The Technical Reference section includes articles covering regulator theory, sizing, selection, overpressure protection, and other topics relating to regulators. This section begins with the basic theory of regulators and ends with conversion tables and other informative charts.

This section is for general reference only. For more detailed information please visit www.emersonprocess.com/regulators or contact your local Sales Office.

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Glossary

Regulator Control Theory

Fundamentals of Gas Pressure Regulators

The primary function of any gas regulator is to match the flow of gas through the regulator to the demand for gas placed upon the system. At the same time, the regulator must maintain the system pressure within certain acceptable limits.

A typical gas pressure system might be similar to that shown in Figure 1, where the regulator is placed upstream of the valve or other device that is varying its demand for gas from the regulator.

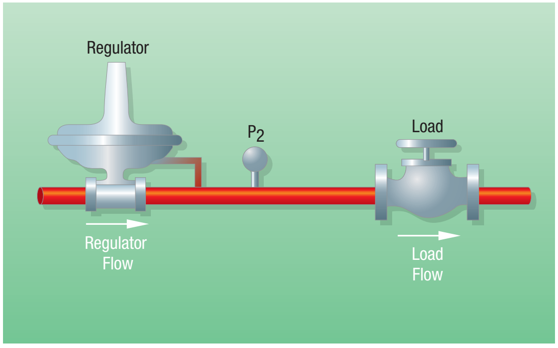


Figure 1

If the load flow decreases, the regulator flow must decrease also. Otherwise, the regulator would put too much gas into the system, and the pressure (P_2) would tend to increase. On the other hand, if the load flow increases, then the regulator flow must increase also in order to keep P_2 from decreasing due to a shortage of gas in the pressure system.

From this simple system it is easy to see that the prime job of the regulator is to put exactly as much gas into the piping system as the load device takes out.

If the regulator were capable of instantaneously matching its flow to the load flow, then we would never have major transient variation in the pressure (P_2) as the load changes rapidly. From practical experience we all know that this is normally not the case, and in most real-life applications, we would expect some fluctuations in P_2 whenever the load changes abruptly.

Because the regulator's job is to modulate the flow of gas into the system, we can see that one of the essential elements of any regulator is a restricting element that will fit into the flow stream and provide a variable restriction that can modulate the flow of gas through the regulator.

Figure 2 shows a schematic of a typical regulator restricting element. This restricting element is usually some type of valve arrangement. It can be a single-port globe valve, a cage style valve, butterfly valve, or any other type of valve that is capable of operating as a variable restriction to the flow.

In order to cause this restricting element to vary, some type of loading force will have to be applied to it. Thus we see that the second essential element of a gas regulator is a Loading Element that can apply the needed force to the restricting element.

The loading element can be one of any number of things such as a weight, a hand jack, a spring, a diaphragm actuator, or a piston actuator, to name a few of the more common ones.

A diaphragm actuator and a spring are frequently combined, as shown in Figure 3, to form the most common type of loading element. A loading pressure is applied to a diaphragm to produce a loading force that will act to close the restricting element. The spring provides a reverse loading force which acts to overcome the weight of the moving parts and to provide a fail-safe operating action that is more positive than a pressure force.

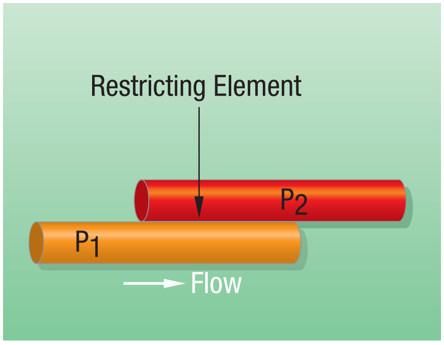


Figure 2

So far, we have a restricting element to modulate the flow through the regulator, and we have a loading element that can apply the necessary force to operate the restricting element. But, how do we know when we are modulating the gas flow correctly? How do we know when we have the regulator flow matched to the load flow? It is rather obvious that we need some type of Measuring Element which will tell us when these two flows have been perfectly matched. If we had some economical method of directly measuring these flows, we could use that approach; however, this is not a very feasible method.

We noted earlier in our discussion of Figure 1 that the system pressure (P_2) was directly related to the matching of the two flows. If the restricting element allows too much gas into the system, P_2 will increase. If the restricting element allows too little gas into the system, P_2 will decrease. We can use this convenient fact to provide a simple means of measuring whether or not the regulator is providing the proper flow.

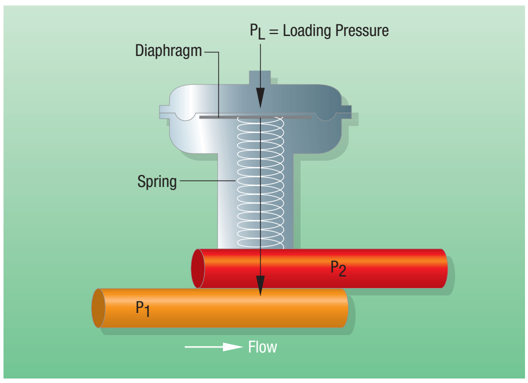


Figure 3

Regulator Control Theory

Manometers, Bourdon tubes, bellows, pressure gauges, and diaphragms are some of the possible measuring elements that we might use. Depending upon what we wish to accomplish, some of these measuring elements would be more advantageous than others. The diaphragm, for instance, will not only act as a measuring element which responds to changes in the measured pressure, but it also acts simultaneously as a loading element. As such, it produces a force to operate the restricting element that varies in response to changes in the measured pressure. If we add this typical measuring element to the loading element and the restricting element that we selected earlier, we will have a complete gas pressure regulator as shown in Figure 4.

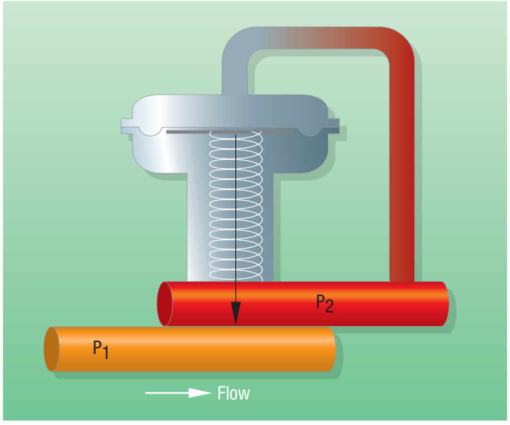


Figure 4

Let's review the action of this regulator. If the restricting element tries to put too much gas into the system, the pressure (P_2) will increase. The diaphragm, as a measuring element, responds to this increase in pressure and, as a loading element, produces a force which compresses the spring and thereby restricts the amount of gas going into the system. On the other hand, if the regulator doesn't put enough gas into the system, the pressure (P_2) falls and the diaphragm responds by producing less force. The spring will then overcome the reduced diaphragm force and open the valve to allow more gas into the system. This type of self-correcting action is known as negative feedback. This example illustrates that there are three essential elements needed to make any operating gas pressure regulator. They are a restricting element, a loading element, and a measuring element. Regardless of how sophisticated the system may become, it still must contain these three essential elements.

Pilot-Operated Regulators

So far we have only discussed direct-operated regulators. This is the name given to that class of regulators where the measured pressure is applied directly to the loading element with no intermediate hardware. There are really only two basic configurations of direct-operated regulators that are practical. These two basic types are illustrated in Figures 4 and 5.

If the proportional band of a given direct-operated regulator is too great for a particular application, there are a number of things we can do. From our previous examples we recall that spring rate, valve travel, and effective diaphragm area were the three parameters that affect the proportional band. In the last section we pointed out the way to change these parameters in order to improve the proportional band. If these changes are either inadequate or impractical, the next logical step is to install a pressure amplifier in the measuring or sensing line. This pressure amplifier is frequently referred to as a pilot.

Conclusion

It should be obvious at this point that there are fundamentals to understand in order to properly select and apply a gas regulator to do a specific job. Although these fundamentals are profuse in number and have a sound theoretical base, they are relatively straightforward and easy to understand.

As you are probably aware by now, we made a number of simplifying assumptions as we progressed. This was done in the interest of gaining a clearer understanding of these fundamentals without getting bogged down in special details and exceptions. By no means has the complete story of gas pressure regulation been told. The subject of gas pressure regulation is much broader in scope than can be presented in a single document such as this, but it is sincerely hoped that this application guide will help to gain a working knowledge of some fundamentals that will enable one to do a better job of designing, selecting, applying, evaluating, or troubleshooting any gas pressure regulation equipment.

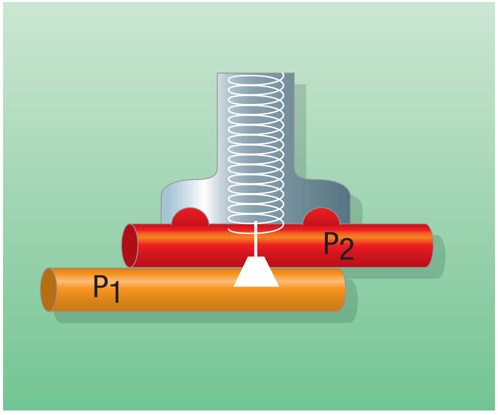
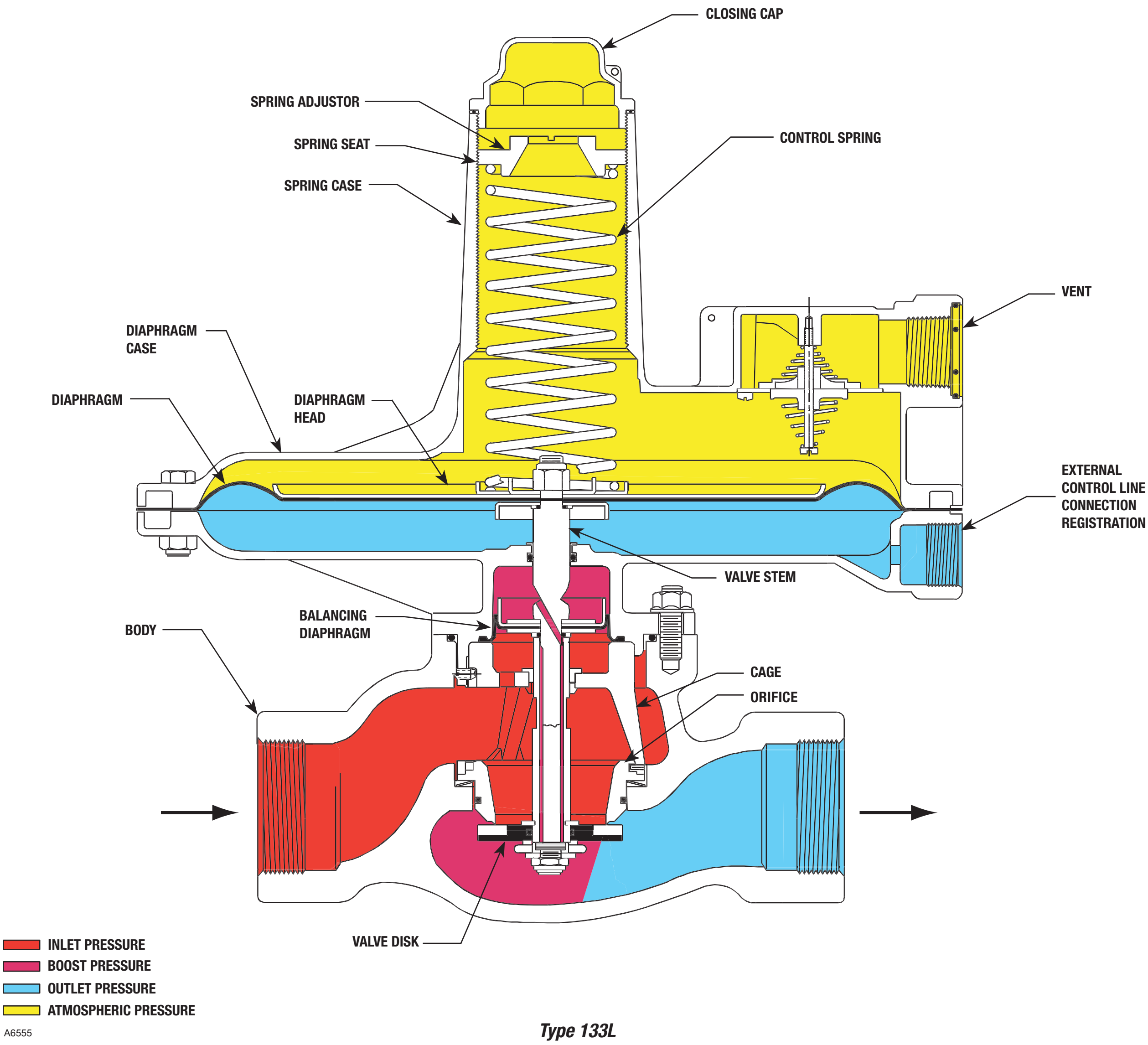


Figure 5

Regulator Components

Straight Stem Style Direct-Operated Regulator Components



Type 133L

NOTE:

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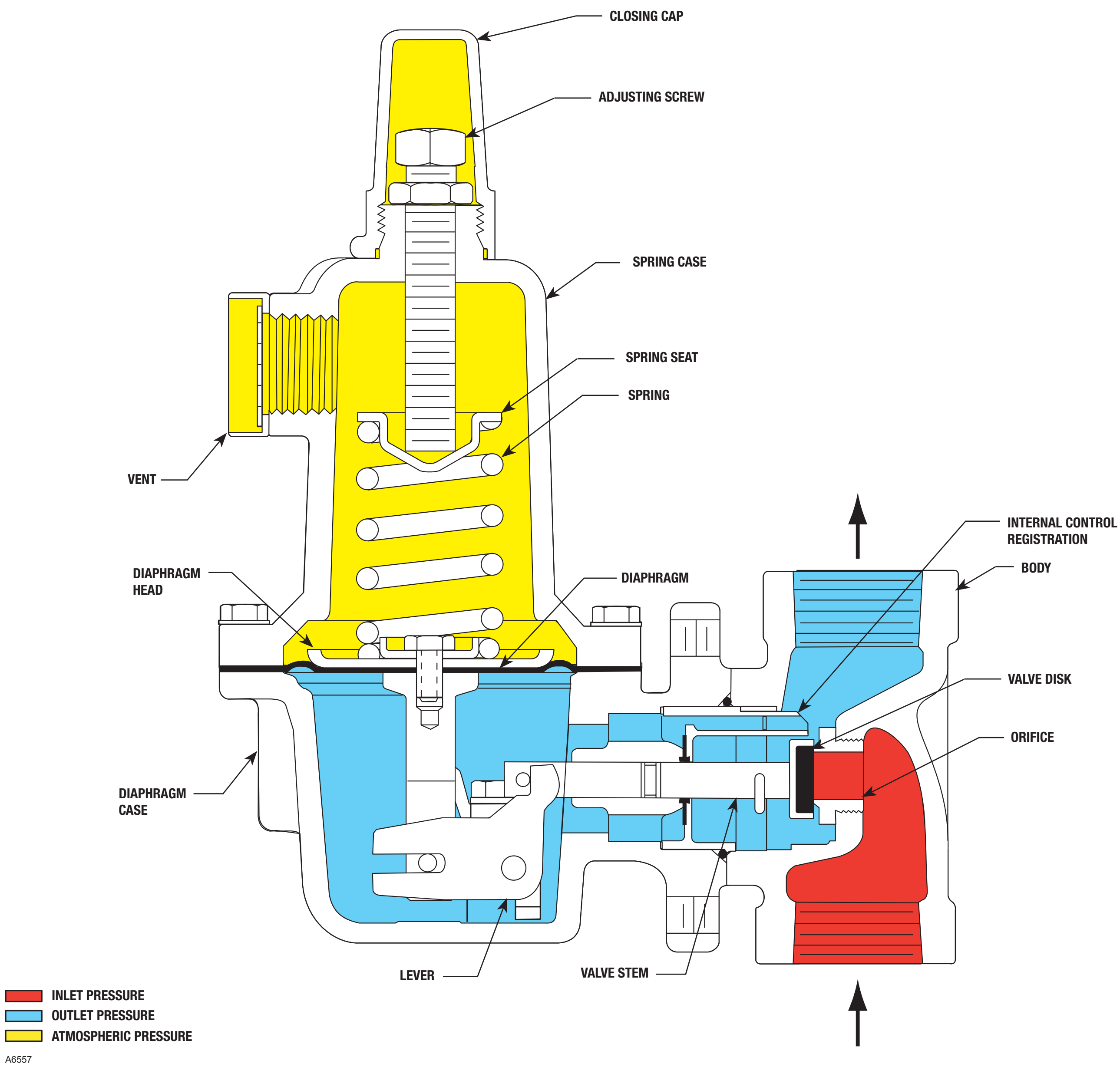
Regulator Components

Lever Style Direct-Operated Regulator Components



Type 627

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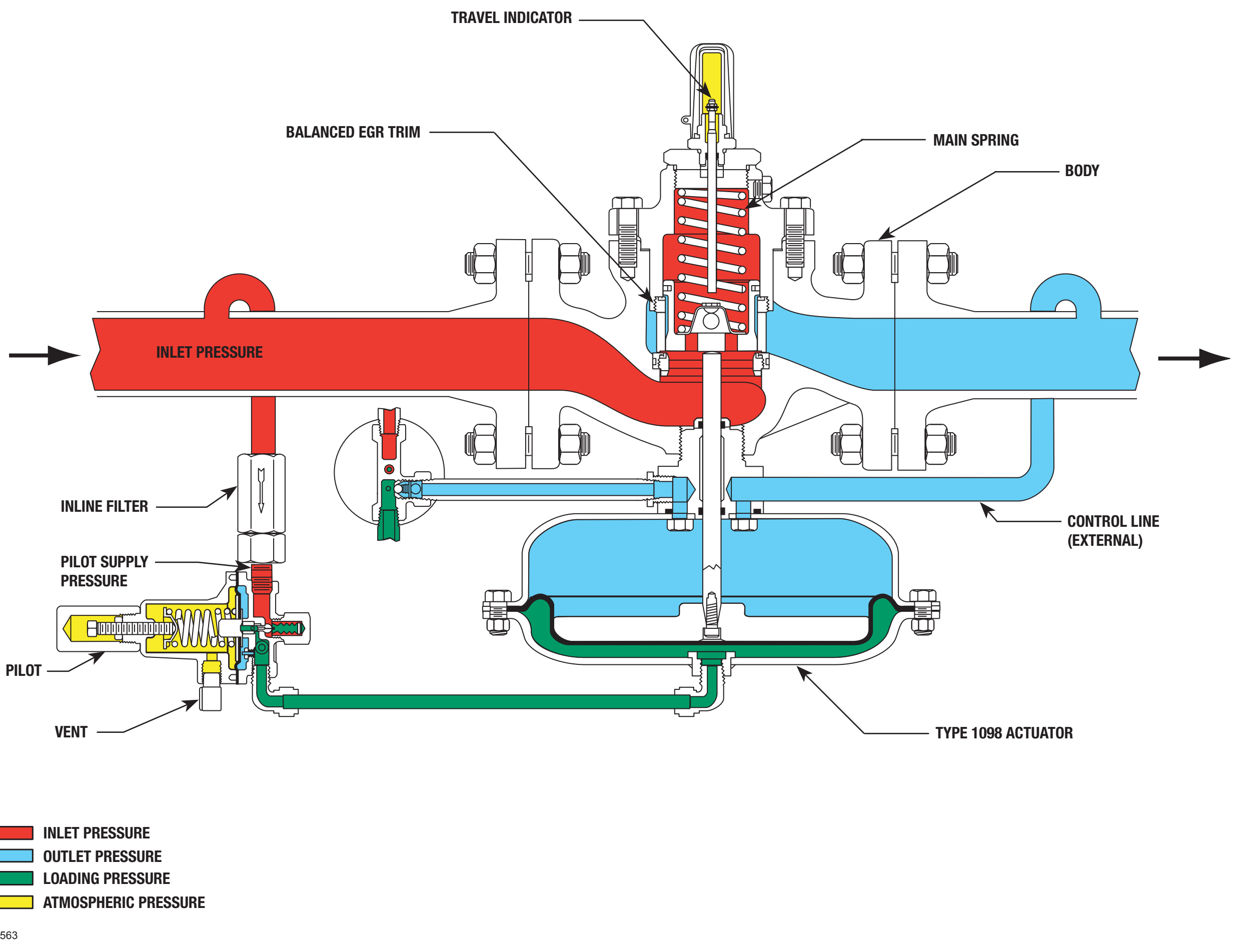
Regulator Components

Loading Style (Two-Path Control) Pilot-Operated Regulator Components



Type 1098-EGR

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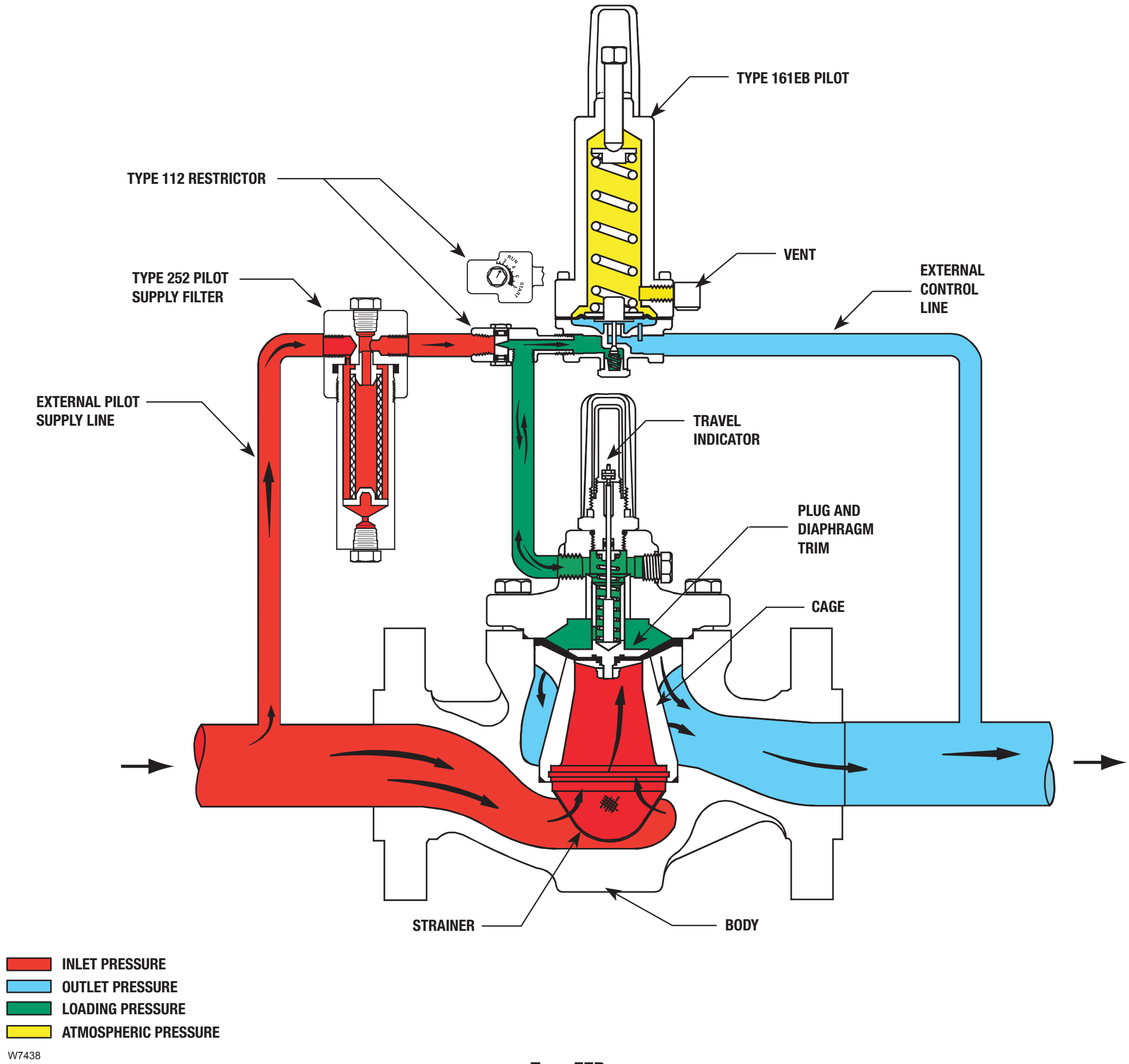
Regulator Components

Unloading Style Pilot-Operated Regulator Components



Type EZR

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Introduction to Regulators

Instrument engineers agree that the simpler a system is the better it is, as long as it provides adequate control. In general, regulators are simpler devices than control valves. Regulators are self-contained, direct-operated control devices which use energy from the controlled system to operate whereas control valves require external power sources, transmitting instruments, and control instruments.

Specific Regulator Types

Within the broad categories of direct-operated and pilot-operated regulators fall virtually all of the general regulator designs, including:

- Pressure reducing regulators
- Backpressure regulators
- Pressure relief valves
- Pressure switching valves
- Vacuum regulators and breakers

Pressure Reducing Regulators

A pressure reducing regulator maintains a desired reduced outlet pressure while providing the required fluid flow to satisfy a downstream demand. The pressure which the regulator maintains is the outlet pressure setting (setpoint) of the regulator.

