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A BestPractices Steam Technical Brief

Industrial Steam System Process-Control Schemes

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This BestPractices Steam Technical Brief was developed to provide a basic understanding of the different process-control schemes used in a typical steam system. This brief provides a fundamental overview, and the reader should be aware that more in-depth knowledge is required to achieve the best process-control results.

This brief will cover the following process-control schemes:

- Feedback
- Feed-forward
- Backpressure
- Ratio
- Cascade
- Differential.

The above control schemes can be applied to the following generic applications:

- Temperature
- Flow
- Level
- Pressure.

A control system will use one or more of the above schemes to achieve process control. The various control schemes are detailed in the typical application examples defined in this brief.

In any control scheme that is applied, the user must define three elements for the control process:

- Process Variable (Sensing device)
  - Flow transmitter
  - Level transmitter
  - Pressure transmitter
  - Differential transmitter
  - Temperature transmitter
- Controller
  - Self-contained
  - Proportional and integral (PI)
  - Proportional, integral, derivative (PID)
- Output control signal (Final controlling mechanism)
  - Control valve
  - Actuator
  - Another device.

This review focuses on control valves, which are generally used as the final element. The control valve has several classifications:

- Regulating design valve
  - Self contained
  - External pilot operated

- Pneumatic actuated valve
  - Globe design
  - Caged trim
  - Ball.

In any process-control selection, understanding the advantages and disadvantages of each selection is important.

The regulating control valve, or regulator, is a device that has a 20 to 1 turndown and limited selections of flow-trim characteristics.

The globe-style control valve has 30 to 1 turndown and is a device that can provide a limited number of selections of flow-trim characteristics. Flow-trim characteristics can be linear, non-linear, or modified equal percentage. Flow-trim selection can enhance control of steam flow at varying load demands.

The cage-trim control valve is the most flexible and may be the most commonly used for precise steam process control. This valve provides the largest selection of different flow-trim characteristics, and the highest turndown capabilities, with a 40 to 1 turndown.

The ball valve has a number of different flow characteristics. The flow profile can be changed by the design of the ball (for example, standard, V-ball, etc.). The ball-valve turndown can be as high as 25 to 1.

- Turndown summary:
  - Regulating valve: 20 to 1
  - Globe style valve: 30 to 1
  - Cage trim valve: 40 to 1
  - Ball valve (with special trim): 25 to 1

Symbol Definitions

CS = Cascade
CT = Controller
FT = Flow transmitter
PT = Pressure transmitter
PV = Process Variable
R = Ratio
SP = Set Point
TT = Temperature transmitter

Feedback Control

One of the simplest process-control schemes that steam applications use is the feedback-control scheme (Figure 1). The advantage of this control scheme is that it is simple; however, it depends on a single transmitter sensing a change in flow, pressure, or level to provide the feedback response to the controller or valve. This control scheme does not take into consideration any of the other variables in the process.

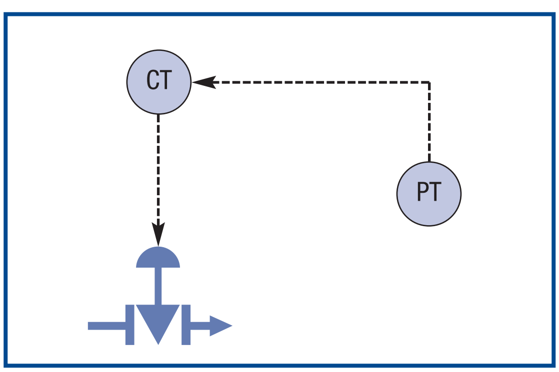

Figure 1: Feedback Control

Feedback Control (Backpressure application)

Feedback control for a steam-system backpressure-control scheme utilizes another parameter to provide the controller with information on process changes (Figure 2). Backpressure control is used to maintain inlet-steam pressure above a predetermined setpoint. Pressure transmitters are located on the inlet and outlet piping, which will notify the controller that changes are occurring. Consequently, backpressure control work in conjunction with feedback control. The most common application for a steam system is the elimination of instant, high demand for steam from a process that will affect the boiler operation.

