a safety related override will always act through a low selector to provide fail-safe action.** In cases where a fail open valve is appropriate, such as pump recycle, a low selector is still the appropriate choice.

Note that a PI or PID controller will wind up if its output is not selected to control the valve. (When it is ignored, it yells louder!) A special type of selector called an "override selector" must be used for override applications. This module or software function block suppresses the integral action of any controller(s) whose output is not selected for control.

If the pressure of the inlet steam is sufficiently high that it poses a serious danger to the condensate system, it may be necessary to apply both a low level override and an independent low low level switch to block in the valve via a solenoid. Since the solenoid would only act during a failure, it should be latched in the closed position.

ACCESSORY INSTRUMENTS. A steam heater has essentially the same needs for accessory instrumentation as any other heat exchanger. Since its purpose is to heat the process stream, some means must be provided to verify how well it is doing this. Therefore thermometers are installed at the inlet and outlet. To warn of plugging, pressure gauges are also required[2].

Thermometers and pressure gauges should also be installed on the steam side inlet. This is especially true if steam throttling is being used, otherwise it is not possible to know what conditions are after the valve. There is generally no need for a measurement at the outlet.

A level gauge should, as always, be installed to cover the span of any level controlling device to verify its operation and to provide coverage during its maintenance.

PARALLEL STEAM HEATERS. Steam heated reboilers are frequently twinned on large distillation columns. These **must** have individual controls, either on the steam side or the condensate side. There is absolutely no way of ensuring an even distribution of load if this is not done. One common solution is to have the output of a single temperature controller split to two separate flow controllers. A simple subtraction unit can be used so that the operator may enter a value between 0 and 100% to establish the proportion of the flow to one controller with the remainder going to the other.

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