Types of Pressure Reducing Regulators

This section describes the various types of regulators. All regulators fit into one of the following two categories:

1. Direct-Operated (also sometimes called Self-Operated)
2. Pilot-Operated

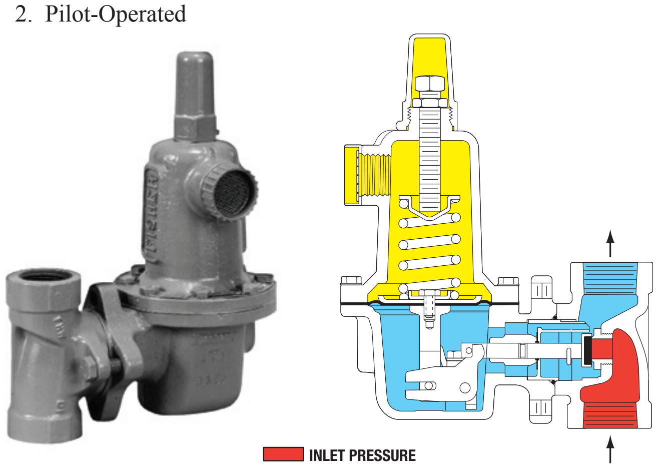


Figure 1. *Type 627 Direct-Operated Regulator and Operational Schematic*

Direct-Operated (Self-Operated) Regulators

Direct-operated regulators are the simplest style of regulators. At low set pressures, typically below 1 psig (0,07 bar), they can have very accurate (±1%) control. At high control pressures, up to 500 psig (34,5 bar), 10 to 20% control is typical.

In operation, a direct-operated, pressure reducing regulator senses the downstream pressure through either internal pressure registration or an external control line. This downstream pressure opposes a spring which moves the diaphragm and valve plug to change the size of the flow path through the regulator.

Pilot-Operated Regulators

Pilot-operated regulators are preferred for high flow rates or where precise pressure control is required. A popular type of pilot-operated system uses two-path control. In two-path control, the main valve diaphragm responds quickly to downstream pressure

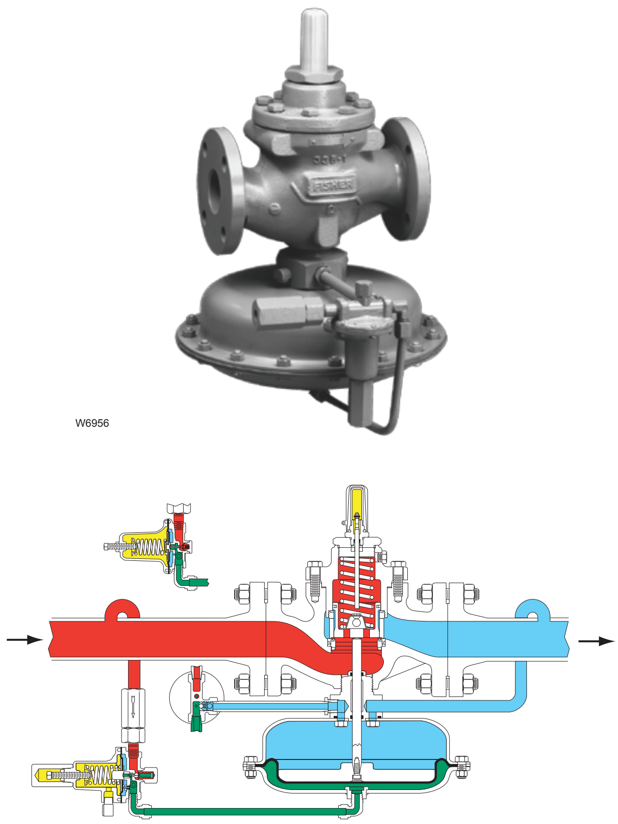


Figure 2. *Type 1098-EGR Pilot-Operated Regulator and Operational Schematic*

Introduction to Regulators

changes, causing an immediate correction in the main valve plug position. At the same time, the pilot diaphragm diverts some of the reduced inlet pressure to the other side of the main valve diaphragm to control the final positioning of the main valve plug. Two-path control results in fast response and accurate control.

Backpressure Regulators and Pressure Relief Valves

A backpressure regulator maintains a desired upstream pressure by varying the flow in response to changes in upstream pressure. A pressure relief valve limits pressure build-up (prevents overpressure) at its location in a pressure system. The relief valve opens to prevent a rise of internal pressure in excess of a specified value. The pressure at which the relief valve begins to open pressure is the relief pressure setting.

Relief valves and backpressure regulators are the same devices. The name is determined by the application. Fisher® relief valves are not ASME safety relief valves.

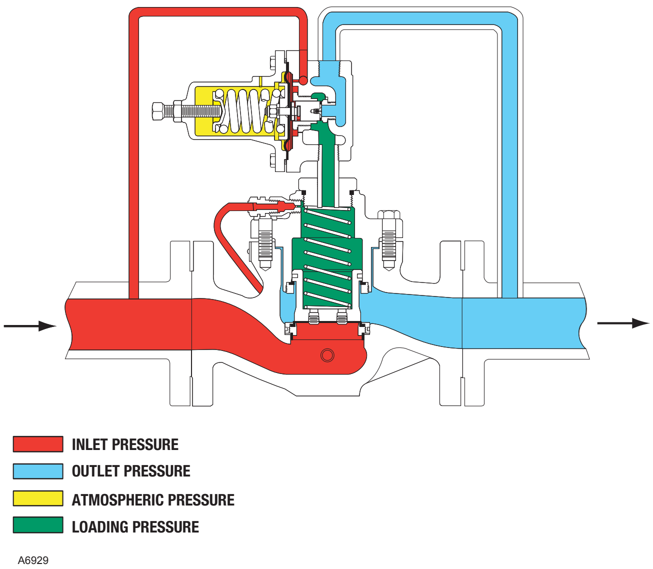


Figure 3. *Type 63EG Backpressure Regulator/Relief Valve Operational Schematic*

Pressure Switching Valves

Pressure switching valves are used in pneumatic logic systems. These valves are for either two-way or three-way switching. Two-way switching valves are used for on/off service in pneumatic systems.

Three-way switching valves direct inlet pressure from one outlet port to another whenever the sensed pressure exceeds or drops below a preset limit.

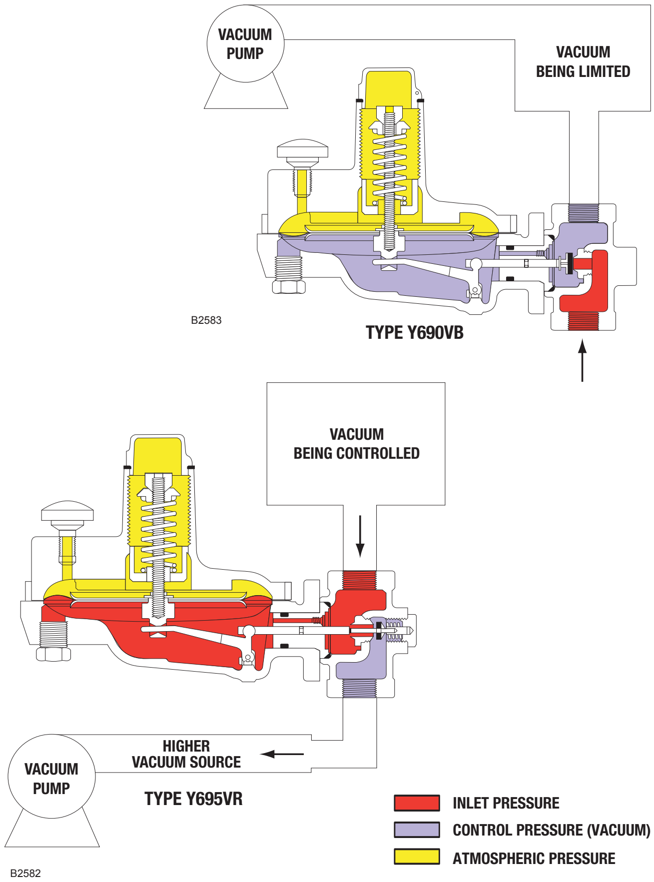


Figure 4. *Type Y690VB Vacuum Breaker and Type V695VR Vacuum Regulator Operational Schematics*

Vacuum Regulators and Breakers

Vacuum regulators and vacuum breakers are devices used to control vacuum. A vacuum regulator maintains a constant vacuum at the regulator inlet with a higher vacuum connected to the outlet. During operation, a vacuum regulator remains closed until a vacuum decrease (a rise in absolute pressure) exceeds the spring setting and opens the valve disk. A vacuum breaker prevents a vacuum from exceeding a specified value. During operation, a vacuum breaker remains closed until an increase in vacuum (a decrease in absolute pressure) exceeds the spring setting and opens the valve disk.

Regulator Selection Criteria

This section describes the procedure normally used to select regulators for various applications. For most applications, there is generally a wide choice of regulators that will accomplish the

Introduction to Regulators

required function. The vendor and the customer, working together, have the task of deciding which of the available regulators is best suited for the job at hand. The selection procedure is essentially a process of elimination wherein the answers to a series of questions narrow the choice down to a specific regulator.

Control Application

To begin the selection procedure, it's necessary to define what the regulator is going to do. In other words, what is the control application? The answer to this question will determine the general type of regulator required, such as:

- Pressure reducing regulators
- Backpressure regulators
- Pressure relief valves
- Vacuum regulators
- Vacuum breaker

The selection criteria used in selecting each of these general regulator types is described in greater detail in the following subsections.

Pressure Reducing Regulator Selection

The majority of applications require a pressure reducing regulator. Assuming the application calls for a pressure reducing regulator, the following parameters must be determined:

- Outlet pressure to be controlled
- Inlet pressure to the regulator
- Capacity required
- Shutoff capability required
- Process fluid
- Process fluid temperature
- Accuracy required
- Pipe size required
- End connection style
- Material requirements
- Control line needed
- Overpressure protection

Outlet Pressure to be Controlled

For a pressure reducing regulator, the first parameter to determine is the required outlet pressure. When the outlet pressure is known, it helps determine:

- Spring requirements
- Casing pressure rating
- Body outlet rating
- Orifice rating and size
- Regulator size

Inlet Pressure of the Regulator

The next parameter is the inlet pressure. The inlet pressure (minimum and maximum) determines the:

- Pressure rating for the body inlet
- Orifice pressure rating and size
- Main spring (in a pilot-operated regulator)
- Regulator size

If the inlet pressure varies significantly, it can have an effect on:

- Accuracy of the controlled pressure
- Capacity of the regulator
- Regulator style (two-stage or unloading)

Capacity Required

The required flow capacity influences the following decisions:

- Size of the regulator
- Orifice size
- Style of regulator (direct-operated or pilot-operated)

Shutoff Capability

The required shutoff capability determines the type of disk material:

- Standard disk materials are Nitrile (NBR) and Neoprene (CR), these materials provide the tightest shutoff.
- Other materials, such as Nylon (PA), Polytetrafluoroethylene (PTFE), Fluoroelastomer (FKM), and Ethylenepropylene (EPDM), are used when standard material cannot be used.
- Metal disks are used in high temperatures and when elastomers are not compatible with the process fluid; however, tight shutoff is typically not achieved.

Process Fluid

Each process fluid has its own set of unique characteristics in terms of its chemical composition, corrosive properties, impurities, flammability, hazardous nature, toxic effect, explosive limits, and molecular structure. In some cases special care must be taken to select the proper materials that will come in contact with the process fluid.

Process Fluid Temperature

Fluid temperature might determine the materials used in the regulator. Standard regulators use Steel and Nitrile (NBR) or Neoprene (CR) elastomers that are good for a temperature range of -40° to 180°F (-40° to 82°C). Temperatures above and below this range may require other materials, such as Stainless steel, Ethylenepropylene (EPDM), or Perfluoroelastomer (FFKM).

Introduction to Regulators

Accuracy Required

The accuracy requirement of the process determines the acceptable droop (also called proportional band or offset). Regulators fall into the following groups as far as droop is concerned:

- **Rough-cut Group—** This group generally includes many first-stage, rough-cut direct-operated regulators. This group usually has the highest amount of droop. However, some designs are very accurate, especially the low-pressure gas or air types, such as house service regulators, which incorporate a relatively large diaphragm casing.
- **Close-control Group—** This group usually includes pilot-operated regulators. They provide high accuracy over a large range of flows. Applications that require close control include these examples:
    - Burner control where the fuel/air ratio is critical to burner efficiency and the gas pressure has a significant effect on the fuel/air ratio.
    - Metering devices, such as gas meters, which require constant input pressures to ensure accurate measurement.

Pipe Size Required

If the pipe size is known, it gives the specifier of a new regulator a more defined starting point. If, after making an initial selection of a regulator, the regulator is larger than the pipe size, it usually means that an error has been made either in selecting the pipe size or the regulator, or in determining the original parameters (such as pressure or flow) required for regulator selection. In many cases, the outlet piping needs to be larger than the regulator for the regulator to reach full capacity.

End Connection Style

In general, the following end connections are available for the indicated regulator sizes:

- Pipe threads or socket weld: 2-inch (DN 50) and smaller
- Flanged: 1-inch (DN 25) and larger
- Butt weld: 1-inch (DN 25) and larger

Note: Not all end connections are available for all regulators.

Required Materials

The regulator construction materials are generally dictated by the application. Standard materials are:

- Aluminum
- Cast iron or Ductile iron
- Steel
- Bronze and Brass
- Stainless steel

Special materials required by the process can have an effect on the type of regulator that can be used. Oxygen service, for example, requires special materials, requires special cleaning preparation, and requires that no oil or grease be in the regulator.

Control Lines

For pressure registration, control lines are connected downstream of a pressure reducing regulator, and upstream of a backpressure regulator. Typically large direct-operated regulators have external control lines, and small direct-operated regulators have internal registration instead of a control line. Most pilot-operated regulators have external control lines, but this should be confirmed for each regulator type considered.

Stroking Speed

Stroking speed is often an important selection criteria. Direct-operated regulators are very fast, and pilot-operated regulators are slightly slower. Both types are faster than most control valves. When speed is critical, techniques can be used to decrease stroking time.

Overpressure Protection

The need for overpressure protection should always be considered. Overpressure protection is generally provided by an external relief valve, or in some regulators, by an internal relief valve. Internal relief is an option that you must choose at the time of purchase. The capacity of internal relief is usually limited in comparison with a separate relief valve. Other methods such as shutoff valves or monitor regulators can also be used.

Regulator Replacement

When a regulator is being selected to replace an existing regulator, the existing regulator can provide the following information:

- Style of regulator
- Size of regulator
- Type number of the regulator
- Special requirements for the regulator, such as downstream pressure sensing through a control line versus internal pressure registration.

Introduction to Regulators

Regulator Price

The price of a regulator is only a part of the cost of ownership. Additional costs include installation and maintenance. In selecting a regulator, you should consider all of the costs that will accrue over the life of the regulator. The regulator with a low initial cost might not be the most economical in the long run. For example, a direct-operated regulator is generally less expensive, but a pilot-operated regulator might provide more capacity for the initial investment. To illustrate, a 2-inch (DN 50) pilot-operated regulator can have the same capacity and a lower price than a 3-inch (DN 80), direct-operated regulator.

Backpressure Regulator Selection

Backpressure regulators control the inlet pressure rather than the outlet pressure. The selection criteria for a backpressure regulator the same as for a pressure reducing regulator.

Relief Valve Selection

An external relief valve is a form of backpressure regulator. A relief valve opens when the inlet pressure exceeds a set value. Relief is generally to atmosphere. The selection criteria is the same as for a pressure reducing regulator.

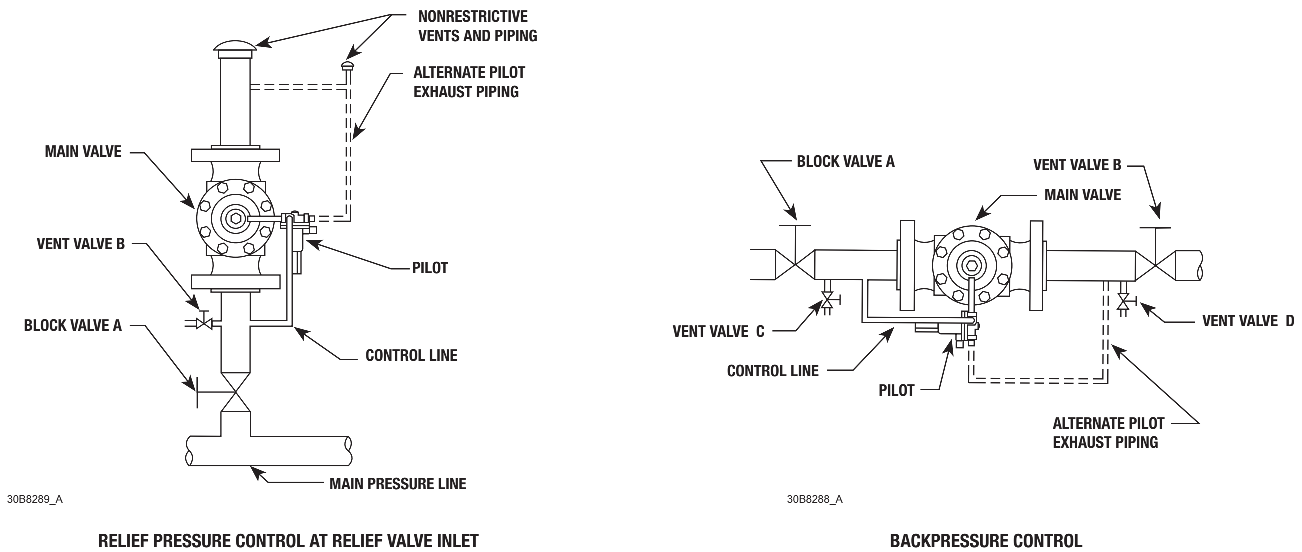


Figure 5. *Backpressure Regulator/Relief Valve Applications*

Principles of Direct-Operated Regulators

Introduction

Pressure regulators have become very familiar items over the years, and nearly everyone has grown accustomed to seeing them in factories, public buildings, by the roadside, and even on the outside of their own homes. As is frequently the case with such familiar items, we have a tendency to take them for granted. It's only when a problem develops, or when we are selecting a regulator for a new application, that we need to look more deeply into the fundamentals of the regulator's operation.

Regulators provide a means of controlling the flow of a gas or other fluid supply to downstream processes or customers. An ideal regulator would supply downstream demand while keeping downstream pressure constant; however, the mechanics of direct-operated regulator construction are such that there will always be some deviation (droop or offset) in downstream pressure.

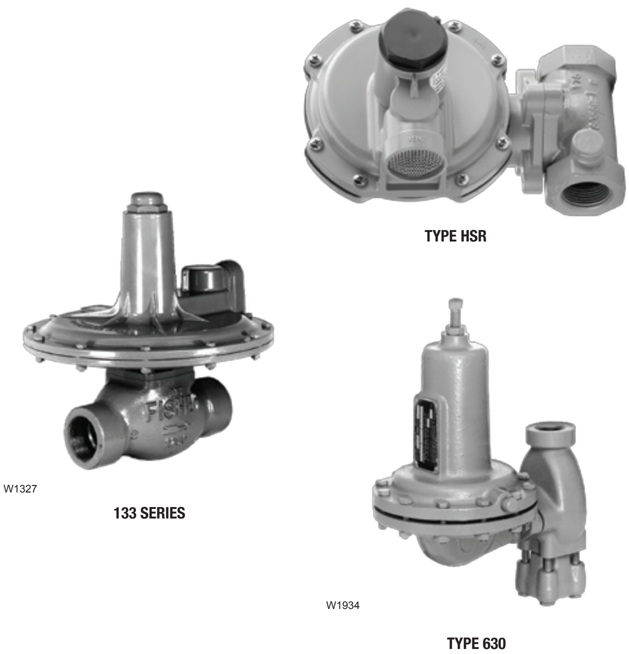


Figure 1. Direct-Operated Regulators

Regulator Basics

A pressure reducing regulator must satisfy a downstream demand while maintaining the system pressure within certain acceptable limits. When the flow rate is low, the regulator plug or disk approaches its seat and restricts the flow. When demand increases, the plug or disk moves away from its seat, creating a larger opening and increased flow. Ideally, a regulator should provide a constant downstream pressure while delivering the required flow.

The service regulator mounted on the meter outside virtually every home serves as an example. As appliances such as a furnace or stove call for the flow of more gas, the service regulator responds by delivering the required flow. As this happens, the pressure should be held constant. This is important because the gas meter, which is the cash register of the system, is often calibrated for a given pressure.

Direct-operated regulators have many commercial and residential uses. Typical applications include industrial, commercial, and domestic gas service, instrument air supply, and a broad range of applications in industrial processes.

Regulators automatically adjust flow to meet downstream demand. Before regulators were invented, someone had to watch a pressure gauge for pressure drops which signaled an increase in downstream demand. When the downstream pressure decreased, more flow was required. The operator then opened the regulating valve until the gauge pressure increased, showing that downstream demand was being met.

Essential Elements

Direct-operated regulators have three essential elements:

- A restricting element— a valve, disk, or plug
- A measuring element— generally a diaphragm
- A loading element— generally a spring

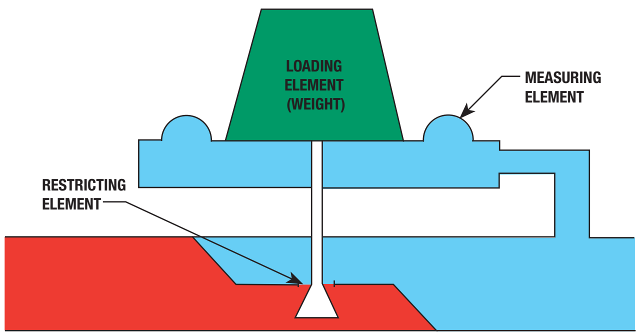


Figure 2. Three Essential Elements

Principles of Direct-Operated Regulators

Restricting Element

The regulator's restricting element is generally a disk or plug that can be positioned fully open, fully closed, or somewhere in between to control the amount of flow. When fully closed, the disk or plug seats tightly against the valve orifice or seat ring to shutoff flow.

Measuring Element

The measuring element is usually a flexible diaphragm that senses downstream pressure (P_2). The diaphragm moves as pressure beneath it changes. The restricting element is often attached to the diaphragm with a stem so that when the diaphragm moves, so does the restricting element.

Loading Element

A weight or spring acts as the loading element. The loading element counterbalances downstream pressure (P_2). The amount of unbalance between the loading element and the measuring element determines the position of the restricting element. Therefore, we can adjust the desired amount of flow through the regulator, or setpoint, by varying the load. Some of the first direct-operated regulators used weights as loading elements. Most modern regulators use springs.

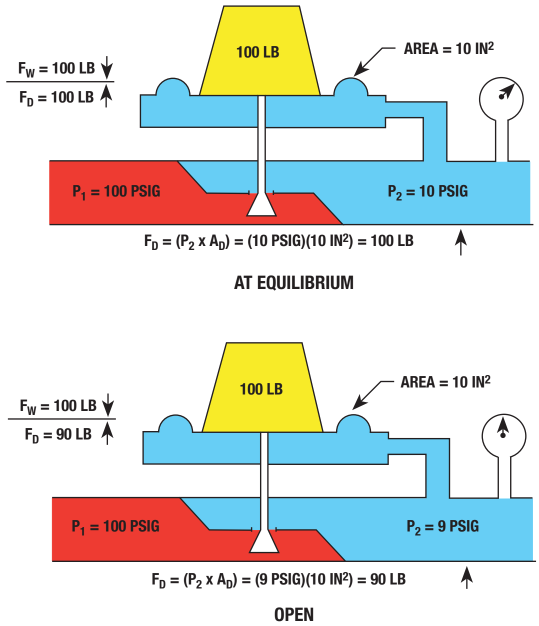


Figure 3. *Elements*

Regulator Operation

To examine how the regulator works, let's consider these values for a direct-operated regulator installation:

- Upstream Pressure (P_1) = 100 psig
- Downstream Pressure (P_2) = 10 psig
- Pressure Drop Across the Regulator (P) = 90 psi
- Diaphragm Area (A_D) = 10 square inches
- Loading Weight = 100 pounds

Let's examine a regulator in equilibrium as shown in Figure 3. The pressure acting against the diaphragm creates a force acting up to 100 pounds.

Diaphragm Force (F_D) = Pressure (P_2) x Area of Diaphragm (A_D)
or
F_D = 10 psig x 10 square inches = 100 pounds

The 100 pounds weight acts down with a force of 100 pounds, so all the opposing forces are equal, and the regulator plug remains stationary.

Increasing Demand

If the downstream demand increases, P_2 will drop. The pressure on the diaphragm drops, allowing the regulator to open further. Suppose in our example P_2 drops to 9 psig. The force acting up then equals 90 pounds (9 psig x 10 square inches = 90 pounds). Because of the unbalance of the measuring element and the loading element, the restricting element will move to allow passage of more flow.