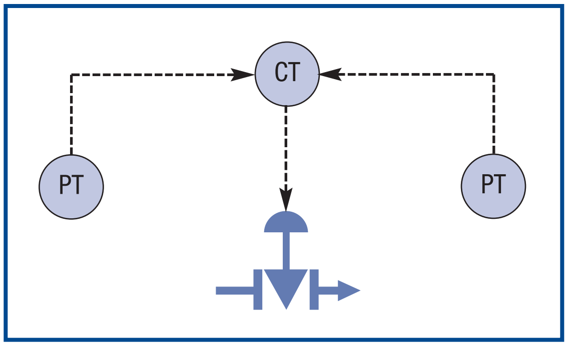

Figure 2: Feedback for a Back-Pressure Application

Feed-Forward Control

Feed-forward control uses a secondary input from another variable to assist or provide the controller with the knowledge that various changes are occurring in the process (Figure 3). Steam flow measurement in pressure-reducing applications adds instant identification that a change is occurring. This allows the controller to make corrective actions before a significant temperature or steam-pressure change has occurred. Consequently, feed-forward control is used in conjunction with feedback control. The feedback loop is used to maintain setpoint control, and feed forward is used to compensate for any errors and unmeasured disturbances. One of the most common applications is a pressure transmitter that is used on a shell-and-tube heat exchanger to sense and feed-forward a change in steam pressure on the shell (steam side). The steam pressure change on the shell side is the first indication that the temperature, or process variable, will change in a short period of time.

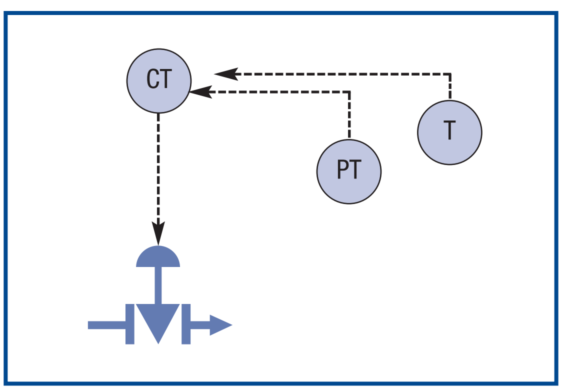

Figure 3: Feed-Forward Control

Ratio Control

Ratio control is a duplex form of feedback control that has two sets of variables, for which the controller calculates a setpoint from the two variables for the control scheme (Figure 4). The object of a ratio-control scheme is to keep the ratio of two variables at different values, depending on the final objective of the control system.

As Figure 4 indicates, on a pressure-control system the control output to the different valves is a ratio that depends on the percentage of travel, 0 to 100%, and the pressure transmitter. This type of control scheme is applied when two or more control valves occur in a pressure-reducing application.

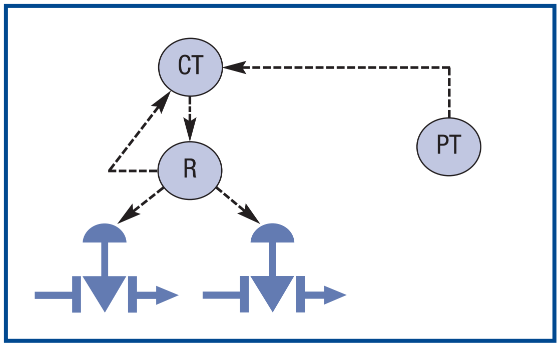

Figure 4: Ratio Control

Cascade Control

Cascade control is widely used within steam-process industries (Figure 5). The conventional cascade scheme has two distinct functions with two control loops. Cascade control is used to improve the response of the single-feedback strategy. A heat exchanger that varies process flow will have different steam requirements depending on the flow. Cascade control "understands" the requirements and adjusts the output to the control valve according to process flow. The main objective is to achieve the desire output temperature of the process, which is the lead process variable. The idea is similar to that of the feed-forward control scheme.

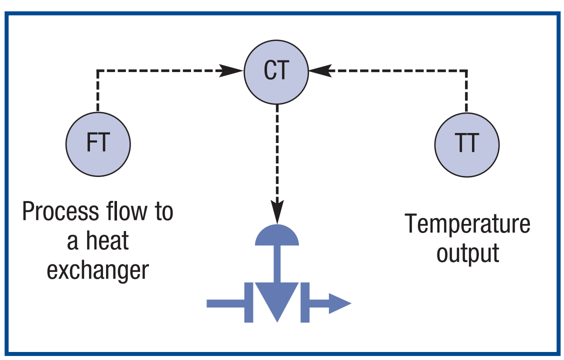

Figure 5: Cascade Control

Differential Control

Differential control is typically used on rotating-cylinder dryers because differential pressure is required across the siphoning joint to assist in evacuating the condensate (Figure 6). The use of rotating cylinders is the only instance where gravity drainage of condensate is not possible from the process. Therefore, using differential control identifies the parameters of inlet (P1) and outlet (P2) process pressures and maintains a lower outlet steam pressure (P1>P2), thus achieving the differential. Other gravity-limited heat-transfer applications will use differential control for condensate evacuation.

