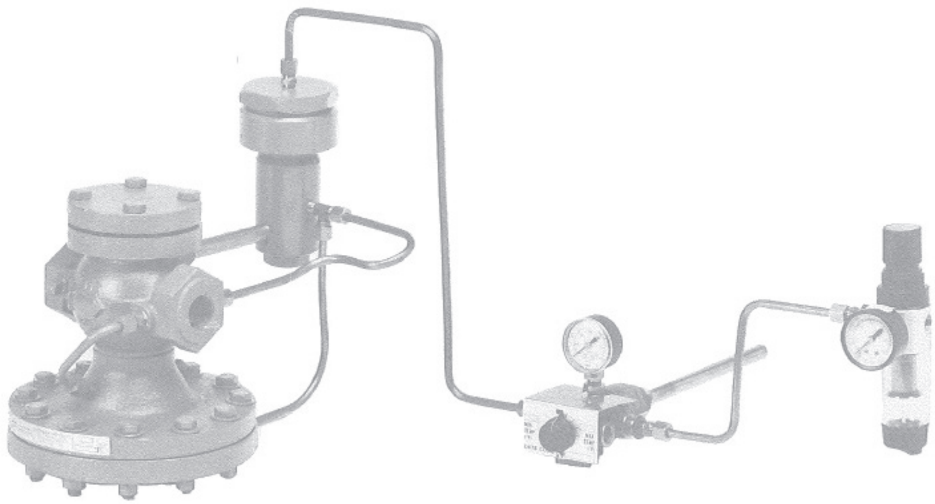
TECHNICAL MANUAL
TES-492B



Hoffman Specialty® Steam Regulating Valves Manual

Bell & Gossett
a xylem brand

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I. INTRODUCTION

Steam regulating valves are found in a variety of light industrial and HVAC applications. They automatically control the flow of steam in order to:

1. regulate downstream steam pressure, or
2. regulate the temperature of some other substance being heated by the steam.

PRESSURE REGULATORS

Most large steam plants generate and distribute steam at high pressure, then lower the pressure at the point of use with a pressure reducing valve, or pressure regulator. They do this because high pressure steam boilers tend to be more efficient than low pressure boilers, and high pressure pipelines cost a great deal less than an equivalent pipeline for lower pressure steam. Also, low pressure steam contains more usable heat energy per pound, and components that operate at lower pressures don't have to be built to withstand the stress of high pressure. Pressure regulators use downstream pressure as a feedback signal to position a valve so that steam at higher pressure upstream will flow through the valve at a rate that will maintain some desired lower pressure downstream.

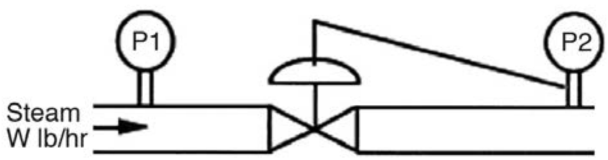


Figure 1
Pressure Regulator

TEMPERATURE REGULATORS

Steam is an excellent heating medium because it carries a lot of heat per pound, it's non toxic, inexpensive, and readily available. Temperature regulating valves control the flow of steam into a heat exchanger in order to heat another fluid. They use the temperature of that other fluid to generate a feedback signal to operate the valve that controls the flow of steam. This "other fluid" can be any liquid or gas, and the nature of that fluid will determine the type of heat exchanger to be used.

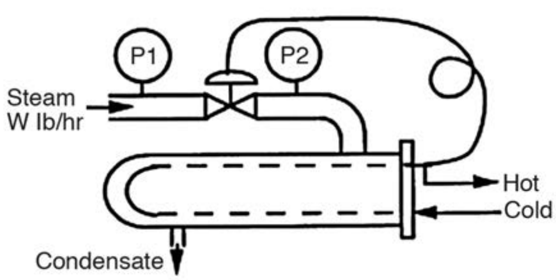


Figure 2
Temperature Regulator

Figure 2 shows a very common type, a shell and tube heat exchanger being used to heat liquid in the tubes by steam condensing in the shell.

DEFINITIONS

In both pressure and temperature regulators, there is an important and predictable relationship among three factors:

(1) pressure ahead of the valve, called "supply pressure", or "P1"
(2) pressure downstream of the valve, called "control pressure", "load pressure", or "P2", and
(3) steam flow rate in pounds of steam per hour, "W".

These three quantities must be known in order to design, operate, or troubleshoot a steam regulating valve installation. Another factor, "pressure drop", is the difference between upstream and downstream pressure. Other terms used to describe pressure drop are "differential" and "ΔP", which is read "delta P".

PRESSURE MEASUREMENT

The pressure in a system can be measured using either of two starting points, absolute zero, or atmospheric pressure:

In **Figure 3** the bottom line represents an absolute vacuum - no pressure at all. Atmospheric pressure, caused by the weight of the atmosphere, is about 14.7 pounds per square inch above absolute zero, psia, but a pressure gage exposed to atmospheric pressure would read O psig (At sea level.). The pressure in System A could be measured from absolute zero in pounds per square inch, absolute, "psia", or it could be measured by a pressure gage starting at atmospheric pressure, in pounds per square inch, gage, or "psig".

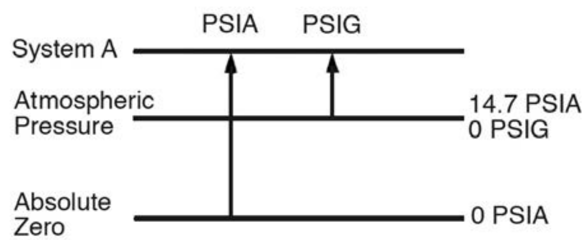


Figure 3
Pressure Measurement

PROPERTIES OF STEAM

The amount of heat transferred is commonly measured in "British Thermal Units" or "Btu". The number of Btu required to bring a pound of ice water to the boiling temperature is called the "sensible heat" because we can sense the effect of the heat addition by observing a rise in temperature of the water. A more formal term for sensible heat is "liquid enthalpy", measured in Btu/lb. The heat that's added to water at boiling temperature is called "latent heat", because it's effect on the water doesn't show up as an increase in temperature. This "latent heat", or "enthalpy of evaporation", causes the water to change from a liquid to a vapor with no change in temperature. The term "saturated steam" refers to the steam generated in a typical boiler. It's the water vapor that forms while heat is added to liquid water at the boiling temperature. Pressure and temperature of saturated steam are related. This relationship, as well as the enthalpy and other properties of steam at various pressures are tabulated in the "Steam Tables", a shortened version of which is shown in **Figure 4**.

The steam tables can provide a great deal of information to help solve problems in steam system operation and design. For example, suppose we want to mold some plastic that has a melting point of 300°F in a plastic molding machine. According to the steam tables, we'll need at least 55 psig steam in the machine heating coils to melt the plastic because the temperature of steam at pressures below 55 psig is less than 300°F. The manufacturer of the molding machine might install a pressure regulator to provide some constant steam pressure in the coils of his machine, say, 150 psig at 366°F. We can't reduce the pressure much below this, because our steam temperature has got to stay well above the plastic melting point in order to melt the plastic quickly and maintain the production rate. On the other hand, if we want to heat water to 140°F, we could use any steam pressure, even steam at 0 psig/212°F, would be hot enough to transfer heat to the water at an acceptable rate. So steam flowing through a temperature regulating valve could drop to almost any low pressure and temperature, but we wouldn't care, as long as we get the desired 140°F temperature in the water.

Notice that the sensible heat of a pound of water at higher pressure is greater than the sensible heat at some lower pressure. Each pound of steam at 0 psig carries 970 of latent heat, but higher pressure steam carries less latent heat. Finally, notice that the total enthalpy of the steam, the sum of sensible plus latent heat, increases with increasing pressure.

PROPERTIES OF SATURATED STEAM

Pressure psig	Temperature °F	Heat in Btu/lb. Sensible	Latent	Total	Specific Volume Cu. ft. per lb.
25 (Inches Vac.)	**134**	**102**	**1017**	**1119**	**142**
20 (Inches Vac.)	162	129	1001	1130	73.9
15 (Inches Vac.)	179	147	990	1137	51.3
10 (Inches Vac.)	192	160	982	1142	39.4
5 (Inches Vac.)	203	171	976	1147	31.8
0	**212**	**180**	**970**	**1150**	**26.8**
1	215	183	968	1151	25.2
2	219	187	966	1153	23.5
3	222	190	964	1154	22.3
4	224	192	962	1154	21.4
5	**227**	**195**	**960**	**1155**	**20.1**
6	230	198	959	1157	19.4
7	232	200	957	1157	18.7
8	233	201	956	1157	18.4
9	237	205	954	1159	17.1
10	**239**	**207**	**953**	**1160**	**16.5**
12	244	212	949	1161	15.3
14	248	216	947	1163	14.3
16	252	220	944	1164	13.4
18	256	224	941	1165	12.6
20	**259**	**227**	**939**	**1166**	**11.9**
22	262	230	937	1167	11.3
24	265	233	934	1167	10.8
26	268	236	933	1169	10.3
28	271	239	930	1169	9.85
30	**274**	**243**	**929**	**1172**	**9.46**
32	277	246	927	1173	9.10
34	279	248	925	1173	8.75
36	282	251	923	1174	8.42
38	284	253	922	1175	8.08
40	**286**	**256**	**920**	**1176**	**7.82**
42	289	258	918	1176	7.57
44	291	260	917	1177	7.31
46	293	262	915	1177	7.14
48	295	264	914	1178	6.94
50	**298**	**267**	**912**	**1179**	**6.68**
55	300	271	909	1180	6.27
60	307	277	906	1183	5.84
65	312	282	901	1183	5.49
70	316	286	898	1184	5.18
75	**320**	**290**	**895**	**1185**	**4.91**
80	324	294	891	1185	4.67
85	328	298	889	1187	4.44
90	331	302	886	1188	4.24
95	335	305	883	1188	4.05
100	**338**	**309**	**880**	**1189**	**3.89**
105	341	312	878	1190	3.74
110	344	316	875	1191	3.59
115	347	319	873	1192	3.46
120	350	322	871	1193	3.34
125	**353**	**325**	**868**	**1193**	**3.23**
130	356	328	866	1194	3.12
140	361	333	861	1194	2.92
145	363	336	859	1195	2.84

Pressure psig	Temperature °F	Heat in Btu/lb. Sensible	Latent	Total	Specific Volume Cu. ft. per lb.
150	**366**	**339**	**857**	**1196**	**2.74**
155	368	341	855	1196	2.68
160	371	344	853	1197	2.60
165	373	346	851	1197	2.54
170	375	348	849	1197	2.47
175	**377**	**351**	**847**	**1198**	**2.41**
180	380	353	845	1198	2.34
185	382	355	843	1198	2.29
190	384	358	841	1199	2.24
195	386	360	839	1199	2.19
200	**388**	**362**	**837**	**1199**	**2.14**
205	390	364	836	1200	2.09
210	392	366	834	1200	2.05
215	394	368	832	1200	2.00
220	396	370	830	1200	1.96
225	**397**	**372**	**828**	**1200**	**1.92**
230	399	374	827	1201	1.89
235	401	376	825	1201	1.85
240	403	378	823	1201	1.81
245	404	380	822	1202	1.78
250	**406**	**382**	**820**	**1202**	**1.75**
255	408	383	819	1202	1.72
260	409	385	817	1202	1.69
265	411	387	815	1202	1.66
270	413	389	814	1203	1.63
275	**414**	**391**	**812**	**1203**	**1.60**
280	416	392	811	1203	1.57
285	417	394	809	1203	1.55
290	418	395	808	1203	1.53
295	420	397	806	1203	1.49
300	**421**	**398**	**805**	**1203**	**1.47**
305	423	400	803	1203	1.45
310	425	402	802	1204	1.43
315	426	404	800	1204	1.41
320	427	405	799	1204	1.38
325	**429**	**407**	**797**	**1204**	**1.36**
330	430	408	796	1204	1.34
335	432	410	794	1204	1.33
340	433	411	793	1204	1.31
345	434	413	791	1204	1.29
350	**435**	**414**	**790**	**1204**	**1.28**
355	437	416	789	1205	1.26
360	438	417	788	1205	1.24
365	440	419	786	1205	1.22
370	441	420	785	1205	1.20
375	**442**	**421**	**784**	**1205**	**1.19**
380	443	422	783	1205	1.18
385	445	424	781	1205	1.16
390	446	425	780	1205	1.14
395	447	427	778	1205	1.13
400	**448**	**428**	**777**	**1205**	**1.12**
450	460	439	766	1205	1.00
500	470	453	751	1204	.89
550	479	464	740	1204	.82
600	489	475	728	1203	.74

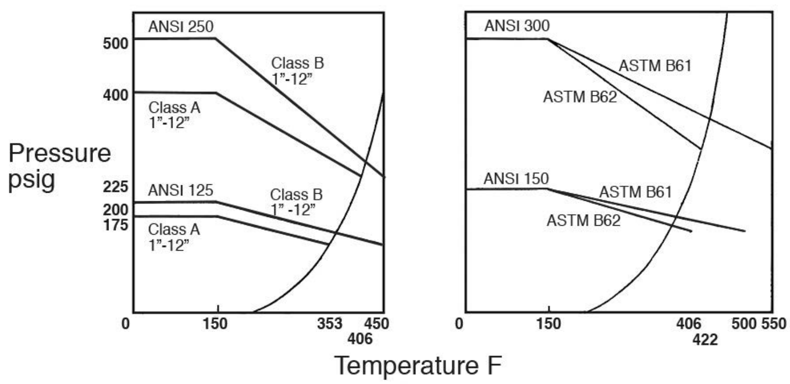
Figure 4
Properties of Saturated Steam

II. REGULATOR CONSTRUCTION

All regulators have a valve body and an actuator to operate it automatically according to the feedback signal it receives.

VALVE DESIGNS

Valve bodies come in a variety of designs. They're usually metal castings with internal passageways to direct the steam flow, openings to allow the moving parts of the valve to operate, and flanges or other means to attach the valve to the piping. They are most often made of cast bronze or cast iron; although designs for very high pressure service use stronger, more costly materials.



ASTM Al26 Cast Iron ASTM B61 & B62 Cast Bronze

Figure 5
Valve Material Pressure and Temperature Ratings

The graphs in **Figure 5** show temperature and pressure limitations for some common valve materials from ANSI B16.1, and B16.24. The pressure rating is sometimes cast into the valve body. The "WSP" or primary rating stands for "working steam pressure". The WSP rating is lower than the "WOG" or secondary rating which applies to "water, oil, or gas" service. For example, a valve could carry the following information:

150 psi WSP
300 psi WOG

which means that it can handle up to 300 psi water, oil, or gas, but only 150 psi steam. The manufacturer of steam regulators always specifies the maximum steam pressure for a given valve model. If a valve can be used for a variety of different fluids, make sure that you don't try to use it at high steam pressures, even though it might be used at higher water, oil, or gas pressures. Sometimes a valve will be limited to pressures and temperatures lower than you would expect for given body materials. This is because the other materials used for stem packing or valve trim may not be able to withstand higher pressures.

"Valve trim" is the term that describes all the parts that come into contact with the steam except for the valve body. The "valve plug", or "disc" is the part that moves to make contact with the valve "seat" to regulate steam flow and close the valve. More accurately, the "disc" is the surface of the plug that actually touches the seat. One end of the valve stem is attached to the plug, and the other end is attached to some kind of actuator which moves the stem to operate the valve. The "valve bonnet" is the part that allows the stem to penetrate the valve without leaking. The bonnet may be threaded to the body and provided with a gasket. It may be attached with a union or even a bolted assembly in higher pressure valves.

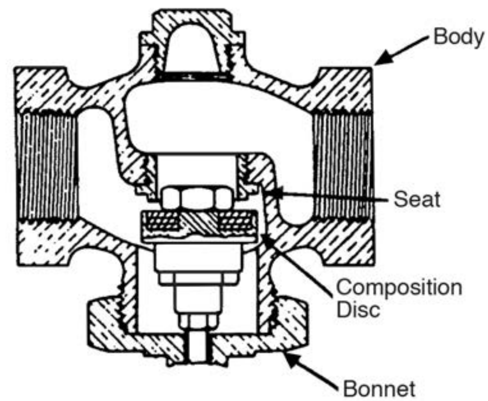


Figure 6
Renewable Disc Valve

A renewable disc valve is similar to a globe valve. It's good for applications that require tight shut off of steam flow, because the pliable composition disc will close in spite of grit or scale that might accumulate on the valve seat. The disc material won't stand up to high steam temperatures, or the erosion caused by high velocity steam flow, so there are tight limits placed on the steam pressure and the amount of pressure drop allowed across the valve. This limits the steam velocity and therefore the erosion of the disc. On the other hand, the valve is inexpensive, and the disc is easily replaced.

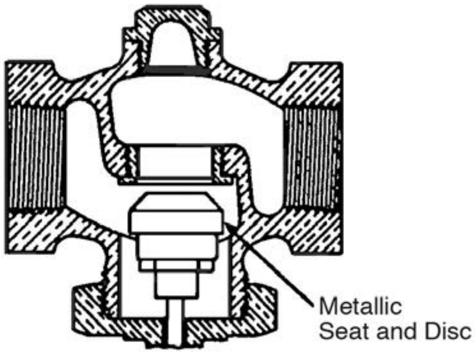


Figure 7
Metallic Disc Valve

A metallic disc valve is also a single seated valve, able to provide tight shut off. The more durable materials, such as stainless steel, or other alloys which are resistant to erosion, allow it to be used with higher temperature steam and with greater pressure drops than the renewable disc valve. These valves are generally more expensive to buy and repair than the composition disc valves. When these kinds of valves are used in simple pressure regulators, they are sometimes described as "unbalanced", meaning that changes in upstream pressure will be reflected as smaller changes in downstream pressure.

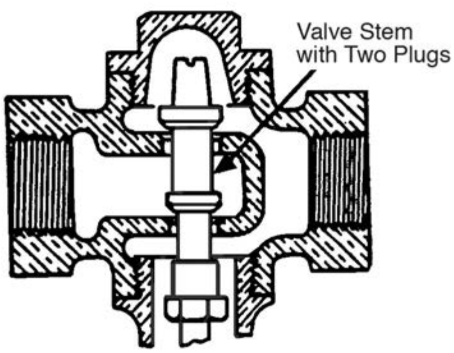


Figure 8
Double Seated Valve

Double seated valves have greater capacity than single seated valves of the same size because they have two flow passages. The valve stem is also easier to position since the steam force on it is partially offset. That is, upstream steam pressure exerts forces in opposite directions against the two valve plugs, partially cancelling each other, and allowing the stem to be positioned more accurately with less actuator force. Double seated valves are likely to allow a little flow (about 1%) even when they are supposed to be closed because of the difficulty in getting both discs to seat at exactly the same time. They are used only where a more or less continuous flow of steam can be condensed, and tight shut off is not required, for example, in a low pressure steam heating system. They are also likely to be a little more expensive than a single seated valve of the same size.

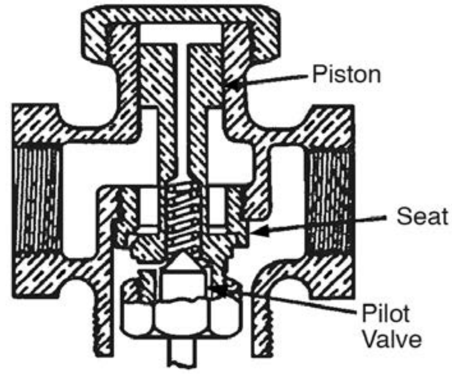


Figure 9
Piston Type Valve

The piston or "internally piloted" valve uses the steam itself to position the valve to achieve very accurate control over steam flow. The valve stern opens a small pilot valve allowing high pressure steam to expand through the piston into the chamber behind the piston. This provides the force to open the main valve passage. By using the energy of the steam to operate the valve, we get quick and accurate valve action to control steam flow. This is a "balanced" valve because small changes in upstream pressure will not effect the downstream pressure. The construction of this valve, requires more engineering and manufacturing time, so you can expect its price to be somewhat higher than others.

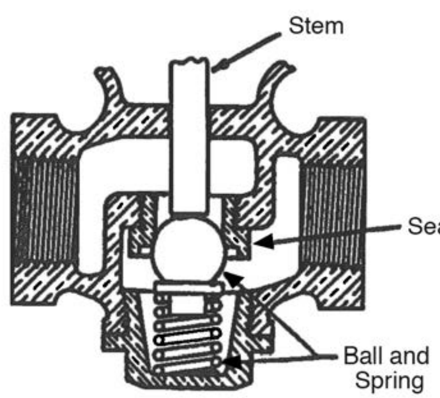


Figure 10
Pilot Type Valve

Another single seated valve depends upon a spring loaded ball to close against the seat. It is opened by a valve stem that pushes against the ball to allow flow. Because the ball can rotate a little as it closes against the seat, this valve design is more resistant to scale or dirt, and wear is not as big a problem since the ball has any number of contact surfaces, or "discs" to mate with the seat. This design is often used as a low cost direct sensing pressure reducer or as an external pilot valve to a larger regulator.