Decreasing Demand

If the downstream demand for flow decreases, downstream pressure increases. In our example, suppose P_2 increases to 11 psig. The force acting up against the weight becomes 110 pounds (11 psig x 10 square inches = 110 pounds). In this case, unbalance causes the restricting element to move up to pass less flow or lockup.

Weights versus Springs

One of the problems with weight-loaded systems is that they are slow to respond. So if downstream pressure changes rapidly, our weight-loaded regulator may not be able to keep up. Always behind, it may become unstable and cycle—continuously going from the fully open to the fully closed position. There are other problems. Because the amount of weight controls regulator setpoint, the regulator is not easy to adjust. The weight will always have to be on top of the diaphragm. So, let's consider using a spring. By using a spring instead of a weight, regulator stability increases because a spring has less stiffness.

Principles of Direct-Operated Regulators

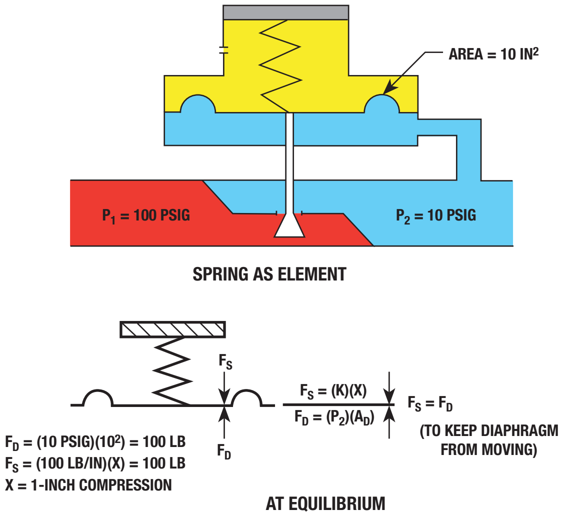


Figure 4. *Spring as Element*

Spring Rate

We choose a spring for a regulator by its spring rate (K). K represents the amount of force necessary to compress the spring one inch. For example, a spring with a rate of 100 pounds per inch needs 100 pounds of force to compress it one inch, 200 pounds of force to compress it two inches, and so on.

Equilibrium with a Spring

Instead of a weight, let's substitute a spring with a rate of 100 pounds per inch. And, with the regulator's spring adjustor, we'll wind in one inch of compression to provide a spring force (F_S) of 100 pounds. This amount of compression of the regulator spring determines setpoint, or the downstream pressure that we want to hold constant. By adjusting the initial spring compression, we change the spring loading force, so P_2 will be at a different value in order to balance the spring force.

Now the spring acts down with a force of 100 pounds, and the downstream pressure acts up against the diaphragm producing a force of 100 pounds ($F_D = P_2 \times A_D$). Under these conditions the regulator has achieved equilibrium; that is, the plug or disk is holding a fixed position.

Spring as Loading Element

By using a spring instead of a fixed weight, we gain better control and stability in the regulator. The regulator will now be less likely to go fully open or fully closed for any change in downstream pressure (P_2). In effect, the spring acts like a multitude of different weights.

Throttling Example

Assume we still want to maintain 10 psig downstream. Consider what happens now when downstream demand increases and pressure P_2 drops to 9 psig. The diaphragm force (F_D) acting up is now 90 pounds.

$$\mathbf{F_D = P_2 \text{ x } A_D}$$
$$\mathbf{F_D = 9 \text{ psig x } 10 \text{ in}^2}$$
$$\mathbf{F_D = 90 \text{ pounds}}$$

We can also determine how much the spring will move (extend) which will also tell us how much the disk will travel. To keep the regulator in equilibrium, the spring must produce a force (F_S) equal to the force of the diaphragm. The formula for determining spring force (F_S) is:

$$\mathbf{F_S = (K)(X)}$$

where K = spring rate in pounds/inch and X = travel or compression in inches.

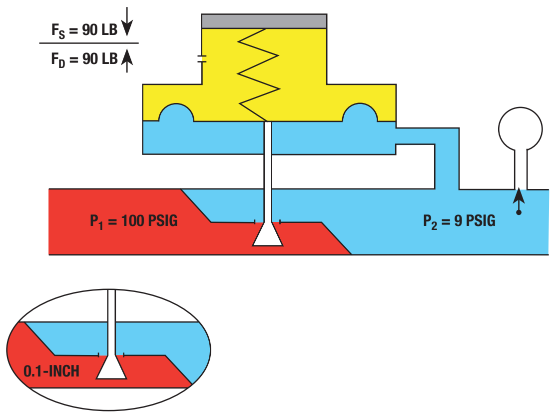
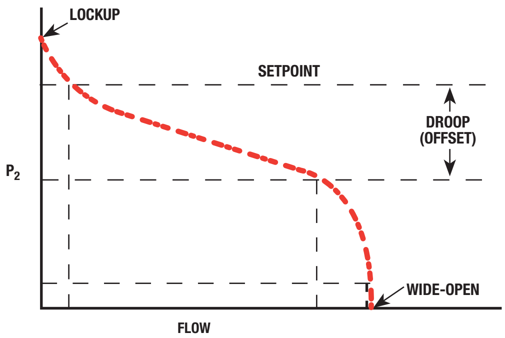


Figure 5. *Plug Travel*

Principles of Direct-Operated Regulators



AS THE FLOW RATE APPROACHES ZERO, P_2 INCREASES STEEPLY. LOCKUP IS THE TERM APPLIED TO THE VALUE OF P_2 AT ZERO FLOW.

Figure 6. *Typical Performance Curve*

We know F_S is 90 pounds and K is 100 pounds/inch, so we can solve for X with:

$X = F_S \div K$
X = 90 pounds ÷ 100 pounds/inch
X = 0.9 inch

The spring, and therefore the disk, has moved down 1/10-inch, allowing more flow to pass through the regulator body.

Regulator Operation and P_2

Now we see the irony in this regulator design. We recall that the purpose of an ideal regulator is to match downstream demand while keeping P_2 constant. But for this regulator design to increase flow, there must be a change in P_2.

Regulator Performance

We can check the performance of any regulating system by examining its characteristics. Most of these characteristics can be best described using pressure versus flow curves as shown in Figure 6.

Performance Criteria

We can plot the performance of an ideal regulator such that no matter how the demand changes, our regulator will match that demand (within its capacity limits) with no change in the downstream pressure (P_2). This straight line performance becomes the standard against which we can measure the performance of a real regulator.

Setpoint

The constant pressure desired is represented by the setpoint. But no regulator is ideal. The downward sloping line on the diagram represents pressure (P_2) plotted as a function of flow for an actual direct-operated regulator. The setpoint is determined by the initial compression of the regulator spring. By adjusting the initial spring compression you change the spring loading force, so P_2 will be at a different value in order to balance the spring force. This establishes setpoint.

Droop

Droop, proportional band, and offset are terms used to describe the phenomenon of P_2 dropping below setpoint as flow increases. Droop is the amount of deviation from setpoint at a given flow, expressed as a percentage of setpoint. This “droop” curve is important to a user because it indicates regulating (useful) capacity.

Capacity

Capacities published by regulator manufacturers are given for different amounts of droop. Let’s see why this is important.

Let’s say that for our original problem, with the regulator set at 10 psig, our process requires 200 SCFH (standard cubic feet per hour) with no more than a 1 psi drop in setpoint. We need to keep the pressure at or above 9 psig because we have a low limit safety switch set at 9 psig that will shut the system down if pressure falls below this point.

Figure 6 illustrates the performance of a regulator that can do the job. And, if we can allow the downstream pressure to drop below 9 psig, the regulator can allow even more flow.

The capacities of a regulator published by manufacturers are generally given for 10% droop and 20% droop. In our example, this would relate to flow at 9 psig and at 8 psig.

Accuracy

The accuracy of a regulator is determined by the amount of flow it can pass for a given amount of droop. The closer the regulator is to the ideal regulator curve (setpoint), the more accurate it is.

Lockup

Lockup is the pressure above setpoint that is required to shut the regulator off tight. In many regulators, the orifice has a knife edge while the disk is a soft material. Some extra pressure, P_2, is

Principles of Direct-Operated Regulators

required to force the soft disk into the knife edge to make a tight seal. The amount of extra pressure required is lockup pressure. Lockup pressure may be important for a number of reasons. Consider the example above where a low pressure limit switch would shut down the system if P_2 fell below 9 psig. Now consider the same system with a high pressure safety cut out switch set a 10.5 psig. Because our regulator has a lockup pressure of 11 psig, the high limit switch will shut the system down before the regulator can establish tight shutoff. Obviously, we'll want to select a regulator with a lower lockup pressure.

Spring Rate and Regulator Accuracy

Using our initial problem as an example, let's say we now need the regulator to flow 300 SCFH at a droop of 10% from our original setpoint of 10 psig. Ten percent of 10 psig = 1 psig, so P_2 cannot drop below 10 to 1, or 9 psi. Our present regulator would not be accurate enough. For our regulator to pass 300 SCFH, P_2 will have to drop to 8 psig, or 20% droop.

Spring Rate and Droop

One way to make our regulator more accurate is to change to a lighter spring rate. To see how spring rate affects regulator accuracy, let's return to our original example. We first tried a spring with a rate of 100 pounds/inch. Let's substitute one with a rate of 50 pounds/inch. To keep the regulator in equilibrium, we'll have to initially adjust the spring to balance the 100 pound force produced by P_2 acting on the diaphragm. Recall how we calculate spring force:

$$\mathbf{F_S = K\ (spring\ rate)\ x\ X\ (compression)}$$

Knowing that F_S must equal 100 pounds and K = 50 pounds/inch, we can solve for X, or spring compression, with:

$$\mathbf{X = F_S \div K,\ or\ X = 2\ inches}$$

So, we must wind in 2-inches of initial spring compression to balance diaphragm force, F_D.

Effect on Plug Travel

We saw before that with a spring rate of 100 pounds/inch, when P_2 dropped from 10 to 9 psig, the spring relaxed (and the valve disk traveled) 0.1 inch. Now let's solve for the amount of disk travel with the lighter spring rate of 50 pounds per inch. The force produced by the diaphragm is still 90 pounds.

$$\mathbf{F_D = P_2\ x\ A_D}$$

To maintain equilibrium, the spring must also produce a force of 90 pounds. Recall the formula that determines spring force:

$$\mathbf{F_S = (K)(X)}$$

Because we know FS must equal 90 pounds and our spring rate (K) is 50 pounds/inch, we can solve for compression (X) with:

$$\mathbf{X = F_S \div K}$$
$$\mathbf{X = 90\ pounds \div 50\ pounds/inch}$$
$$\mathbf{X = 1.8\ inches}$$

To establish setpoint, we originally compressed this spring 2 inches. Now it has relaxed so that it is only compressed 1.8 inches, a change of 0.2-inch. So with a spring rate of 50 pounds/inch, the regulator responded to a 1 psig drop in P_2 by opening twice as far as it did with a spring rate of 100 pounds/inch. Therefore, our regulator is now more accurate because it has greater capacity for the same change in P_2. In other words, it has less droop or offset. Using this example, it is easy to see how capacity and accuracy are related and how they are related to spring rate.

Light Spring Rate

Experience has shown that choosing the lightest available spring rate will provide the most accuracy (least droop). For example, a spring with a range of 35 to 100 psig is more accurate than a spring with a range of 90 to 200 psig. If you want to set your regulator at 100 psig, the 35 to 100 psig spring will provide better accuracy.

Practical Limits

While a lighter spring can reduce droop and improve accuracy, using too light a spring can cause instability problems. Fortunately, most of the work in spring selection is done by regulator manufacturers. They determine spring rates that will provide good performance for a given regulator, and publish these rates along with other sizing information.

Diaphragm Area and Regulator Accuracy

Diaphragm Area

Until this point, we have assumed the diaphragm area to be constant. In practice, the diaphragm area changes with travel. We're interested in this changing area because it has a major influence on accuracy and droop.

Diaphragms have convolutions in them so that they are flexible enough to move over a rated travel range. As they change position,

Principles of Direct-Operated Regulators

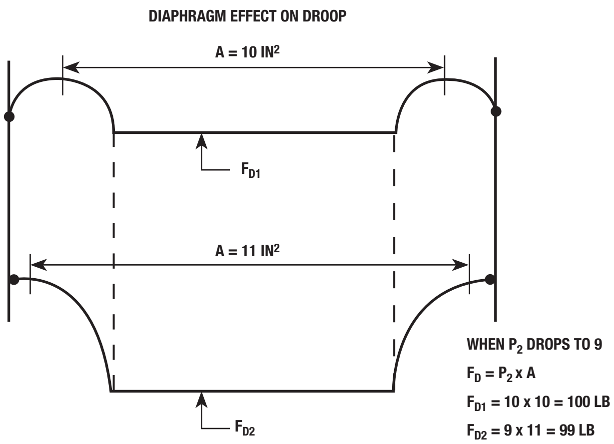


Figure 7. *Changing Diaphragm Area*

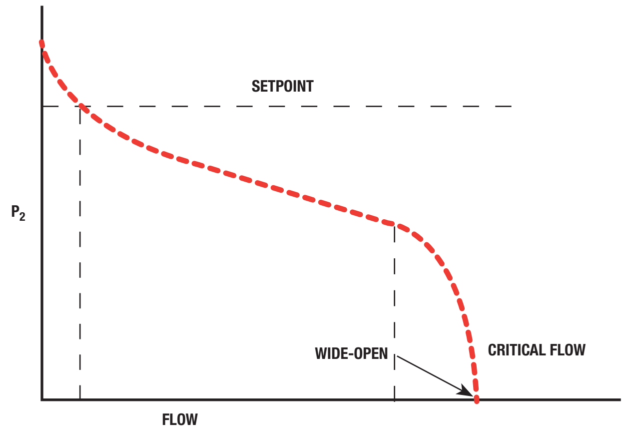


Figure 8. *Critical Flow*

they also change shape because of the pressure applied to them. Consider the example shown in Figure 7. As downstream pressure (P_2) drops, the diaphragm moves down. As it moves down, it changes shape and diaphragm area increases because the centers of the convolutions become further apart. The larger diaphragm area magnifies the effect of P_2 so even less P_2 is required to hold the diaphragm in place. This is called diaphragm effect. The result is decreased accuracy because incremental changes in P_2 do not result in corresponding changes in spring compression or disk position.

Increasing Diaphragm Area

To better understand the effects of changing diaphragm area, let's calculate the forces in the exaggerated example given in Figure 7. First, assume that the regulator is in equilibrium with a downstream pressure P_2 of 10 psig. Also assume that the area of the diaphragm in this position is 10 square inches. The diaphragm force (F_D) is:

$F_D = (P_2)(A_D)$
F_D = (10 psi) (10 square inches)
F_D = 100 pounds

Now assume that downstream pressure drops to 9 psig signaling the need for increased flow. As the diaphragm moves, its area increases to 11 square inches. The diaphragm force now produced is:

F_D = (9 psi) (11 square inches)
F_D = 99 pounds

The change in diaphragm area increases the regulator's droop. While it's important to note that diaphragm effect contributes to droop, diaphragm sizes are generally determined by manufacturers for different regulator types, so there is rarely a user option.

Diaphragm Size and Sensitivity

Also of interest is the fact that increasing diaphragm size can result in increased sensitivity. A larger diaphragm area will produce more force for a given change in P_2. Therefore, larger diaphragms are often used when measuring small changes in low-pressure applications. Service regulators used in domestic gas service are an example.

Restricting Element and Regulator Performance

Critical Flow

Although changing the orifice size can increase capacity, a regulator can pass only so much flow for a given orifice size and inlet pressure, no matter how much we improve the unit's accuracy. Shown in Figure 8, after the regulator is wide-open, reducing P_2 does not result in higher flow. This area of the flow curve identifies critical flow. To increase the amount of flow through the regulator, the flowing fluid must pass at higher and higher velocities. But, the fluid can only go so fast. Holding P_1 constant while decreasing P_2, flow approaches a maximum which is the speed of sound in that particular gas, or its sonic velocity. Sonic velocity depends on the inlet pressure and temperature for the flowing fluid. Critical flow is generally anticipated when downstream pressure (P_2) approaches a value that is less than or equal to one-half of inlet pressure (P_1).

Principles of Direct-Operated Regulators

Orifice Size and Capacity

One way to increase capacity is to increase the size of the orifice. The variable flow area between disk and orifice depends directly on orifice diameter. Therefore, the disk will not have to travel as far with a larger orifice to establish the required regulator flow rate, and droop is reduced. Sonic velocity is still a limiting factor, but the flow rate at sonic velocity is greater because more gas is passing through the larger orifice.

Stated another way, a given change in P_2 will produce a larger change in flow rate with a larger orifice than it would with a smaller orifice. However, there are definite limits to the size of orifice that can be used. Too large an orifice makes the regulator more sensitive to fluctuating inlet pressures. If the regulator is overly sensitive, it will have a tendency to become unstable and cycle.

Orifice Size and Stability

One condition that results from an oversized orifice is known as the "bathtub stopper" effect. As the disk gets very close to the orifice, the forces of fluid flow tend to slam the disk into the orifice and shutoff flow. Downstream pressure drops and the disk opens. This causes the regulator to cycle—open, closed, open, closed. By selecting a smaller orifice, the disk will operate farther away from the orifice so the regulator will be more stable.

Orifice Size, Lockup, and Wear

A larger orifice size also requires a higher shutoff pressure, or lockup pressure. In addition, an oversized orifice usually produces faster wear on the valve disk and orifice because it controls flow with the disk near the seat. This wear is accelerated with high flow rates and when there is dirt or other erosive material in the flow stream.

Orifice Guideline

Experience indicates that using the smallest possible orifice is generally the best rule-of-thumb for proper control and stability.

Increasing P_1

Regulator capacity can be increased by increasing inlet pressure (P_1).

Factors Affecting Regulator Accuracy

As we have seen, the design elements of a regulator—the spring, diaphragm, and orifice size—can affect its accuracy. Some of these inherent limits can be overcome with changes to the regulator design.

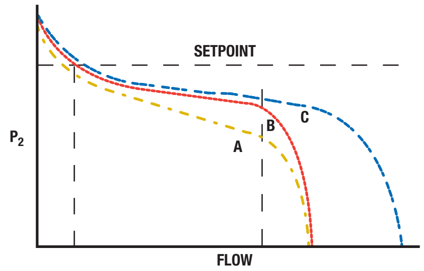


Figure 9. *Increased Sensitivity*

Performance Limits

The three curves in Figure 9 summarize the effects of spring rate, diaphragm area, and orifice size on the shape of the controlled pressure-flow rate curve. Curve A is a reference curve representing a typical regulator. Curve B represents the improved performance from either increasing diaphragm area or decreasing spring rate. Curve C represents the effect of increasing orifice size. Note that increased orifice size also offers higher flow capabilities. But remember that too large an orifice size can produce problems that will negate any gains in capacity.

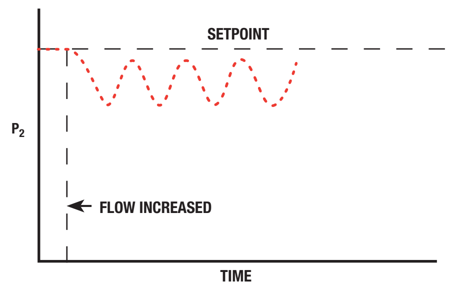


Figure 10. *Cycling*

Cycling

The sine wave in Figure 10 might be what we see if we increase regulator sensitivity beyond certain limits. The sine wave indicates instability and cycling.

Design Variations

All direct-operated regulators have performance limits that result from droop. Some regulators are available with features designed to overcome or minimize these limits.

Principles of Direct-Operated Regulators

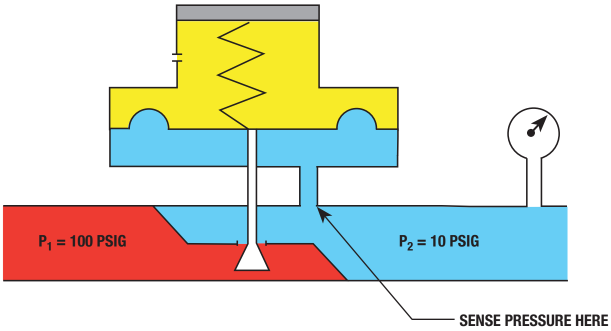


Figure 11. *Pitot Tube*

Improving Regulator Accuracy with a Pitot Tube

In addition to the changes we can make to diaphragm area, spring rate, orifice size, and inlet pressure, we can also improve regulator accuracy by adding a pitot tube as shown in Figure 11. Internal to the regulator, the pitot tube connects the diaphragm casing with a low-pressure, high velocity region within the regulator body. The pressure at this area will be lower than P_2 further downstream. By using a pitot tube to measure the lower pressure, the regulator will make more dramatic changes in response to any change in P_2. In other words, the pitot tube tricks the regulator, causing it to respond more than it would otherwise.

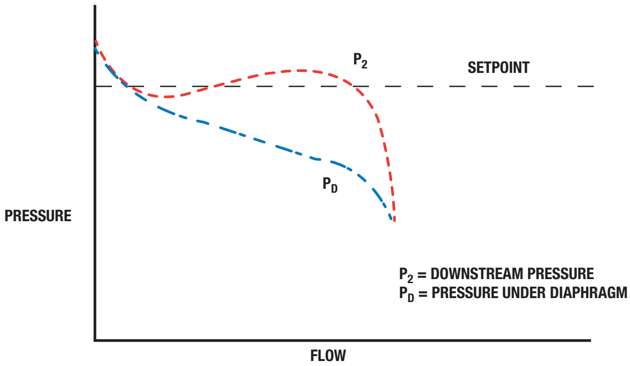


Figure 12. *Performance with Pitot Tube*

Numerical Example

For example, we'll establish setpoint by placing a gauge downstream and adjusting spring compression until the gauge reads 10 psig for P_2. Because of the pitot tube, the regulator might actually be sensing a lower pressure. When P_2 drops from 10 psig to 9 psig, the pressure sensed by the pitot tube may drop from 8 psig to 6 psig. Therefore, the regulator opens further than it would if it were sensing actual downstream pressure.

Decreased Droop (Boost)

The pitot tube offers one chief advantage for regulator accuracy, it decreases droop. Shown in Figure 12, the diaphragm pressure, P_D, must drop just as low with a pitot tube as without to move the disk far enough to supply the required flow. But the solid curve shows that P_2 does not decrease as much as it did without a pitot tube. In fact, P_2 may increase. This is called boost instead of droop. So the use of a pitot tube, or similar device, can dramatically improve droop characteristics of a regulator.

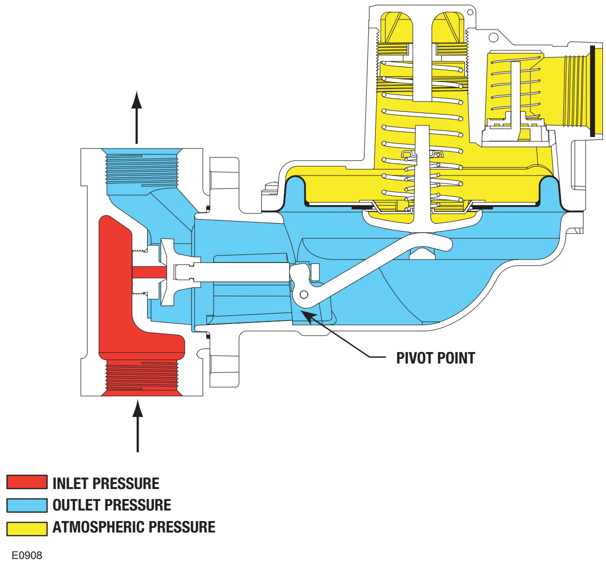


Figure 13. *Lever Style Regulator*

Improving Performance with a Lever

The lever style regulator is a variation of the simple direct-operated regulator. It operates in the same manner, except that it uses a lever to gain mechanical advantage and provide a high shutoff force.

In earlier discussions, we noted that the use of a larger diaphragm can result in increased sensitivity. This is because any change in P_2 will result in a larger change in diaphragm force. The same result is obtained by using a lever to multiply the force produced by the diaphragm as shown in Figure 13.

The main advantage of lever designs is that they provide increased force for lockup without the extra cost, size, and weight associated with larger diaphragms, diaphragm casings, and associated parts.

Principles of Pilot-Operated Regulators

Pilot-Operated Regulator Basics

In the evolution of pressure regulator designs, the shortcomings of the direct-operated regulator naturally led to attempts to improve accuracy and capacity. A logical next step in regulator design is to use what we know about regulator operation to explore a method of increasing sensitivity that will improve all of the performance criteria discussed.