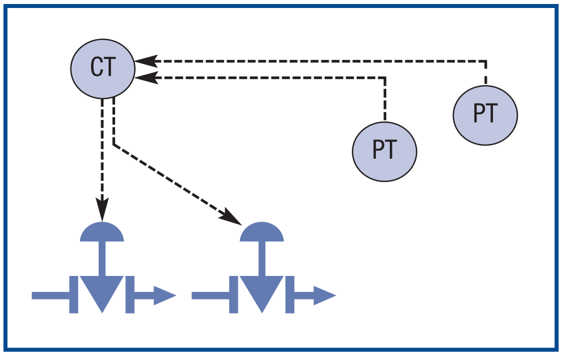

Figure 6: Differential Control

Control Actions

The controller's output to the final control element, the valve or actuator, is accomplished in different ways:

- On/off
  - Simplest
  - Least accurate
- PI (Proportional and integral)
  - Medium cost factor
  - Medium accuracy
- PID (Proportional, integral and derivative)
  - Highest cost
  - Highest accuracy.

On/Off Control

Control schemes using a feedback control parameter can use on/off control. On/off control is the simplest control scheme with the highest degree of inaccuracy. The controller has a set point with high- and low-control action points, similar to a home air conditioning or heating system. The thermostat has a desired setpoint (SP) and the system is actually operated between two temperature points: on/off. The desired outlet temperature is 180°F (SP) and the on/off control activates the steam valve to heat the product to 185°F. At 185°F, the steam valve deactivates and this allows the process to cool down to 175°F, a lower set point. The steam is activated and deactivated between the high and low process setpoints.

Proportional and Integral (PI) Control

PI control uses an algorithm that is proportional to the difference between a setpoint (SP) and a process variable (PV), and integral time-function algorithms, which provide a continuous-control process output to meet the desired setpoint. This is similar to a residential light dimmer switch versus an on/off light switch. The dimmer mechanism provides a light variable from off to full brightness, or anywhere in between. PI controls the steam flow from zero to full flow, or anywhere in between, on a continuous basis.

Proportional, Integral, and Derivative (PID) Control

PID control has proportional, integral, and derivative algorithms available to maintain the setpoint of the process. Steam applications use the proportional and integral part of "PID;" the derivative algorithm is seldom used, and then only by experts who are experienced in control algorithms. If the heat-transfer equipment, control valve, and the controller are properly selected, then proportional and integral are the only parameters required to maintain a highly accurate process result.

Applications of Control Schemes

Steam Pressure Control

The majority of industrial steam systems will have a pressure-reducing valve application. High-pressure steam is reduced to lower-pressure steam for a process or heating application. Used throughout all types of industries, some plants will have from one to more than one hundred different pressure-control valves. The feedback control scheme is simply a pressure transmitter and a controller, or a sensing line coming back to a pilot on a valve.

In a simple regulator-type control system for pressure control, a sensing line is providing the feedback to the external pilot, which is the controlling device (Figure 7). The main valve is the final controlling element.

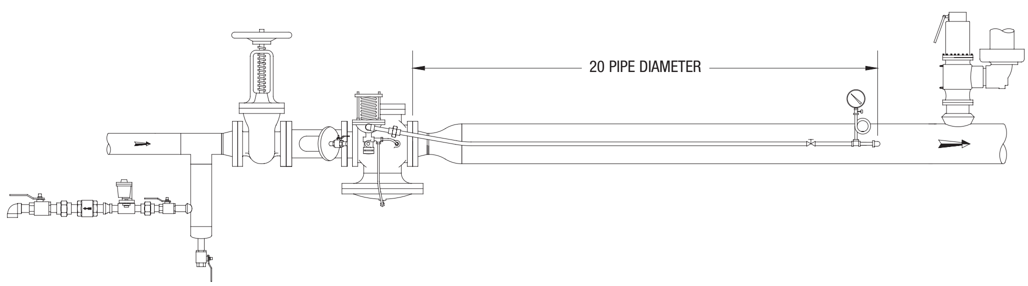

Figure 7: Regulating Valve Using a Feedback-Control Scheme

A control-valve layout uses a pressure transmitter as the feedback-sensing device with the controller providing the correct control action (Figure 8). The pneumatic valve is the final controlling element.