ACTUATORS

All automatic pressure or temperature regulators require some kind of actuator to position the valve plug so that the steam flow will be controlled to the proper rate. One of the most common kinds of actuators is a diaphragm, or bellows which flexes as the feedback pressure signal on it changes. The diaphragm exerts a force on the valve stem and plug that depends on the area of the diaphragm and the signal pressure on it.

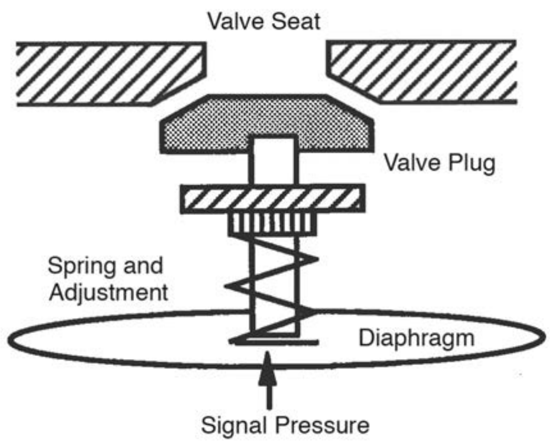


Figure 11
Signal Pressure x Area = Actuating Force

In a pressure regulator, the signal pressure is simply the downstream steam pressure being fed back to the regulator diaphragm.

In a temperature regulator, the feedback signal comes from a temperature sensing bulb or rod which is inserted in the fluid to be heated. The temperature sensing device may develop the required signal pressure in several different ways, depending upon the design of the temperature sensor, the accuracy and responsiveness required, and the cost of the unit. Different types of temperature sensing devices will be described in the section on temperature regulators.

A spring opposes the action of the diaphragm, allowing the regulator to reopen as the signal pressure is reduced. The actuator always has some kind of adjustment to set the level of signal pressure required to operate the valve. That setting determines the pressure or temperature set point of the regulator.

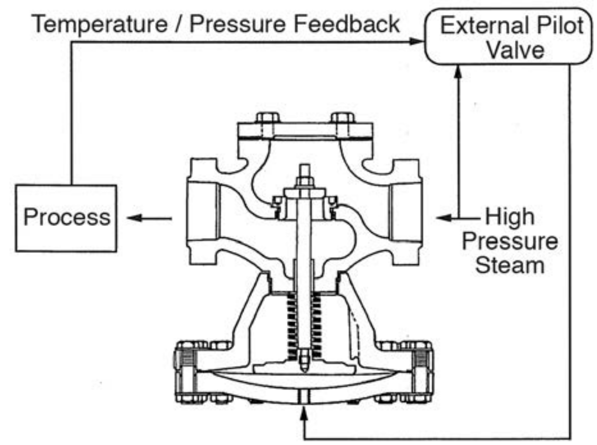


Figure 12
Externally Piloted Regulator

A very popular regulator design uses a single seated main valve operated by one or more external pilot valves. The external pilot valve controls the flow of steam to a large diaphragm which opens and closes the main valve, so the external pilot valve and the main valve diaphragm act together as the actuator. The pressure or temperature set point can be adjusted at the pilot valve. A variety of pilot valves is available to regulate pressure, or temperature, or both temperature and pressure.

III. PRESSURE REGULATION

Pressure regulators are most often found in one of the following designs: direct sensing, remote sensing, or externally piloted as shown in **Figure 13**.

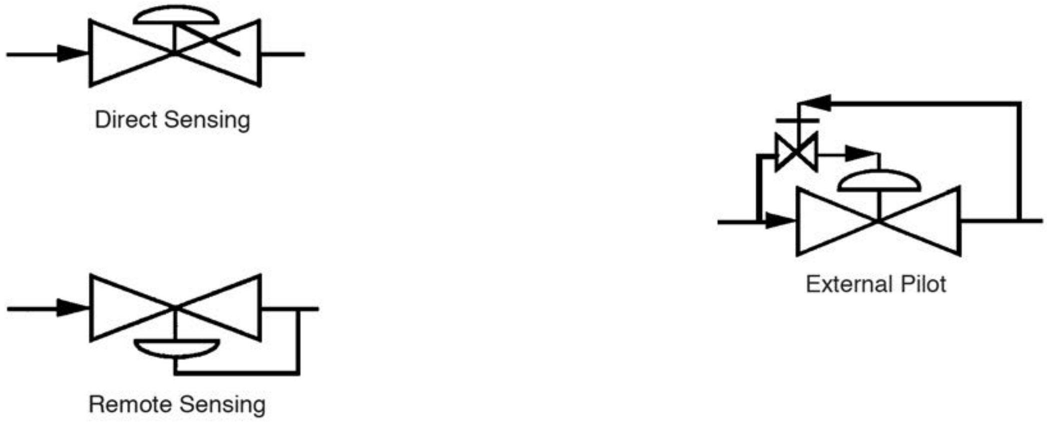


Figure 13
Types of Pressure Regulators

The direct sensing valve has an internal passageway that exposes the bottom of the diaphragm to downstream pressure. The remote sensing regulator has an external feedback line, usually 1/4" copper tubing, extending from the downstream pipeline back to the valve diaphragm. The remote sensing regulator is usually more costly, and requires more installation time and space, but it gives better control quality since the source of the feedback signal is removed from the turbulent steam flow around the valve. The direct sensing valve is less expensive, more compact, and gives adequate control for many applications.

The externally piloted regulator has a number of different pilot valves for pressure regulation. They provide very responsive and accurate pressure regulation, although the installation is more complex than the direct or remote sensing valves. Costs of remote sensing and externally piloted regulators are usually about the same.

PRESSURE REGULATOR OPERATION

The valve body, spring, and diaphragm of the remote sensing regulator in **Figure 14** have been chosen and installed to accomplish a pressure reduction from 100 psig to 50 psig at a steam flow rate of 1500 lbs per hour. **Figure 14** shows how this valve will react to maintain the downstream pressure in response to different conditions of steam demand.

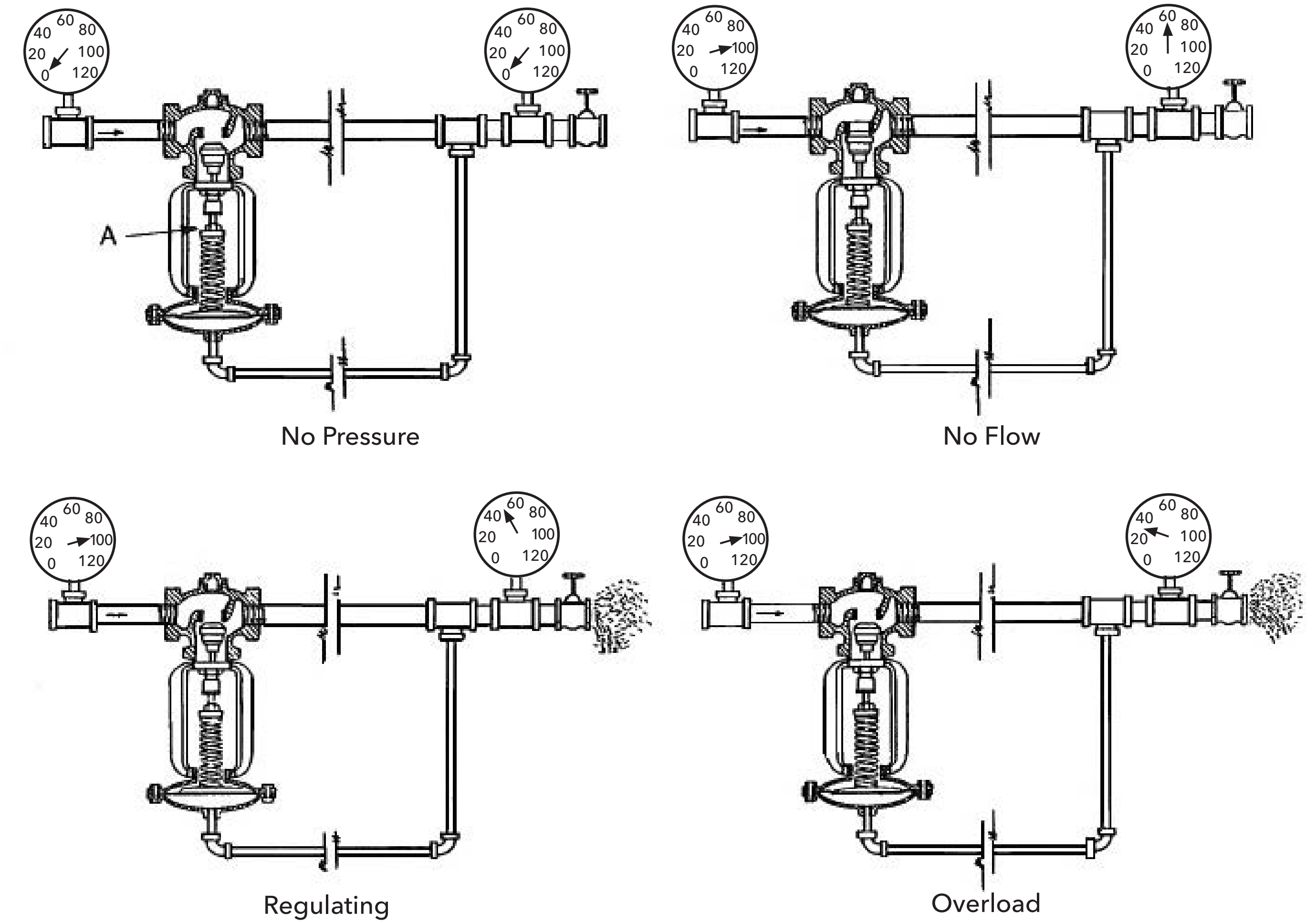


Figure 14
Pressure Regulation

NO PRESSURE

The pressure reducing valve is installed in the steam pipe with a remote pressure sensing line leading back to the bottom of the valve diaphragm. Before we cut in steam, both pressure gages show 0 psig, and the valve is wide open. That's because the regulating nut, A, has been adjusted on its threaded sleeve, so it's compressing the spring, causing the diaphragm to bulge downward. The valve stem is connected to the button above the diaphragm, so this stem movement pulls the plug off the seat.

NO FLOW

If we keep the discharge valve shut and open the steam supply valve, the upstream gauge will read 100 psig, the downstream gauge almost 60 psig, and the valve will close as the downstream pipe fills with steam. Rising pressure in the downstream piping acts through the sensing line on the diaphragm, exerting an actuating force upward, further compressing the spring and closing the valve. It takes somewhat greater force to overcome friction and get the valve plug to start moving. That's why the downstream pressure in this "lock up" or no flow situation is a little higher than the desired set point of 50 psig.

REGULATING

When we open the discharge valve, steam flows out of the pipe, and pressure in the sensing line drops. Decreased pressure below the diaphragm means less force acting upward, so the spring starts to relax downward, opening the valve and allowing flow. Steam flow and pressure drop through a valve are related in a definite, predictable way. As the demand for steam downstream of the valve rises and falls, the pressure in the sensing line will also vary, repositioning the valve plug to allow enough flow to maintain about 50 psig at the sensing point. This is the normal operating situation for the valve - changes in pressure at the sensing point are converted into changes in actuator force at the diaphragm, opening or closing the valve to increase or reduce the flow as required.

OVERLOAD

As the demand for steam increases, the feedback process works until the valve is wide open. With further increases in demand, the wide open valve will no longer be able to pass enough steam to maintain the desired pressure, and downstream pressure will start to drop off. It's generally accepted that a drop of steam pressure greater than 10% below the set point means that the valve is undersized, or too small, for that flow rate.

DIRECT SENSING VALVE

Direct sensing valves operate in the same way as the remote sensing valve except that downstream pressure is led from within the valve to the underside of the diaphragm without need for a remote sensing line. In **Figure 15** steam flows from left to right. A small passage in the valve body, or a generous fit around the valve stem allows downstream pressure to act against the bottom of the diaphragm to balance the spring force exerted on top of the diaphragm. Because the downstream pressure is likely to be unsteady due to turbulence as steam flows through the valve, the quality of pressure regulation in a direct sensing valve is not likely to be as good as in a remote sensing valve, although the smaller size, easier installation, and lower cost often suit them for simple applications.

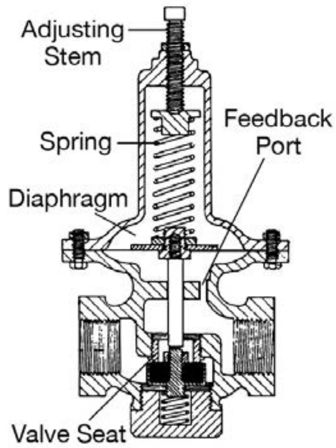


Figure 15
Direct Sensing Valve

EXTERNALLY PILOTED REGULATORS

The same principles of pressure drop and feedback control operate in external pilot operated valves.

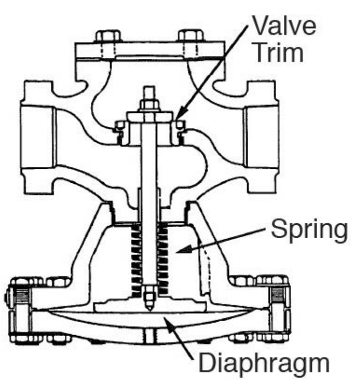


Figure 16
Main Valve

The main valve in an externally piloted regulator is installed in the steam piping with threaded, or flanged fittings depending on the valve size. It has a single metallic seat and plug, the "valve trim", often made of hardened stainless steel to resist erosion and corrosion. Different size valve seats can be screwed into the body in order to provide some flexibility in designing the capacity of the valve. More details on the use of different size valve trim are included in the example on regulator sizing.

The main valve is held closed by a spring which is compressed between the valve body and the double stainless steel diaphragm at the bottom of the valve as well as steam pressure acting on top of the valve plug. In order to open the valve, steam pressure must be exerted on the bottom of that diaphragm to further compress the spring and open the valve. An external balance tube insures that there will be no difference between the pressure on top of the diaphragm and pressure at the valve exit, and tappings are provided in the valve body to mount the pilot valve on either side. Smaller, external pilot valves regulate steam flow to the diaphragm to operate the main valve.

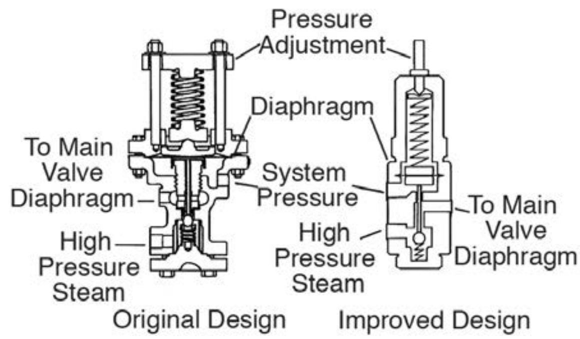


Figure 17
Spring Type Pressure Pilot Valves

The spring type external pressure pilot valve gets its source of steam from the high pressure side of the main valve, and regulates steam flow to the main valve diaphragm in order to provide reduced steam pressure downstream. The pilot valve also has a feedback connection which applies system steam pressure against the bottom of a small diaphragm. Force on top of the diaphragm is adjusted by the amount of spring compression set by the operator. If the downstream pressure is lower than the set point, the pilot will open, allowing steam to flow to the main valve diaphragm. Both the original design and the improved design for the spring pressure pilot have a number of springs of different stiffness to provide a range of downstream pressures. Pilot valves are often equipped with strainers to remove any grit or scale which might damage the pilot or cause it to stick open. **Figure 18** shows how the main valve and spring pressure pilot valves work together to regulate downstream pressure.

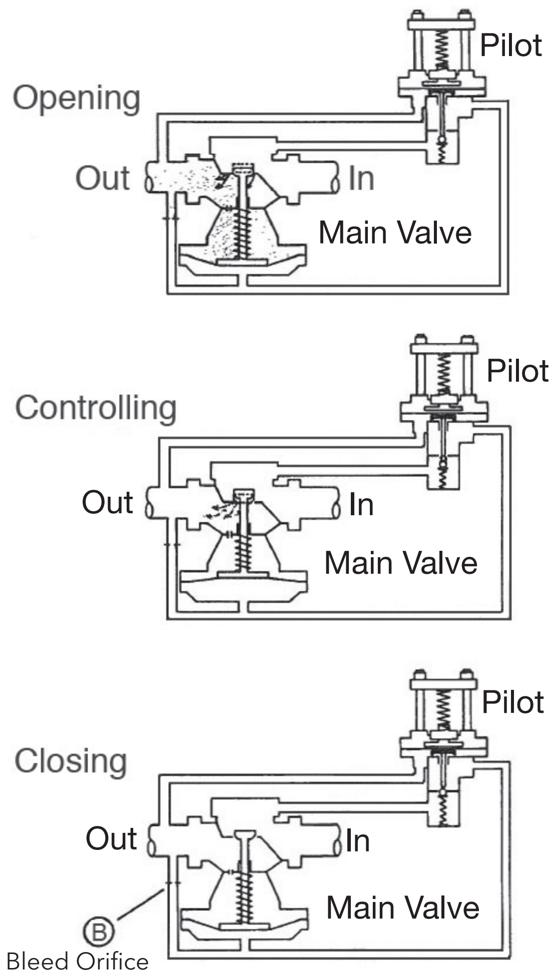


Figure 18
External Pressure Pilot Operation

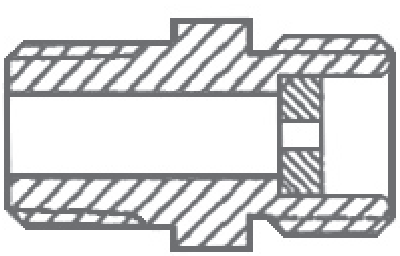


Figure 19
Typical Bleed Orifice

OPENING

If system pressure on the bottom of the pilot diaphragm is less than the spring compression above, there will be a net force acting down from the pilot diaphragm, forcing the ball off the pilot valve seat, and allowing steam to flow to the main valve diaphragm.

CONTROLLING

As pressure builds under the main valve diaphragm, the spring is compressed, and the valve opens. High pressure steam flows through the valve, raising the downstream pressure toward the set point. Pressure of the steam acting under the main diaphragm will be partway between the high pressure upstream and the low pressure downstream of the main valve.

CLOSING

As downstream pressure builds, the force imbalance across the pilot valve diaphragm is corrected, allowing the pilot to close. As steam pressure below the main valve diaphragm starts to fall, the main valve spring can expand, closing the main valve and pushing the remaining steam from below the diaphragm to the downstream side of the valve via a "bleed orifice", shown at "B"

The bleed orifice most commonly used is a compression fitting with a drilled orifice. It's installed in the tubing from the main valve diaphragm in the tapping at the downstream side of the valve. Any time the pilot valve is open, there will be some small flow through the bleed orifice, but flow through the pilot as it opens is much greater than flow through the bleed orifice. This allows pressure to build under the main valve diaphragm to open the valve. The bleed orifice is required in order to allow the regulator to close quickly when the pilot closes. Without the bleed orifice, the main valve wouldn't close until the steam below its diaphragm condensed, and that would cause an unacceptable lack of responsiveness, and wide swings in pressure downstream.

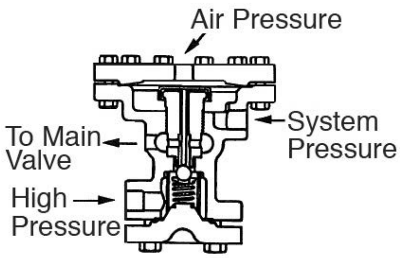


Figure 20
Original Style Pneumatic Pilot

PNEUMATIC PRESSURE PILOT

The spring controlled pilot valve is useful for reducing steam pressure to some constant lower pressure, but it's often inconvenient to change the pilot valve setting. Pneumatic pilot valves can be easily reset if a different downstream pressure set point is desired. Of course a low pressure air compressor must be available to provide "shop air" to set the pilot. The original style pneumatic pressure pilot is identical to the original style spring operated pilot except that the spring and yoke assembly of the spring pilot is replaced by a pneumatic diaphragm as shown in **Figure 20**. With pneumatic pilots, the reduced steam pressure setting can be changed simply by increasing or decreasing air pressure to the top of the pneumatic diaphragm. For higher downstream pressures, the single air diaphragm can be replaced by a set of two diaphragms which give a 3:1 or 5:1 area ratio to multiply the pneumatic force.