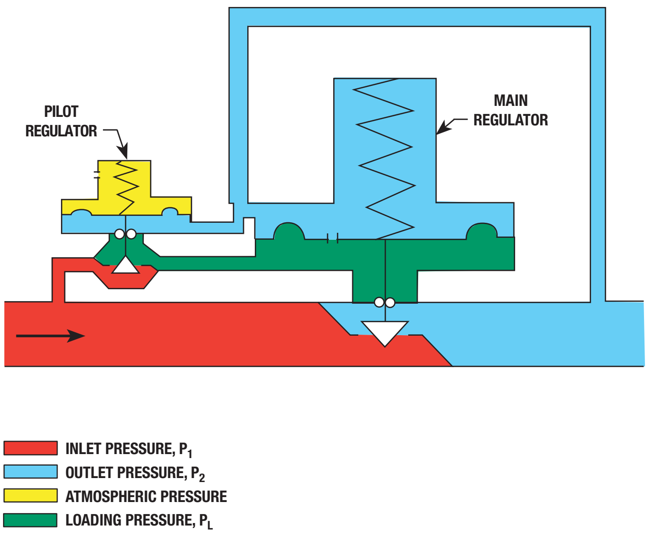


Figure 1. *Pilot-Operated Regulator*

Regulator Pilots

To improve the sensitivity of our regulator, we would like to be able to sense P_2 and then somehow make a change in loading pressure (P_L) that is greater than the change in P_2. To accomplish this, we can use a device called a pilot, or pressure amplifier.

The major function of the pilot is to increase regulator sensitivity. If we can sense a change in P_2 and translate it into a larger change in P_L, our regulator will be more responsive (sensitive) to changes in demand. In addition, we can significantly reduce droop so its effect on accuracy and capacity is minimized.

Gain

The amount of amplification supplied by the pilot is called “gain”. To illustrate, a pilot with a gain of 20 will multiply the effect of a 1 psi change on the main diaphragm by 20. For example, a decrease in P_2 opens the pilot to increase P_L 20 times as much.

Identifying Pilots

Analysis of pilot-operated regulators can be simplified by viewing them as two independent regulators connected together. The smaller of the two is generally the pilot.

Setpoint

We may think of the pilot as the “brains” of the system. Setpoint and many performance variables are determined by the pilot. It senses P_2 directly and will continue to make changes in P_L on the main regulator until the system is in equilibrium. The main regulator is the “muscle” of the system, and may be used to control large flows and pressures.

Spring Action

Notice that the pilot uses a spring-open action as found in direct-operated regulators. The main regulator, shown in Figure 1, uses a spring-close action. The spring, rather than loading pressure, is used to achieve shutoff. Increasing P_L from the pilot onto the main diaphragm opens the main regulator.

Pilot Advantage

Because the pilot is the controlling device, many of the performance criteria we have discussed apply to the pilot. For example, droop is determined mainly by the pilot. By using very small pilot orifices and light springs, droop can be made small. Because of reduced droop, we will have greater usable capacity. Pilot lockup determines the lockup characteristics for the system. The main regulator spring provides tight shutoff whenever the pilot is locked up.

Gain and Restrictions

Stability

Although increased gain (sensitivity) is often considered an advantage, it also increases the gain of the entire pressure regulator system. If the system gain is too high, it may become unstable. In other words, the regulator might tend to oscillate; over-reacting by continuously opening and closing. Pilot gain can be modified to tune the regulator to the system. To provide a means for changing gain, every pilot-operated regulator system contains both a fixed and a variable restriction. The relative size of one restriction compared to the other can be varied to change gain and speed of response.

Principles of Pilot-Operated Regulators

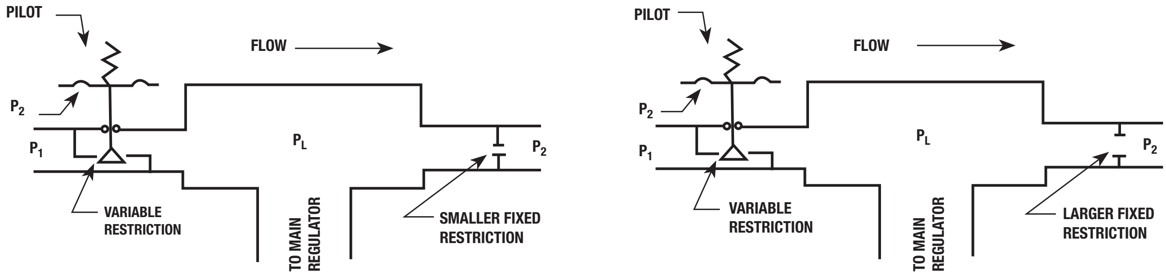


Figure 2. *Fixed Restrictions and Gain (Used on Two-Path Control Systems)*

Restrictions, Response Time, and Gain

Consider the example shown in Figure 2 with a small fixed restriction. Decreasing P_2 will result in pressure P_L increasing. Increasing P_2 will result in a decrease in P_L while P_L bleeds out through the small fixed restriction.

If a larger fixed restriction is used with a variable restriction, the gain (sensitivity) is reduced. A larger decrease in P_2 is required to increase P_L to the desired level because of the larger fixed restriction.

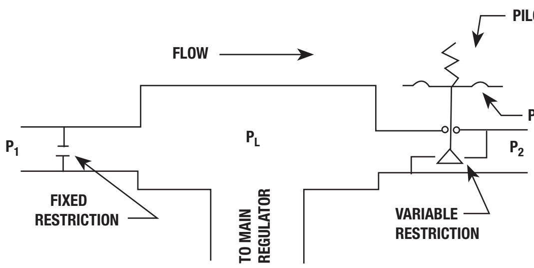


Figure 3. *Unloading Systems*

Loading and Unloading Designs

A loading pilot-operated design (Figure 2), also called two-path control, is so named because the action of the pilot loads P_L onto the main regulator measuring element. The variable restriction, or pilot orifice, opens to increase P_L.

An unloading pilot-operated design (Figure 3) is so named because the action of the pilot unloads P_L from the main regulator.

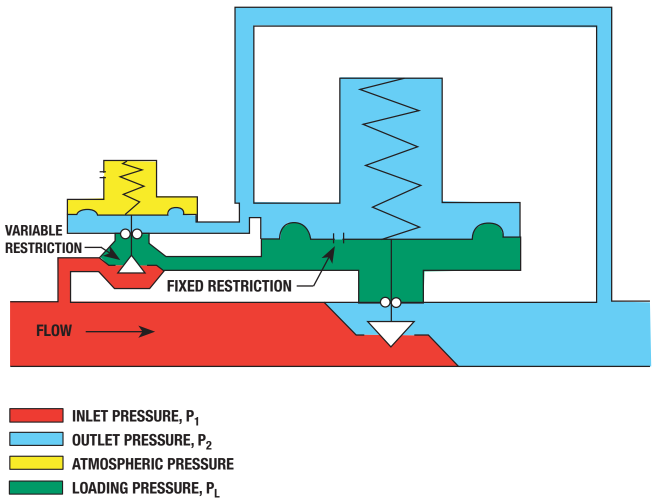


Figure 4. *Two-Path Control*

Two-Path Control (Loading Design)

In two-path control systems (Figure 4), the pilot is piped so that P_2 is registered on the pilot diaphragm and on the main regulator diaphragm at the same time. When downstream demand is constant, P_2 positions the pilot diaphragm so that flow through the pilot will keep P_2 and P_L on the main regulator diaphragm. When P_2 changes, the force on top of the main regulator diaphragm and on the bottom of the pilot diaphragm changes. As P_2 acts on the main diaphragm, it begins repositioning the main valve plug. This immediate reaction to changes in P_2 tends to make two-path designs faster than other pilot-operated regulators. Simultaneously, P_2 acting on the pilot diaphragm repositions the pilot valve and

Principles of Pilot-Operated Regulators

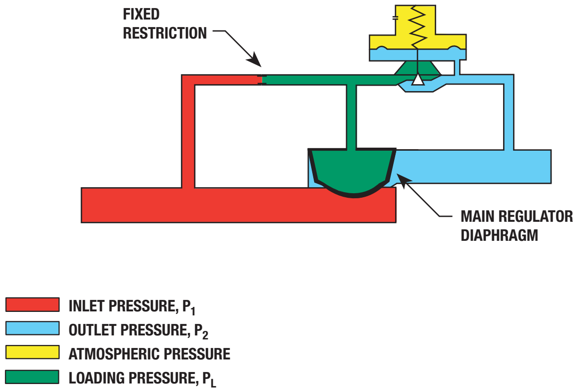


Figure 5. *Unloading Control*

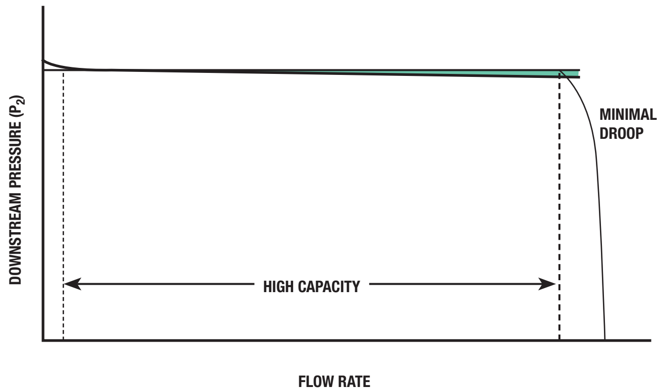


Figure 6. *Pilot-Operated Regulator Performance*

changes P_L on the main regulator diaphragm. This adjustment to P_L accurately positions the main regulator valve plug. P_L on the main regulator diaphragm bleeds through a fixed restriction until the forces on both sides are in equilibrium. At that point, flow through the regulator valve matches the downstream demand.

Two-Path Control Advantages

The primary advantages of two-path control are speed and accuracy. These systems may limit droop to less than 1%. They are well suited to systems with requirements for high accuracy, large capacity, and a wide range of pressures.

Unloading Control

Unloading systems (Figure 5) locate the pilot so that P_2 acts only on the pilot diaphragm. P_1 constantly loads under the regulator diaphragm and has access to the top of the diaphragm through a fixed restriction.

When downstream demand is constant, the pilot valve is open enough that P_L holds the position of the main regulator diaphragm. When downstream demand changes, P_2 changes and the pilot diaphragm reacts accordingly. The pilot valve adjusts P_L to reposition and hold the main regulator diaphragm.

Unloading Control Advantages

Unloading systems are not quite as fast as two-path systems, and they can require higher differential pressures to operate. However, they are simple and more economical, especially in large regulators. Unloading control is used with popular elastomer diaphragm style regulators. These regulators use a flexible membrane to throttle flow.

Performance Summary

Accuracy

Because of their high gain, pilot-operated regulators are extremely accurate. Droop for a direct-operated regulator might be in the range of 10 to 20 % whereas pilot-operated regulators are between one and 3% with values under 1% possible.

Capacity

Pilot-operated designs provide high capacity for two reasons. First, we have shown that capacity is related to droop. And because droop can be made very small by using a pilot, capacity is increased. In addition, the pilot becomes the “brains” of the system and controls a larger, sometimes much larger, main regulator. This also allows increased flow capabilities.

Principles of Pilot-Operated Regulators

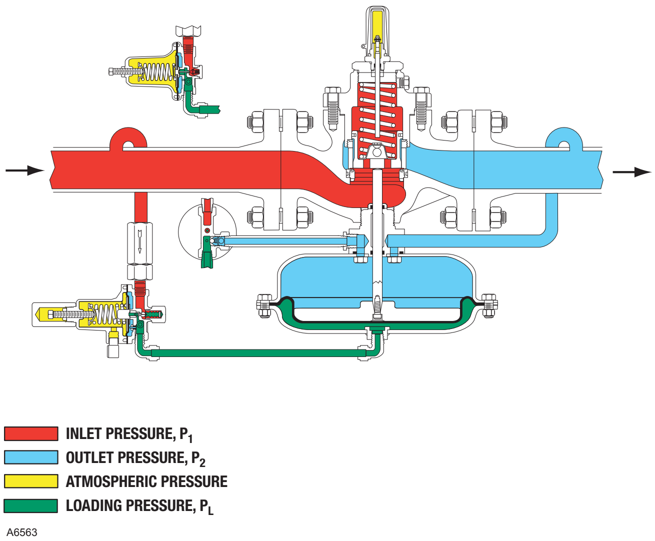


Figure 7. *Type 1098-EGR, Typical Two-Path Control*

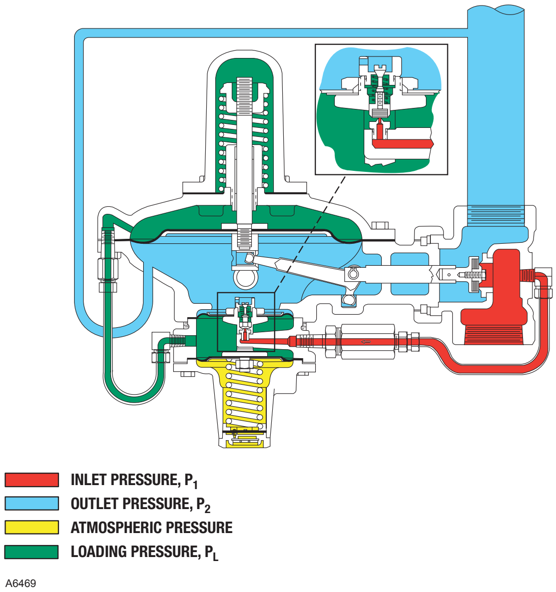


Figure 8. *Type 99, Typical Two-Path Control with Integrally Mounted Pilot*

Lockup

The lockup characteristics for a pilot-operated regulator are the lockup characteristics of the pilot. Therefore, with small orifices, lockup pressures can be small.

Applications

Pilot-operated regulators should be considered whenever accuracy, capacity, and/or high pressure are important selection criteria. They can often be applied to high capacity services with greater economy than a control valve and actuator with controller.

Two-Path Control

In some designs (Figure 7), the pilot and main regulator are separate components. In others (Figure 8), the system is integrated into a single package. All, however, follow the basic design concepts discussed earlier.

Type 1098-EGR

The schematic in Figure 7 illustrates the Type 1098-EGR regulator's operation. It can be viewed as a model for all two-path, pilot-operated regulators. The pilot is simply a sensitive direct-operated regulator used to send loading pressure to the main regulator diaphragm.

Identify the inlet pressure (P_1). Find the downstream pressure (P_2). Follow it to where it opposes the loading pressure on the main regulator diaphragm. Then, trace P_2 back to where it opposes the control spring in the pilot. Finally, locate the route of P_2 between the pilot and the regulator diaphragm.

Changes in P_2 register on the pilot and main regulator diaphragms at the same time. As P_2 acts on the main diaphragm, it begins repositioning the main valve plug. Simultaneously, P_2 acting on the pilot diaphragm repositions the pilot valve and changes P_L on the main regulator diaphragm. This adjustment in P_L accurately positions the main regulator valve plug.

Principles of Pilot-Operated Regulators

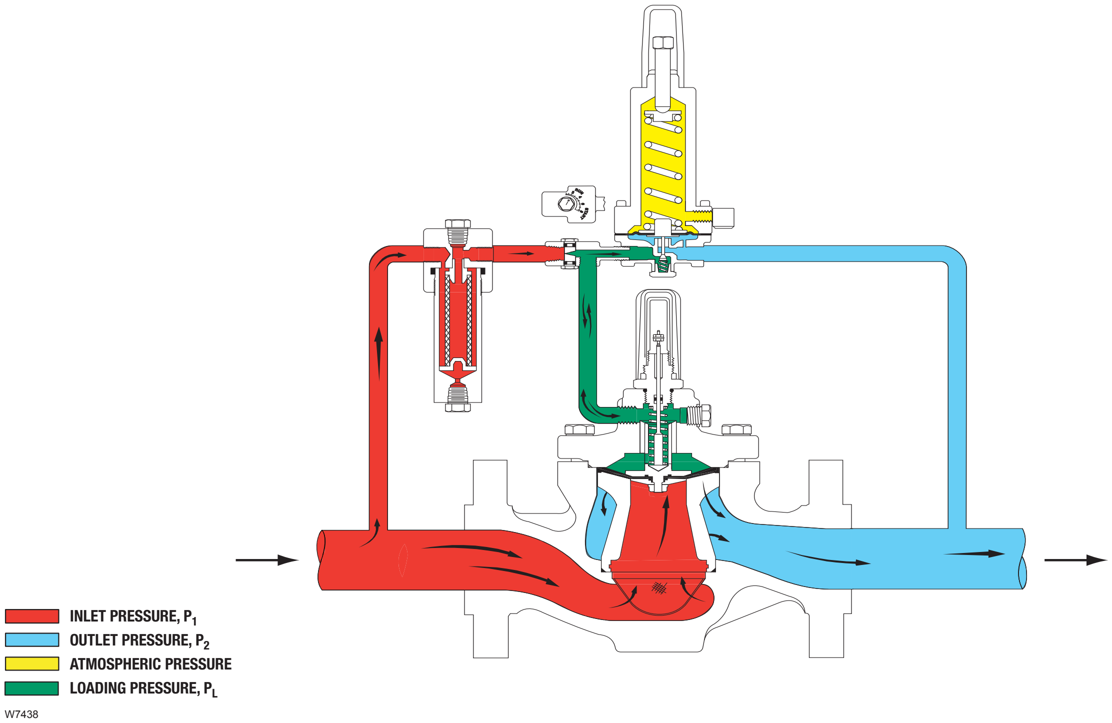


Figure 9. *Type EZR, Unloading Design*

As downstream demand is met, P_2 rises. Because P_2 acts directly on both the pilot and main regulator diaphragms, this design provides fast response.

Type 99

The schematic in Figure 8 illustrates another typical two-path control design, the Type 99. The difference between the Type 1098-EGR and the Type 99 is the integrally mounted pilot of the Type 99.

The pilot diaphragm measures P_2. When P_2 falls below the pilot setpoint, the diaphragm moves away from the pilot orifice and allows loading pressure to increase. This loads the top of the main regulator diaphragm and strokes the main regulator valve open further.

Unloading Design

Unloading designs incorporate a molded composition diaphragm that serves as the combined loading and restricting component of the main regulator. Full upstream pressure (P_1) is used to load the regulator diaphragm when it is seated. The regulator shown in Figure 9 incorporates an elastomeric valve closure member.

Unloading regulator designs are slower than two-path control systems because the pilot must first react to changes in P_2 before the main regulator valve moves. Recall that in two-path designs, the pilot and main regulator diaphragms react simultaneously.

P_1 passes through a fixed restriction and fills the space above the regulator diaphragm. This fixed restriction can be adjusted to increase or decrease regulator gain. P_1 also fills the cavity below the regulator diaphragm. Because the surface area on the top side of the diaphragm is larger than the area exposed to P_1 below, the diaphragm is forced down against the cage to close the regulator.

When downstream demand increases, the pilot opens. When the pilot opens, regulator loading pressure escapes downstream much faster than P_1 can bleed through the fixed restriction. As pressure above the regulator diaphragm decreases, P_1 forces the diaphragm away from its seat.

When downstream demand is reduced, P_2 increases until it's high enough to compress the pilot spring and close the pilot valve. As the pilot valve closes, P_1 continues to pass through the fixed restriction and flows into the area above the main regulator diaphragm. This loading pressure, P_L, forces the diaphragm back toward the cage, reducing flow through the regulator.

Selecting and Sizing Pressure Reducing Regulators

Introduction

Those who are new to the regulator selection and sizing process are often overwhelmed by the sheer number of regulator types available and the seemingly endless lists of specifications in manufacturer's literature. This application guide is designed to assist you in selecting a regulator that fits your application's specific needs.

Although it might seem obvious, the first step is to consider the application itself. Some applications immediately point to a group of regulators designed specifically for that type of service. The Application Guide has sections to help identify regulators that are designed for specific applications. There are Application Maps, Quick Selection Guides, an Applications section, and Product Pages. The Application Map shows some of the common applications and the regulators that are used in those applications. The Quick Selection Guide lists the regulators by application, and provides important selection information about each regulator. The Applications section explains the applications covered in the section and it also explains many of the application considerations. The Product Pages provide specific details about the regulators that are suitable for the applications covered in the section. To begin selecting a regulator, turn to the Quick Selection Guide in the appropriate Applications section.

Quick Selection Guides

Quick Selection Guides identify the regulators with the appropriate pressure ratings, outlet pressure ranges, and capacities. These guides quickly narrow the range of potentially appropriate regulators. The choices identified by using a Quick Selection Guide can be narrowed further by using the Product Pages to find more information about each of the regulators.

Product Pages

Identifying the regulators that can pass the required flow narrows the possible choices further. When evaluating flow requirements, consider the minimum inlet pressure and maximum flow requirements. Again, this worst case combination ensures that the regulator can pass the required flow under all anticipated conditions.

After one or more regulators have been identified as potentially suitable for the service conditions, consult specific Product Pages to check regulator specifications and capabilities. The application requirements are compared to regulator specifications to narrow the range of appropriate selections. The following specifications can be evaluated in the Product Pages:

- Product description and available sizes
- Maximum inlet and outlet pressures (operating and emergency)
- Outlet pressure ranges
- Flow capacity
- End connection styles
- Regulator construction materials
- Accuracy
- Pressure registration (internal or external)
- Temperature capabilities

After comparing the regulator capabilities with the application requirements, the choices can be narrowed to one or a few regulators. Final selection might depend upon other factors including special requirements, availability, price, and individual preference.

Special Requirements

Finally, evaluate any special considerations, such as the need for external control lines, special construction materials, or internal overpressure protection. Although overpressure protection might be considered during sizing and selection, it is not covered in this section.

The Role of Experience

Experience in the form of knowing what has worked in the past, and familiarity with specific products, has great value in regulator sizing and selection. Knowing the regulator performance characteristics required for a specific application simplifies the process. For example, when fast speed of response is required, a direct-operated regulator may come to mind; or a pilot-operated regulator with an auxiliary, large capacity pilot to speed changes in loading pressure.

Sizing Equations

Sizing equations are useful when sizing pilot-operated regulators and relief valves. They can also be used to calculate the wide-open flow of direct-operated regulators. Use the capacity tables or curves in this application guide when sizing direct-operated regulators and relief/backpressure regulators. The sizing equations are in the Valve Sizing Calculations section.

Selecting and Sizing Pressure Reducing Regulators

General Sizing Guidelines

The following are intended to serve only as guidelines when sizing pressure reducing regulators. When sizing any regulator, consult with experienced personnel or the regulator manufacturer for additional guidance and information relating to specific applications.

Body Size

Regulator body size should never be larger than the pipe size. However, a properly sized regulator may be smaller than the pipeline.

Construction

Be certain that the regulator is available in materials that are compatible with the controlled fluid and the temperatures used. Also, be sure that the regulator is available with the desired end connections.

Pressure Ratings

While regulators are sized using minimum inlet pressures to ensure that they can provide full capacity under all conditions, pay particular attention to the maximum inlet and outlet pressure ratings.

Wide-Open Flow Rate

The capacity of a regulator when it has failed wide-open is usually greater than the regulating capacity. For that reason, use the regulating capacities when sizing regulators, and the wide-open flow rates only when sizing relief valves.

Outlet Pressure Ranges and Springs

If two or more available springs have published outlet pressure ranges that include the desired pressure setting, use the spring with the lower range for better accuracy. Also, it is not necessary to attempt to stay in the middle of a spring range, it is acceptable to use the full published outlet pressure range without sacrificing spring performance or life.

Accuracy

Of course, the need for accuracy must be evaluated. Accuracy is generally expressed as droop, or the reduction of outlet pressure experienced as the flow rate increases. It is stated in percent, inches of water column, or pounds per square inch. It indicates the difference between the outlet pressure at low flow rates and the outlet pressure at the published maximum flow rate. Droop is also called offset or proportional band.

Inlet Pressure Losses

The regulator inlet pressure used for sizing should be measured directly at the regulator inlet. Measurements made at any distance upstream from the regulator are suspect because line loss can significantly reduce the actual inlet pressure to the regulator. If the regulator inlet pressure is given as a system pressure upstream, some compensation should be considered. Also, remember that downstream pressure always changes to some extent when inlet pressure changes.

Orifice Diameter

The recommended selection for orifice size is the smallest diameter that will handle the flow. This can benefit operation in several ways: instability and premature wear might be avoided, relief valves may be smaller, and lockup pressures may be reduced.

Speed of Response

Direct-operated regulators generally have faster response to quick flow changes than pilot-operated regulators.

Turn-Down Ratio

Within reasonable limits, most soft-seated regulators can maintain pressure down to zero flow. Therefore, a regulator sized for a high flow rate will usually have a turndown ratio sufficient to handle pilot-light sized loads during periods of low demand.

Sizing Exercise: Industrial Plant Gas Supply

Regulator selection and sizing generally requires some subjective evaluation and decision making. For those with little experience, the best way to learn is through example. Therefore, these exercises present selection and sizing problems for practicing the process of identifying suitable regulators.