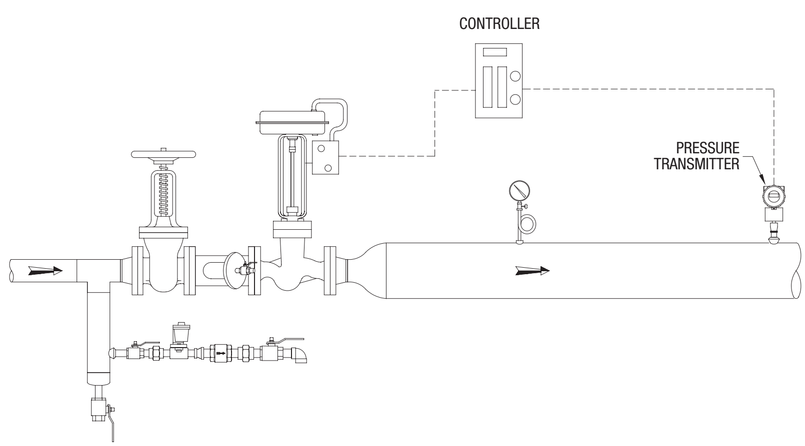

Figure 8: Controller Using Feedback To Control a Valve

Many applications require the use of one or more valves to achieve the necessary turndown. Control valves that are used in any type of control scheme should utilize a secondary pressure drop if the control valve is in a sub-critical flow operation. Figure 9 shows the use of a simple orifice plate, placed after the control valve, to provide a secondary pressure drop. This type of installation has been used for more than 60 years. The inlet pressure to the control valve is P1, the pressure between the control valve and the orifice is P2, and the final control point or outlet pressure to the control valve is P3. Orifice plates, when properly sized and installed, prevent the valve from operating at a sub-critical flow and causing premature failure.

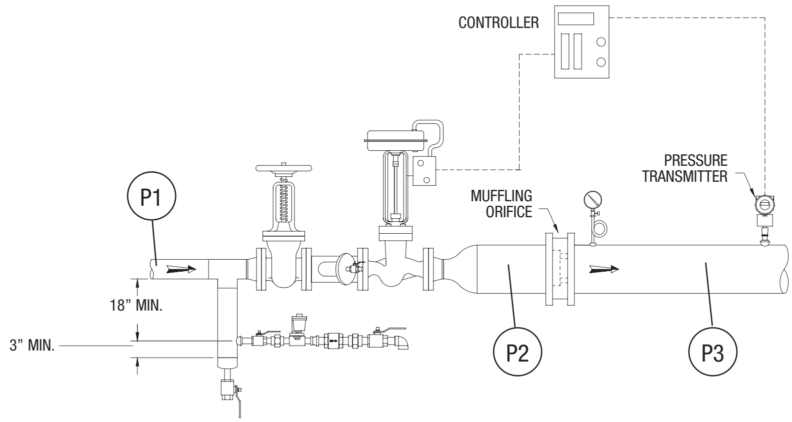

Figure 9: Feedback Control with Muffling Orifice

Backpressure Control

The backpressure control is a type of feedback-control scheme (Figure 10), typically used on smaller boilers without large steam reservoir capabilities for instant steam load demands. High instantaneous demands for steam can cause unwanted shutdowns of the boiler. Using backpressure control prevents the shutdown. A transmitter sensing the inlet pressure to the valve identifies a reduction of pressure beyond the predetermined set point, and the valve begins to close down to maintain the steam set-pressure on the inlet of the valve. This action overrides any pressure requirements or needs on the downstream side of the valve.

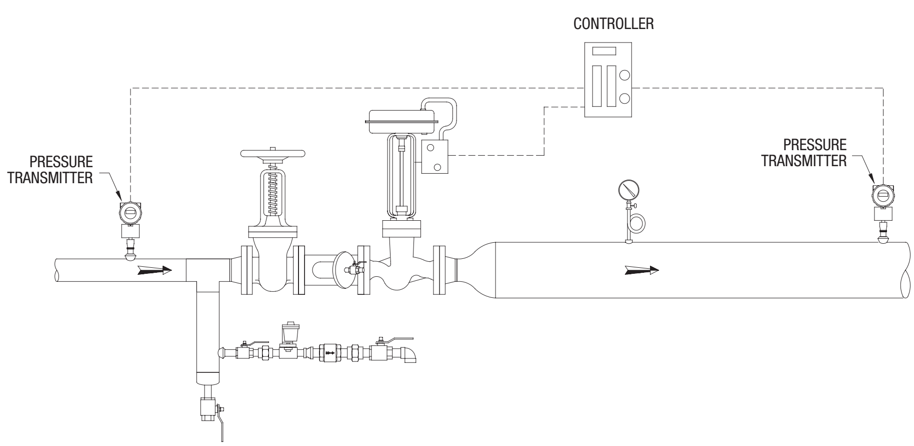

Figure 10: Backpressure Control

Feedforward Control

Figure 11 shows a feedforward/feedback control system. The orifice steam flow meter is providing the feedforward information to the controller. The pressure transmitter is providing the feedback to the controller. The pneumatic control valve is the final element.