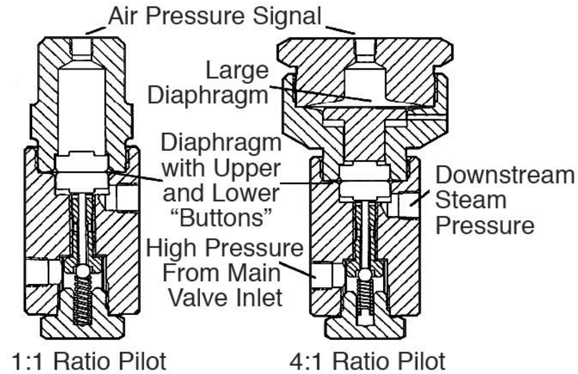


Figure 21
Pneumatic Pilot Valves

An improved design pneumatic pilot valve operates in much the same way as the original style, but has either a single diaphragm which gives a 1:1 ratio or two diaphragms, which give a 4:1 ratio of downstream steam pressure to air signal pressure. The large diaphragm has an area four times greater than the lower diaphragm, so a given air pressure signal on top of the large diaphragm will require four times more downstream steam pressure below the smaller diaphragm to achieve balance and close the pilot. The outlet port which supplies steam to the main valve diaphragm and the bleed orifice is located just above the high pressure steam inlet, at 90° to it, so it doesn't appear in this view. The buttons and large diaphragm cap are designed to limit the amount of diaphragm movement to prevent damage.

SOLENOID PILOT

Solenoid pilot valves are electrically operated on/off valves which can control the flow of steam from the main valve to other pilots, providing a simple means to control the regulator. The solenoid pilots are either normally on, requiring an electric signal to close, or normally off, requiring an electric signal to open. They may be used with any combination of other pilots to provide remote, automatic, or timed operation of the regulator system, or to act as safety over-ride.

Figure 22
Solenoid Pilot Valve

SUMMARY

The performance of a pressure regulator is summarized in **Figure 23**, although the figure misrepresents actual regulator performance by compressing the horizontal scale in order to show the effect of different size valve trim. An actual regulator would provide acceptable downstream pressure over a wide range of flow rates.

Legend:

- A. Steam flow through the regulator as it increases from zero at the left.
- B. Three curves describe the performance of a given size regulator body when different size valve trim is installed.
- C. The minimum controllable flow.
- D. Pressure rise at no flow.
- E. Pressure set point minus 10%.
- F. Maximum normal flow for the given main valve trim.

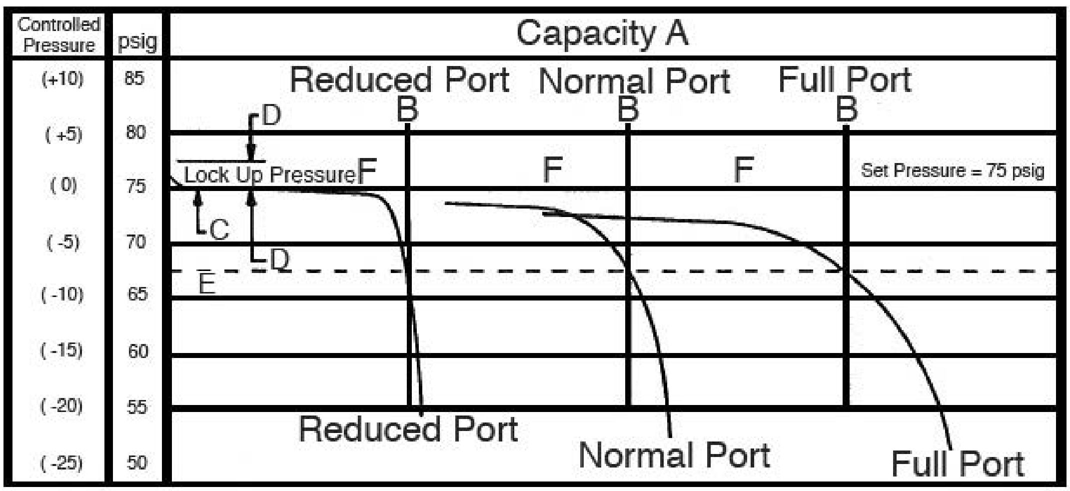


Figure 23
Pressure Regulator Performance

Some additional terms are sometimes used to describe the performance of pressure regulators.

Rangeability of a regulator is the ratio of maximum to minimum controllable flow. In terms of **Figure 23**;

$$\text{rangeability} = \frac{\text{flow at E}}{\text{flow at C}}$$

Turn down ratio is the ratio of maximum normal flow to minimum controllable flow. In terms of **Figure 23**;

$$\text{turn down ratio} = \frac{\text{flow at F}}{\text{flow at C}}$$

SELECTING AND SIZING PRESSURE REGULATORS

There are a number of decisions or calculations involved in choosing a steam pressure regulator:

(a) Materials used for the valve body, trim, and actuator must be compatible with the steam pressure to be used, the design differential pressure, and the durability and precision expected from the valve.

(b) Valve design must provide suitable service. Among the choices available:
- single or double seated valve design
- balanced or unbalanced design
- remote sensing, direct sensing, or externally piloted design

(c) The pressure reduction required must not be excessive. Valves have definite limitations on the maximum pressure drop allowed across a single valve. Observing these limits will provide longer life and quieter operation. If your system requires a pressure drop greater than that allowed for a single valve, then two or more valves can be used in series to achieve the total drop in acceptable stages. Section V has more details on valves in series.

(d) Steam flow required through the valve can often be determined simply by noting the steam requirements on the nameplate of the condensing equipment. Steam flow rate requirements can also be calculated from the heat transfer required, and the steam enthalpy of evaporation at the reduced pressure. See the section on temperature regulator sizing for additional details and a sample calculation. Maximum and minimum flow rates should be estimated too. A single valve that is large enough to handle the maximum flow may be oversized at the minimum flow rate. In this case, valves should be used in parallel. See Section V for details about designing and installing valves in parallel.

(e) The valve size required can be determined by,
  (1) using sizing formulas to calculate a required valve flow coefficient,
  (2) using regulator capacity tables provided by the valve manufacturer, or
  (3) using special selection software. The valve flow coefficient, Cv, for a given valve is defined as the flow rate in gallons per minute of water at standard temperature, that would pass through the wide open valve if a constant pressure differential of one psi were maintained across the valve. The flow coefficient thus becomes a measure of a valve's capacity relative to other valves.

Sizing formula

(1) Calculate the valve flow coefficient, Cv, required for the given steam pressure drop and flow rate by using the formulas or other methods provided in this section.

(2) Select a valve from the manufacturer's catalog that has a Cv rating equal to, or greater than the one calculated. Sample valve data sheets giving the flow coefficients and other typical data for sample regulators are also included in this section.

Capacity tables

(1) Obtain the capacity table for the valve model you've chosen. Each valve model has its own capacity table, determined by tests conducted at the factory. Enter the table with the steam inlet pressure, usually listed vertically along the left side of the table. (See **Figure 28**.)

(2) Go to the desired outlet pressure and read across that row until you find a flow rate that meets or exceeds the capacity required. The valve body size is listed across the top of the table.

Computer equipment selection programs

Follow the on screen prompts to input values for initial and reduced pressure required, and for the design flow rate. The principles used in developing these programs are illustrated in the following examples. These programs are "user friendly". Simply refer to the program for details.

Regardless of the method used, be careful not to add capacity safety factors since that will result in selection of a valve that is oversized for your application. Oversized valves have higher initial cost, provide poorer quality of control, and are likely to wear out more quickly than a properly sized valve.

(f) Choose the valve actuator or pilot based upon the initial and downstream pressures desired. The actuator may consist of a diaphragm, diaphragm case, and spring, or it may be an externally mounted pilot valve that supplies steam pressure to the main valve diaphragm depending on the type of regulator chosen.

STEAM VALVE SIZING FORMULAS

DEFINITIONS:

P1 = pressure at valve inlet, psia
P2 = pressure at downstream sensing point, psia
ΔP = P1 - P2
W = flow rate of saturated steam, lb/hr

Calculating the valve flow coefficient, C_v

$$C_v = \frac{W}{2.1\sqrt{\Delta P(P1+P2)}}$$ when P_2 is greater than 0.5 P_1

$$C_v = \frac{W}{2.6\sqrt{\Delta P(P1)}}$$ when P_2 is less than or equal to 0.5 P_1

In order to correct the steam flow rate for superheat or moisture in the steam flow, use the following relationships.

MOISTURE CORRECTION:

W_w = flow rate of "wet" steam at X% quality, lb/hr
X = steam quality, in percent, (X = 1 - % moisture)

$$W = \frac{W_w}{X}$$

SUPERHEAT CORRECTION:

W_{sh} = flow rate of superheated steam at S°F superheat, lb/hr
S = degrees of superheat, °F
= superheated steam temperature - saturation temperature at the given pressure.
W = $W_{sh}(1 + 0.00065S)$

Example: Select a regulator using the flow coefficient formula.

We need a valve that will provide tight shut off and reasonably long life to supply 3800 lb/hr of 75 psig steam from an initial pressure of 150 psig. We'll use the valve sizing formulas to determine the required size.

Step 1.Convert the given gage pressures to absolute pressures:

P_1 = 150 + 14.7 = 164.7 psia or about 165 psia
P_2 = 75 + 14.7 = 89.7 psia or about 90 psia

Step 2. Choose the right formula on the basis of the ratio of P_2 to P_1, and calculate the required valve flow coefficient.

$$\frac{P_2}{P_1} = \frac{90}{165} = 0.54$$

Since the ratio is greater than 0.5, we choose the first formula, and substitute the proper values as follows:

$$C_v = \frac{W}{2.1\sqrt{\Delta P(P_1+P_2)}}$$

$$C_v = \frac{3800}{2.1\sqrt{(165 - 90)(165 + 90)}}$$

$$C_v = \frac{3800}{2.1\sqrt{(75)(255)}}$$

$$C_v = \frac{3800}{290}$$

$$C_v = 13.1$$

Alternate methods for finding the valve flow coefficient are available. Some manufacturers publish tables, like the one shown on pg. 17, to help you calculate the C_v required without using the formulas.

To find the C_v required for a pressure regulator designed to reduce 150 psig saturated steam to 75 psig at a flow rate of 3800 lb/hr using **Figure 24**:

Enter the table at the top of the column for 150 psig inlet pressure, and run down to the row corresponding to 75 psig outlet pressure.

In this case, 75 is not listed, but we know that it lies halfway between 291 and 283 in the table, so we interpolate, or "split the difference".

291 – 283 = 8 and 8 ÷ 2 = 4

283 + 4 = 287 or, 291 – 4 = 287

Therefore, 287 is the "basic steam number" corresponding to a steam pressure reduction of 150 to 75 psig.

Calculate the C_v by dividing the flow rate by the basic steam number.

$$C_v = \frac{\text{steam flow required}}{\text{basic steam number}}$$

$$= \frac{3800}{287}$$

$$= 13.2$$

(Note the similarity between the flow coefficient formula and the formula we used with the basic steam number. In effect, the Basic Steam Table allows us to calculate the denominator of the C_v formula without extracting square roots.)

Step 3. After using either method to calculate the required C_v, we now turn to the catalog to find some suitable choices. Manufacturers provide summary sheets like the one in **Figure 25**, to help in selecting valves. Using the sample page, we eliminate all valves that are not made for steam service such as the model 758. Next, we eliminate all valves that are too small for this application as indicated by their C_v range such as the model 752. Finally, we note that the models 760 and 765 are back pressure or relief valves, so we are left with the model 710 and 720 valves as possibilities for this application.

BASIC STEAM TABLE (POUNDS PER HOUR)

OUTLET PRESSURE PSIG	INLET PRESSURE PSIG																		
	5	10	15	20	25	30	40	50	60	70	80	90	100	125	150	175	200	225	250
2	21	38	52	63	73	82	100	118	136	154	172	191	209	254	300	345	391	436	482
5		29	46	57	73	82	100	118	136	154	172	191	209	254	300	345	391	436	482
10			35	50	65	77	100	118	136	154	172	191	209	254	300	345	391	436	482
15				37	55	69	96	118	136	154	172	191	209	254	300	345	391	436	482
20					40	58	88	110	136	154	172	191	209	254	300	345	391	436	482
25						43	77	107	130	154	172	191	209	254	300	345	391	436	482
30							67	96	126	150	172	191	209	254	300	345	391	436	482
40								74	107	125	162	186	209	254	300	345	391	436	482
50									79	115	146	171	197	254	300	345	391	436	482
60										82	122	154	182	247	300	345	391	436	482
70											90	130	163	230	291	345	391	436	482
80												95	130	214	283	345	391	436	482
90													96	193	264	332	391	436	482
100														168	245	315	382	436	482
115														109	213	289	357	423	482
125															174	267	340	410	472
150																197	266	383	434

NOTE: Multiply basic steam number from this table with the selected valve C_V number to get the maximum pounds per hour of steam capacity of the type and size valve selected.

Figure 24

TABLE 1
SELECTION CHART

	Model No.	Description	Cv Range	Intended Service				Page No.
				Steam	Water	Air	Oil	
SELF CONTAINED	758	Single seated, bronze body Sizes ¼" thru ½" NPT Reduced pressure range: 1-180 psig Maximum pressure drop: 50 psig Maximum temperature: 100°F	1.0 to 1.5		X	X	X	9
SELF CONTAINED	740	Single seated, balanced Sizes ½" thru 2½" NPT—bronze body Sizes 3" thru 8" flanged—cast iron body Reduced pressure range: 5-125 psig Maximum pressure drop: 100 psig Maximum temperature: 150°F	2.5 to 170		X	X		10
SELF CONTAINED	752	Single seated, bronze body Sizes ½" thru 1" NPT Reduced pressure range: 1-125 psig Maximum pressure drop: 100 psig Maximum temperature: 400°F	1.4 to 2.3	X				12
SELF CONTAINED	753	Single seated, bronze body Sizes ½" thru 1" NPT Reduced pressure range: 1-125 psig Maximum pressure drop: 100 psig Maximum temperature: 200°F	1.5 to 2.5		X	X	X	12
SELF CONTAINED	RE1	Single seated, brass body Sizes ½" thru 1" NPT Reduced pressure range: 7-140 psig Maximum reducing ratio: 10:1 Maximum temperature: 400°F	1.1 to 2.9	X				13
REMOTE SENSING	710, 715	Single seated Sizes ½" thru 1½" NPT—bronze body Size 2" NPT and flanged—cast iron body Reduced pressure range: 5-125 psig Maximum pressure drop: 100 psig Maximum temperature: 406°F	2.0 to 20	X	X	X	X	14
REMOTE SENSING	720	Single seated, balanced Sizes ¾" thru 1½" NPT—bronze body Sizes 2" NPT and 2" thru 6" flanged—cast iron body Reduced pressure range: 1-125 psig Maximum pressure drop: 100 psig Maximum temperature: 406°F	4.5 to 115	X		X		16
REMOTE SENSING	705	Double seated—not recommended for dead-end service Sizes ½" thru 1½" NPT—bronze body Sizes 2" NPT and 2" thru 8" flanged—cast iron body Reduced pressure range: 1-125 psig Maximum pressure drop: 100 psig Maximum temperature: 406°F	3.5 to 250	X	X	X	X	18
REMOTE SENSING	760, 765	Relief and back pressure valves Model 760—single seated Model 765—double seated Sizes ½" thru 1½" NPT—bronze body Size 2" NPT and 2" thru 8" flanged—cast iron body Reduced pressure range: 1-125 psig Maximum temperature: 353°F	2.5 to 250	X	X		X	20

For Illustration Only

Figure 25
Regulator Summary Chart

MODEL 710 and 715
PRESSURE REDUCING VALVES

for steam, water, air or oil systems

Valve is single seated, unbalanced, tight closing, for dead-end service.

APPLICATION:
Hoffman Model 710 and 715 Pressure Reducing Valves are single seated, tight closing, recommended for dead-end or continuous service. These valves are used for reducing steam, water, or other fluid pressure on applications such as:
- Unit Heaters
- Laundry Equipment
- Pressing Machines
- Small Heating Systems

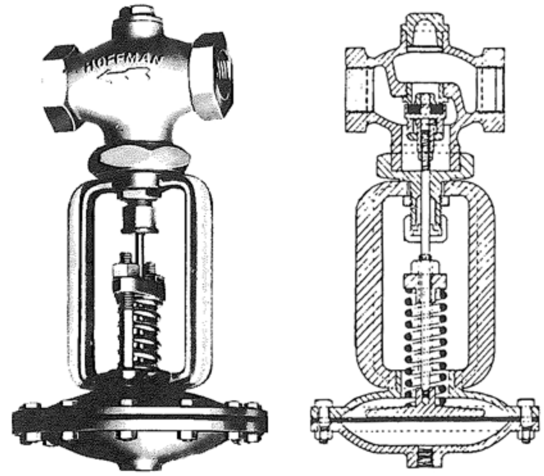
CONSTRUCTION:
The Model 710 valves are supplied with bronze body in sizes 1/2" to 1-1/2". The Model 715 2" valves have a high tensile iron body. Standard trim is replaceable PTFE disc and Stainless steel seat on all size valves. The diaphragm is neoprene with a nylon insert. The spring is selected in accordance with the control pressure specified and is made of cadmium plated steel.

OPERATION:
The Model 710 and 715 Pressure Reducing Valve is single seated, with inlet pressure entering under the seating area. The valve is diaphragm actuated, spring loaded to normally open the valve. The downstream or control pressure is admitted to the diaphragm through a 1/4" or 3/8" hole at the top of the diaphragm case, which is connected by pipe, not less than 10 pipe diameters downstream from the valve. When the spring is properly adjusted this upward force plus the inlet force under disc area will equal the downward force of the diaphragm when the desired downstream pressure is reached. (Note: this unbalanced valve will deviate. from the set pressure if inlet pressure changes either up or down.)

RECOMMENDATIONS:
The Model 710 and 715 Pressure Reducing Valves are suitable for initial pressures up to 250 psi. Control pressures from 5 to 125 psi can be supplied with various diaphragms and springs.

VALVE MATERIAL LIST
Body 1/2" to 1-1/2" .... Bronze
Body 2" .... Cast Iron
Diaphragm Case .... Cast Iron
Diaphragm .... Neoprene-Nylon Inserted
Spring .... Steel-Cadmium Plated
Trim .... Stainless Steel Seat, PTFE Disc

CAPACITY CHARTS
Capacity tables and formulas can be found on pages 22 and 23.



For Illustration Only

Figure 26
Model 710 and 715

Maximum High Pressure: 250 psig
Reduced Pressure Range: 5-125 psig
Sizes: Model 710 - 1/2" - 1-1/2"
Model 715 - 2" only

VALVE SIZE

Initial Pressure PSIG	1-1/2"		
	Reduced Pressure Range PSIG	Case Size Inches	Spring No.
101-200	18-28	8"	2
	27-36	6"	3
	35-54	6"	2
	44-82	6"	1
	76-116	5"	2
	96-125	5"	1

MAXIMUM PRESSURES & TEMPERATURES
Bronze–Screwed .... 250 PSI @ 406°F
Cast Iron–Screwed .... 250 PSI @ 406°F
Cast Iron–125 lbs. Flanged .... 125 PSI @ 353°F
Cast Iron–250 lbs. Flanged .... 250 PSI @ 406F
ABOVE ARE NON-SHOCK RATINGS

Cv Factors

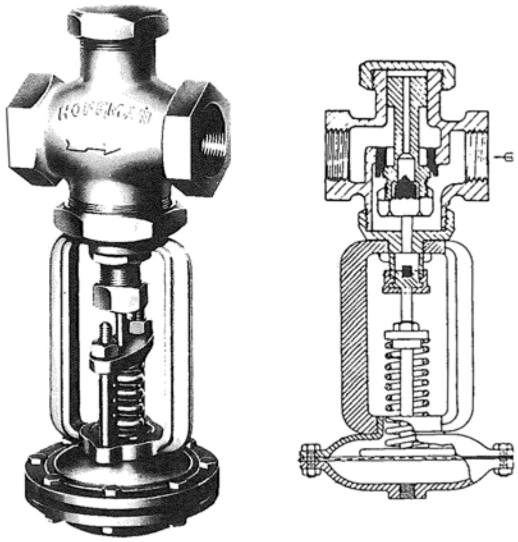
Size	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
Cv	2.0	3.0	6.0	10	14	20

NOTE: The models 710 and 715 are unbalanced single seated valves. Therefore, any fluctuation of the supply pressure (inlet pressure) will be reflected in the control pressure (outlet pressure). The example below shows the changes that occur when the supply of pressure changes. Example: A 1" valve purchased for inlet of 100 psi and control of 8 to 14 psi will control between 5 and 11 psi if used on inlet pressure of 50 psi. The same valve will control between 11 and 16 psi if used on inlet of 150 psi.

MODEL 720
PRESSURE REDUCING VALVES

for steam or air systems

Single balanced seat, internal pilot, dead-end or continuous service.



APPLICATION:
The model 720 pressure reducing valves are balanced, single seated, tight closing, recommended for dead-end or continuous service. They are used for the reduction of air or steam pressure in industrial plants, institutions, and other public buildings on applications such as:

- Hospital sterilizing equipment
- Tire vulcanizing equipment
- Hot water heaters with regulators
- Laundry equipment

CONSTRUCTION:
The Model 720 Pressure Reducing Valves are supplied with bronze body in sizes 3/4" to 1-1/2" with screwed ends. The 2" screwed and the 2" and 6" size flanged valves are supplied with high tensile iron body. Bronze and iron body valves are rated up to 250 psig initial pressure at 406°F. Standard trim is bronze with stainless steel trim also available. The diaphragm is neoprene with a nylon insert. The spring is cadmium plated steel.