Our task is to select a regulator to supply reduced pressure natural gas to meet the needs of a small industrial plant. The regulated gas is metered before entering the plant. The selection parameters are:

- Minimum inlet pressure, P_{1min} = 30 psig
- Maximum inlet pressure, P_{1max} = 40 psig
- Outlet pressure setting, P_2 = 1 psig
- Flow, Q = 95 000 SCFH
- Accuracy (droop required) = 10% or less

Selecting and Sizing Pressure Reducing Regulators

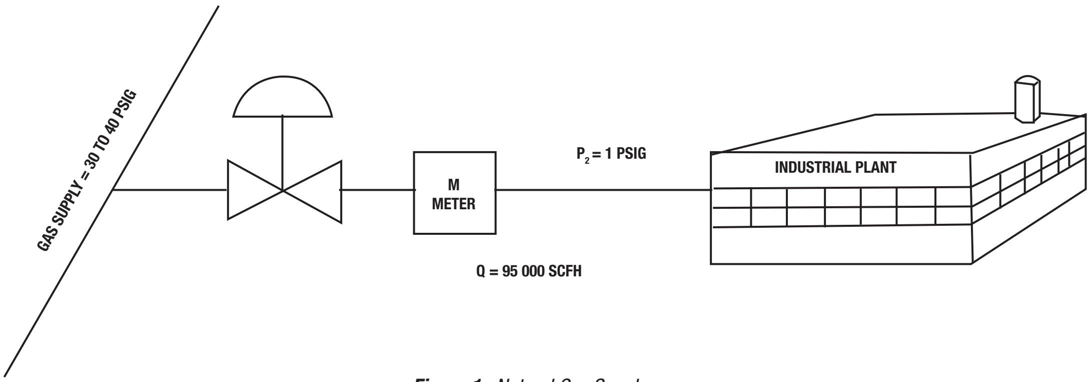


Figure 1. Natural Gas Supply

Quick Selection Guide

Turn to the Commercial/Industrial Quick Selection Guide. From the Quick Selection Guide, we find that the choices are:

- Type 133
- Type 1098-EGR

Product Pages

Under the product number on the Quick Selection Guide is the page number of the product page. Look at the flow capacities of each of the possible choices. From the product pages we found the following:

- At 30 psig inlet pressure and 10% droop, the Type 133 has a flow capacity of 90 000 SCFH. This regulator does not meet the required flow capacity.
- At 30 psig inlet pressure, the Type 1098-EGR has a flow capacity of 131 000 SCFH. By looking at the Proportional Band (Droop) table, we see that the Type 6352 pilot with the yellow pilot spring and the green main valve has 0.05 psig droop. This regulator meets the selection criteria.

Final Selection

We find that the Type 1098-EGR meets the selection criteria.

Overpressure Protection Methods

Overpressure protective devices are of vital concern. Safety codes and current laws require their installation each time a pressure reducing station is installed that supplies gas from any system to another system with a lower maximum allowable operating pressure.

Methods of Overpressure Protection

The most commonly used methods of overpressure protection, not necessarily in order of use or importance, include:

- Relief Valves (Figure 1)
- Monitors (Figures 2 and 3)
- Series Regulation (Figure 4)
- Shutoff (Figure 5)
- Relief Monitor (Figure 6)

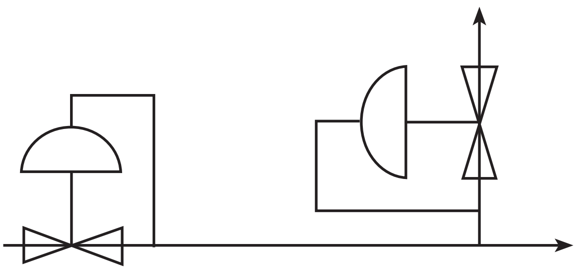


***Figure 1.** Relief Valve Schematic*

Relief Valves

A relief valve is a device that vents process fluid to atmosphere to maintain the pressure downstream of the regulator below the safe maximum pressure. Relief is a common form of overpressure protection typically used for low to medium capacity applications. (Note: Fisher® relief valves are not ASME safety relief valves.)

Types of Relief Valves

The basic types of relief valves are:

- Pop type
- Direct-operated relief valves
- Pilot-operated relief valves
- Internal relief valves

The pop type relief valve is the simplest form of relief. Pop relief valves tend to go wide-open once the pressure has exceeded its setpoint by a small margin. The setpoint can drift over time, and because of its quick opening characteristic the pop relief can sometimes become unstable when relieving, slamming open and closed. Many have a non-adjustable setpoint that is set and pinned at the factory.

If more accuracy is required from a relief valve, the direct-operated relief valve would be the next choice. They can throttle better than a pop relief valve, and tend to be more stable, yet are still relatively simple. Although there is less drift in the setpoint of the direct-operated relief valve, a significant amount of build-up is often required to obtain the required capacity.

The pilot-operated relief valves have the most accuracy, but are also the most complicated and expensive type of relief. They use a pilot to dump loading pressure, fully stroking the main valve with very little build-up above setpoint. They have a large capacity and are available in larger sizes than other types of relief.

Many times, internal relief will provide adequate protection for a downstream system. Internal relief uses a relief valve built into the regulator for protection. If the pressure builds too far above the setpoint of the regulator, the relief valve in the regulator opens up, allowing excess pressure to escape through the regulator vent.

Advantages

The relief valve is considered to be the most reliable type of overpressure protection because it is not subject to blockage by foreign objects in the line during normal operations. It also imposes no decrease in the regulator capacity which it is protecting, and it has the added advantage of being its own alarm when it vents. It is normally reasonable in cost and keeps the customer in service despite the malfunction of the pressure reducing valve.

Disadvantages

When the relief valve blows, it could possibly create a hazard in the surrounding area by venting. The relief valve must be sized carefully to relieve the gas or fluid that could flow through the pressure reducing valve at its maximum inlet pressure and in the wide-open position, assuming no flow to the downstream. Therefore, each application must be sized individually. The requirement for periodic testing of relief valves also creates an operational and/or public relations problem.

Overpressure Protection Methods

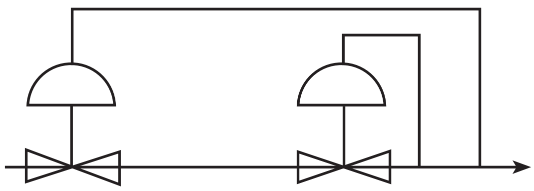


Figure 2. Monitoring Regulators Schematic

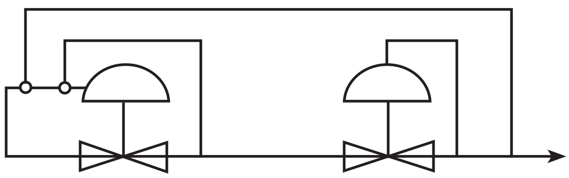


Figure 3. Working Monitor Schematic

Monitoring Regulators

Monitoring is overpressure control by containment. When the working pressure reducing valve ceases to control the pressure, a second regulator installed in series, which has been sensing the downstream pressure, goes into operation to maintain the downstream pressure at a slightly higher than normal pressure. The monitoring concept is gaining in popularity, especially in low-pressure systems, because very accurate relay pilots permit reasonably close settings of the working and monitoring regulators.

The two types of wide-open monitoring are upstream and downstream monitoring. One question often asked is, "Which is better, upstream or downstream monitoring?" Using two identical regulators, there is no difference in overall capacity with either method.

When using monitors to protect a system or customer who may at times have zero load, a small relief valve is sometimes installed downstream of the monitor system with a setpoint just above the monitor. This allows for a token relief in case dust or dirt in the system prevents bubble tight shutoff of the regulators.

Advantages

The major advantage is that there is no venting to atmosphere. During an overpressure situation, monitoring keeps the customer on line and keeps the downstream pressure relatively close to the setpoint of the working regulator. Testing is relatively easy and safe. To perform a periodic test on a monitor, increase the outlet set pressure of the working device and watch the pressure to determine if the monitor takes over.

Disadvantages

Compared to relief valves, monitoring generally requires a higher initial investment. Monitoring regulators are subject to blocking, which is why filters or strainers are specified with increasing frequency. Because the monitor is in series, it is an added restriction in the line. This extra restriction can sometimes force one to use a larger, more expensive working regulator.

Working Monitor

A variation of monitoring overpressure protection that overcomes some of the disadvantages of a wide-open monitor is the "working monitor" concept wherein a regulator upstream of the working regulator uses two pilots. This additional pilot permits the monitoring regulator to act as a series regulator to control an intermediate pressure during normal operation. In this way, both units are always operating and can be easily checked for proper operation. Should the downstream pressure regulator fail to control, however, the monitoring pilot takes over the control at a slightly higher than normal pressure and keeps the customer on line. This is pressure control by containment and eliminates public relations problems.

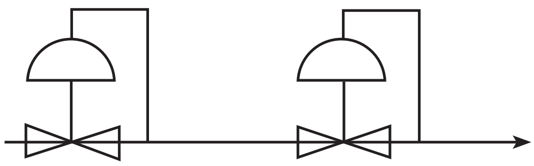


Figure 4. Series Regulation Schematic

Series Regulation

Series regulation is also overpressure protection by containment in that two regulators are set in the same pipeline. The first unit maintains an inlet pressure to the second valve that is within the maximum allowable operating pressure of the downstream system. Under this setup, if either regulator should fail, the resulting downstream pressure maintained by the other regulator would not exceed the safe maximum pressure.

This type of protection is normally used where the regulator station is reducing gas to a pressure substantially below the maximum allowable operating pressure of the distribution system being supplied. Series regulation is also found frequently in farm taps and in similar situations within the guidelines mentioned above.

Overpressure Protection Methods

Advantages

Again, nothing is vented to atmosphere.

Disadvantages

Because the intermediate pressure must be cut down to a pressure that is safe for the entire downstream, the second-stage regulator often has very little pressure differential available to create flow. This can sometimes make it necessary to increase the size of the second regulator significantly. Another drawback occurs when the first-stage regulator fails and no change in the final downstream pressure is noticed because the system operates in what appears to be a "normal" manner without benefit of protection. Also, the first-stage regulator and intermediate piping must be capable of withstanding and containing maximum upstream pressure.

The second-stage regulator must also be capable of handling the full inlet pressure in case the first-stage unit fails to operate. In case the second-stage regulator fails, its actuator will be subjected to the intermediate pressure set by the first-stage unit. The second-stage actuator pressure ratings should reflect this possibility.

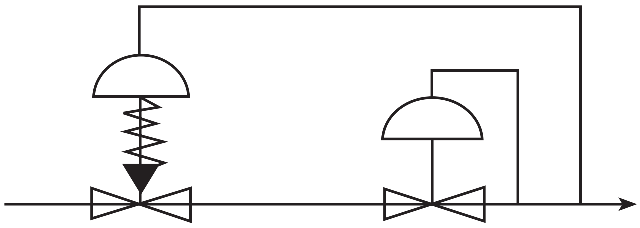


Figure 5. *Shutoff Schematic*

Shutoff Devices

The shutoff device also accomplishes overpressure protection by containment. In this case, the customer is shutoff completely until the cause of the malfunction is determined and the device is manually reset. Many gas distribution companies use this as an added measure of protection for places of public assembly such as schools, hospitals, churches, and shopping centers. In those cases, the shutoff device is a secondary form of overpressure protection. Shutoff valves are also commonly used by boiler manufacturers in combustion systems.

Advantages

By shutting off the customer completely, the safety of the downstream system is assured. Again, there is no public relations problem or hazard from venting gas or other media.

Disadvantages

The customer may be shutoff because debris has temporarily lodged under the seat of the operating regulator, preventing tight shutoff. A small relief valve can take care of this situation.

On a distribution system with a single supply, using a slam-shut can require two trips to each customer, the first to shutoff the service valve, and the second visit after the system pressure has been restored to turn the service valve back on and re-light the appliances. In the event a shutoff is employed on a service line supplying a customer with processes such as baking, melting metals, or glass making, the potential economic loss could dictate the use of an overpressure protection device that would keep the customer online.

Another problem associated with shutoffs is encountered when the gas warms up under no-load conditions. For instance, a regulator locked up at approximately 7-inches w.c. could experience a pressure rise of approximately 0.8-inch w.c. per degree Fahrenheit rise, which could cause the high-pressure shutoff to trip when there is actually no equipment failure.

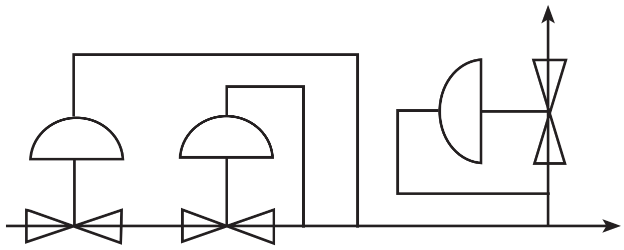


Figure 6. *Relief Monitor Schematic*

Relief Monitor

Another concept in overpressure protection for small industrial and commercial loads, up to approximately 10 000 cubic feet per hour, incorporates both an internal relief valve and a monitor. In this device, the relief capacity is purposely restricted to prevent excess venting of gas in order to bring the monitor into operation more quickly. The net result is that the downstream pressure is protected, in some cases to less than 1 psig. The amount of gas vented under maximum inlet pressure conditions does not exceed the amount vented by a domestic relief type service regulator.

Overpressure Protection Methods

Types of Overpressure Protection						
PERFORMANCE QUESTIONS	RELIEF	WORKING MONITOR	MONITOR	SERIES REGULATION	SHUTOFF	RELIEF MONITOR
Keeps application online?	Yes	Yes	Yes	Yes	No	Yes
Venting to atmosphere?	Yes	No	No	No	No	Minor
Manual resetting required after operation?	No	No	No	No	Yes	No
Reduces capacity of regulator?	No	Yes	Yes	Yes	No	No
Constantly working during normal operation?	No	Yes	No	Yes	No	Yes
Demands “emergency” action?	Yes	No	No	No	Yes	Maybe
Will surveillance of pressure charts indicate partial loss of performance of overpressure devices?	No	Yes	Maybe	Yes	No	No
Will surveillance of pressure charts indicate regulator has failed and safety device is in control?	Yes	Yes	Yes	Yes	Yes	Yes

With this concept, the limitation by regulator manufacturers of inlet pressure by orifice size, as is found in “full relief” devices, is overcome. Downstream protection is maintained, even with abnormally high inlet pressure. Public relations problems are kept to a minimum by the small amount of vented gas. Also, the unit does not require manual resetting, but can go back into operation automatically.

Dust or dirt can clear itself off the seat, but if the obstruction to the disk closing still exists when the load goes on, the customer would be kept online. When the load goes off, the downstream pressure will again be protected. During normal operation, the monitoring portion of the relief monitor is designed to move slightly with minor fluctuations in downstream pressure or flow.

Summary

From the foregoing discussion, it becomes obvious that there are many design philosophies available and many choices of equipment to meet overpressure protection requirements. Also, assume the overpressure device will be called upon to operate sometime after it is installed. The overall design must include an analysis of the conditions created when the protection device operates.

The accompanying table shows:

- What happens when the various types of overpressure protection devices operate
- The type of reaction required
- The effect upon the customer or the public
- Some technical conditions

These are the general characteristics of the various types of safety devices. From the conditions and results shown, it is easier to decide which type of overpressure equipment best meets your needs. Undoubtedly, compromises will have to be made between the conditions shown here and any others which may govern your operating parameters.

Principles of Relief Valves

Overpressure Protection

Overpressure protection is a primary consideration in the design of any piping system. The objective of overpressure protection is to maintain the pressure downstream of a regulator at a safe maximum value.

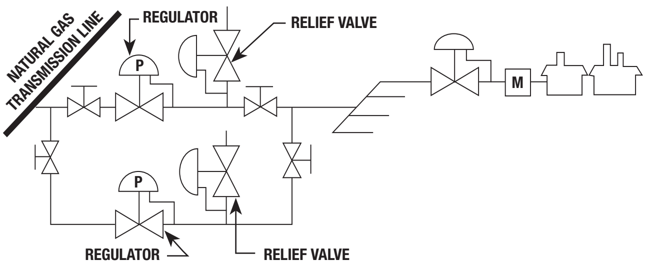


Figure 1. Distribution System

In the system shown in Figure 1, a high-pressure transmission system delivers natural gas through a pressure reducing regulator to a lower pressure system that distributes gas to individual customers. The regulators, the piping, and the devices that consume gas are protected from overpressure by relief valves. The relief valve's setpoint is adjusted to a level established by the lowest maximum pressure rating of any of the lower pressure system components.

Maximum Pressure Considerations

Overpressure occurs when the pressure of a system is above the setpoint of the device controlling its pressure. It is evidence of some failure in the system (often the upstream regulator), and it can cause the entire system to fail if it's not limited. To implement overpressure protection, the weakest part in the pressure system is identified and measures are taken to limit overpressure to that component's maximum pressure rating. The most vulnerable components are identified by examining the maximum pressure ratings of the:

- Downstream equipment
- Low-pressure side of the main regulator
- Piping

The lowest maximum pressure rating of the three is the maximum allowable pressure.

Downstream Equipment

The downstream component (appliance, burner, boiler, etc.) with the lowest maximum pressure rating sets the highest pressure that all the downstream equipment can be subjected to.

Main Regulator

Pressure reducing regulators have different pressure ratings which refer to the inlet, outlet, and internal components. The lowest of these should be used when determining the maximum allowable pressure.

Piping

Piping is limited in its ability to contain pressure. In addition to any physical limitations, some applications must also conform to one or more applicable pressure rating codes or regulations.

Relief Valves

Relief involves maintaining the pressure downstream of a regulator at a safe maximum pressure using any device that vents fluid to a lower pressure system (often the atmosphere). Relief valve exhaust must be directed or piped to a safe location. Relief valves perform this function. They are considered to be one of the most reliable types of overpressure protection available and are available in a number of different types. Fisher® relief valves are not ASME safety relief valves.


W1921

H200 SERIES POP TYPE


W1870

TYPE 289 DIRECT-OPERATED


W3167

TYPE 289P-6358 PILOT-OPERATED


W4793

TYPE 627 WITH INTERNAL RELIEF

Figure 2. Types of Relief Valves

Principles of Relief Valves

Relief Valve Popularity

Relief valves are popular for several reasons. They do not block the normal flow through a line. They do not decrease the capacities of the regulators they protect. And, they have the added advantage of being an alarm if they vent to atmosphere.

Relief Valve Types

Relief valves are available in four general types. These include: pop type, direct-operated, pilot-operated, and internal relief valves.

Selection Criteria

Pressure Build-up

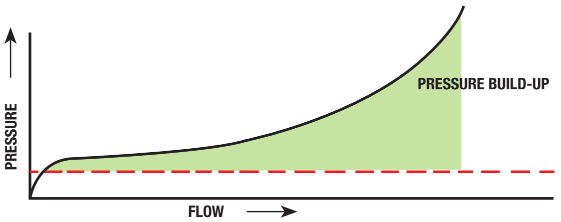


Figure 3. Pressure Build-up

A relief valve has a setpoint at which it begins to open. For the valve to fully open and pass the maximum flow, pressure must build up to some level above the setpoint of the relief valve. This is known as pressure build-up over setpoint, or simply build-up.

Periodic Maintenance

A relief valve installed in a system that normally performs within design limits is very seldom exercised. The relief valve sits and waits for a failure. If it sits for long periods it may not perform as expected. Disks may stick in seats, setpoints can shift over time, and small passages can become clogged with pipeline debris. Therefore, periodic maintenance and inspection is recommended. Maintenance requirements might influence the selection of a relief valve.

Cost Versus Performance

Given several types of relief valves to choose from, selecting one type is generally based on the ability of the valve to provide adequate protection at the most economical cost. Reduced pressure build-up and increased capacity generally come at an increased price.

Installation and Maintenance Considerations

Initial costs are only a part of the overall cost of ownership. Maintenance and installation costs must also be considered over the life of the relief valve. For example, internal relief might be initially more economical than an external relief valve. However, maintaining a regulator with internal relief requires that the system be shut down and the regulator isolated. This may involve additional time and the installation of parallel regulators and relief valves if flow is to be maintained to the downstream system during maintenance operations.

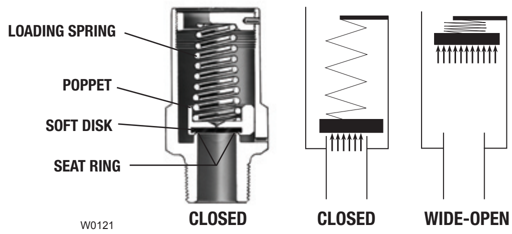


Figure 4. Pop Type Relief Valve Construction and Operation

Pop Type Relief Valve

The most simple type of relief valve is the pop type. They are used wherever economy is the primary concern and some setpoint drift is acceptable.

Operation

Pop type relief valves are essentially on-off devices. They operate in either the closed or wide-open position. Pop type designs register pressure directly on a spring-opposed poppet. The poppet assembly includes a soft disk for tight shutoff against the seat ring. When the inlet pressure increases above setpoint, the poppet assembly is pushed away from the seat. As the poppet rises, pressure registers against a greater surface area of the poppet. This dramatically increases the force on the poppet. Therefore, the poppet tends to travel to the fully open position reducing pressure build-up.

Principles of Relief Valves

Build-up Over Setpoint

Recall that pressure build-up relates capacity to pressure; increasing capacity requires some increase in pressure. In throttling relief valves, pressure build-up is related to accuracy. In pop type relief valves, build-up over setpoint results largely because the device is a restriction to flow rather than the spring rate of the valve's loading spring.

Fixed Setpoint

The setpoint of a pop type valve cannot be adjusted by the user. The spring is initially loaded by the manufacturer. A pinned spring retainer keeps the spring in position. This is a safety measure that prevents tampering with the relief valve setpoint.

Typical Applications

This type of relief valve may be used where venting to the atmosphere is acceptable, when the process fluid is compatible with the soft disk, and when relief pressure variations are allowable. They are often used as inexpensive token relief. For example, they may be used simply to provide an audible signal of an overpressure condition.

These relief valves may be used to protect against overpressure stemming from a regulator with a minimal amount of seat leakage. Unchecked, this seat leakage could allow downstream pressure to build to full P_1 over time. The use of a small pop type valve can be installed to protect against this situation.

These relief valves are also commonly installed with a regulator in a natural gas system farm tap, in pneumatic lines used to operate air drills, jackhammers, and other pneumatic equipment, and in many other applications.

Advantages

Pop type relief valves use few parts. Their small size allows installation where space is limited. Also, low initial cost, easy installation, and high capacity per dollar invested can result in economical system relief.

Disadvantages

The setpoint of a pop type relief valve may change over time. The soft disk may stick to the seat ring and cause the pop pressure to increase.

As an on-off device, this style of relief valve does not throttle flow over a pressure range. Because of its on-off nature, this type of relief valve may create pressure surges in the downstream system.

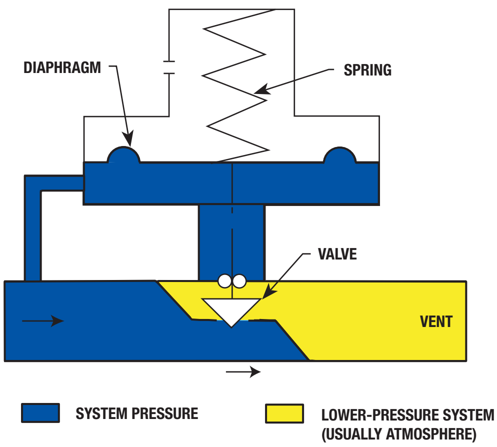


Figure 5. *Direct-Operated Relief Valve Schematic*

If the relief valve capacity is significantly larger than the failed regulator's capacity, the relief valve may over-compensate each time it opens and closes. This can cause the downstream pressure system to become unstable and cycle. Cycling can damage the relief valve and downstream equipment.

Direct-Operated Relief Valves

Compared to pop type relief valves, direct-operated relief valves provide throttling action and may require less pressure build-up to open the relief valve.

Operation

A schematic of a direct-operated relief valve is shown in Figure 5. It looks like an ordinary direct-operated regulator except that it senses upstream pressure rather than downstream pressure. And, it uses a spring-close rather than a spring-open action. It contains the same essential elements as a direct-operated regulator:

- A diaphragm that measures system pressure
- A spring that provides the initial load to the diaphragm and is used to establish the relief setpoint
- A valve that throttles the relief flow

Principles of Relief Valves

Opening the Valve

As the inlet pressure rises above the setpoint of the relief valve, the diaphragm is pushed upward moving the valve plug away from the seat. This allows fluid to escape.

Pressure Build-up Over Setpoint

As system pressure increases, the relief valve opens wider. This allows more fluid to escape and protects the system. The increase in pressure above the relief setpoint that is required to produce more flow through the relief valve is referred to as pressure build-up. The spring rate and orifice size influence the amount of pressure build-up that is required to fully stroke the valve.

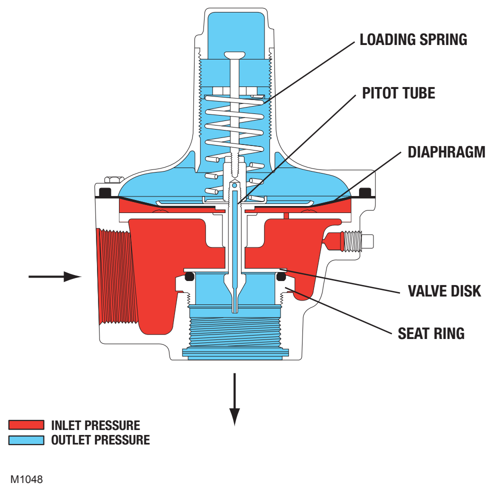


Figure 6. *Type 289 Relief Valve with Pitot Tube*

Product Example

Pitot Tube

The relief valve shown in Figure 6 includes a pitot tube to reduce pressure build-up. When the valve is opening, high fluid velocity through the seat ring creates an area of relatively low pressure. Low pressure near the end of the pitot tube draws fluid out of the volume above the relief valve diaphragm and creates a partial vacuum which helps to open the valve. The partial vacuum above the diaphragm increases the relief valve capacity with less pressure build-up over setpoint.