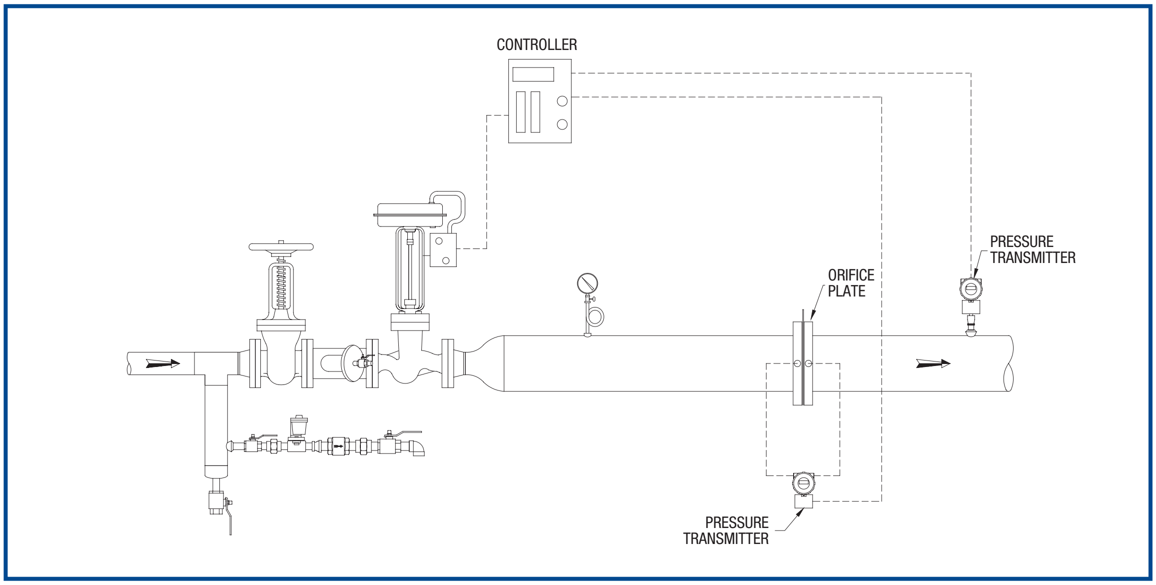

Figure 11: Feedforward/Feedback Control

Ratio Control

Another way to accomplish the goal of meeting large steam-flow requirements is the use of multiple valves (Figure 12). Multiple valves can provide better control in meeting the process requirements. In a two-stage pressure-control scheme, the stages use a feedback-control scheme and then ratio the controller output to the valves. As shown in Figure 12, the system is the ratio or position of the primary and secondary valve depending on the required flow rates. Parallel positioning valves are quite commonly used in process-heating applications where load conditions vary greatly from the coldest part of the season to the warmest part of the season.