OPERATION:
The Model 720 Pressure Reducing Valves are actuated by a diaphragm and the loading is a spring, which is adjustable within the reduced pressure ranges shown on the opposite page. Downstream or control pressure is admitted to the diaphragm housing through a 3/4" or 3/8" hole at the top of the diaphragm case connected by pipe to the downstream side not less than 10 pipe diameters from the valve. The loading tends to open the valve against the closing force of the diaphragm. When the loading is properly adjusted it counterbalances the pressure on the diaphragm, with the main valve in position to maintain the desired controlled pressure.

RECOMMENDATIONS:
For initial pressures of 50 psig or more use stainless steel trim. For pressure drops of 100 psig or more use two stage reduction.

VALVE MATERIAL LIST

Body 3/4" to 1-1/2" .... Bronze-Scre~ed
Body 2" .... Cast Iron Screwed
Body 2" to 6" .... Cast Iron Flanged
Diaphragm Case 3/4" to 1-1/2" .... Bronze
Diaphragm Case 2" to 6" .... Cast Iron
Diaphragm .... Neoprene-Nylon Inserted
Valve Trim .... Bronze (Stainless Steel-if required)
Spring .... Steel-Cadmium Plated

Maximum High Pressure: 250 psig
Reduced Pressure Range: 1-125 psig
Sizes: 3/4" - 6"

Valve Size In.	Reduced Pressure Range PSIG	Case Size Inches	Spring No.
3/4" – 1-1/2"	1-6	6"	5
3/4" – 1-1/2"	5-20	6"	3
3/4" – 1-1/2"	15-45	6"	2
3/4" – 1-1/2"	40-70	6"	1
3/4" – 1-1/2"	60-125	5"	1

Cv Factors

Size	3/4"	1"	1-1/4"	1-1/2"	2"
Cv	4.5	9.0	13	19	27

Size	2-1/2"	3"	4"	5"	6"
Cv	42	56	70	90	115

For Illustration Only

Figure 27
Model 720

Step 4. Turning to the data pages for these valve models, we see that the model 710 comes in sizes of 1/2" through 2" with corresponding C_V ratings of 2.0 through 20. The 1 1/2" valve, with a C_V of 14 looks like a suitable choice. Similarly, the model 720 1 1/4" with a C_V of 13 or the 1 1/2" with a C_V of 19 might be suitable. We can evaluate the capacity of each of these choices by substituting the actual valve C_V in the expression we used earlier.

$$C_V = \frac{\text{steam flow}}{\text{basic number}}$$

Therefore, steam flow = C_V x basic number, and actual steam flow for the 1710 1-1/2" valve is 14 x 287, or 4018 lb/hr.

We can summarize the selection process so far in a table like this:

Design Capacity	Inlet Press.	Outlet Press.	Basic Number	C_v Req'd	Possible Valves	Actual C_v	Actual Capacity
3800	150	75	287	13.1	1.50"/710	14	4018
3800	150	75	287	13.1	1.25"/720	13	3731
3800	150	75	287	13.1	1.50"/720	19	5453

This kind of capacity evaluation can be valuable in avoiding the over sizing that is so often the source of performance problems. In our case, we found a 1-1/4" model 720 valve that had a C_V of only 13; not quite great enough to meet the requirement of 13.1 that we had calculated. By determining the actual flow rate we can expect from that valve, we are in a position to evaluate if that valve will be "close enough". For example, we calculate that the model 720 will have a capacity of 13 x 287 = 3731 lb/hr. Compared to the design flow rate of 3800, we can see that the model 720 is within about 1.8% of the requirement. Now we can ask if a safety factor has been included in the original figure of 3800 lb/hr. If a significant safety factor has been included in the calculation of the required flow rate, then we may choose the smaller, less costly valve. But if the 3800 lb/hr flow rate is truly required, then we can confidently choose the larger capacity valve.

A good rule of thumb for determining if one of these valves is properly sized is to compare the design flow rate to the tabulated or calculated capacity of the valve. The design capacity should be between 65% and 75% of the tabulated capacity. This allows some excess capacity in case the valve is required to supply unusually heavy demands, while insuring that the valve will be comfortably wide open most of the time, thus avoiding the high velocity, noise, and poor control that results from oversized valves. Following this rule of thumb, a 1-1/2" model 720 valve that has a C_V value of 19 has a capacity of 5453 lb/hr. Our design flow rate is 70% of this valves tabulated capacity. Many manufacturers suggest even broader guidelines. They suggest simply that the valve be at 50% or more of its tabulated capacity when it's passing the design flow rate.

Another factor could be evaluated in choosing between the model 710 and 720. Although they are both described as single seated valves suitable for tight shut off, and both are able to operate in the required upstream and reduced pressure ranges, one of them is described as a "balanced valve" while the other is not. The unbalanced valve will allow variations in downstream pressure should the upstream pressure change. This could be an important reason to choose the balanced valve design. On the other hand, if the application will not have much variation in pressure upstream of the regulator, or if small variations in downstream pressure will not cause a problem, then the unbalanced valve might be an acceptable choice, particularly if it has a price advantage.

Step 5. Finally, we must choose the actuator for the valve. Assuming we've chosen the model 710, we turn to the data sheet for that valve, and select the 6" diaphragm case and the #1 spring based on the initial and reduced pressures in the application.

Example: Select a regulator for the previous application using the manufacturer's capacity tables.

When the valve manufacturer provides capacity tables for his valves, the sizing and selection process is much faster and less complicated. Capacity tables are not only easier to use, but they also provide more accurate sizing than the C_V calculation since the tables are based on actual tests of a sample of valves under actual upstream and downstream pressure conditions, and they don't assume the valve is wide open as the C_V definition does. Under some conditions of differential pressure, the main valve in an externally piloted regulator may operate only partly open. The capacity tables for those regulators automatically take this into account.

Suppose we have chosen to use an external pilot operated pressure regulator in the same application we just described. Three tables are provided in **Figure 28** for this family of valves to describe the different capacities available from the reduced port, normal port, and full port trim. These choices arise because each main valve body can come equipped with valve trim, or seat and plug sets, of different sizes to tailor the valve capacity. This would be valuable for example, if a valve is required for a limited capacity now, but future plans call for an increase in capacity. Without a choice of trim, we would have to choose between a smaller capacity valve that's not oversized now, but that will become undersized in the near future, or a valve that will be able to handle the future requirement, but that will be oversized until that level of demand is reached. By having some choices of trim available, we can install a larger size valve body with reduced trim now, then simply increase the regulator capacity later by substituting a larger capacity trim without changing the valve body.

If future changes in capacity are not important now, start with the table based on full port trim. This will give the smallest valve body size, and most economical choice. Find the steam inlet pressure along the left side, 150 psig, and the outlet pressure in the next column, 75 psig. Follow along the row, and notice that the capacity figures, in pounds per hour, increase as the valve sizes increase. Since we need a capacity of 3800 lb/hr, we would choose the 1-1/4" main valve with a capacity of 4900 lb/hr. That same valve body size with a normal port would have a capacity of 4000 lb/hr, and the reduced port would give only 2760 lb/hr. Once again, we can apply the 50% rule of thumb to get a properly sized valve.

For the full port trim: $\frac{3800}{4900} = 0.77$

For the normal port trim: $\frac{3800}{4000} = 0.95$

In this case, the normal trim would not allow much extra capacity, while the full port trim would fit the requirement very well.

Reduced Port

Pressure psig IN	OUT	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	6"
20	5	50	220	280	460	620	860	1360	1840	3090	7120
25	10	57	250	300	550	700	970	1560	2100	3670	8200
	5	58	260	400	620	780	1080	1630	2240	3940	8500
30	15	62	290	430	700	800	1100	1710	2400	4000	9500
	10	65	300	460	780	920	1180	1835	2520	4500	10170
40	25	72	320	360	730	950	1260	2050	2500	4650	10000
	20	78	370	480	840	1150	1380	2250	3000	5400	11500
50	35	81	370	480	900	1150	1450	2300	3200	5200	11100
	30	93	410	530	1050	1400	1680	2700	3520	6100	13000
	25	100	420	580	1100	1460	1800	2800	3700	6640	14000
60	45	95	420	530	1000	1300	1650	2650	3350	5800	14000
	40	104	450	610	1100	1600	1850	3000	3860	6800	15200
	35	111	470	660	1150	1720	1970	3150	4200	7300	15800
	30	115	480	680	1200	1820	2200	3300	4450	7800	17100
75	55	118	550	720	1350	1900	2150	3400	4800	8000	16200
	50	127	570	750	1400	2030	2400	3500	5050	8500	16700
	45	134	580	800	1430	2120	2550	3650	5300	9100	17800
	40	138	590	860	1450	2200	2650	3750	5520	9300	20000
100	75	151	600	900	1740	2450	3100	4300	6200	10400	21200
	60	174	670	990	1830	2750	3450	5000	7000	11300	25000
	50	177	690	1000	1870	2880	3600	5100	7300	11970	27000
125	100	175	650	1000	1900	2700	3350	4950	7000	12000	24000
	75	213	750	1200	2150	3250	4300	6000	8350	14000	30000
	50	215	800	1230	2200	3400	4400	6100	8700	14600	32200
150	125	198	810	1200	2300	3250	4100	5750	8000	13600	27800
	100	240	930	1400	2750	3850	4800	6900	9500	16300	35700
	75	254	950	1480	2760	4000	5200	7100	10400	17200	39500
175	150	220	920	1400	2600	3600	4500	6600	9300	15300	31150
	125	226	1050	1570	3000	4360	5320	7600	10800	18200	40150
	100	290	1100	1640	3100	4600	5800	7900	11700	19960	45700
	75	295	1150	1680	3200	4650	5800	8000	11750	20100	46400
200	150	291	1130	1650	3100	4600	5800	8400	11380	16900	44500
	125	327	1200	1850	3250	5000	6500	9100	13100	20100	52200
	100	330	1250	1900	3300	5200	6800	9100	13300	22600	52500
225	175	315	1260	1750	3150	5150	6400	8800	12330	21500	45800
	150	355	1370	2000	3650	5730	7150	9870	14000	24080	53300
	125	370	1430	2050	4020	5950	7500	10300	14760	25400	58640
250	200	339	1350	1880	3400	5500	6850	9090	13260	23110	50400
	175	380	1480	2150	3970	6150	7680	10400	15050	25860	58500
	150	405	1550	2250	4440	6600	8300	11300	16300	27800	63400
	125	410	1550	2250	4500	6650	8330	11360	16400	28100	64300

Normal Port

Pressure psig IN	OUT	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"
20	5	140	260	280	620	660	980	1480	2370	3860
25	10	160	300	300	700	800	1140	1700	2750	4500
	5	165	400	410	780	900	1290	1900	3600	5100
30	15	175	320	430	800	950	1250	1950	3100	4800
	10	185	460	460	920	1100	1530	2450	4200	5800
40	25	200	360	410	950	1200	1550	2200	3650	5600
	20	221	480	480	1150	1250	1750	2600	4100	7000
50	35	238	480	700	1150	1250	1950	2350	4500	5900
	30	250	530	760	1400	1550	2100	2900	5300	7300
	25	266	580	800	1460	1650	2400	3500	5600	8400
60	45	275	530	760	1300	1350	2100	3150	4750	8200
	40	288	610	850	1600	1650	2300	3600	5500	8700
	35	310	660	920	1720	1750	2600	3800	6300	9300
	30	320	680	980	1820	1850	2700	4200	6900	9900
75	55	335	720	830	1900	2000	2850	4150	6700	10200
	50	351	750	1060	2030	2250	3100	4450	7500	10800
	45	370	800	1120	2120	2400	3350	4700	7800	11900
	40	385	860	1300	2200	2600	3550	4900	8000	12100
100	75	440	900	1150	2450	2500	3700	5300	8700	13200
	60	460	980	1300	2750	3000	4650	6000	10000	15200
	50	475	1000	1480	2880	3400	4700	6550	10700	16000
125	100	525	1000	1300	2700	3150	4200	6250	10200	15000
	75	545	1200	1700	3250	4000	5400	7600	12500	18300
	50	570	1230	1770	3400	4200	5850	8350	13400	19700
150	125	565	1200	1600	3250	3800	5150	7500	11800	17200
	100	660	1400	1860	3850	4500	6300	8650	14400	20800
	75	680	1480	2100	4000	4900	6800	9500	15600	22800
175	150	636	1400	1850	3600	4100	5900	8250	13600	18800
	125	755	1570	2150	4360	5000	7000	9700	16650	23200
	100	800	1640	2280	4600	5500	7600	10600	18500	26000
	75	810	1680	2400	4650	5800	7900	11250	18820	27200
200	150	815	1650	2400	4600	5500	7700	10700	18540	25700
	125	865	1850	2600	5000	6000	8400	11800	21150	29900
	100	880	1900	2680	5200	6500	8600	12400	21490	30850
225	175	910	1750	2480	5150	5980	8260	11800	20080	28200
	150	983	2000	2790	5730	6840	9250	13420	22900	32370
	125	1020	2050	3000	5950	7200	9640	14150	24000	34440
250	200	980	1520	2670	5500	6480	8850	12890	21970	30300
	175	1080	1880	3000	6150	7350	9900	14600	25600	34760
	150	1130	2150	3250	6600	7970	10640	15620	26250	37500
	125	1140	2250	3280	6650	8050	10680	15750	26500	38000

Full Port ⟶

Pressure psig IN	OUT	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"
20	5	220	260	360	660	850	1200	2020	3000	5160
25	10	250	300	410	800	1000	1420	2300	3300	6200
	5	260	410	470	900	1100	1730	2900	4000	7000
30	15	290	320	460	950	1100	1900	3000	3500	6800
	10	300	460	530	1100	1240	2060	3450	4600	8300
40	25	320	410	650	1200	1150	1300	3250	3800	7500
	20	370	480	720	1250	1500	2120	3800	4800	9400
50	35	370	700	770	1250	1500	2500	3500	4800	9500
	30	410	760	850	1550	1850	2900	4500	5700	11500
	25	420	800	890	1650	2050	3050	4900	6500	11900
60	45	420	760	840	1350	1700	2700	4400	5800	11000
	40	450	850	1000	1650	2000	3050	4800	6800	13500
	35	470	920	1100	1750	2200	3250	5600	7400	14000
	30	480	980	1140	1850	2350	3600	5950	8400	14700
75	55	550	830	1200	2000	2300	3750	5800	8500	15100
	50	570	1060	1320	2250	2560	3900	6100	8900	16300
	45	580	1120	1380	2400	2800	4300	6450	9500	17800
	40	590	1200	1400	2600	3200	4500	6750	10000	18100
100	75	600	1150	1480	2400	3100	4900	7800	10800	20500
	60	670	1300	1800	3000	3900	5350	8900	12200	21750
	50	690	1480	1850	3400	4400	5850	9100	13500	22960
125	100	650	1300	1700	3150	3550	5300	8650	12200	22000
	75	750	1700	2000	4000	4600	6750	10500	15400	26800
	50	800	1770	2100	4200	5600	7500	11400	16800	27720
150	125	810	1600	2050	3800	4450	6200	9900	15000	26200
	100	930	1860	2450	4500	5350	7500	11900	17800	31000
	75	950	2100	2700	4900	6150	8000	13200	18600	32950
175	150	920	1850	2250	4100	5000	6900	11400	16100	28940
	125	1050	2150	2700	5000	6200	8600	13300	20220	34800
	100	1100	2280	3000	5500	6900	9500	14700	21900	37500
	75	1150	2400	3100	5800	7400	9750	15600	22070	38000
200	150	1130	2400	2850	5500	6700	9200	14400	22440	38000
	125	1200	2600	3200	6000	7600	10450	15600	25170	43000
	100	1250	2680	3400	6500	7800	11000	16200	25340	43350
225	175	1260	2480	3080	5980	7180	10150	15850	24300	41221
	150	1370	2790	3540	6840	8370	11600	17770	27250	46200
	125	1430	3000	3770	7200	9120	12200	18450	28300	47980
250	200	1350	2670	3250	6480	7340	10920	17050	20400	44330
	175	1480	3000	3700	7350	8650	12370	19100	29250	49600
	150	1550	3250	4150	7970	9650	13360	20400	31250	53000
	125	1550	3280	4300	8050	9960	13720	20400	31250	53000

HOFFMAN SPECIALTY®

Series 2000
Pressure and Temperature Regulators

Steam Capacity Table

(in pounds per hour, assuming saturated steam at valve inlet)

For Training Purposes Only

Figure 28
Full, Normal and Reduced Trim Capacity Tables

The external pilot valve required for this application is selected first by determining if low pressure air is available to operate a pneumatic pilot. If it is, then we must choose between the pneumatic and the spring operated pilots. The pneumatic pilot's set point is easily changed compared to the spring operated pilot. On the other hand, if the set point will not be changed often in this application, then the simpler spring pilot is probably a better choice. The spring pilot is selected on the basis of downstream pressure. If a pneumatic pilot is the choice, then the selection must take into account the control air pressure as well as the desired downstream steam pressure.

For example, many plants use 20 psig air in their regulators. But all of that 20 psi is not available to use as a pilot set point because of friction and inertia in the pilot. In the single diaphragm pilot, air pressure on top of the diaphragm is balanced by steam pressure below it. It takes about 9 psi air pressure to overcome the spring force, friction, and inertia, to get the pilot started. In other words, the pilot valve stays closed as we start to increase air pressure on top of the diaphragm. Only after the air pressure has risen to about 9 psig does the pilot start to operate to open the main valve. After that point, each additional one psi of air pressure will increase the set point by one psi, up to a maximum of:

$$20 - 9 = 11 \text{ psi (approximately)}$$

For many low pressure applications, that's good enough, but if higher steam pressures are required, we need a different pilot valve.

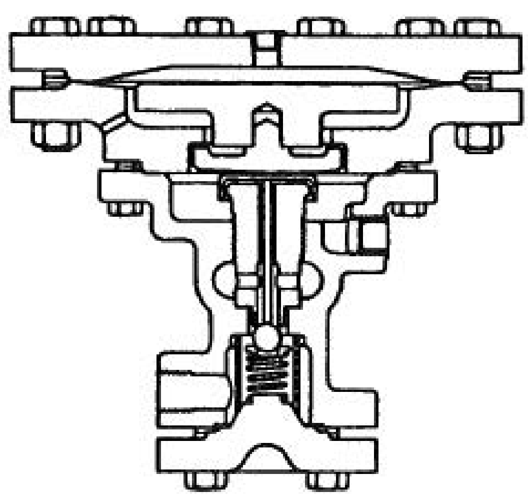


Figure 29
Pneumatic Pilot for Higher Pressures

The 3:1 and 5:1 pilots have two diaphragms instead of one. Pneumatic pressure is exerted on top of the larger diaphragm, while downstream steam pressure is below the smaller one. This gives a mechanical advantage to the pneumatic signal, since a pound of pressure exerted over the larger area results in a greater force. This greater force means that more of the 20 psig low pressure air signal can be used as the set point, since less of it must be used to overcome friction and inertia. Once friction is overcome, an increase of pneumatic pressure by one psi results in a steam pressure increase of 3 or 5 pounds depending on the area ratio. Assuming a pneumatic pressure of 20 psig to the pilot, the 3:1 pilot can control steam pressures in a range up to about 50 psig, and the 5:1 pilot up to about 90 psig.

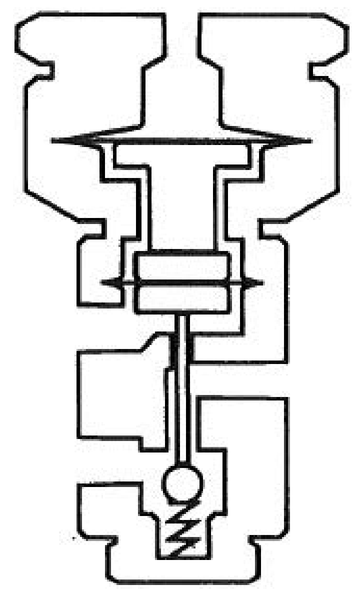


Figure 30
New Design Pneumatic Pilot

The new design pneumatic pilots have either a 1:1 or a 4:1 area ratio. The 4:1 model is shown in **Figure 30**. About 9 psi air preloading pressure is required, after which each additional psi of air pressure will increase the downstream steam pressure by 4 psi, so a 20 psi air signal will allow a maximum of about 44 psi. If higher pressures are required, simply increase the pneumatic pressure to the pilot.

PRESSURE REGULATOR INSTALLATION

Proper installation is every bit as important as the design thought process that precedes it because the system will not work as planned if the installation is faulty. Insure that you follow all of the manufacturer's instructions that come with the regulator. The following ideas apply in general to a large number of pressure reducing valves.