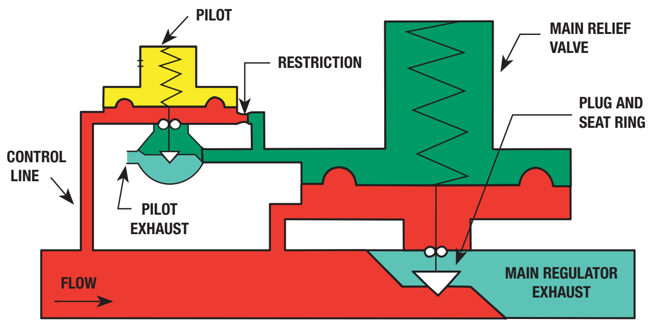
Typical Applications

Direct-operated relief valves are commonly used in natural gas systems supplying commercial enterprises such as restaurants and laundries, and in industry to protect industrial furnaces and other equipment.

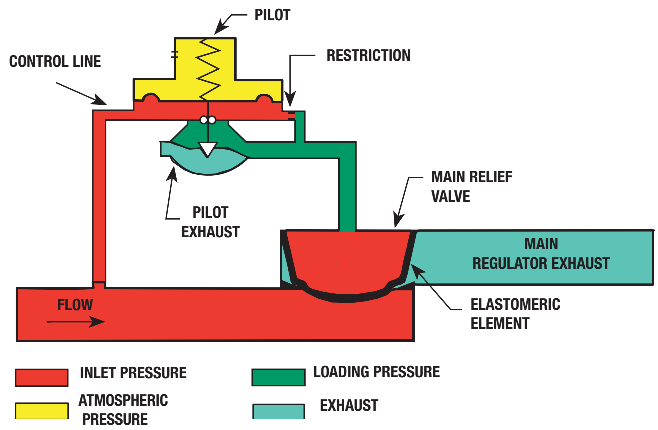
Selection Criteria

Pressure Build-up

Some direct-operated relief valves require significant pressure build-up to achieve maximum capacity. Others, such as those using pitot tubes, often pass high flow rates with minimal pressure build-up. Direct-operated relief valves can provide good accuracy within their design capacities.



PLUG AND SEAT RING MAIN VALVE



ELASTOMERIC ELEMENT MAIN VALVE

Figure 7. *Pilot-Operated Designs*

Principles of Relief Valves

Cost Versus Performance

The purchase price of a direct-operated relief valve is typically lower than that of a pilot-operated design of the same size. However, pilot-operated designs may cost less per unit of capacity at very high flow rates.

Pilot-Operated Relief Valves

Pilot-operated relief valves utilize a pair of direct-operated relief valves; a pilot and a main relief valve. The pilot increases the effect of changes in inlet pressure on the main relief valve.

Operation

The operation of a pilot-operated relief valve is quite similar to the operation of a pilot-operated pressure reducing regulator. In normal operation, when system pressure is below setpoint of the relief valve, the pilot remains closed. This allows loading pressure to register on top of the main relief valve diaphragm. Loading pressure on top of the diaphragm is opposed by an equal pressure (inlet pressure) on the bottom side of the diaphragm. With little or no pressure differential across the diaphragm, the spring keeps the valve seated. Notice that a light-rate spring may be used because it does not oppose a large pressure differential across the diaphragm. The light-rate spring enables the main valve to travel to the wide-open position with little pressure build-up.

Increasing Inlet Pressure

When the inlet pressure rises above the relief setpoint, the pilot spring is compressed and the pilot valve opens. The open pilot bleeds fluid out of the main valve spring case, decreasing pressure above the main relief valve diaphragm. If loading pressure escapes faster than it can be replaced through the restriction, the loading pressure above the main relief valve diaphragm is reduced and the relief valve opens. System overpressure exhausts through the vent.

Decreasing Inlet Pressure

If inlet pressure drops back to the relief valve setpoint, the pilot loading spring pushes the pilot valve plug back against the pilot valve seat. Inlet pressure again loads the main relief valve diaphragm and closes the main valve.

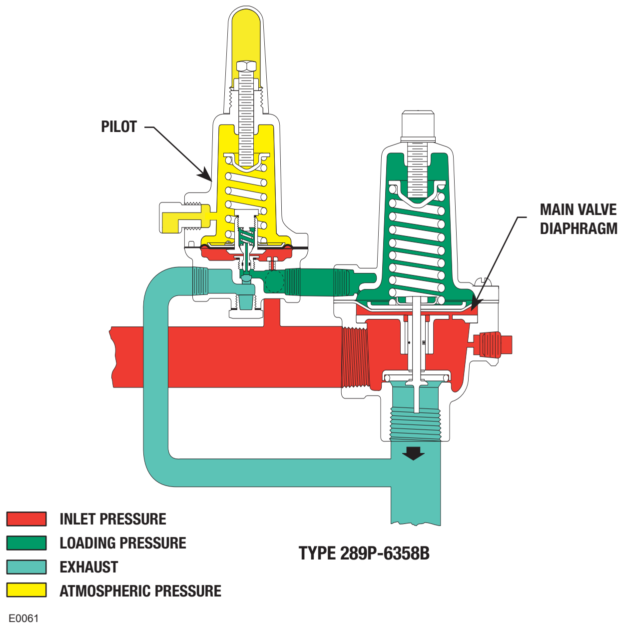


Figure 8. *Pilot-Operated Relief Valve*

Control Line

The control line connects the pilot with the pressure that is to be limited. When overpressure control accuracy is a high priority, the control line tap is installed where protection is most critical.

Product Example

Physical Description

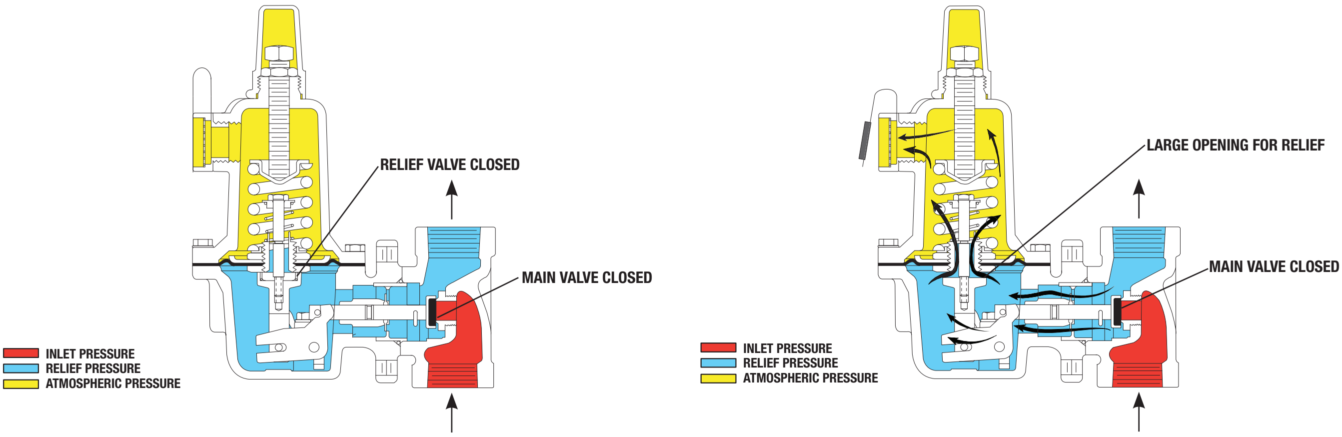
This relief valve is a direct-operated relief valve with a pilot attached (Figure 8). The pilot is a modified direct-operated relief valve, the inlet pressure loads the diaphragm and flows through a restriction to supply loading pressure to the main relief valve diaphragm.

Operation

During normal operation, the pilot is closed allowing loading pressure to register above the main relief valve's diaphragm. This pressure is opposed by inlet pressure acting on the bottom of the diaphragm.

If inlet pressure rises above setpoint, the pilot valve opens, exhausting the loading pressure. If loading pressure is reduced above the main relief valve diaphragm faster than it is replaced through the pilot fixed restriction, loading pressure is reduced and inlet pressure below the diaphragm will cause the main regulator to open.

Principles of Relief Valves



REGULATORS THAT INCLUDE INTERNAL RELIEF VALVES OFTEN ELIMINATE THE REQUIREMENT FOR EXTERNAL OVERPRESSURE PROTECTION. THE ILLUSTRATION ON THE LEFT SHOWS THE REGULATOR WITH BOTH THE RELIEF VALVE AND THE REGULATOR VALVE IN THE CLOSED POSITION. THE ILLUSTRATION ON THE RIGHT SHOWS THE SAME UNIT AFTER P_2 HAS INCREASED ABOVE THE RELIEF VALVE SETPOINT. THE DIAPHRAGM HAS MOVED OFF THE RELIEF VALVE SEAT ALLOWING FLOW (EXCESS PRESSURE) TO EXHAUST THROUGH THE SCREENED VENT.

Figure 9. *Internal Relief Design*

If inlet pressure falls below the relief set pressure, the pilot spring will again close the pilot exhaust, increasing loading pressure above the main relief valve diaphragm. This increasing loading pressure causes the main valve to travel towards the closed position.

Performance

Pilot-operated relief valves are able to pass large flow rates with a minimum pressure build-up.

Typical Applications

Pilot-operated relief valves are used in applications requiring high capacity and low pressure build-up.

Selection Criteria

Minimal Build-up

The use of a pilot to load and unload the main diaphragm and the light-rate spring enables the main valve to travel wide-open with little pressure build-up over setpoint.

Throttling Action

The sensitive pilot produces smooth throttling action when inlet pressure rises above setpoint. This helps to maintain a steady downstream system pressure.

Internal Relief

Regulators that include internal relief valves may eliminate the requirement for external overpressure protection.

Operation

The regulator shown in Figure 9 includes an internal relief valve. The relief valve has a measuring element (the main regulator diaphragm), a loading element (a light spring), and a restricting element (a valve seat and disk). The relief valve assembly is located in the center of the regulator diaphragm.

Build-up Over Setpoint

Like other spring-loaded designs, internal relief valves will only open wider if the inlet pressure increases. The magnitude of pressure build-up is determined by the spring rates of the loading spring plus the main spring. Both springs are considered because they act together to resist diaphragm movement when pressure exceeds the relief valve setpoint.

Product Example

A typical internal relief regulator construction is shown in Figure 9. The illustration on the left shows the regulator with both the relief valve and regulator valve in the closed position. The illustration on the right shows the same unit after the inlet

Principles of Relief Valves

pressure has increased above the relief valve setpoint. The diaphragm has moved off the relief valve seat allowing the excess pressure to exhaust through the vent.

Performance and Typical Applications

This design is available in configurations that can protect many pressure ranges and flow rates. Internal relief is often used in applications such as farm taps, industrial applications where atmospheric exhaust is acceptable, and house service regulators.

Selection Criteria

Pressure Build-up

Relief setpoint is determined by a combination of the relief valve and regulator springs; this design generally requires significant pressure build-up to reach its maximum relief flow rate. For the same reason, internal relief valves have limited relief capacities. They may provide full relief capacity, but should be carefully sized for each application.

Space

Internal relief has a distinct advantage when there is not enough space for an external relief valve.

Cost versus Performance

Because a limited number of parts are simply added to the regulator, this type of overpressure protection is relatively inexpensive compared to external relief valves of comparable capacity.

Maintenance

Because the relief valve is an integral part of the regulator's diaphragm, the regulator must be taken out of service when maintenance is performed. Therefore, the application should be able to tolerate either the inconvenience of intermittent supply or the expense of parallel regulators and relief valves.

Selection and Sizing Criteria

There are a number of common steps in the relief valve selection and sizing process. For every application, the maximum pressure conditions, the wide-open regulator flow capacity, and constant downstream demand should be determined. Finally, this information is used to select an appropriate relief valve for the application.

Maximum Allowable Pressure

Downstream equipment includes all the components of the system that contain pressure; household appliances, tanks, tools, machines, outlet rating of the upstream regulators, or other equipment. The component with the lowest maximum pressure rating establishes the maximum allowable system pressure.

Regulator Ratings

Pressure reducing regulators upstream of the relief valve have ratings for their inlet, outlet, and internal components. The lowest rating should be used when determining maximum allowable pressure.

Piping

Piping pressure limitations imposed by governmental agencies, industry standards, manufacturers, or company standards should be verified before defining the maximum overpressure level.

Maximum Allowable System Pressure

The smallest of the pressure ratings mentioned above should be used as the maximum allowable pressure. This pressure level should not be confused with the relief valve setpoint which must be set below the maximum allowable system pressure.

Determining Required Relief Valve Flow

A relief valve must be selected to exhaust enough flow to prevent the pressure from exceeding the maximum allowable system pressure. To determine this flow, review all upstream components for the maximum possible flow that will cause overpressure. If overpressure is caused by a pressure reducing regulator, use the regulator's wide-open flow coefficient to calculate the required flow of the relief valve. This regulator's wide-open flow is larger than the regulating flow used to select the pressure reducing regulator.

Sizing equations have been developed to standardize valve sizing. Refer to the Valve Sizing Calculations section to find these equations and explanations on how they are used.

Principles of Relief Valves

Determine Constant Demand

In some applications, the required relief capacity can be reduced by subtracting any load that is always on the system. This procedure should be approached with caution because it may be difficult to predict the worst-case scenario for downstream equipment failures. It may also be important to compare the chances of making a mistake in predicting the level of continuous flow consumption with the potential negative aspects of an error. Because of the hazards involved, relief valves are often sized assuming no continuous flow to downstream equipment.

Selecting Relief Valves

Required Information

We have already reviewed the variables required to calculate the regulator's wide-open flow rate. In addition, we need to know the type and temperature of the fluid in the system, and the size of the piping. Finally, if a vent stack will be required, any additional build-up due to vent stack resistance should be considered.

Regulator Lockup Pressure

A relief valve setpoint is adjusted to a level higher than the regulator's lockup pressure. If the relief valve setpoint overlaps lockup pressure of the regulator, the relief valve may open while the regulator is still attempting to control the system pressure.

Identify Appropriate Relief Valves

Once the size, relief pressure, and flow capacity are determined, we can identify a number of potentially suitable relief valves using the Quick Selection Guide in the front of each application section in this application guide. These selection guides give relief set (inlet) pressures, capacities, and type numbers. These guides can then be further narrowed by reviewing individual product pages in each section.

Final Selection

Final selection is usually a matter of compromise. Relief capacities, build-up levels, sensitivity, throttling capabilities, cost of installation and maintenance, space requirements, initial purchase price, and other attributes are all considered when choosing any relief valve.

Applicable Regulations

The relief valves installed in some applications must meet governmental, industry, or company criteria.

Sizing and Selection Exercise

To gain a better understanding of the selection and sizing process, it may be helpful to step through a typical relief valve sizing exercise.

Initial Parameters

We'll assume that we need to specify an appropriate relief valve for a regulator serving a large plant air supply. There is sufficient space to install the relief valve and the controlled fluid is clean plant air that can be exhausted without adding a vent stack.

Performance Considerations

The plant supervisor wants the relief valve to throttle open smoothly so that pressure surges will not damage instruments and equipment in the downstream system. This will require the selection of a relief valve that will open smoothly. Plant equipment is periodically shut down but the air supply system operates continuously. Therefore, the relief valve must also have the capacity to exhaust the full flow of the upstream system.

Upstream Regulator

The regulator used is 1-inch in size with a 3/8-inch orifice. The initial system parameters of pressure and flow were determined when the regulator was sized for this application.

Pressure Limits

The plant maintenance engineer has determined that the relief valve should begin to open at 20 psig, and downstream pressure should not rise above 30 psig maximum allowable system pressure.

Relief Valve Flow Capacity

The wide-open regulator flow is calculated to be 23 188 SCFH.

Principles of Relief Valves

Relief Valve Selection

Quick Selection Guide

Find the Relief Valve Quick Selection Guide in this Application Guide; it gives relief set (inlet) pressures and comparative flow capacities of various relief valves. Because this guide is used to identify potentially suitable relief valves, we can check the relief set (inlet) pressures closest to 20 psig and narrow the range of choices. We find that two relief valves have the required flow capacity at our desired relief set (inlet) pressure.

Product Pages

If we look at the product pages for the potential relief valves, we find that a 1-inch Type 289H provides the required capacity within the limits of pressure build-up specified in our initial parameters.

Checking Capacity

Capacity curves for the 1-inch Type 289H with this spring are shown in Figure 10. By following the curve for the 20 psig setpoint to the point where it intersects with the 30 psig division, we find that our relief valve can handle more than the 23 188 SCFH required.

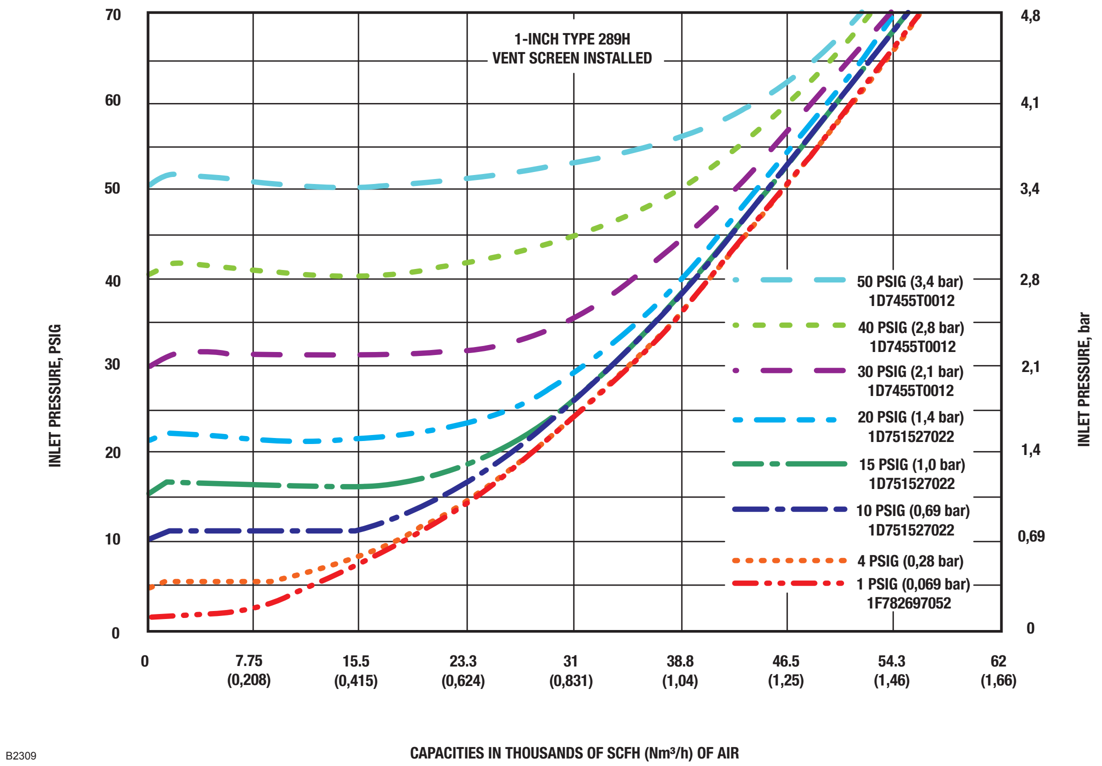


Figure 10. *Type 289H Flow Capacities*

Principles of Series Regulation and Monitor Regulators

Series Regulation

Series regulation is one of the simplest systems used to provide overpressure protection by containment. In the example shown in Figure 1, the inlet pressure is 100 psig, the desired downstream pressure is 10 psig, and the maximum allowable operating pressure (MAOP) is 40 psig. The setpoint of the downstream regulator is 10 psig, and the setpoint of the upstream regulator is 30 psig.

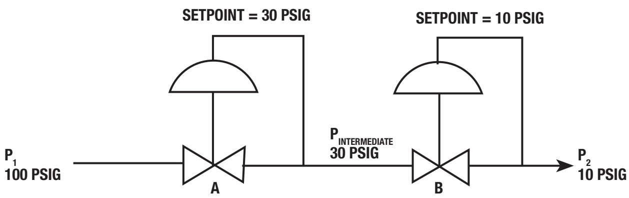


Figure 1. *Series Regulation*

Failed System Response

If regulator B fails, downstream pressure (P_2) is maintained at the setpoint of regulator A less whatever drop is required to pass the required flow through the failed regulator B. If regulator A fails, the intermediate pressure will be 100 psig. Regulator B must be able to withstand 100 psig inlet pressure.

Regulator Considerations

Either direct-operated or pilot-operated regulators may be used in this system. Should regulator A fail, $P_{Intermediate}$ will approach P_1 so the outlet rating and spring casing rating of regulator A must be high enough to withstand full P_1. This situation may suggest the use of a relief valve between the two regulators to limit the maximum value of $P_{Intermediate}$.

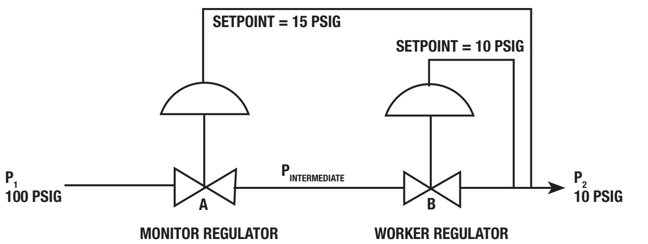
Applications and Limitations

A problem with series regulation is maintaining tight control of P_2 if the downstream regulator fails. In this arrangement, it is often impractical to have the setpoints very close together. If they are, the pressure drop across regulator B will be quite small. With a small pressure drop, a very large regulator may be required to pass the desired flow.

Because of the problem in maintaining close control of P_2, series regulation is best suited to applications where the regulator station is reducing pressure to a value substantially below the maximum allowable operating pressure of the downstream system. Farm taps are a good example. The problem of low-pressure drop across the second regulator is less pronounced in low flow systems.

Upstream Wide-Open Monitors

The only difference in configuration between series regulation and monitors is that in monitor installations, both regulators sense downstream pressure, P_2. Thus, the upstream regulator must have a control line.



IN WIDE-OPEN MONITOR SYSTEMS, BOTH REGULATORS SENSE DOWNSTREAM PRESSURE. SETPOINTS MAY BE VERY CLOSE TO EACH OTHER. IF THE WORKER REGULATOR FAILS, THE MONITOR ASSUMES CONTROL AT A SLIGHTLY HIGHER SETPOINT. IF THE MONITOR REGULATOR FAILS, THE WORKER CONTINUES TO PROVIDE CONTROL.

Figure 2. *Wide-Open Upstream Monitor*

System Values

In the example shown in Figure 2, assume that P_1 is 100 psig, and the desired downstream pressure, P_2, is 10 psig. Also assume that the maximum allowable operating pressure of the downstream system is 20 psig; this is the limit we cannot exceed. The setpoint of the downstream regulator is set at 10 psig to maintain the desired P_2 and the setpoint of the upstream regulator is set at 15 psig to maintain P_2 below the maximum allowable operating pressure.

Normal Operation

When both regulators are functioning properly, regulator B holds P_2 at its setpoint of 10 psig. Regulator A, sensing a pressure lower than its setpoint of 15 psig tries to increase P_2 by going wide-open. This configuration is known as an upstream wide-open monitor where upstream regulator A monitors the pressure established by regulator B. Regulator A is referred to as the monitor or standby regulator while regulator B is called the worker or the operator.

Principles of Series Regulation and Monitor Regulators

Worker Regulator B Fails

If regulator B fails open, regulator A, the monitor, assumes control and holds P_2 at 15 psig. Note that pressure $P_{Intermediate}$ is now P_2 plus whatever drop is necessary to pass the required flow through the failed regulator B.

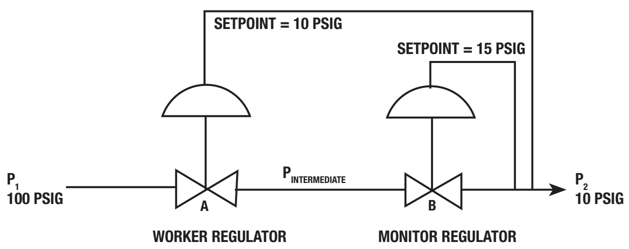
Equipment Considerations

Wide-open monitoring systems may use either direct- or pilot-operated regulators, the choice of which is dependent on other system requirements. Obviously, the upstream regulator must have external registration capability in order to sense downstream pressure, P_2.

In terms of ratings, $P_{Intermediate}$ will rise to full P_1 when regulator A fails, so the body outlet of regulator A and the inlet of regulator B must be rated for full P_1.

Downstream Wide-Open Monitors

The difference between upstream and downstream monitor systems (Figure 3) is that the functions of the two regulators are reversed. In other words, the monitor, or standby regulator, is downstream of the worker, or operator. Systems can be changed from upstream to downstream monitors, and vice-versa, by simply reversing the setpoints of the two regulators.