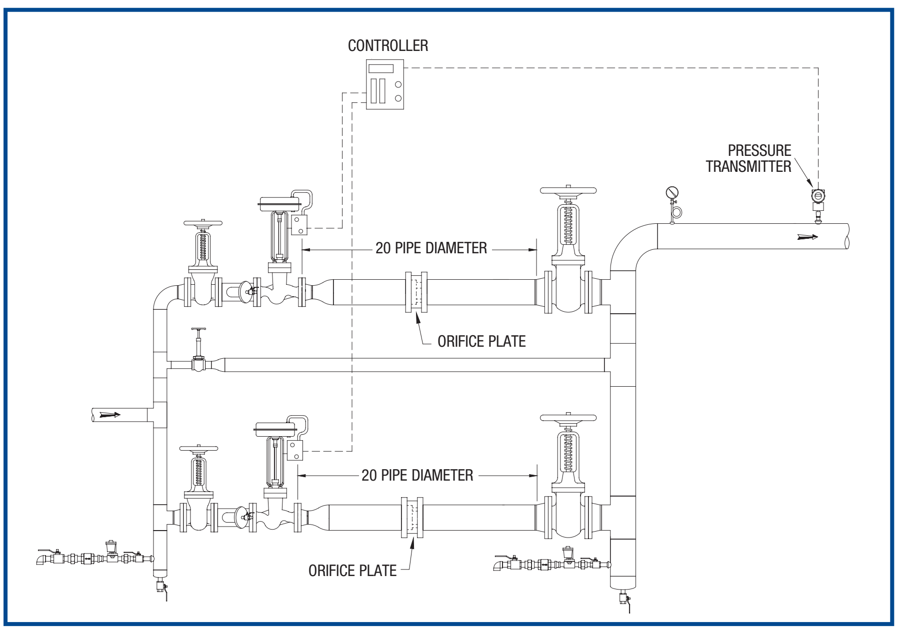

Figure 12: Ratio Control

Differential Control

Differential control provides the condensate removal of a rotating cylinder dryer (Figure 13). This goal is accomplished by maintaining a lower steam pressure (pressure transmitter no. 2) than the inlet steam pressure (pressure transmitter no. 1).

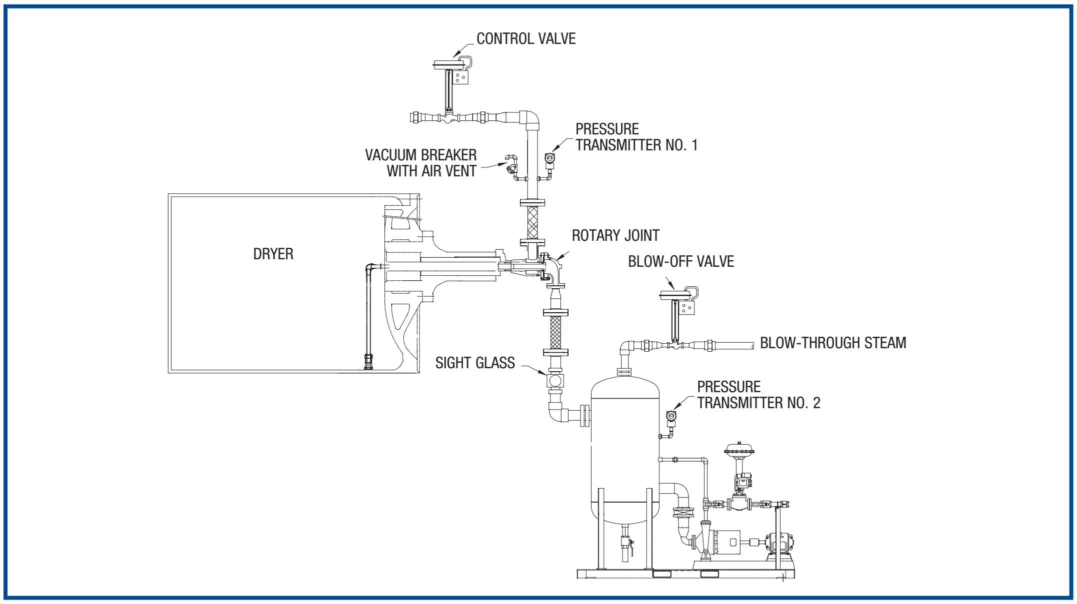

Figure 13: Differential Control (Inlet steam pressure > outlet steam pressure).

Heat-Transfer Feedback Control

One of the most simple and most common control scheme used in heat transfer is simple-feedback control (Figure 14). This is a simple system, but this control scheme does not account for any upsets, disturbances, or unknown factors that might occur in the system and affect the heat-transfer process.