Most regulators must be installed in horizontal pipe runs in order to avoid excessive stress on the valve bracket and diaphragm assembly. Valves that have a large diaphragm case and long bracket are particularly vulnerable to stress that can cause the valve stem to bind if they are installed in a vertical pipe run. Some direct sensing valves might be installed in a vertical pipe because of their small size, but the preferred orientation is to install it in a horizontal pipe with the valve stem in the vertical, or near vertical position. Direct sensing regulators are installed with the diaphragm case above the pipeline in order to keep the internal downstream pressure sensing passageway clear of dirt and debris. On the other hand, it is preferable to install remote sensing regulators with the diaphragm case below the pipeline so that a condensate seal can form in the remote sensing line to protect the diaphragm from high temperature steam. The remote sensing line itself should be taken from the top of the main to avoid clogging by solid grit or rust. In all cases, insure that the valve is installed with the flow arrow, which is cast into the valve body, pointing in the right direction.

Plan for future inspection and service. Allow room above the valve to inspect and remove the actuator, as well as access to see the valve stem as it strokes during operation.

Blow out all piping with steam or compressed air before installing the valve to remove mill scale and dirt. Install a steam strainer upstream of the valve, and equip it with a blow down valve to periodically remove solid debris, or even a steam trap in large size piping to remove condensate.

Good piping practice must be observed throughout the installation. For threaded and union valves:

(a) Wire brush and inspect all threads to insure they are clean and undamaged.
(b) Use pipe sealant on male threads only to keep it out of the system. It's best not to coat the first two threads at all.
(c) Don't over tighten the joint, especially if you're using PTFE tape. Over tightening can force the pipe too far into the valve body, warping and damaging it. Teflon tape is such a good lubricant, it's easy to force the pipe too far into the valve.
(d) Always use a wrench on the flats of the valve body to tighten the joint, using the valve bracket to turn the valve onto the pipe can bend the stem. Also, use the wrench on the side of the valve that's being tightened. If you use it on the other side, the valve body may be distorted.

For flanged valves:

(a) Clean and inspect all flange faces and gaskets.
(b) Align and support the pipe properly. Don't use the valve flange bolts to pull the pipe sections into alignment.
(c) Use the right gasket for the type of flange. Never try to join raised face flanges to plain face flanges.
(d) Tighten all bolts evenly using a star pattern.

A complete valve installation includes isolation valves, a bypass, steam traps, and gages as shown in **Figure 31**.

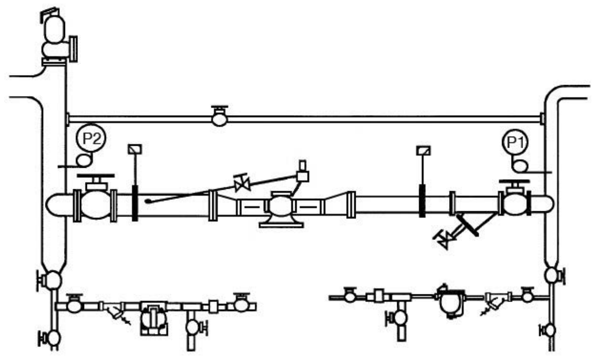


Figure 31
Pressure Reducing Station

Valve and pipe sizing are two different processes. Though they depend on the same factors, each aims for different results. In sizing pipe, we control pressure drop and keep steam velocity within limits by choosing large pipe sizes. We avoid valve over sizing by maintaining a comfortable ratio of design to tabulated flow. The point is: valves should not be chosen by pipe size or vice versa. If valid sizing methods are used for piping and the valve, the valve will usually be smaller than the upstream pipe, and the downstream pipe will be larger than the upstream pipe.

All piping must be securely supported, and provided with means to allow for thermal expansion and condensate drainage. Thermal insulation is required to cut down on heat loss, and protect plant operators from burns.

In a small plant, each valve installation may be tailored to the application; but in larger plants it's better to make up standard valve manifold designs to avoid constantly "reinventing the wheel".

Isolation valves should be installed in the steam main on both sides of the regulator. These valves should present little resistance to flow, so line size valves suitable for on/off service such as gate valves should be used. If a remote sensing feedback line is required, it should have an isolation valve too, but a small valve suitable for throttling service such as a needle valve or globe valve would be the best choice here since regulator performance can sometimes be improved by restricting the pressure feedback signal.

Allow straight pipe runs upstream and downstream of the regulator to minimize noise and allow steam pressure to steady out. Specific pipe lengths in terms of minimum number of pipe diameters are provided in the manufacture's installation instructions. Usually they require a minimum of three to five pipe diameters of straight pipe directly upstream of the valve, and as many as 20 pipe diameters downstream. It is especially important to install the feedback pressure tap far enough downstream of any fitting to permit an accurate and steady pressure signal to the valve. Ten pipe diameters from the nearest fitting upstream is usually recommended as a minimum.

Bypass piping must be provided to allow operation of the system when the regulator is out of service. The bypass piping and valve should be the same size as the regulator, and the bypass valve should be suitable for throttling, for example, a globe valve. In normal operation, the isolation valves are fully open and the bypass is closed. When the regulator is out of service, the isolation valves are closed and the bypass will be cracked open to provide downstream pressure.

Pressure gages should be installed upstream and downstream of the regulator far enough from fittings so that they will register an accurate pressure reading. The gage should be selected so that the normal pressure reading will be at about half scale; and each gage should be mounted on a "pigtail" to provide a condensate trap to protect the gage from full steam temperature and to isolate it from shock and vibration. The downstream gage must be located where it can be seen when the regulator is adjusted, and when the bypass must be throttled. Insure that it is not located where closing the downstream isolation valve will isolate it from the system.

Relief valves are required to protect downstream components if they are not rated for full upstream pressure. The relief valve should be ASME rated to handle full steam flow through the regulator without excessive pressure build up on the downstream side if the regulator should fail wide open. Relief valves are often set to open at five psi over normal downstream pressure.

Finally, install steam traps to drain the condensate from any section of piping where it might accumulate. At a minimum, any vertical legs of piping upstream and downstream of the regulator should be equipped with condensate collection pockets, strainers, isolation valves, traps, and check valves. Under normal operation, these traps will collect the relatively small amounts of condensate formed as heat escapes from the pipe walls, but they may have to handle much larger amounts of condensate on system warm up. Insure that the traps are properly selected to handle the condensate load expected.

Troubleshooting

CAUTION

(1) Always use care and common sense when working with steam systems. Serious burns or scalding can result from: failure to wear proper protective gear such as gloves, long sleeves, and eye protection, failure to relieve pressure before opening joints in piping or steam components that have been under pressure, and failure to allow these components to cool down.

(2) Pressure can remain in a piping system even though all valves are "closed" because isolation valves, check valves, and bypass valves may leak. Open all pressure relief fittings and strainer blowdown valves to relieve pressure.

(3) When taking apart a flanged connection, always make it leak before removing all of the bolts. Gaskets may have been sealed by heat to both flange faces, allowing the joint to hold pressure even after the bolts are removed.

(4) Always warm up a steam system gradually, allowing plenty of time for condensate to drain and for all components to reach their normal operating temperature. Monitor drainage to avoid the build up of condensate that can cause damaging water hammer.

Daily checks during normal operation.

You can often identify a small problem before it gets large enough to disrupt normal operation. For example:

1. Check the pressure in heat exchangers and steam mains when the pressure regulator should be shut. If pressure is above the set point, the regulator or bypass may be failing to close, or leaking.
2. Raise and lower the pressure set point and observe that the regulator valve stem moves smoothly, and in the right direction. If you can't see the valve stem, observe the pressure gages downstream of the valve.
3. Regularly analyze trouble calls, maintenance logs, and routine gage readings to see if there's a pattern of excessive or insufficient pressure in a particular section of the plant. See if that pattern points to a specific valve or valve group as the source of the problem .

Troubleshooting Direct Acting Pressure Regulators

Problem	Cause	Action
Valve won't close.	Scale build up on the valve seat or disc.	Inspect & clean.
	Seat or disc is damaged.	Regrind or replace if possible.
	Internal feedback channel clogged.	Clean or replace.
	Ruptured diaphragm.	Replace diaphragm.
P2 hunts	Valve is oversized.	Test by throttling inlet isolation valve.
	Pressure drop limits exceeded.	Check pressure drop.
P2 too high	Bypass valve open	Check for damaged bypass valve.
	Valve seat or disc damaged.	Inspect and replace.
P2 too low	Valve seat or strainer clogged.	Clean.
	Upstream isolation valve partially closed.	Inspect isolation valve, insure it's open.
	Regulator is undersized at heavy loads.	Test by cracking open the bypass valve.

Troubleshooting Remotely Sensed Pressure Regulators

Problem	Cause	Action
Valve noisy	Lack of throttling in feedback line.	Slowly close feedback valve until regulator operates quietly.
	Loose trim or fittings.	Adjust or replace.
Valve won't close	Stuffing gland nut too tight.	Adjust nut finger tight.
	Stem rusted or scaled.	Clean.
	Feedback line clogged.	Insure line is clear. It should be connected to the top of the steam pipe.
	Dirt or scale on valve seat.	Clean.
	Ruptured or leaking diaphragm.	Inspect and replace, or tighten nuts around diaphragm case.
P2 hunts	Insufficient throttling in feedback line.	Slowly close valve in feedback line until hunting stops.
	Bypass leaking.	Insure bypass is closed tight.
	Regulator is oversized.	Test by throttling upstream isolation valve.
	Downstream pressure tap is too close to a fitting.	Insure minimum of ten pipe diameters from nearest upstream fitting.
	Downstream pipe is too small.	Replace downstream pipe with larger size.
P2 falls off at heavy load	Regulator is undersized.	Test by cracking open the bypass valve. Replace regulator.
	Isolation valves partially closed.	Insure both valves fully open.

The tests for determining if the regulator is oversized or undersized can be carried out simply by using the bypass or isolation valves. If you suspect that the regulator is undersized, test it by opening the bypass valve one or one and a half turns. If downstream pressure can be maintained at maximum load with the bypass partly open, the regulator is undersized. If you suspect that the regulator is oversized, partially close the inlet isolation valve to the regulator. If the downstream pressure steadies out with the isolation valve throttled, then the regulator is oversized.

EXTERNALLY PILOTED REGULATORS

Most of the troubleshooting tips in the tables above apply to externally piloted valves too. The major difference is that with an externally piloted regulator, either the external pilot or the main valve could be the source of a problem. Here's a quick way to find out which valve is malfunctioning. The main valve is normally closed, it needs a signal from the pilot before it can open. You can check to see if the main valve is leaking by closing the inlet isolation valve, and carefully disconnecting the copper tubing from the pilot at the bottom of the main valve diaphragm. Observe the pressure gage downstream of the regulator or listen for steam flow as you slowly open the upstream isolation valve again. If the regulator is leaking, there will be an increase in downstream pressure, or flow noise in the main valve. If the main valve is not leaking, you can check the pilot operation by slowly increasing the pressure set point to observe that steam can flow from the copper tubing to load the main valve diaphragm. If steam will not flow through the pilot after the set point is increased, then the pilot is malfunctioning. It can be analyzed like any other diaphragm operated valve. Often, the cause of the problem is simply clogging of the strainer in the pilot valve. The most common cause of problems with externally piloted regulators is the bleed orifice. Insure that it is properly installed, and not clogged.

IN ALL OF THESE TESTS, BE CAREFUL TO AVOID INJURY BY USING HEAVY GLOVES AND OTHER PROTECTIVE CLOTHING.

When replacing the valve trim in an externally piloted regulator, make sure you provide a source of pressure underneath the main valve diaphragm before you remove the nut that holds the valve plug to the stem. Air pressure below the diaphragm will compress the spring, and allow you to remove the plug without damaging the diaphragm. There are stops built into the valve body to prevent excess upward motion of the diaphragm. A spanner tool will be required to remove the valve seat.

NOISE IN PRESSURE REGULATORS

Noise pollution is a growing concern to plant operators and regulatory agencies such as the Occupational Safety and Health Administration, (OSHA) . Noise from a regulator could be caused by simple mechanical problems such as loose fitting or broken components that vibrate in the steam flow, or by the aerodynamic noise generated when steam expands to a lower pressure at high velocity. Steam pressure regulators may be the source of hazardous aerodynamic noise if the steam flow rate, pressure drop, and pressure drop ratio are large enough. (Pressure drop ratio is defined as $\frac{\Delta P}{P1}$)

In most cases, valves less than 2" in size will not have flow rates great enough to be of concern, but larger valves may develop a high pitched screaming sound, especially if the manufacturer's instructions have not been followed.

Noise is measured in terms of "decibels", dB, which relate the sound pressure level at the point of measurement to the lowest pressure level detectable by the human ear. "Hazardous" noise exposure as defined by the regulatory agencies, must be avoided, but lower levels of noise even if not hazardous, may still be objectionable. The following rough rules of thumb may help in estimating if a proposed valve installation is likely to develop noise levels greater than 90 db, the current definition of hazardous noise.

Multiply P1, in psia, by the valve C_v.

If the result is less than 500, hazardous aerodynamic noise is unlikely, although other sources of noise e.g., loose valve trim, are always possible.

If the result is between 500 and 1,000, then aerodynamic noise is likely, but it probably will not be above the "hazardous" definition.

If the result is greater than 1,000 you should anticipate hazardous aerodynamic noise.

Manufacturers sometimes provide computer programs to help in regulator sizing and selection. These computer programs can provide an estimate of noise levels.

Some practices that will reduce aerodynamic noise in steam pressure regulators include:

Observe the limits on pressure drop across a single regulator as advised by the manufacturer.

Limit velocities of steam to 10,000 ft/min at the valve inlet and 12,000 ft/min at the outlet by sizing the piping generously for the maximum flow rate expected.

Use tapered pipe expansions to avoid abrupt changes in pipe diameter, especially in the downstream piping. Insure that condensate is removed by the use of properly installed steam traps.

Allow 20 pipe diameters of enlarged pipe downstream of the regulator be fore the first turn. Use long radius elbows.

Use heavier schedule pipe downstream of the regulator. Aerodynamic noise is actually generated in the downstream piping. Heavier pipe walls will reduce the amount of noise transmitted to the atmosphere.

Use special acoustic insulation on the downstream piping. Each inch of acoustic insulation will attenuate noise by about 9 dB, up to a maximum of 25 dB. Heavy thermal insulation can also reduce noise, but is less effective. Each inch of heavy thermal insulation reduces noise about 4 dB, up to a maximum of 14 dB.

SOME TYPICAL APPLICATIONS FOR PRESSURE REGULATORS

Application: Convenient manual control of the steam system.

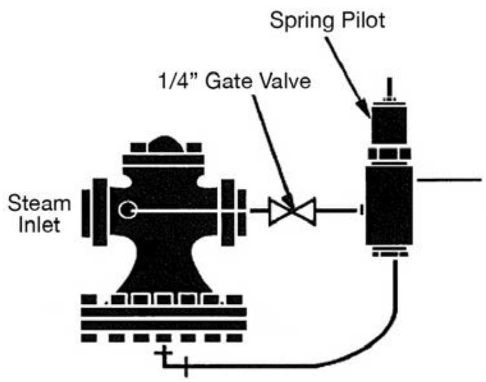


Figure 32

System operation: Closing the steam supply to the pilot valve automatically closes the main valve. A 1/4" gate valve at the pilot, or located as far as 50' away in a loop of 1/2" piping, will permit remote manual operation of the system.

Application: Electrical control of the steam system.

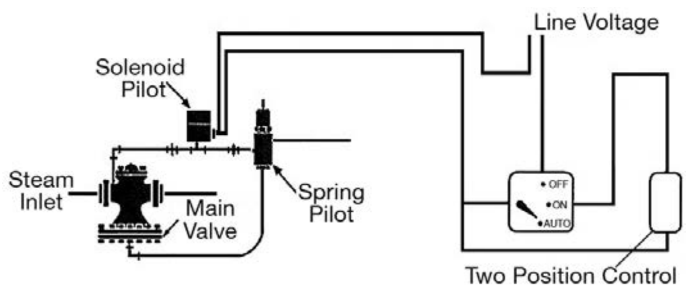


Figure 33

System operation: A solenoid pilot can be opened or closed by any type of two position control such as a pressure switch, aquastat, or timer.

Application: Choice of downstream pressure.

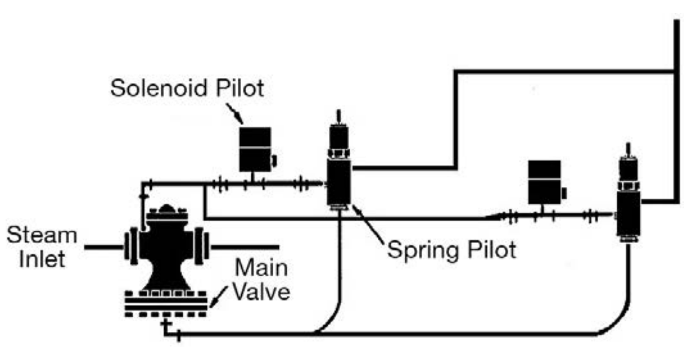


Figure 34

System operation: Set each pilot to a different pressure required by, for example, night/day operation. Control solenoid pilots with a toggle switch to open one while closing the other to provide a convenient way to change downstream pressure.

Application: Pressure regulator to maintain constant pressure input to a low pressure rated temperature regulator.

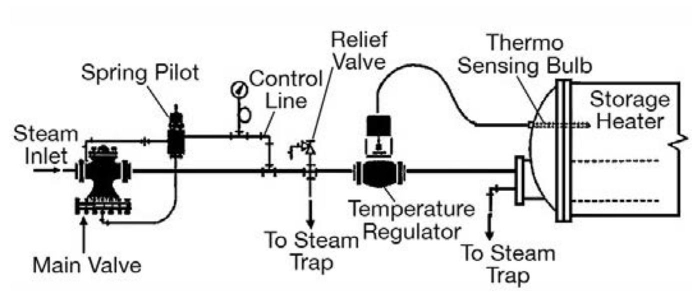


Figure 35

System operation: Main valve maintains tight shut off until temperature regulator calls for steam to maintain temperature in storage tank.

Application: Provide automatic control of room temperature and unit heater pressure

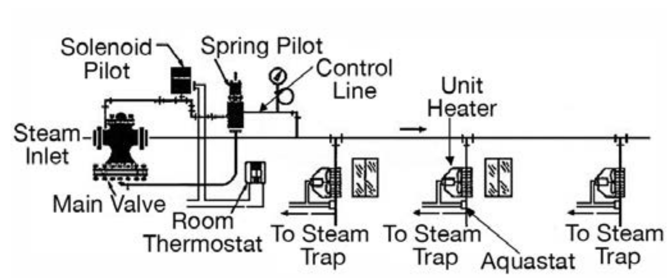


Figure 36

System operation: The spring pilot is set to provide specified steam pressure to the unit heaters. The solenoid pilot opens only when the room thermostat calls for heat, avoiding heat loss. After warm up, aquastats start the fans.

Application: Automatic preheating and pressurization of steam mains

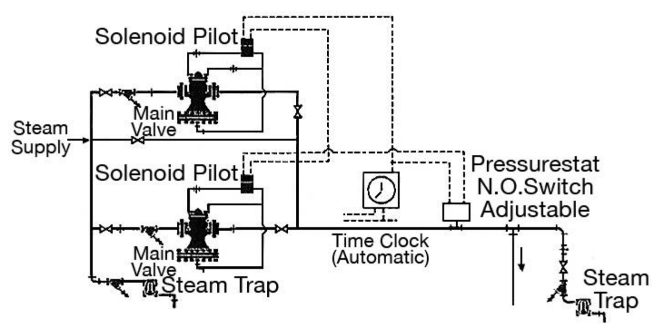


Figure 37

System operation: The timer opens the smaller regulator early enough to warm-up and pressurize the mains by the start of the work day. The pressurestat closes at operating pressure, closing the solenoid to the warm up regulator, and opening the pilots to the larger regulator which is capable of handling the system demand for steam.

IV TEMPERATURE REGULATION

VAPOR TENSION TEMPERATURE REGULATORS

A temperature regulator varies steam flow to a heat exchanger to maintain a set fluid temperature at the heat exchanger outlet in spite of changes in the inlet temperature and flow rate of the fluid being heated. This results in a varying steam pressure inside the heat exchanger, unlike the more constant pressure maintained by a pressure regulator. The temperature regulator requires a feedback signal based upon the outlet temperature of the fluid being heated. There are several ways to achieve this temperature feedback depending upon the type of regulator. The two broad categories of temperature regulators are vapor tension, and externally piloted temperature regulators.

In a vapor tension temperature regulator, the temperature feedback signal is generated by means of a thermal bulb made of some material like copper that conducts heat well.