THE ONLY DIFFERENCE BETWEEN UPSTREAM WIDE-OPEN MONITOR SYSTEMS AND DOWNSTREAM WIDE-OPEN MONITOR SYSTEMS IS THE ROLE EACH REGULATOR PLAYS. WORKERS AND MONITORS MAY BE SWITCHED BY SIMPLY REVERSING THE SETPOINTS.

Figure 3. *Wide-Open Downstream Monitor*

Normal Operation

Again, assume an inlet pressure of 100 psig and a controlled pressure (P_2) of 10 psig. Regulator A is now the worker so it maintains P_2 at its setpoint of 10 psig. Regulator B, the monitor, is set at 15 psig and so remains open.

Worker Regulator A Fails

If the worker, regulator A, fails in an open position, the monitor, regulator B, senses the increase in P_2 and holds P_2 at its setpoint of 15 psig. Note that $P_{Intermediate}$ is now P_1 minus whatever drop is taken across the failed regulator A.

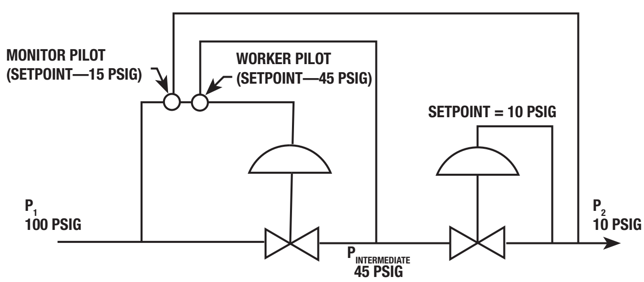
Upstream Versus Downstream Monitors

The decision to use either an upstream or downstream monitor system is largely a matter of personal preference or company policy.

In normal operation, the monitor remains open while the worker is frequently exercised. Many users see value in changing the system from an upstream to a downstream monitor at regular intervals, much like rotating the tires on an automobile. Most fluids have some impurities such as moisture, rust, or other debris, which may deposit on regulator components, such as stems, and cause them to become sticky or bind. Therefore, occasionally reversing the roles of the regulators so that both are exercised is sometimes seen as a means of ensuring that protection is available when needed. The job of switching is relatively simple as only the setpoints of the two regulators are changed. In addition, the act of changing from an upstream to a downstream monitor requires that someone visit the site so there is an opportunity for routine inspection.

Working Monitors

Working monitors (Figure 4) use design elements from both series regulation and wide-open monitors. In a working monitor installation, the two regulators are continuously working as series regulators to take two pressure cuts.



WORKING MONITOR SYSTEMS MUST USE A PILOT-OPERATED REGULATOR AS THE MONITOR, WHICH IS ALWAYS IN THE UPSTREAM POSITION. TWO PILOTS ARE USED ON THE MONITOR REGULATOR; ONE TO CONTROL THE INTERMEDIATE PRESSURE AND ONE TO MONITOR THE DOWNSTREAM PRESSURE. BY TAKING TWO PRESSURE DROPS, BOTH REGULATORS ARE ALLOWED TO EXERCISE.

Figure 4. *Working Monitor*

Principles of Series Regulation and Monitor Regulators

Downstream Regulator

The downstream regulator may be either direct or pilot-operated. It is installed just as in a series or wide-open monitor system. Its setpoint controls downstream pressure, P_2.

Upstream Regulator

The upstream regulator must be a pilot-operated type because it uses two pilots; a monitor pilot and a worker pilot. The worker pilot is connected just as in series regulation and controls the intermediate pressure $P_{Intermediate}$. Its setpoint (45 psig) is at some intermediate value that allows the system to take two pressure drops. The monitor pilot is in series ahead of the worker pilot and is connected so that it senses downstream pressure, P_2. The monitor pilot setpoint (15 psig) is set slightly higher than the normal P_2 (10 psig).

Normal Operation

When both regulators are performing properly, downstream pressure is below the setting of the monitor pilot, so it is fully open trying to raise system pressure. Standing wide-open, the monitor pilot allows the worker pilot to control the intermediate pressure, $P_{Intermediate}$ at 45 psig. The downstream regulator is controlling P_2 at 10 psig.

Downstream Regulator Fails

If the downstream regulator fails, the monitor pilot will sense the increase in pressure and take control at 15 psig.

Upstream Regulator Fails

If the upstream regulator fails, the downstream regulator will remain in control at 10 psig. Note that the downstream regulator must be rated for the full system inlet pressure P_1 of 100 psig because this will be its inlet pressure if the upstream regulator fails. Also note that the outlet rating of the upstream regulator, and any other components that are exposed to $P_{Intermediate}$, must be rated for full P_1.

Sizing Monitor Regulators

The difficult part of sizing monitor regulators is that $P_{Intermediate}$ is needed to determine the flow capacity for both regulators. Because $P_{Intermediate}$ is not available, other sizing methods are used to determine the capacity. There are three methods for sizing monitor regulators: estimating flow when pressure drop is critical, assuming $P_{Intermediate}$ to calculate flow, and the Fisher® Monitor Sizing Program.

Estimating Flow when Pressure Drop is Critical

If the pressure drop across both regulators from P_1 to P_2 is critical (assume $P_{Intermediate} = P_1 - P_2/2 + P_2$, $P_1 - P_{Intermediate} \geq P_1$, and $P_{Intermediate} - P_2 \geq 1/2\ P_{Intermediate}$), and both regulators are the same type, the capacity of the two regulators together is 70 to 73% of a single regulator reducing the pressure from P_1 to P_2.

Assuming $P_{Intermediate}$ to Determine Flow

Assume $P_{Intermediate}$ is halfway between P_1 and P_2. Guess a regulator size. Use the assumed $P_{Intermediate}$ and the C_g for each regulator to calculate the available flow rate for each regulator. If $P_{Intermediate}$ was correct, the calculated flow through each regulator will be the same. If the flows are not the same, change $P_{Intermediate}$ and repeat the calculations. ($P_{Intermediate}$ will go to the correct assumed pressure whenever the flow demand reaches maximum capacity.)

Fisher® Monitor Sizing Program

Emerson Process Management - Regulator Technologies offers a Monitor Sizing Program on the Regulator Technologies Literature CD. Call your local Sales Office to request a copy of the CD. To locate your local Sales Office, log on to: www.emersonprocess.com/regulators.

Vacuum Control

Vacuum Applications

Vacuum regulators and vacuum breakers are widely used in process plants. Conventional regulators and relief valves might be suitable for vacuum service if applied correctly. This section provides fundamentals and examples.

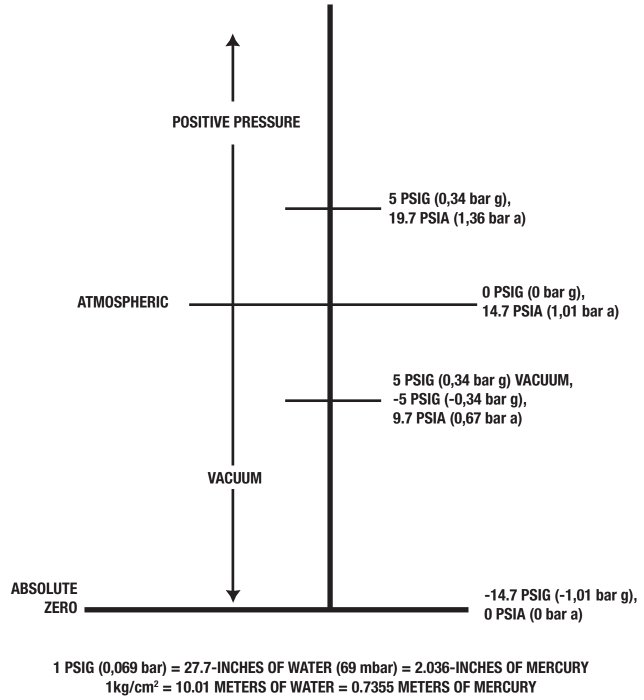


Figure 1. *Vacuum Terminology*

Vacuum Terminology

Engineers use a variety of terms to describe vacuum, which can cause some confusion. Determine whether the units are in absolute pressure or gauge pressure (0 psi gauge (0 bar gauge) is atmospheric pressure).

- 5 psig (0,34 bar g) vacuum is 5 psi (0,34 bar) below atmospheric pressure.
- -5 psig (-0,34 bar g) is 5 psi (0,34 bar) below atmospheric pressure.
- 9.7 psia (0,67 bar a) is 9.7 psi (0,67 bar) above absolute zero or 5 psi (0,34 bar) below atmospheric pressure (14.7 psia - 5 psi = 9.7 psia (1,01 bar a - 0,34 bar = 0,67 bar a)).

Vacuum Control Devices

Just like there are pressure reducing regulators and pressure relief valves for positive pressure service, there are also two basic types of valves for vacuum service. The terms used for each are sometimes confusing. Therefore, it is sometimes necessary to ask further questions to determine the required function of the valve. The terms vacuum regulator and vacuum breaker will be used in these pages to differentiate between the two types.

Vacuum Regulators

Vacuum regulators maintain a constant vacuum at the regulator inlet. A loss of this vacuum (increase in absolute pressure) beyond setpoint registers on the diaphragm and opens the disk. It depends on the valve as to which side of the diaphragm control pressure is measured. Opening the valve plug permits a downstream vacuum of lower absolute pressure than the controlled vacuum to restore the upstream vacuum to its original setting.

Besides the typical vacuum regulator, a conventional regulator can be suitable if applied correctly. Any pressure reducing regulator (spring to open device) that has an external control line connection and an O-ring stem seal can be used as a vacuum regulator. Installation requires a control line to connect the vacuum being controlled and the spring case. The regulator spring range is now a negative pressure range and the body flow direction is the same as in conventional pressure reducing service.

Vacuum Breakers (Relief Valves)

Vacuum breakers are used in applications where an increase in vacuum must be limited. An increase in vacuum (decrease in absolute pressure) beyond a certain value causes the diaphragm to move and open the disk. This permits atmospheric pressure or a positive pressure, or an upstream vacuum that has higher absolute pressure than the downstream vacuum, to enter the system and restore the controlled vacuum to its original pressure setting.

A vacuum breaker is a spring-to-close device, meaning that if there is no pressure on the valve the spring will push the valve plug into its seat. There are various Fisher® brand products to handle this application. Some valves are designed as vacuum breakers. Fisher brand relief valves can also be used as vacuum breakers.

Vacuum Control

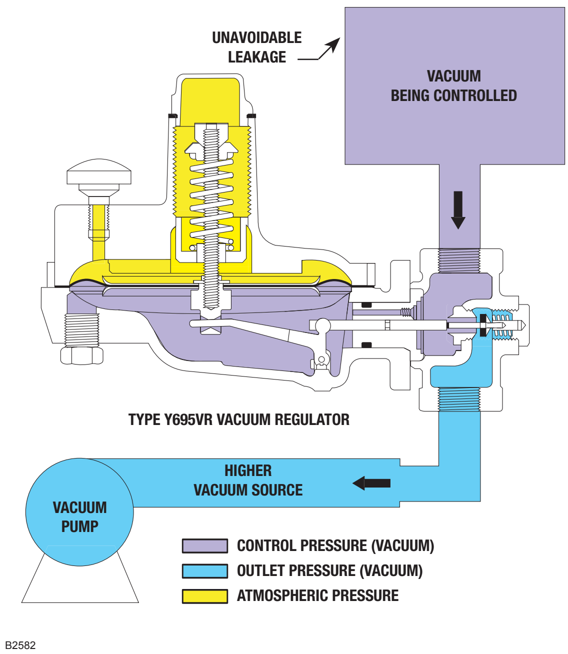


Figure 2. *Typical Vacuum Regulator*

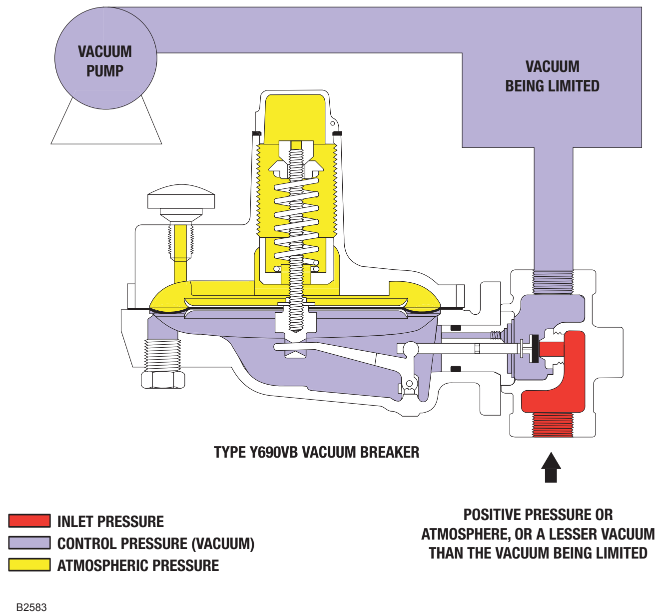


Figure 3. *Typical Vacuum Breaker*

A conventional relief valve can be used as a vacuum breaker, as long as it has a threaded spring case vent so a control line can be attached. If inlet pressure is atmospheric air, then the internal pressure registration from body inlet to lower casing admits atmospheric pressure to the lower casing. If inlet pressure is not atmospheric, a relief valve in which the lower casing can be vented to atmosphere when the body inlet is pressurized must be chosen. In this case, the terminology “blocked throat” and “external registration with O-ring stem seal” are used for clarity.

A spring that normally has a range of 6 to 11-inches w.c. (15 to 27 mbar) positive pressure will now have a range of 6 to 11-inches w.c. (15 to 27 mbar) vacuum (negative pressure). It may be expedient to bench set the vacuum breaker if the type chosen uses a spring case closing cap. Removing the closing cap to gain access to the adjusting screw will admit air into the spring case when in vacuum service.

Vacuum Control

Vacuum Regulator Installation Examples

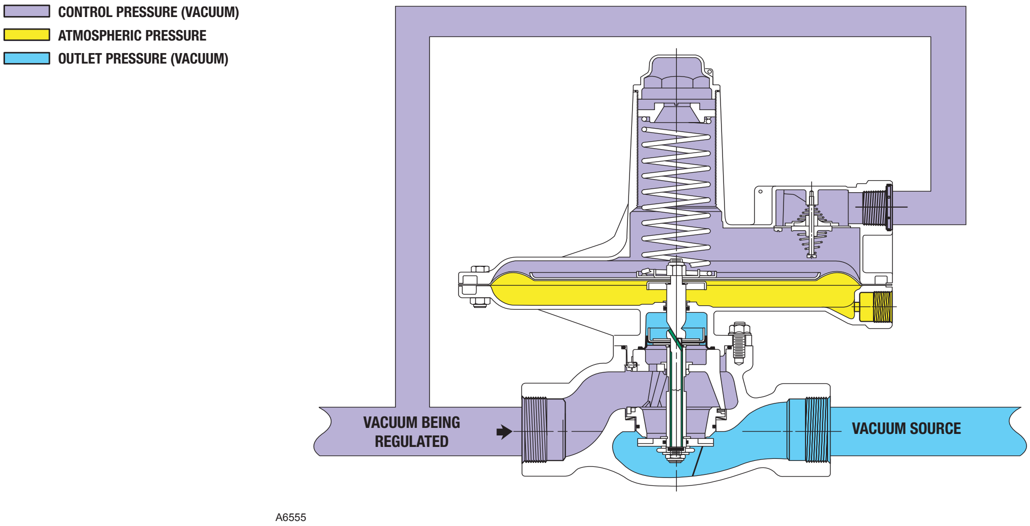


Figure 4. *Type 133L*

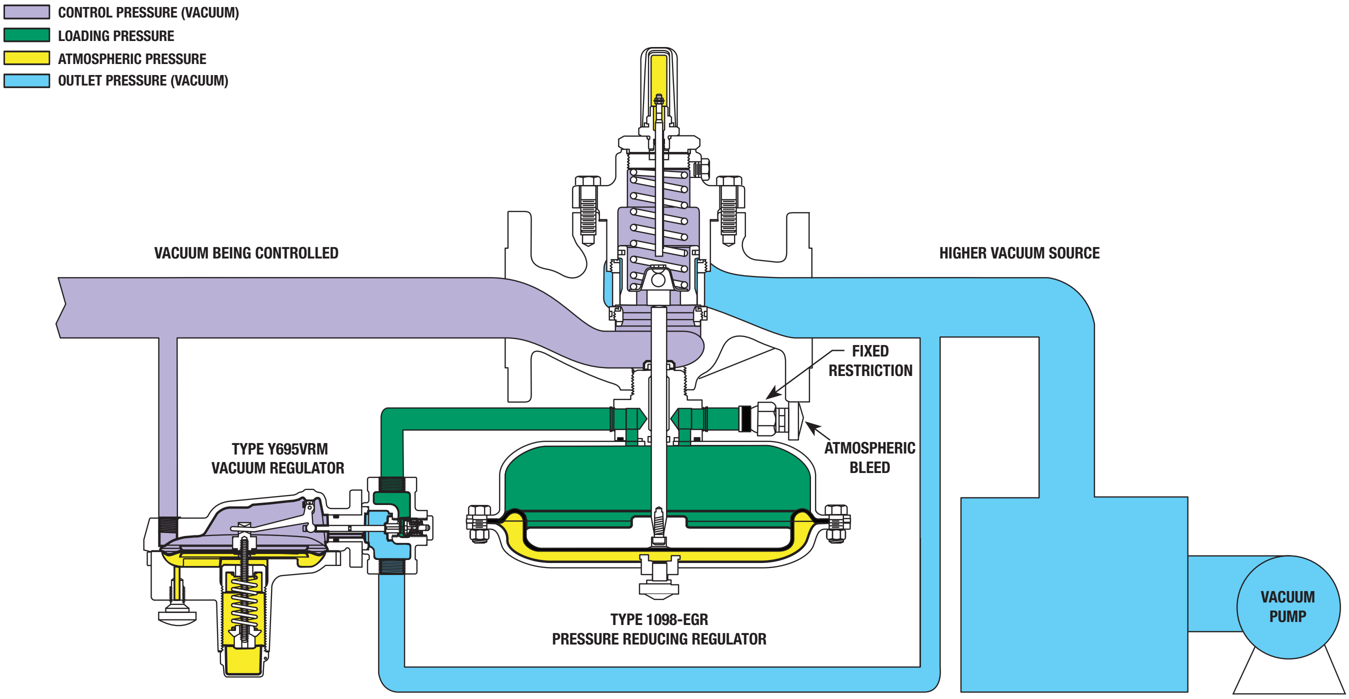


Figure 5. *Type Y695VRM used with Type 1098-EGR in a Vacuum Regulator Installation*

Vacuum Control

Vacuum Breaker Installation Examples

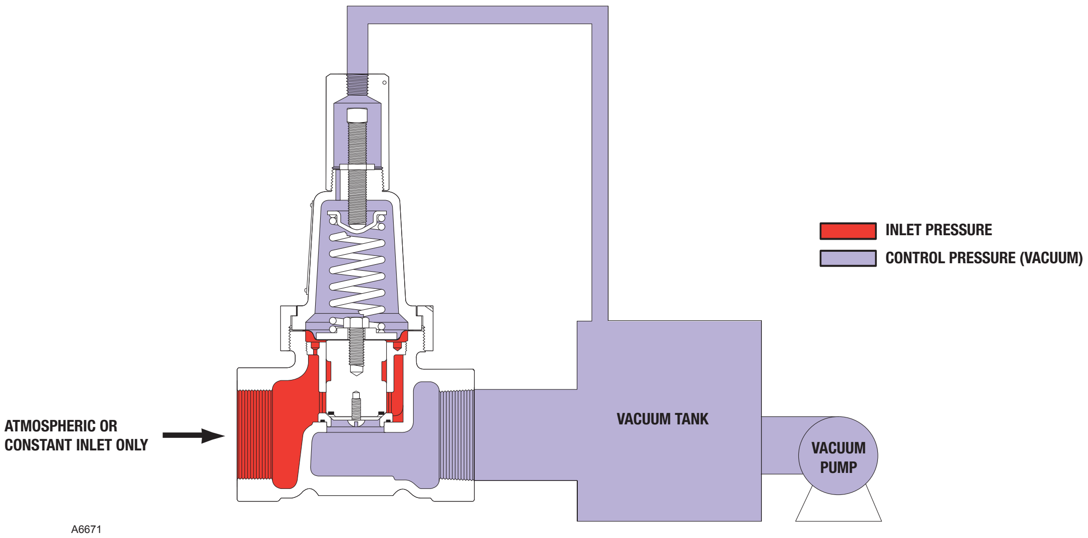


Figure 6. *Type 1805*

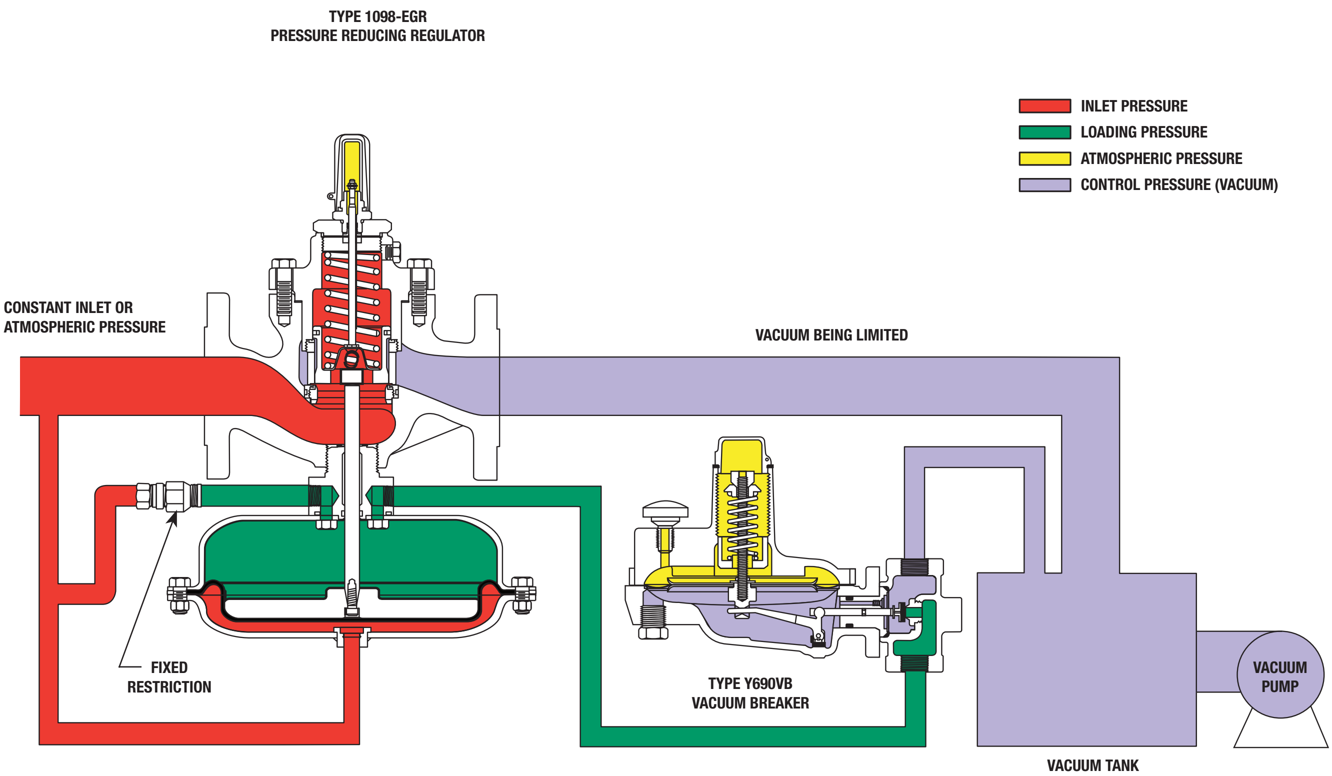


Figure 7. *Type Y690VB used with Type 1098-EGR in a Vacuum Breaker Installation. If the positive pressure exceeds the Type 1098-EGR casing rating, then a Type 67CF with a Type H800 relief valve should be added.*

Vacuum Control

Vacuum Breaker Installation Examples

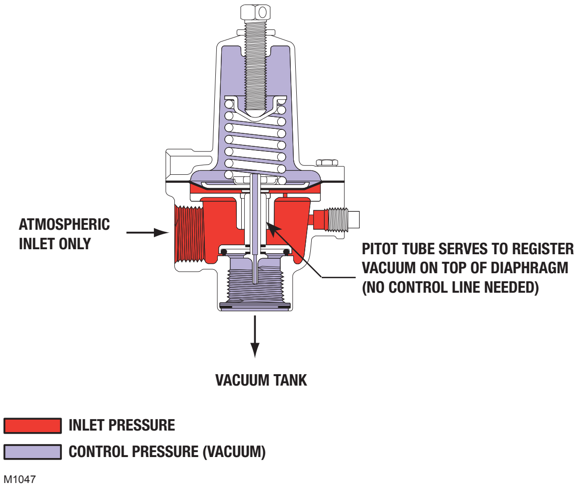
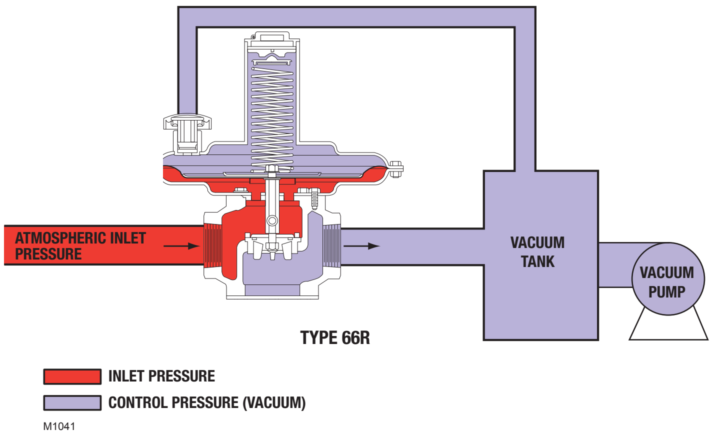


Figure 8. *Type 289H Relief Valve used in a Vacuum Breaker Installation*



If inlet is positive pressure:

- Select balancing diaphragm and tapped lower casing construction.
- Leave lower casing open to atmospheric pressure.