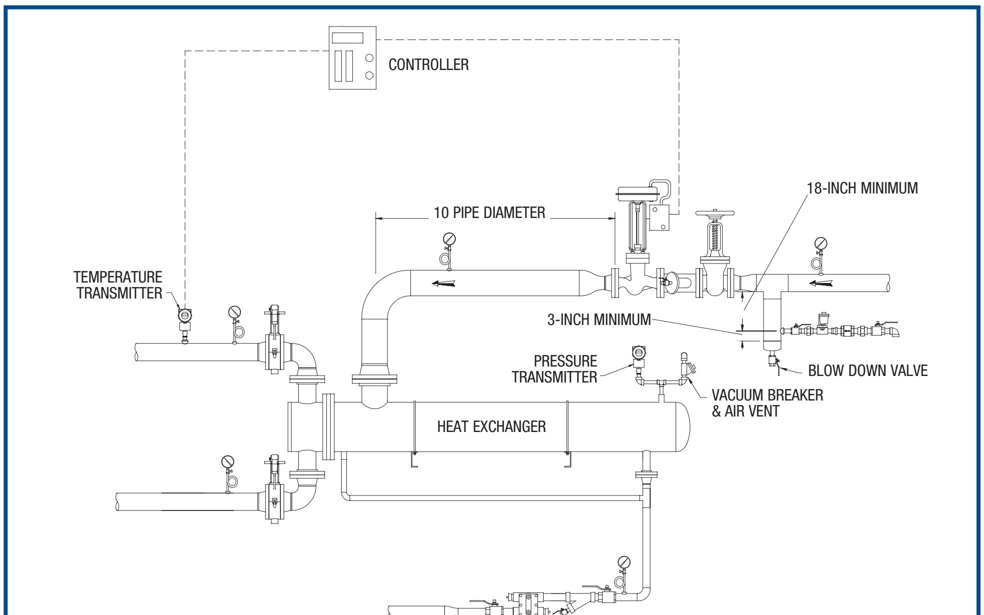

Figure 14: Feedback Control On a Shell-and-Tube Heat Exchanger

Heat-Transfer Feed Forward Control

The heat-transfer feed forward control scheme uses feedback to control temperature, and uses pressure as the feedforward (Figure 15). A disturbance or change in process immediately causes a pressure drop to occur in the heat transfer because of the collapsing of the steam. The steam-pressure feed-forward anticipates the temperature change in process-flow stream before the change actually occurs. This provides anticipation of process changes.

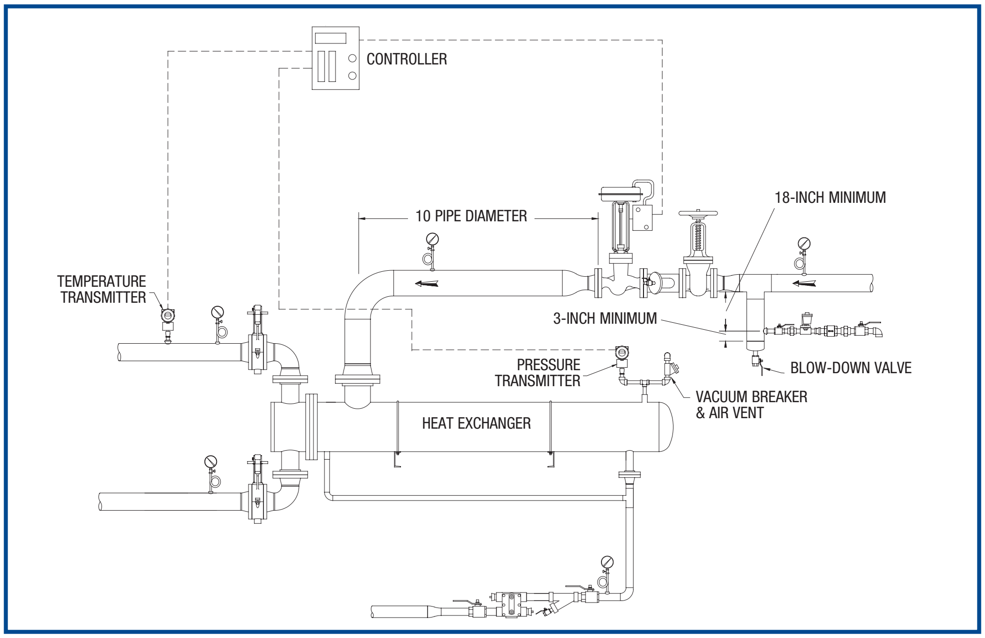

Figure 15: Feedforward Control for Heat Transfer

Heat-Transfer Feedback, Feedforward, Cascade Control

The control system in heat transfer can have feedback (temperature), feed-forward (steam pressure), and cascade product flow into the control scheme (Figure 16). Using all possible variables, heat-transfer control can provide the highest degree of accuracy.