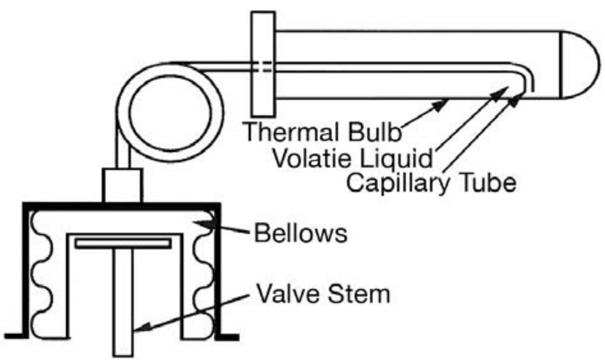


Figure 38
Vapor Tension Actuator

This bulb is surrounded by the fluid to be heated. The bulb is partly filled, under vacuum, with a volatile fluid selected to have a boiling point somewhere near the desired fluid temperature. As fluid temperature rises toward the set point, the volatile fluid boils, increasing vapor pressure in the thermal bulb and forcing some of the liquid through a capillary tube to a bellows mounted on the valve. As the bellows expands due to this increased pressure, it compresses the temperature adjusting spring and forces the valve stem down to close the valve. Vapor tension temperature regulators can be adjusted to any temperature within the range determined by the fluid used in the bulb, however it is best to choose the temperature range so that the desired temperature set point is near the middle of the range rather than at either extreme. The temperature adjustment wheel is raised to increase the temperature setting. As the wheel is raised, the spring is compressed, requiring more vapor pressure in the bellows, and higher temperature in the fluid to close the valve.

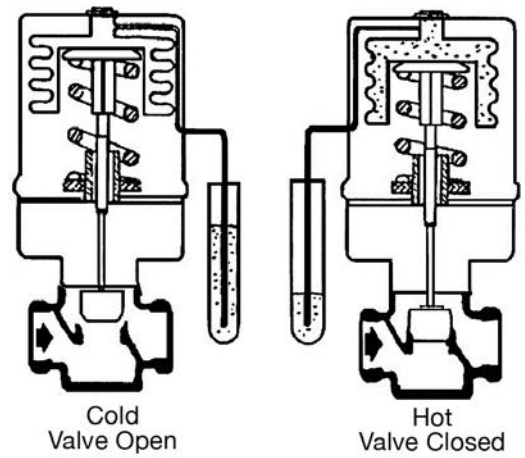


Figure 39
Vapor Tension Regulator

This kind of valve is "direct acting" because it closes to reduce the steam flow to the heat exchanger when the temperature of the fluid rises. "Reverse acting" valves which open on a rise in temperature are also available but they are used in cooling applications to increase the flow of coolant on a rise in temperature.

EXTERNALLY PILOTED TEMPERATURE REGULATORS

The externally pilot operated main valve described in the pressure regulation section can also be used to regulate temperature. Temperature regulators that use an external pilot can use either of two means to sense the temperature of the fluid and generate a feedback signal to the main valve: a liquid expansion principle as used in the self contained pilot or the solid expansion device used with the pneumatic temperature pilot.

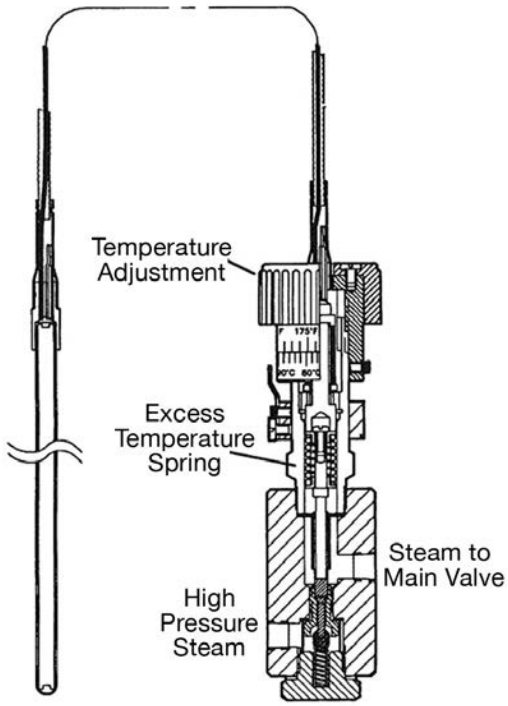


Figure 40
Self Contained Temperature Pilot

SELF CONTAINED TEMPERATURE PILOT

The self contained temperature pilot is installed much the same as a pressure control pilot at the high pressure side of the main valve with a steam connection to the main valve diaphragm. Its temperature sensing bulb is inserted directly in the fluid to be heated, or in a temperature sensing well in the tank or piping where it will sense the true average temperature of the liquid in a tank, or the outlet temperature of a liquid leaving a heat exchanger.

The bulb and capillary are filled with a liquid that expands and contracts with changes in temperature, but unlike the vapor tension device, it will not boil in the application temperature range. The particular fluid used to fill the pilot bulb will determine the temperature range of the pilot. As the fluid flowing over the bulb heats up, the liquid inside the bulb expands and closes the pilot valve against the return spring at the bottom of the pilot. There is a temperature adjustment on the temperature pilot which is used to set the pilot closing temperature. There is also an over temperature spring to absorb excessive expansion forces in the capillary which could be caused by exposing the bulb to temperatures above its normal range.

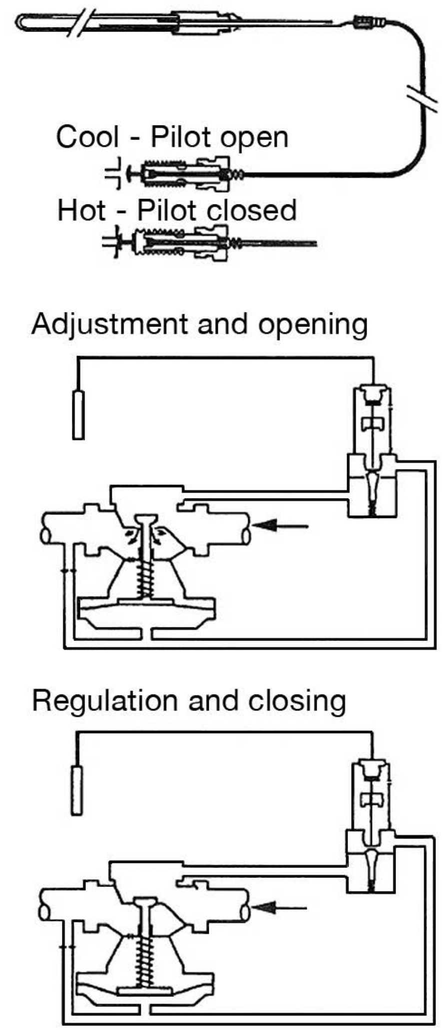


Figure 41
Self Contained Temperature Pilot Operation

SELF CONTAINED TEMPERATURE PILOT OPERATION

The main valve is normally closed, just as in the pressure regulating application. It is installed in the steam line to control the flow of steam to the heat exchanger. The temperature pilot will open as it's bulb is exposed to low temperature fluid from the heat exchanger outlet.

Steam flowing through the pilot from the upstream side of the main valve will pressurize the main valve diaphragm, open the main valve, and allow steam to flow to the heat exchanger.

As steam in the heat exchanger heats the fluid flowing across the pilot bulb, the liquid in the bulb expands and closes the pilot. When the desired fluid temperature set point is reached and the pilot valve closes, the steam pressure under the main valve diaphragm is allowed to bleed off through the bleed orifice, and the main valve closes just as in pressure regulation.

PNEUMATIC TEMPERATURE PILOT

The main valve and pneumatic pressure pilot described in the section on pressure regulators are often used together to regulate temperature by adding a pneumatic temperature pilot.

The pneumatic temperature pilot requires a source of low pressure air and, usually, a pneumatic pressure pilot. The "shop air" system is generally adequate as long as it's equipped with an air pressure regulator and filter to remove most of the oil and water normally found in shop air.

An air supply of 18 to 36 psig is connected to the reverse action supply port of the pneumatic temperature pilot, and the direct action supply port is left open in order to generate an increasing air signal pressure as fluid temperature drops, or a "reverse acting" operation. The device could also be used to provide "direct action", an increase in air signal pressure on a rise of fluid temperature, which would be useful in other applications or valve constructions.

The outer brass temperature sensing rod expands and contracts as the fluid surrounding it heats and cools. Movement of the "Invar" rod attached inside the sensing rod changes an orifice setting in the control creating a variable air pressure at the signal port. Invar is an alloy that doesn't change length very much with changes in temperature. The temperature is set by moving the adjustment piston to raise or lower the air pressure at the signal port. Since this device has no temperature readout, it must be set by referring to a thermometer in the fluid.

The variable air pressure signal from the pneumatic temperature pilot is sent to the top of the pneumatic pressure pilot where it, in effect, changes the pilot set point to control the flow of steam to the heat exchanger as described earlier.

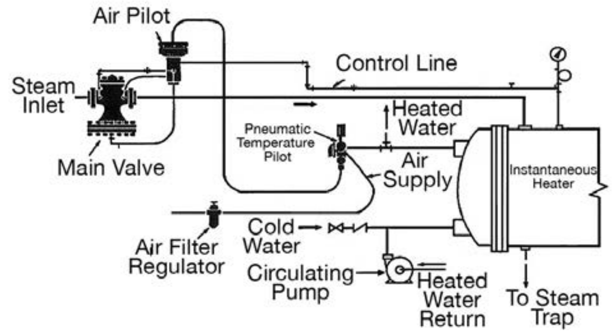
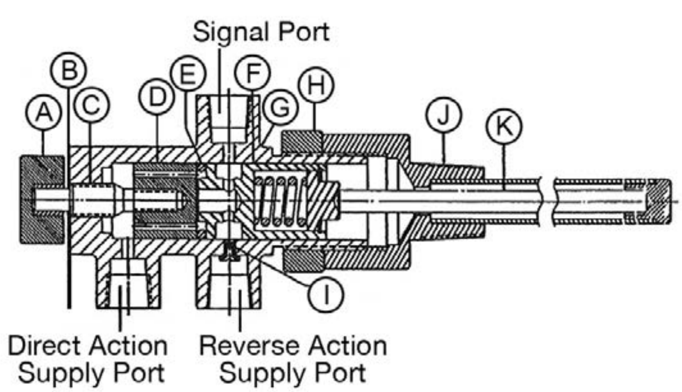


Figure 43
Pneumatic Temperature Control

A pressure feedback pipe from the heat exchanger to the system pressure sensing port of the pneumatic pressure pilot opens the regulator on start up and serves as a pressure override to stop the flow of steam if pressure in the heat exchanger should build too high. This type of modulating temperature regulator provides very accurate and responsive temperature control; and is preferred whenever a relatively large volume of steam is used to heat a relatively small volume of fluid, or when demand on the system is likely to be highly variable, as in a domestic hot water application. This is the case in the common shell and tube or "instantaneous" heat exchanger.

Other pneumatic temperature pilots, which use less air volume, and provide an adjustable throttling range to minimize temperature overshoot are also available. They require a supply of conditioned air, that is, oil and water free "control air".



Sym.	Description
A	Knob
B	Dial Plate
C	Adjustment Screw
D	Adjustment Piston
E	O-Ring
F	Sensor Piston Assembly
G	Body
H	Locknut
I	Orifice
J	Thermal Bulb Assembly
K	Sensor Rod

Figure 42
PNT Pneumatic Temperature Pilot

SELECTING AND SIZING A VAPOR TENSION TEMPERATURE REGULATOR

Many of the decisions involved in selecting a pressure regulator apply equally to the selection of a temperature regulator, so we can concentrate here on the additional considerations that are unique to temperature regulators.

DETERMINING THE VALVE PRESSURE DROP

Unlike a pressure regulator, a temperature regulator will have a varying pressure differential in normal operation. Pressure at the inlet to a temperature regulating valve is determined by boiler pressure, or a pressure regulator located upstream, and by the pressure drop that occurs due to friction losses as the steam flows through the pipe and fittings to the temperature regulator. This valve inlet pressure must be allocated as pressure drops across the regulator, through the steam inlet piping to the heat exchanger, in the heat exchanger itself, in the condensate drainage piping, and across the steam trap.

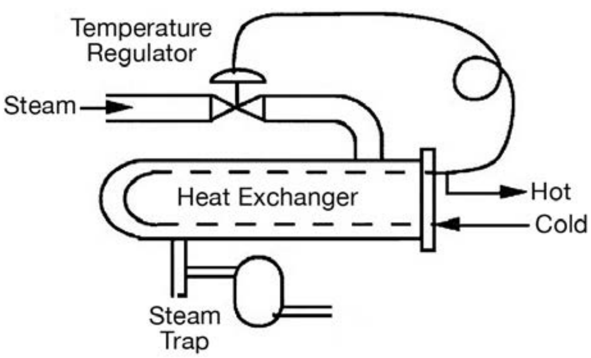


Figure 44
Temperature Regulator Installation

The piping pressure drops in most installations are minimized by keeping the connecting piping short, straight, and generously sized according to the design flow rate, so we can usually ignore the piping pressure drops between the temperature regulator and heat exchanger, and the heat exchanger and trap. However, unusual installations do exist where piping pressure losses can become significant.

Pressure at the regulator outlet will be determined by the heat exchanger and it's heat load. Steam pressure in the heat exchanger is determined by the heat transfer load imposed upon it up to some maximum load called the "design load". At design load, the heat transfer rate, the steam flow rate, and the steam pressure in the heat exchanger are at design values. Most heat exchangers operate most of the time at some heat load less than the design value. Therefore, the steam flow and steam pressure will be less than design values. Heat exchangers are often equipped with vacuum breakers installed to open and introduce air at atmospheric pressure in the event that the heat load drops so low as to create a vacuum in the heat exchanger. Vacuum is a problem because it can allow condensate to collect, resulting in damage to the heat exchanger.

These are some of the important factors in sizing and operating heat exchangers. That's why we can't determine the valve pressure drop without considering the heat exchanger operation as well.

Let's assume we're using a temperature regulator to control steam flow into the tube bundle of a storage tank water heater.

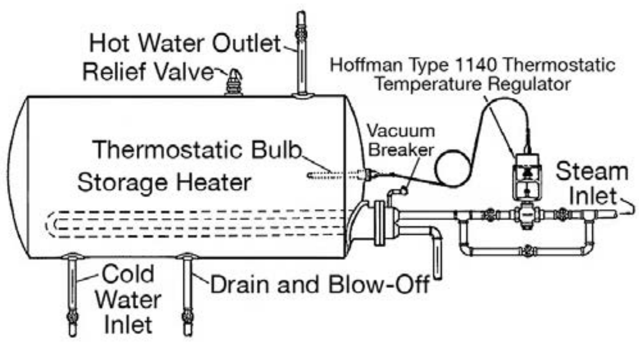


Figure 45
Storage Tank and
Vapor Tension Temperature Regulator

Cold water enters the tank, is heated as it flows across the tube bundle, and leaves at design temperature. Steam inside the tubes condenses and transfers heat through the tube walls to the water. In order to get an idea of how steam pressure in the tubes rises and falls with changes in other factors, consider what happens as the incoming water changes in temperature and flow rate.

	Tube side steam Pressure	**Outlet water temperature**	**Temperature regulator action**
Water flow through tank increases	Drops	Drops	Opens
Inlet water temperature increases	Rises	Rises	Closes

In selecting a temperature regulator, we use the pressure drop that will exist at the design conditions of flow and temperature in the heat exchanger, even though we know that this pressure drop will not always exist in normal operation.

The most common mistake in selecting a temperature regulator is to oversize the valve. For example, a valve that's chosen to match an existing pipe size will usually be too large, as will a valve that's been chosen after a large "safety factor" has been added to the design steam flow rate. A valve that's oversized with respect to the design flow rate will obviously have a low pressure drop. It will be more expensive, will allow greater variations in fluid temperature, and will probably wear out faster than a smaller, properly sized valve.

The initial cost for the oversized valve is greater simply because the larger valve has higher manufacturing and transportation costs. The oversized valve will be able to pass the design flow rate using only a fraction of its full stroke because the flow area is so large. As the load decreases from the design point, the valve will try to modulate, but in doing so, it will overcorrect since even a very small movement of the valve stem is likely to result in too much change in steam flow. Finally, if the valve operates for a long time just barely open, the high velocity flow of steam will erode and "wire draw" the valve seat or plug or both. Once a valve is "steam cut", it will not be able to shut tight without regrinding or replacement of the damaged parts. Therefore, it's better to select a valve that will have a significant pressure drop at the design flow rate.

The following guidelines apply in choosing valve pressure drop:

(1) If the heat exchanger is gravity drained:
   (a) and P1 is less than 15 psig, choose ΔP to be 100% of P1 in **psig**.
   (b) and P1 is greater than 15 psig, choose ΔP to be 50% of P1 in **psia**.

(2) If the heat exchanger is drained to a vacuum:
   (a) and P1 is less than 2 **psig**, choose ΔP to be 2 psi.
   (b) and P1 is between 2-15 psig, choose ΔP to be equal to P1 **psig**.

Figure 46 illustrates that there are limits to the amount of pressure drop required for good valve performance. When P1 and P2 are the same, there is, of course, no flow through the valve. As P2 decreases, the differential increases, acting as a driving force to cause flow.

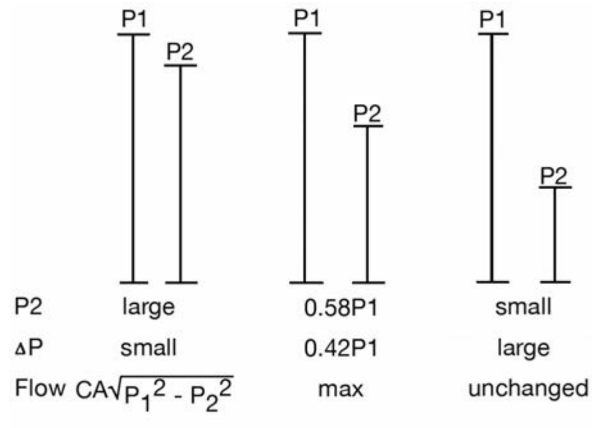


Figure 46
Steam Flow Varies with Pressure Drop

In **Figure 46**, when P2 is a large fraction of P1 at design flow then the pressure drop is small, the valve capacity is large relative to design flow, and the steam flow through the valve can be calculated by the expression:

$$W = CA\sqrt{P_1^2 - P_2^2}$$

where:

W = steam flow rate
C = a constant depending on the valve design
A = cross section flow area through the valve
P_1 = upstream pressure, psia
P_2 = downstream pressure, psia

In this situation, closing the valve, or reducing the value of A, in order to reduce the steam flow rate will also cause a reduction in P_2 because of the increased velocity of steam flow and because the heat exchanger pressure drops with decreasing load. This reduction in P_2 will partly offset the desired effect by increasing ΔP, acting to increase the flow. The result is poor control over flow.

In the second case, the valve pressure drop at the design flow rate is such that the steam is expanding as fast as it possibly can right in the narrowest part of the valve. This happens in steam when P_2 is equal to the "critical value" of 0.58 P_1. For values of ΔP in this range, the offsetting effect of increasing ΔP is negligible so we get better control over the steam flow. Reducing the flow area gives an immediate reduction in steam flow, and the quality of the valve's performance improves.

In the third case, P_2 is very low with respect to P_1, below the critical value. In this case, further reductions of P_2 will have no further effect on the flow rate, because the steam is flowing at sonic velocity. For this reason, valve capacity tables do not list flow rates for P_2 lower than about 50% of P_1. Since reductions of P_2 below the critical value no longer help improve performance, and because large pressure drops across a valve can lead to rapid erosion and noise problems, it's a good idea to avoid pressure drops greater than the critical value. For all practical purposes, we like to choose a pressure drop of about 50% of P_1 for temperature regulator applications.

A common mistake is to base the heat exchanger design on full supply steam pressure without taking the regulator pressure drop requirement into account. In this case, choose a minimum pressure drop for the valve according to the following guide lines:

Supply Pressure	Pressure Drop
15 psi	5 psi
50 psi	7.5 psi
100 psi	10 psi
over 100 psi	10% of P1

This will give a reasonable balance between the need for design pressure at the heat exchanger and the need for a good pressure drop across the valve so that it will perform well. In most cases, a fouling allowance is used to increase the heat transfer area of the heat exchanger. This offsets the effect of tarnish and scale buildup on the heat transfer surfaces which will eventually degrade the heat exchanger's performance. It is often the case that a new heat exchanger can operate at design flow rates, but at substantially lower than design pressures due to the fouling allowance and conservative design

If the heat exchanger has not been selected yet, then some consideration should be given to the fact that system efficiency can be improved by designing the heat exchanger with low design pressure.