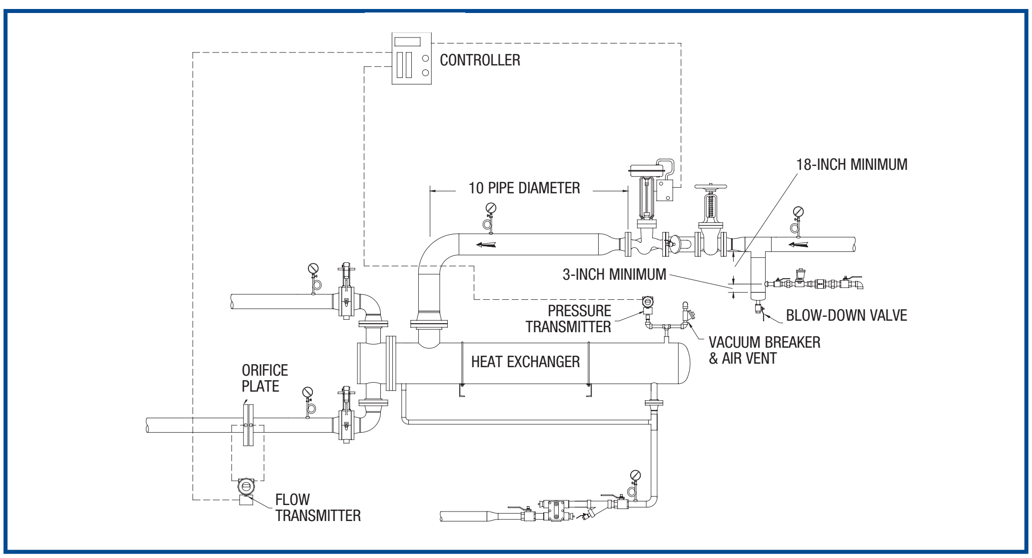

Figure 16: Feedback, Feedforward, Cascade Control

Feedback-Condensate Control

A condensate feedback-control scheme is used in condensate removal and is typically a simple-level transmitter, controller, and control valve (Figure 17). This system is typically used on a heat transfer application.

In process-flow operations where condensate flow rates are 8,000 pounds per hour (lbs/h) or higher, steam traps are not advised. Instead, use a level transmitter, controller, and control valve with a feedback-control scheme. This feedback-control scheme gives you the ability to remove the condensate from the heat-transfer process on a continuous basis. In these high-flow rates, a control valve provides a high degree of accuracy and control in the removal of condensate from heat transfer.

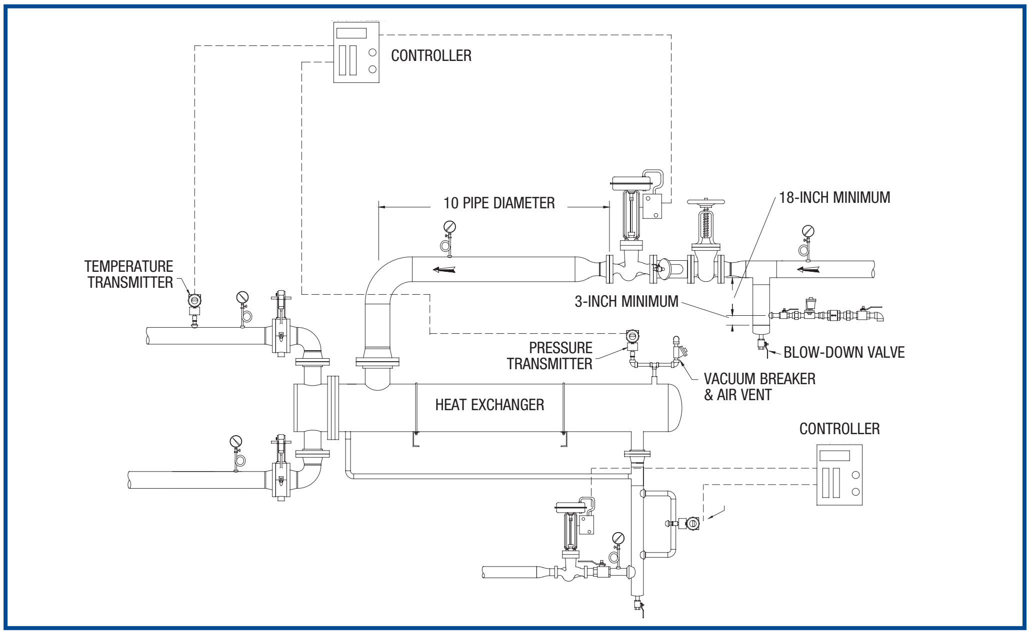

Figure 17: Feedback-Condensate Control

Control Versus Cost

The best process-control scheme is one that provides the system with the most information possible; to do this, the user must evaluate cost factor. The more information that is provided to the control scheme, the higher the cost for the field devices—and the more complex the controller, control strategy, and wiring. Therefore, the user must consider cost justification to identify the correct control scheme for the process application.

Conclusions and Recommendations

Control strategies, when evaluated from basic inputs and outputs, are simple and straightforward. Control schemes should be determined based on the level of control necessary, the cost, and the process.

When determining control-scheme selection:

- Outline objectives and goals clearly before starting the selection process
- Select the correct control scheme for the process
- Select the proper equipment for the application.

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