- Where the final temperature of the load is less than 200°F, low pressure steam is hot enough to provide a temperature difference to heat the load efficiently without being so hot that poor temperature control will result. High temperature steam trapped in the shell of a heat exchanger just at the instant the valve closes, will have to transfer heat into the tube side fluid, possibly overheating the fluid and causing wide swings of temperature. This is especially important in heat exchangers that heat a small volume of fluid with a relatively large volume of steam like the typical shell and tube heat exchanger.
- Low pressure steam contains more available latent heat per pound than higher pressure steam, reducing the steam flow rate requirement.
- The temperature of lower pressure condensate leaving the heat exchanger will be lower, reducing the need for wasteful condensate cooling or flashing in a flash tank.

Determining the Steam Flow Rate Required

A major factor in sizing a temperature regulator is calculation of the steam flow rate it must handle. The purpose of the steam system is to transfer heat from the boiler to the load. Steam is the medium that carries the heat, most of it as latent heat. The following sample calculations show the relationship between the sensible heat transfer desired in the process and the latent heat transfer that is accomplished as the steam condenses.

Examples of sensible heat transfer:

Heating a liquid, "A":

$$Q\,\frac{[\text{Btu}]}{\text{hr}} = \frac{\text{gal A}}{\text{min}} \times \frac{8.34\text{ lbs}}{\text{gal water}} \times \frac{60\text{ min}}{\text{hr}} \times \frac{\text{Btu}}{\text{lb A °F}} \times \text{sp gr A} \times \Delta T\text{°F}$$

Heating a solid, "B" :

$$Q\,\frac{[\text{Btu}]}{\text{hr}} = \frac{\text{lb B}}{\text{hr}} \times \frac{\text{Btu}}{\text{lb B °F}} \times \Delta T\text{°F}$$

Heating a gas, "C":

$$Q\,\frac{[\text{Btu}]}{\text{hr}} = \frac{\text{cu ft C}}{\text{min}} \times \frac{\text{lb C}}{\text{cu ft C}} \times \frac{60\text{ min}}{\text{hr}} \times \frac{\text{Btu}}{\text{lb C °F}} \times \Delta T\text{°F}$$

Example of latent heat transfer:

Steam condensing:

$$Q\,\frac{[\text{Btu}]}{\text{hr}} = \frac{\text{lb steam}}{\text{hr}} \times \frac{\text{Btu}}{\text{lb steam}}$$

Remember that "sensible heat" refers to the kind of heat transfer that can be sensed by means of a thermometer. In each of the three sample calculations grouped under the sensible heat category, some substance is being heated from an initial temperature to a final temperature. The difference between the two temperatures is the "ΔT" in each expression. In the first case, a liquid "A" flowing at so many gallons per minute is being heated, in the second case, a solid "B" at so many pounds per hour, and in the third case, a gas, C, at so many cubic feet per minute. All the other terms required to complete the calculation, such as specific heat, density, and so on are included in each case to arrive at the heat transfer rate, "Q", in Btu/hr. Always use the maximum expected temperature rise and material flow in order to get the greatest heat transfer requirement you could reasonably expect in the process. Once we know this "design heat transfer rate", we assume that all the heat required to go into the process will come out of the steam, and that these two quantities of heat are equal. This ignores any losses of heat that could occur, but it's close enough in practice because the heat transfer equipment is designed and insulated in order to keep these losses small.

Now we can turn to the second part of the sample heat transfer calculations - the "latent heat" transfer. Remember that this refers to the kind of heat transfer that occurs with no change in temperature, such as the large amount of heat that becomes available when steam condenses to a liquid at constant temperature. The amount of heat available from the steam is equal to the weight of steam flowing times the specific enthalpy of evaporation as listed in the Steam Tables. Now that we know two of the quantities, latent heat and total heat required, we can solve for the steam flow rate in pounds per hour. This kind of thought process is fundamental to a large number of steam heating applications.

Returning to our example in **Figure 45**. Suppose we need 20 gpm of water heated from 40°F to 140°F at design conditions, and the tube bundle has been selected for that capacity with 20 psig steam condensing in the tubes. The following four step procedure will allow us to find the right temperature regulator.

Step 1. Determine the steam flow rate required.
If the heat exchanger, the tube bundle in this case, is being selected at the same time as the valve, then the steam flow requirement will be available from the heat transfer calculations completed for the heat exchanger. If the regulator is being selected for some existing heat exchanger, the steam flow required might be obtained by referring to the nameplate of the tube bundle. If none of these are available, you can always calculate the steam flow rate by dividing the required heat transfer rate by the enthalpy of evaporation of the steam at the design pressure.

Since our "process" is simply heating water, we can use the first of the sensible heat examples to calculate the heat transfer required at design conditions. Water has a specific gravity of 1 and a specific heat of 1. Values for these factors are available for a wide range of substances in common engineering references or in the valve manufacturer's literature. For our problem, we have:

a flow rate of 20 gpm,
and a temperature rise of 140 – 40 = 100°F

so,

Q = 20 gpm x 8.34 lbs/gal x 60 min/hr x 1 Btu/lb °F x 1x100°F
= 1,000,800 Btu/hr into the water.

According to the steam tables, the steam enthalpy of evaporation, h_{fg}, at 20 psig is 939 Btu/lb. Therefore, the steam flow rate required is:

$$W = \frac{Q}{h_{fg}} = \frac{1000800}{939} = 1065 \text{ lb/hr steam at 20 psig}$$

Step 2. Determine the valve pressure drop.
Upstream pressure may be boiler pressure if the regulator is installed nearby. If the regulator is far away from the boiler, then piping friction losses may be significant, particularly in a low pressure steam system where these losses may be large compared to the initial pressure. Downstream pressure, as we've noted, depends upon the capacity and load on the heating unit. In this example, the regulator pressure drop is simply the supply pressure of 50 psig minus the design tube bundle pressure of 20 psig,

or, $\Delta P = 30$ psi.

In this example, pressure drop works out easily. Notice that it is about half of the upstream pressure in terms of psia.

Step 3. Select the valve body type and valve size.
In selecting the temperature regulator, consider the need for tight shut off, the expense and durability of the materials used in the valve, the allowable response time and accuracy of control required. A large number of different valve designs are available for use in this type of regulator. Each has a capacity table for ease in sizing the valve. In this application, we need tight shut off, and good accuracy of steam control. Therefore, we'll select an internally piloted, balanced, single seat valve. The manufacturer has given this design the identifying body code 03. A portion of the table for this valve is provided as an example.

Balanced Single Seated Valves – Code 03										
Size			¾	1	1¼	1½	2	2½"	3"	4"
Cv			4.3	7.9	13	20	25	42	61	97
Pressure			Steam Flow Lbs/Hr							
Inlet	Out	Drop								
3	2	1	52	96	159	244	305	517	738	1182
	1	2	72	133	218	336	420	719	1027	1643
5	3	2	77	141	231	356	445	762	1089	1743
	2	3	91	167	276	424	530	904	1291	2066
10	8	2	87	160	263	404	505	858	1226	1962
	6	4	117	216	355	546	683	1188	1697	2716
	4	6	138	251	413	636	795	1421	1772	3248
15	12	3	115	212	348	536	670	1147	1638	2622
	9	6	154	283	465	716	895	1578	2255	3608
	6	9	176	323	532	818	1020	2270	3243	5189
20	16	4	143	262	432	664	830	1426	2037	3260
	12	8	188	346	569	876	1100	1954	2792	4468
	8	12	213	391	644	990	1240	2652	3789	6062
25	20	5	170	312	514	790	988	1701	2430	3888
	15	10	222	408	672	1030	1290	2323	3319	5311
	10	15	248	456	750	1150	1440	3034	4335	6936
30	25	5	182	334	550	846	1060	1811	2588	4141
	20	10	240	442	727	1120	1400	2485	3550	5680
	15	15	272	500	823	1270	1580	3416	4881	7809
40	35	5	203	374	615	946	1180	2015	2878	4606
	30	10	273	501	824	1270	1590	2780	3972	6355
	20	20	340	624	1030	1580	1980	4181	5973	9557
50	40	10	302	555	913	1400	1760	3047	4353	6966
	30	20	386	709	1170	1790	2240	4125	5893	9430
	20	30	416	765	1260	1940	2420	4945	7065	11304
60	50	10	328	603	992	1530	1910	3293	4704	7527
	40	20	427	784	1290	1980	2480	4486	6409	10256
	30	30	473	869	1430	2200	2750	5710	8157	13051
70	60	10	353	648	1070	1640	2050	3521	5030	8048
	50	20	464	853	1400	2160	2700	4821	6887	11019
	40	30	525	964	1590	2440	3050	5703	8148	13037
	30	40	546	1000	1650	2540	3180	6474	9249	14798

For Illustration Only

Figure 47
Hoffman Specialty Body Code 03 Temperature Regulating Valve

This valve comes in sizes ¾" through 4" as listed across the top of the table. Valve inlet and outlet pressures are listed along the left side, and the body of the table contains the steam flow rate in pounds per hour. In our example, the pressure at the inlet to the valve is 50 psig, and the design pressure in the tube bundle is 20 psig so we can move right along that line until we find a valve capacity that meets or slightly exceeds the flow we need, in this case 1065 lb/hr. A 1¼" valve under these conditions of inlet and outlet pressure will pass 1260 lb/hr. Obviously, the valve is large enough for this application, but is it too large?
We can apply the 50% rule of thumb to answer the question.

$$\frac{\text{design flow rate}}{\text{maximum flow rate}} \text{ should be 50\% or better}$$

$$\frac{1065}{1260} = 0.84$$

This tells us that the 1¼" valve will have to be comfortably wide open in order to handle the 1065 lb/hr flow our application requires at design conditions. This will help avoid wear, and will lead to good control over the steam flow as the load drops away from design conditions. On the other hand, it will have some additional capacity available in case of unusually high demand, so it looks like a good choice.

Step 4. Determine if unusual conditions must be satisfied. In this example, the regulator bulb will be immersed in water, so standard bulb materials like copper can be used. Many industrial processes require bulb materials that will withstand contact with other chemicals. Always consult with the manufacturer to insure that the bulb material will be compatible with the fluid to be heated or plan to use an "immersion well" to contain the bulb without direct contact with the fluid. The well is a good idea even if the bulb and fluid are compatible since the use of the well allows removal of the bulb for service without draining the system. Other unusual conditions that may have to be addressed might include high ambient temperatures, longer than usual capillary lengths, or unusual mountings for the thermal bulb. Some of these topics are covered in the section on troubleshooting.

Example: Selecting externally piloted temperature regulators. The same main valve that was used with one of the pressure regulating pilots can also be used to regulate temperature. There are two kinds of temperature pilot valves: self contained, and pneumatic.

The main valve is selected for the steam flow rate and appropriate pressure drop using the capacity tables just as described in the pressure regulator section.

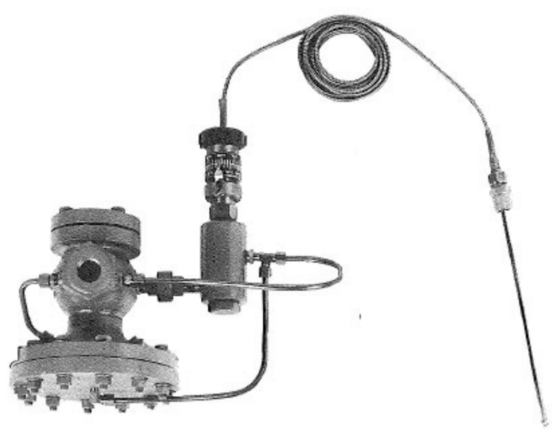


Figure 48
Regulator with Self Contained Pilot

The self contained pilot is selected for the temperature range of the fluid to be heated. It's best if the application temperature is somewhere near the middle of the range, rather than at either extreme. If the regulator is designed to maintain temperature only, with no control over the maximum pressure in the heat exchanger, the main valve and self contained temperature pilot will be sufficient. Pressure in the heat exchanger will be limited only by the initial supply pressure, the capacity of the heat exchanger and it's load.

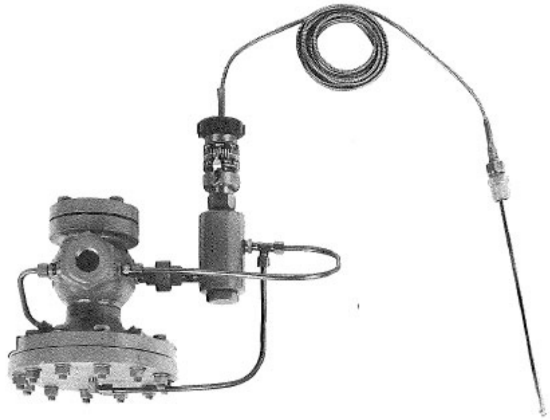


Figure 49
Temperature Pilot and Pressure Pilot

Adding a spring operated pressure pilot in series with the temperature pilot provides a more positive way to limit pressure in the heat exchanger while controlling temperature. If either the temperature or the pressure set point is satisfied, one of the pilots will close, thereby closing the main valve.

The externally piloted main valve with a pneumatic temperature pilot and a pneumatic pressure pilot will accurately and responsively control both temperature and pressure within the following broad pressure ranges as the air pressure signal from the pneumatic temperature pilot ranges from 9 psig to 30 psig:

Regulator outlet steam pressure required (psig)	Pilot valves required
0 to 21	Single diaphragm (1:1 area ratio) pneumatic pressure pilot and pneumatic temperature
0 to 84	Double diaphragm (4:1 area ratio) pneumatic pressure pilot and pneumatic temperature pilot.

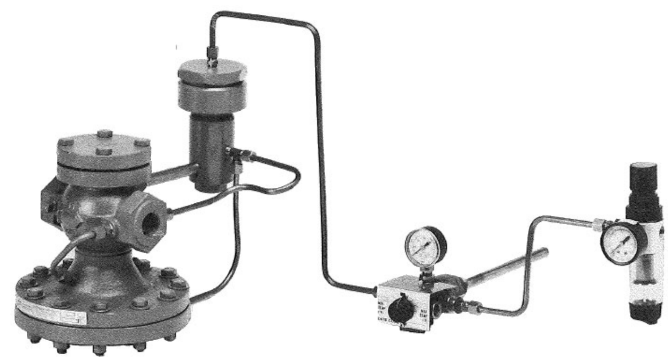


Figure 50
Main Valve with Pneumatic Pressure and Temperature Pilots and Air Filter/Regulator

INSTALLATION OF TEMPERATURE REGULATORS

All of the general ideas regarding pressure regulator installation apply to temperature regulators as well. The following ideas apply specifically to temperature regulators.

The temperature regulator must be installed so that it is accessible for inspection and maintenance. It is particularly important to avoid locating the actuator or capillary too close to sources of heat such as steam or hot water piping, and the area around the regulator should be adequately ventilated to prevent excessive ambient temperatures. Some of the thermal actuators used in vapor tension regulators today are designed to operate in hot environments, a "cross ambient" design. They generally have much larger thermal bulbs that can absorb the vaporization of the volatile fluid caused by external sources of heat without sending a signal to close the regulator.

Always provide shut off valves or unions to allow for easy removal of the regulator when it must be serviced. A throttling bypass valve can provide limited heating capability where service must be maintained while the regulator is out of service. Since the bypass valve cannot provide automatic temperature regulation, it's important to insure that adequate safeguards such as relief valves, are installed to prevent over heating and over pressure. Frequent inspection and adjustment of the bypass is required until the regulator is back in service.

Always provide a strainer upstream of the regulator, and some provision for removing condensate from the piping upstream of the regulator. A collection pocket and steam trap is the best idea, or, for short pipe runs, simply pitching the pipe back toward the main will keep condensate out of the regulator. If condensate is not removed, operation of the regulator will be sluggish, and water hammer may damage the bellows.

Location of the temperature sensing bulb is extremely important. It must be located where a truly representative temperature exists. In a tank where liquid is being heated by steam condensing in a tube bundle, the bulb should be in a region of average temperature; somewhere above the center of the tank, but neither directly over the tube bundle, nor directly at the cold water inlet. In a shell and tube heat exchanger, the bulb must be located as close as possible to the hot fluid outlet.

A vapor tension bulb must be installed horizontally or vertically with the mounting flange at the top. If it's installed vertically with the flange at the bottom, then vapor, rather than liquid will be forced into the capillary when the fluid starts to boil. This vapor will condense in the capillary, and the valve bellows will not receive the feedback signal to close, resulting in overheating. A related problem may exist in a bulb installed horizontally. The bulb mounting flange must be turned so that the curved end of the capillary inside the bulb is submerged in the liquid. In this way, the liquid, rather than the vapor will be forced through the capillary to close the valve. The portion of the mounting flange marked "TOP" must be at the 12:00 o'clock position to insure the end of the capillary is in the liquid rather than the vapor. It's best to install the bulb horizontally, and pitched down toward the bulb end to insure that the capillary will always be flooded.

If the bulb has been installed in a separate piping well, the well should be packed with heat transfer grease to improve heat transfer to the bulb. All temperature sensing bulbs must be fully inserted into the fluid or well. If an existing immersion well is too small to hold the entire bulb, the well must be replaced with a larger one. Excess capillary tubing between the bulb and the regulator should be wound into a four inch or larger diameter coil to prevent kinking.

TROUBLESHOOTING

Most temperature regulators must be set by referring to an accurate thermometer installed where it can give a good indication of actual fluid temperature. The newer self contained temperature pilot has it's own temperature setting, but it should be compared to a thermometer after installation as a check. If necessary, the pilot can be easily re-calibrated after installation After changing the temperature setting, always wait several minutes for the temperature to stabilize before making further adjustments. Many problems in regulating temperature are due to improper sizing or selection of the valve. An undersized valve may be satisfactory at low demand, but will allow temperatures to drop off at high demand. An oversized valve will give erratic temperatures, with wide swings above and below set point. In addition to valve size, the valve's pressure and pressure drop limitations must be observed. For example, a pressure drop greater than the maximum allowed may hold the valve open, since the actuator may not be able to exert sufficient force to close the valve, or the valve seat and disc may be wire drawn in a short period of time resulting in overheating.

Vapor Tension Regulators

Another possible source of problems in vapor tension temperature regulators can be the valve stroke. Valve stroke is measured on the valve stem by marking it at the stuffing box when the temperature at the sensing bulb is raised above the set point. Make another mark after the bulb is cooled and the bellows is completely contracted. The distance between the two marks measures the amount of stem travel between the wide open and closed positions. The acceptable stroke is determined by the size of the valve, ranging from 1/4" for small valves to as much as 7/16" for larger valves. The manufacturer lists the stroke value in the technical literature. If the stroke is too long or too short, the valve will not operate properly.

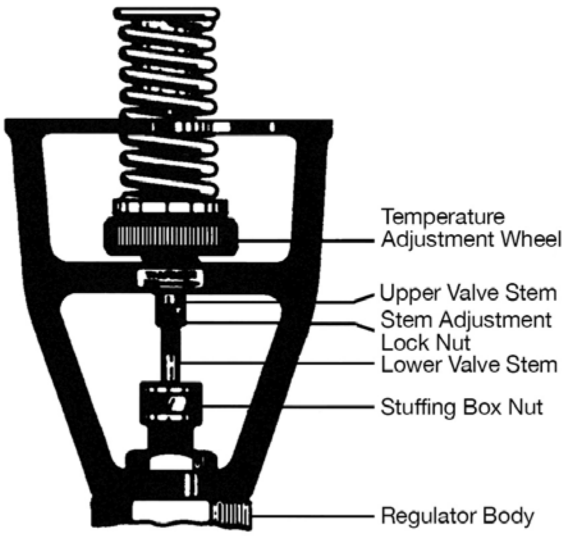


Figure 51
Temperature Regulator Bracket

The proper stroke can be established at the connection between the upper and lower valve stems. The lower stem is attached to the valve plug and screws into the upper stem just above the stuffing box. The two are held in position by a locknut. To increase the stroke, grip the lock nut with one pliers, and the lower stem with another pliers. Hold the lower stem so it cannot turn, and loosen the lock nut. Grip the upper stem (above the locknut) and turn the lower stem to the right. This will raise the stem, increasing the stroke. Tighten the locknut after the proper setting is achieved. To decrease the stroke, simply turn the lower stem to the left and then tighten the locknut.

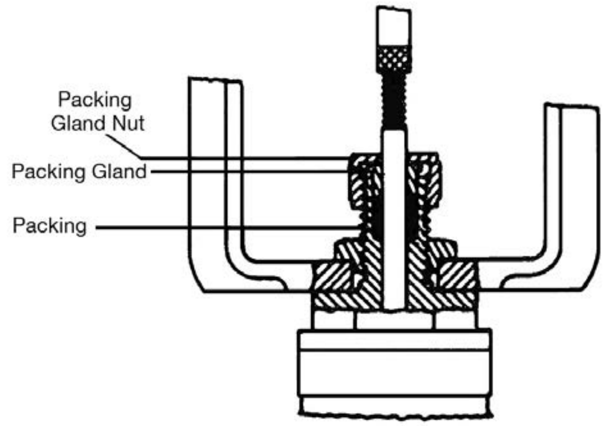


Figure 52
Valve Stem and Packing Gland

Buildup of scale or rust around the valve stem can slow or stop the valve response to temperature changes because of increased friction as the stem tries to slide through the packing. Periodically clean off the stem at the packing nut with some fine emery cloth to avoid this problem. Insure that the split packing rings are replaced if they dry out or become hard. Add a drop of oil to the packing occasionally, and insure that the gland nut is only finger tight. If the gland nut is too tight, the stem will not slide through the gland as it should resulting in poor temperature regulation.

If the actuator or capillary should develop a leak, the regulator will fail open, since the temperature adjusting wheel and spring will tend to open the direct acting valve as bellows pressure is reduced. This will result in loss of temperature control, and high temperatures in the heated fluid. If the bulb in the fluid should develop a leak, the heated fluid could leak into the vacuum filled bulb, causing the bellows to expand and close the direct acting valve.

When a vapor tension actuator must be replaced, insure that the replacement unit has the right temperature range. Always close the steam supply valves, allow the system to cool off and pressure to drop to 0 psig. Drain the tank or pipeline to a level below the bulb insertion point. If a temperature well is used, it's not necessary to drain the system. Loosen the four bulb bushing screws, and break the bulb connection slowly to insure that fluid will not leak from the bushing. Remove the four bulb bushing screws and the bulb from the tank.

Turn the temperature adjustment wheel to the lowest position. Cool the bulb and bellows at least 20°F below the low limit of the temperature range indicated on the nameplate. This is particularly important for actuators with temperature ranges at or below 120°F. The bellows must be cooled until it can be compressed by hand. Failure to cool the bellows will destroy the actuator because the bellows will expand and rupture when the restraining force of the bellows housing screws is removed. Remove the bellows housing nuts and screws and lift the bellows off the bracket. Make sure you keep the bulb and bellows cool. Push the upper valve stem plate down until the valve is shut. Mark the stem at the stuffing box so that the stroke can be checked after the new actuator is installed. Cool the new actuator at least 20°F below it's minimum temperature rating, and make sure you can compress the bellows by hand before removing the shipping clip. Remove the clip, and attach the new actuator to the bracket using all the screws and nuts provided. Work quickly, and keep the bulb cool while the actuator is being attached to the bracket. Check the valve stem stroke as described above.

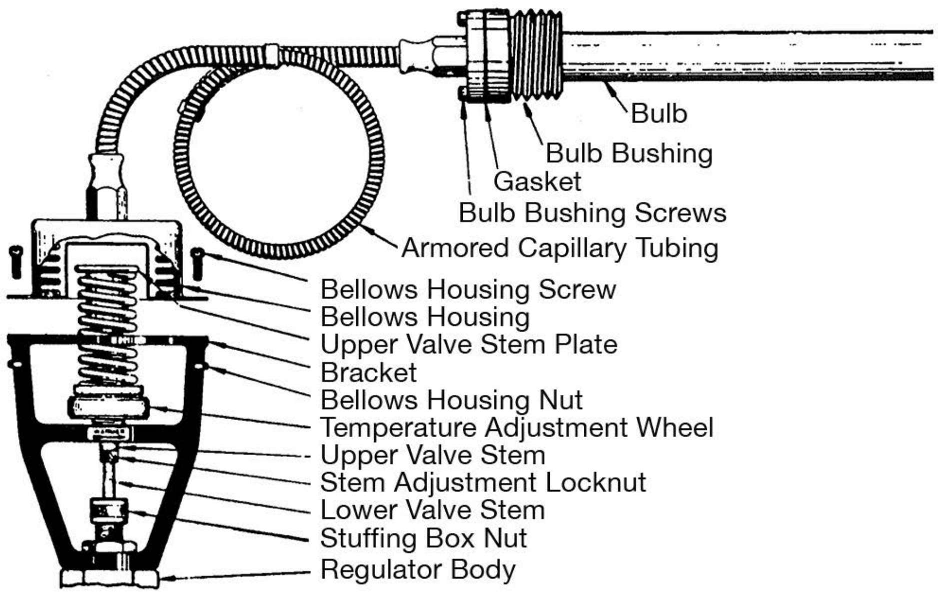


Figure 53
Vapor Tension Actuator and Bracket

SOME TYPICAL APPLICATIONS OF TEMPERATURE REGULATORS

Application: Tank and external heat exchanger combined to meet demand for domestic hot water.

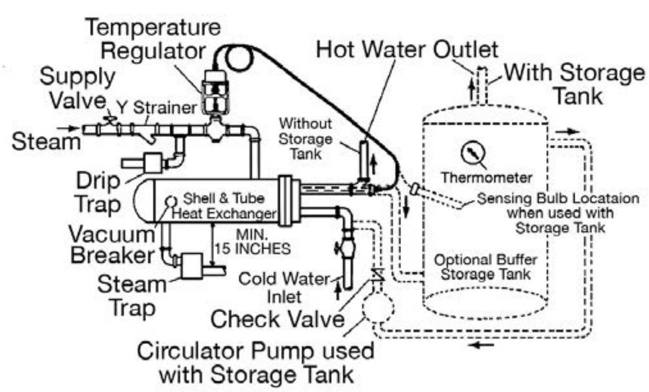


Figure 54

System operation: The heat exchanger has little volume to accomplish the mixing and provide storage to meet the short, heavy demands typical in domestic water systems. The storage tank acts as a buffer to meet peak loads and allow mixing to average temperatures and prevent wide temperature swings. The vapor tension type temperature regulator provides adequate responsiveness and accuracy of temperature control in spite of irregular and heavy peak demands for hot water.

Notes: The pump which provides circulation from tank to heat exchanger must be capable of handling oxygen rich, corrosive water.
Recirculation from the system should flow across the thermal bulb in order to provide instant hot water throughout the system and tube heat exchanger.

Application: Temperature regulator controls fluid temperature from a shell and tube heat exchanger.

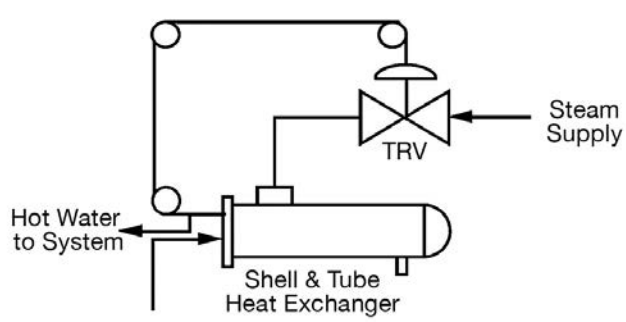


Figure 55

System operation: Steam flow into the heat exchanger is controlled by a vapor tension temperature regulator.

Note: Vapor tension regulators are not recommended for applications where a shell and tube heat exchanger will be expected to meet sudden changes in flow rate, because wide swings in temperature may result.

Application: Control of temperature in a storage tank with steam pressure limitation.

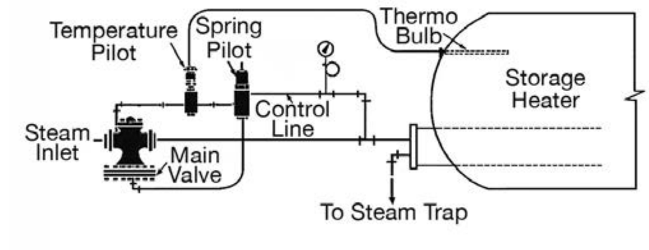


Figure 56

System operation: The temperature regulator controls steam flow to maintain tank temperature. The large tank volume allows the system to meet heavy demands, and allows mixing to achieve a satisfactory average temperature at the outlet. The spring pilot prevents excess pressure in the tube bundle.

Application: Steam to hot water converter for hydronic heating system using spring and temperature pilots.

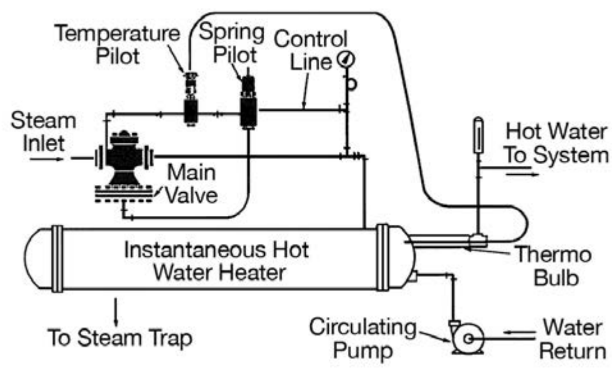


Figure 57

System operation: The spring pilot controls steam pressure to the converter on start-up. As the thermal sensing bulb senses the increase in water temperature, the temperature pilot signals the main valve to modulate and maintain a constant temperature at the converter outlet.

Application: Heat exchanger high limit safety control.

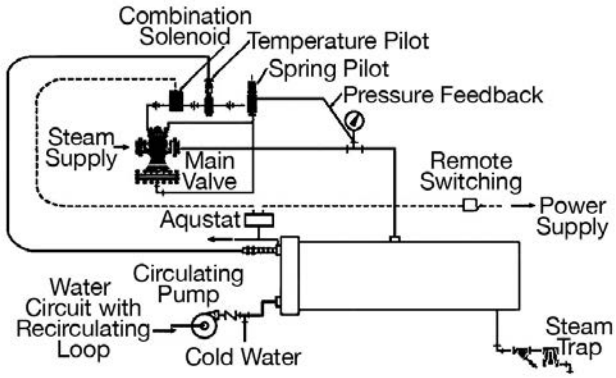


Figure 58

System operation: A solenoid pilot is wired in series with an aquastat set at 5-10°F above the control temperature to limit the outlet temperature.

Notes: This automatic system would be used where the temperature limits for a process are critical or as a safety override for other systems such as domestic hot water. A flow switch mounted in the hot water outlet from the heat exchanger can be used to shut off the steam supply at periods of no flow.

V. SPECIAL PROBLEMS

HANDLING LARGE PRESSURE REDUCTIONS

Manufacturers establish a limit for pressure drop across a single regulator in order to minimize noise and premature wear. When a pressure reduction greater than that limit is required, we must use two or more regulators in series.

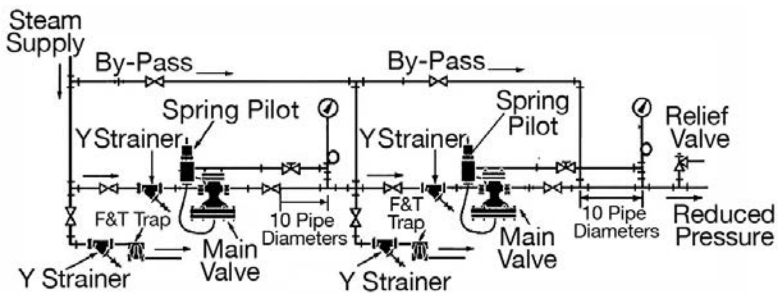


Figure 59
Pressure Regulators in Series

The total pressure drop is taken in stages. Each pilot valve is set to achieve its portion of the overall pressure drop, and the pressure sensing point must be at least 10 pipe diameters downstream of the nearest upstream fitting. Each main valve must be able to handle the total required steam flow rate at the pressure drop it will accomplish. Each regulator is equipped with a bypass and isolation valves to allow manual operation with either regulator out of service, as well as strainers, and steam traps as described earlier. The piping which connects the two regulators must be long enough for steady pressure to develop at the inlet to the downstream valve, and large enough to reduce the steam velocity and avoid excessive noise. Twenty pipe diameters of the expanded pipe size is usually sufficient.

SUPERHEAT DOWNSTREAM OF A VALVE

Whenever large pressure drops are taken, the possibility of superheating the steam exists, because steam that expands without doing any work will have the same total enthalpy at the lower pressure that it had at the higher pressure. This is called a "throttling process".

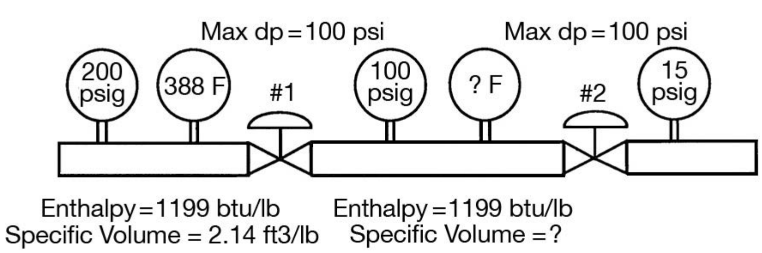


Figure 60
Regulators in Series
Provide Two Stage Pressure Reduction

For example, suppose that steam at 200 psig expands to 100 psig across the first valve, then to 15 psig across the second. We'll assume that the steam entering the first valve is at saturation conditions, pure vapor at 200 psig. Since there's no work being done in the valve, the total enthalpy at the outlet of the first valve will be the same as it was at the inlet, but what will be the temperature and specific volume? Saturated steam tables say that the temperature of 100 psig steam should be 338°F, it's specific volume should be 3.89 ft ^{3}/lb, and it's enthalpy should be 1189 Btu/lb. Compare the figure to the steam table data and you'll notice that the actual energy content of the 100 psig steam is 10 Btu/lb greater than the saturated steam tables would predict for that pressure. This "excess" energy shows up as an increase in the steam temperature above saturation temperature. In order to determine how much the temperature has increased, we need to look at the tables for superheated steam, a small portion of these tables is provided below.

Properties of Superheated Steam

	Temperature		
Pressure	350°F	354°F	360°F
100 psig	h = 1196.8 v =3.996	h = 1199.0 v = 4.022	h = 1202.7 v = 4.060

h stands for enthalpy, in Btu/lb
v stands for specific volume in ft ^{3}/lb

The only condition where we find a pressure of 100 psig and an enthalpy of 1199 Btu/lb is at a temperature of 354°F. At this condition, we say that the steam is superheated to 354°F, or that it has 354 - 338 = 16 degrees of superheat. Notice that the steam temperature did not increase as it expanded through the valve, in fact it dropped from 388°F to 354°F. The "superheating" refers to the 16 degree increase above the temperature we would expect at saturation conditions.

A quick way to determine the amount of superheat resulting from a given pressure drop is to use the Mollier diagram that is often part of the steam tables. On this diagram, horizontal lines represent constant enthalpy, so all you have to do is find the intersection of the inlet pressure and the saturation condition lines, then move horizontally to the right until you reach the lower pressure. The amount of superheat can be read right off the chart as shown where "a" represents the inlet and "b" the outlet pressure.

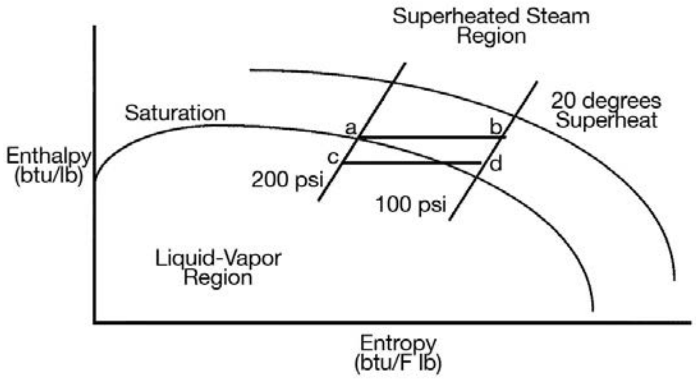


Figure 61
Mollier Diagram

In this example we assumed that the steam entering the valve was at saturation, but steam may actually carry some liquid along with it as it leaves the boiler. Additionally, steam loses heat through the pipe walls and insulation as it flows to the valve. This heat loss condenses some of the steam and adds to the percentage of liquid in the steam flow. Therefore, the steam entering the first valve probably is not at point "a" on the diagram, but at point "c", carrying some amount of liquid. If that's the case, then the amount of superheating achieved for the given pressure drop will be much less than the theoretical maximum shown at point "b". If there's enough liquid at the entrance to the first valve, we may have merely saturated steam at the outlet - no superheat at all, because the "excess" energy will merely evaporate the liquid water droplets rather than superheat the steam.

What difference does this superheating make? Notice that the specific volume of the steam at the superheated condition, 4.022 ft ^{3}/lb, is greater than 3.89 we would expect for saturated steam at the same pressure. This increase in volume, or decrease in density, means that the flow through the second valve will not be quite as great as we would expect if we had saturated steam and the same pressure drop. So one of the most common consequences of superheating is the correction of flow rates for the second valve. A rule of thumb allows us to calculate a correction to the valve capacity tables, which are always based on flow of saturated steam at the valve inlet.

Correction factor= 1 + (0.00065 x superheat degrees)

This correction factor is applied to the flow rate in the valve capacity table as follows:

$$\text{Flow of superheated steam} = \frac{\text{Tabulated flow rate}}{\text{correction factor}}$$

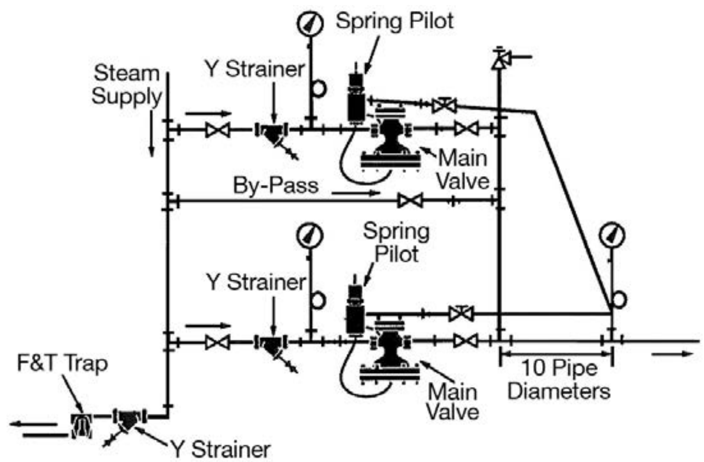


Figure 62
Pressure Regulators in Parallel

In our example, the correction factor would be about 1.011, so it wouldn't make a great deal of difference in sizing the second valve. In fact, the size of that correction factor rarely makes much difference so far as valve capacity is concerned. It may be more important to calculate the superheat so that we can insure all of the components downstream of the valve are rated to handle the higher than expected temperature, or that the heat exchanger will have adequate capacity to desuperheat the steam and then condense it at an acceptable rate.

Handling Highly Variable Loads

We saw in **Figure 23** that all pressure regulators have a characteristic capacity curve which describes the way that downstream pressure changes with increasing load through the regulator. Notice that the major part of the curve is not quite horizontal. It has a definite droop or slope indicating that downstream pressure drops off as load increases. In the section on pressure regulators, we defined the regulator's maximum capacity as the flow which corresponds to a drop of 10% from set point pressure. Obviously, if the system requires steam flow greater than that, we'll need to install a larger capacity regulator, or perhaps a larger size trim. On the other hand, we've discussed the problems of control quality, excessive initial cost, and early failure due to steam cutting that arise when a regulator is oversized with respect to its design flow rate.

A system that requires a wide range of flow rates cannot be supplied by a single regulator without encountering these problems. If the valve is large enough to handle the maximum expected flow rate without excessive drop in downstream pressure, it will be so large that control quality and wear will be a problem at the low flow rate. When a system must be able to supply a wide range of flow rates, the solution is to use regulators in parallel.

Each regulator has the same inlet and outlet pressure, but the regulator capacities will be selected so that one of them will be about 30% of the maximum expected system flow rate, the other, about 70%. The larger of the two regulators will be set to maintain a pressure slightly lower than the setting of the smaller valve.

As demand for steam flow increases from zero, the smaller regulator is able to meet the demand until it's fully open. The larger regulator is closed during this period because its set point is satisfied. As the smaller regulator opens wide, further increases in demand will cause the outlet pressure to droop to the point where the larger regulator will begin to open. From that point on, the increasing demand can be satisfied by the wide open smaller valve plus the modulating larger valve all the way to maximum capacity when both valves will be wide open.

The exact proportion used to establish the regulator capacities is not significant, a $^1/_3$ - $^2/_3$ proportion is often used. Similarly, the difference between the set points is not critical. Within the limits of precision established by the valve manufacturing process, they can be set as close as possible to minimize the change in pressure as the second regulator begins to open.

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Heat Exchanger Product Selection

• ESP – Thermal Plate Heat Exchanger Selection Program

Steam and Water Pressure Reducing Valves

• Steam – 2000 Pressure and Temperature Regulator
• Steam – 1140 Temperature Regulator
• Water – 1140 Temperature Regulator
• Steam – Traps

Sizing Tools

• Steam – Pipe
• Steam – Loss
• Flash – Steam
• Condensate – Pipe

Xylem |'zīləm|

1) The tissue in plants that brings water upward from the roots;
2) a leading global water technology company.

We're a global team unified in a common purpose: creating innovative solutions to meet our world's water needs. Developing new technologies that will improve the way water is used, conserved, and re-used in the future is central to our work. We move, treat, analyze, and return water to the environment, and we help people use water efficiently, in their homes, buildings, factories and farms. In more than 150 countries, we have strong, long-standing relationships with customers who know us for our powerful combination of leading product brands and applications expertise, backed by a legacy of innovation..

For more information on how Xylem can help you, go to www.xyleminc.com

xylem
Let's Solve Water

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