Figure 9. *Type 66R Relief Valve used in a Vacuum Breaker Installation*

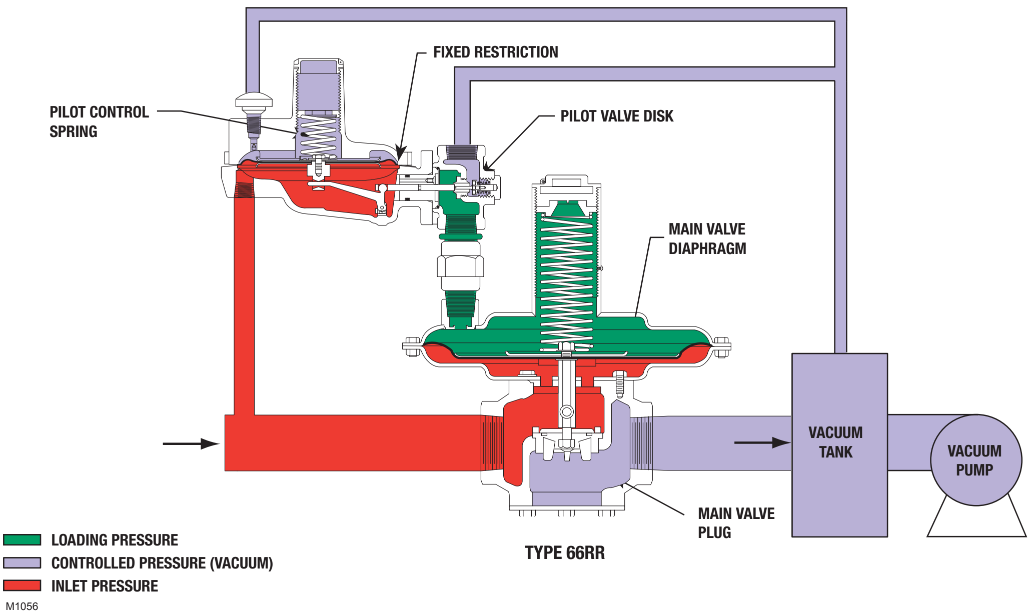


Figure 10. *Type 66RR Relief Valve used in a Vacuum Breaker Installation*

Vacuum Control

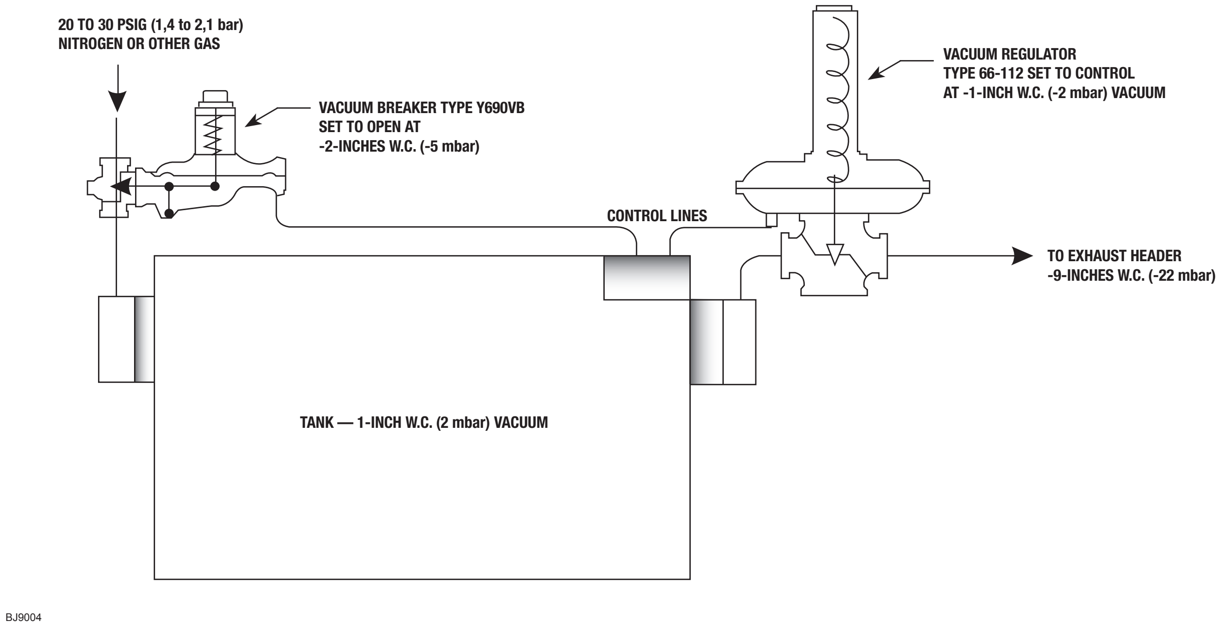


Figure 11. *Example of Gas Blanketing in Vacuum*

Gas Blanketing in Vacuum

When applications arise where the gas blanketing requirements are in vacuum, a combination of a vacuum breaker and a regulator may be used. For example, in low inches of water column vacuum, a Type Y690VB vacuum breaker and a Type 66-112 vacuum regulator can be used for very precise control.

Vacuum blanketing is useful for vessel leakage to atmosphere and the material inside the vessel is harmful to the surrounding environment. If leakage were to occur, only outside air would enter the vessel because of the pressure differential in the tank. Therefore, any process vapors in the tank would be contained.

Features of Fisher® Brand Vacuum Regulators and Breakers

- **Precision Control of Low Pressure Settings—**Large diaphragm areas provide more accurate control at low pressure settings. Some of these regulators are used as pilots on our Tank Blanketing and Vapor Recovery Regulators. Therefore, they are designed to be highly accurate, usually within 1-inch w.c. (2 mbar).
- **Corrosion Resistance**—Constructions are available in a variety of materials for compatibility with corrosive process gases. Wide selection of elastomers compatible with flowing media.
- **Rugged Construction—**Diaphragm case and internal parts are designed to withstand vibration and shock.
- **Wide Product Offering—**Fisher® brand regulators can be either direct-operated or pilot-operated regulators.
- **Fisher Brand Advantage**—Widest range of products and a proven history in the design and manufacture of process control equipment. A sales channel that offers local stock and support.
- **Spare Parts**—Low cost parts that are interchangeable with other Fisher brand in your plant.
- **Easy Sizing and Selection**—Most applications can be sized utilizing the Fisher brand Sizing Program and Sizing Coefficients.

Valve Sizing Calculations (Traditional Method)

Introduction

Fisher® regulators and valves have traditionally been sized using equations derived by the company. There are now standardized calculations that are becoming accepted worldwide. Some product literature continues to demonstrate the traditional method, but the trend is to adopt the standardized method. Therefore, both methods are covered in this application guide.

Improper valve sizing can be both expensive and inconvenient. A valve that is too small will not pass the required flow, and the process will be starved. An oversized valve will be more expensive, and it may lead to instability and other problems.

The days of selecting a valve based upon the size of the pipeline are gone. Selecting the correct valve size for a given application requires a knowledge of process conditions that the valve will actually see in service. The technique for using this information to size the valve is based upon a combination of theory and experimentation.

Sizing for Liquid Service

Using the principle of conservation of energy, Daniel Bernoulli found that as a liquid flows through an orifice, the square of the fluid velocity is directly proportional to the pressure differential across the orifice and inversely proportional to the specific gravity of the fluid. The greater the pressure differential, the higher the velocity; the greater the density, the lower the velocity. The volume flow rate for liquids can be calculated by multiplying the fluid velocity times the flow area.

By taking into account units of measurement, the proportionality relationship previously mentioned, energy losses due to friction and turbulence, and varying discharge coefficients for various types of orifices (or valve bodies), a basic liquid sizing equation can be written as follows

$$Q = C_V \sqrt{\Delta P / G} \qquad (1)$$

where:

- Q = Capacity in gallons per minute
- C_v = Valve sizing coefficient determined experimentally for each style and size of valve, using water at standard conditions as the test fluid
- ΔP = Pressure differential in psi
- G = Specific gravity of fluid (water at 60°F = 1.0000)

Thus, C_v is numerically equal to the number of U.S. gallons of water at 60°F that will flow through the valve in one minute when the pressure differential across the valve is one pound per square inch. C_v varies with both size and style of valve, but provides an index for comparing liquid capacities of different valves under a standard set of conditions.

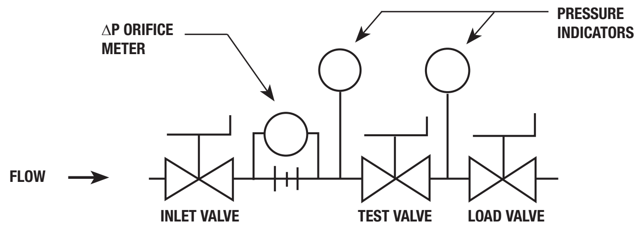


Figure 1. *Standard FCI Test Piping for C_v Measurement*

To aid in establishing uniform measurement of liquid flow capacity coefficients (C_v) among valve manufacturers, the Fluid Controls Institute (FCI) developed a standard test piping arrangement, shown in Figure 1. Using such a piping arrangement, most valve manufacturers develop and publish C_v information for their products, making it relatively easy to compare capacities of competitive products.

To calculate the expected C_v for a valve controlling water or other liquids that behave like water, the basic liquid sizing equation above can be re-written as follows

$$C_V = Q \sqrt{\frac{G}{\Delta P}} \qquad (2)$$

Viscosity Corrections

Viscous conditions can result in significant sizing errors in using the basic liquid sizing equation, since published C_v values are based on test data using water as the flow medium. Although the majority of valve applications will involve fluids where viscosity corrections can be ignored, or where the corrections are relatively small, fluid viscosity should be considered in each valve selection.

Emerson Process Management has developed a nomograph (Figure 2) that provides a viscosity correction factor (F_v). It can be applied to the standard C_v coefficient to determine a corrected coefficient (C_{vr}) for viscous applications.

Finding Valve Size

Using the C_v determined by the basic liquid sizing equation and the flow and viscosity conditions, a fluid Reynolds number can be found by using the nomograph in Figure 2. The graph of Reynolds number vs. viscosity correction factor (F_v) is used to determine the correction factor needed. (If the Reynolds number is greater than 3500, the correction will be ten percent or less.) The actual required C_v (C_{vr}) is found by the equation:

$$C_{vr} = F_V\, C_V \qquad (3)$$

From the valve manufacturer's published liquid capacity information, select a valve having a C_v equal to or higher than the required coefficient (C_{vr}) found by the equation above.

Valve Sizing Calculations (Traditional Method)

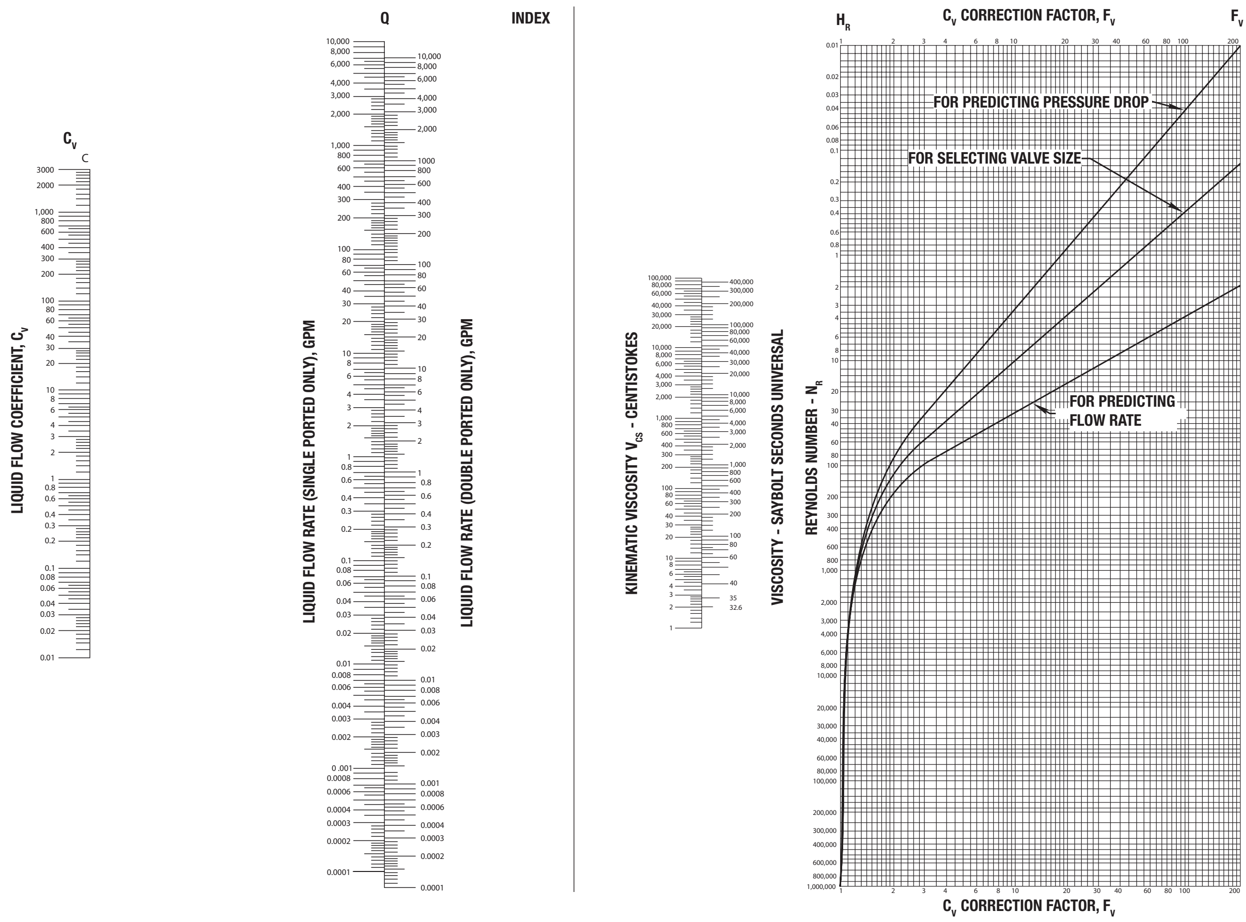


Figure 2. *Nomograph for Determining Viscosity Correction*

Nomograph Instructions

Use this nomograph to correct for the effects of viscosity. When assembling data, all units must correspond to those shown on the nomograph. For high-recovery, ball-type valves, use the liquid flow rate Q scale designated for single-ported valves. For butterfly and eccentric disk rotary valves, use the liquid flow rate Q scale designated for double-ported valves.

Nomograph Equations

1. Single-Ported Valves: $N_R = 17250 \dfrac{Q}{\sqrt{C_V \nu_{CS}}}$

2. Double-Ported Valves: $N_R = 12200 \dfrac{Q}{\sqrt{C_V \nu_{CS}}}$

Nomograph Procedure

1. Lay a straight edge on the liquid sizing coefficient on C_v scale and flow rate on Q scale. Mark intersection on index line. Procedure A uses value of C_{vc}; Procedures B and C use value of C_{vr}.
2. Pivot the straight edge from this point of intersection with index line to liquid viscosity on proper n scale. Read Reynolds number on N_R scale.
3. Proceed horizontally from intersection on N_R scale to proper curve, and then vertically upward or downward to F_v scale. Read C_v correction factor on F_v scale.

Valve Sizing Calculations (Traditional Method)

Predicting Flow Rate

Select the required liquid sizing coefficient (C_{vr}) from the manufacturer's published liquid sizing coefficients (C_v) for the style and size valve being considered. Calculate the maximum flow rate (Q_{max}) in gallons per minute (assuming no viscosity correction required) using the following adaptation of the basic liquid sizing equation:

$$Q_{max} = C_{vr}\sqrt{\Delta P / G} \qquad (4)$$

Then incorporate viscosity correction by determining the fluid Reynolds number and correction factor F_v from the viscosity correction nomograph and the procedure included on it.

Calculate the predicted flow rate (Q_{pred}) using the formula:

$$Q_{pred} = \frac{Q_{max}}{F_V} \qquad (5)$$

Predicting Pressure Drop

Select the required liquid sizing coefficient (C_{vr}) from the published liquid sizing coefficients (C_v) for the valve style and size being considered. Determine the Reynolds number and correct factor F_v from the nomograph and the procedure on it. Calculate the sizing coefficient (C_{vc}) using the formula:

$$C_{VC} = \frac{C_{vr}}{F_v} \qquad (6)$$

Calculate the predicted pressure drop (ΔP_{pred}) using the formula:

$$\Delta P_{pred} = G\,(Q/C_{vc})^2 \qquad (7)$$

Flashing and Cavitation

The occurrence of flashing or cavitation within a valve can have a significant effect on the valve sizing procedure. These two related physical phenomena can limit flow through the valve in many applications and must be taken into account in order to accurately size a valve. Structural damage to the valve and adjacent piping may also result. Knowledge of what is actually happening within the valve might permit selection of a size or style of valve which can reduce, or compensate for, the undesirable effects of flashing or cavitation.

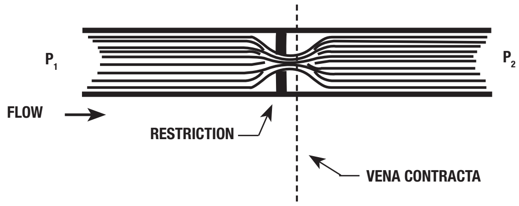


Figure 3. *Vena Contracta*

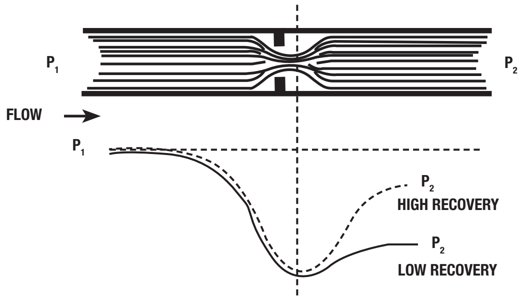


Figure 4. *Comparison of Pressure Profiles for High and Low Recovery Valves*

The "physical phenomena" label is used to describe flashing and cavitation because these conditions represent actual changes in the form of the fluid media. The change is from the liquid state to the vapor state and results from the increase in fluid velocity at or just downstream of the greatest flow restriction, normally the valve port. As liquid flow passes through the restriction, there is a necking down, or contraction, of the flow stream. The minimum cross-sectional area of the flow stream occurs just downstream of the actual physical restriction at a point called the vena contracta, as shown in Figure 3.

To maintain a steady flow of liquid through the valve, the velocity must be greatest at the vena contracta, where cross sectional area is the least. The increase in velocity (or kinetic energy) is accompanied by a substantial decrease in pressure (or potential energy) at the vena contracta. Farther downstream, as the fluid stream expands into a larger area, velocity decreases and pressure increases. But, of course, downstream pressure never recovers completely to equal the pressure that existed upstream of the valve. The pressure differential (ΔP) that exists across the valve

Valve Sizing Calculations (Traditional Method)

is a measure of the amount of energy that was dissipated in the valve. Figure 4 provides a pressure profile explaining the differing performance of a streamlined high recovery valve, such as a ball valve and a valve with lower recovery capabilities due to greater internal turbulence and dissipation of energy.

Regardless of the recovery characteristics of the valve, the pressure differential of interest pertaining to flashing and cavitation is the differential between the valve inlet and the vena contracta. If pressure at the vena contracta should drop below the vapor pressure of the fluid (due to increased fluid velocity at this point) bubbles will form in the flow stream. Formation of bubbles will increase greatly as vena contracta pressure drops further below the vapor pressure of the liquid. At this stage, there is no difference between flashing and cavitation, but the potential for structural damage to the valve definitely exists.

If pressure at the valve outlet remains below the vapor pressure of the liquid, the bubbles will remain in the downstream system and the process is said to have "flashed." Flashing can produce serious erosion damage to the valve trim parts and is characterized by a smooth, polished appearance of the eroded surface. Flashing damage is normally greatest at the point of highest velocity, which is usually at or near the seat line of the valve plug and seat ring.

However, if downstream pressure recovery is sufficient to raise the outlet pressure above the vapor pressure of the liquid, the bubbles will collapse, or implode, producing cavitation. Collapsing of the vapor bubbles releases energy and produces a noise similar to what one would expect if gravel were flowing through the valve. If the bubbles collapse in close proximity to solid surfaces, the energy released gradually wears the material leaving a rough, cylinder like surface. Cavitation damage might extend to the downstream pipeline, if that is where pressure recovery occurs and the bubbles collapse. Obviously, "high recovery" valves tend to be more subject to cavitation, since the downstream pressure is more likely to rise above the vapor pressure of the liquid.

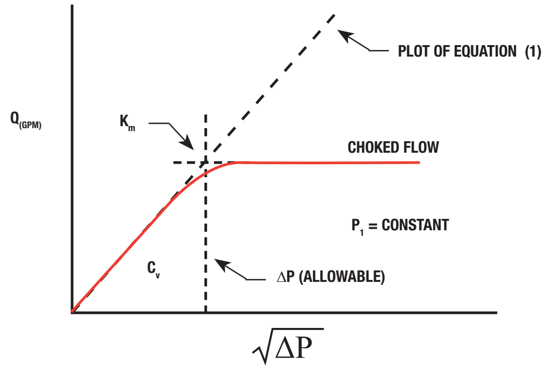


Figure 5. *Flow Curve Showing C_v and K_m*

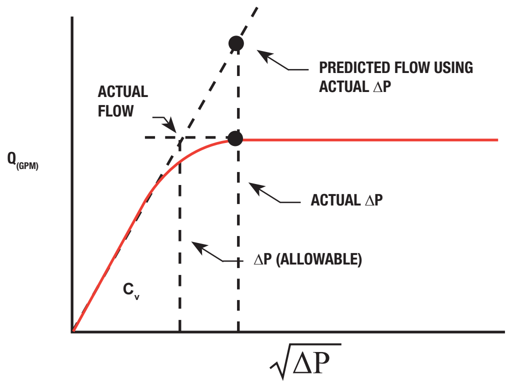


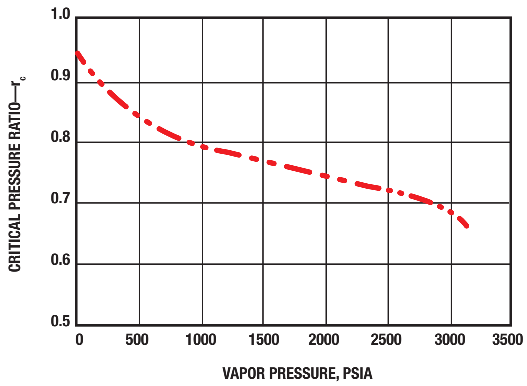
Figure 6. *Relationship Between Actual ΔP and ΔP Allowable*

Choked Flow

Aside from the possibility of physical equipment damage due to flashing or cavitation, formation of vapor bubbles in the liquid flow stream causes a crowding condition at the vena contracta which tends to limit flow through the valve. So, while the basic liquid sizing equation implies that there is no limit to the amount of flow through a valve as long as the differential pressure across the valve increases, the realities of flashing and cavitation prove otherwise.

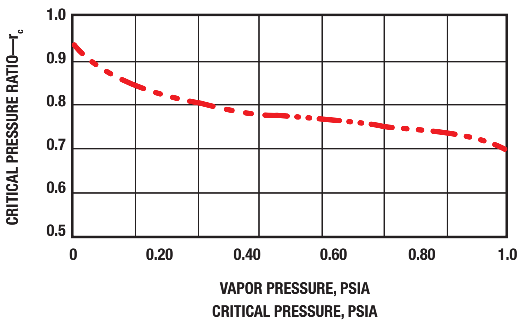
If valve pressure drop is increased slightly beyond the point where bubbles begin to form, a choked flow condition is reached. With constant upstream pressure, further increases in pressure drop (by reducing downstream pressure) will not produce increased flow. The limiting pressure differential is designated ΔP_{allow} and the valve recovery coefficient (K_m) is experimentally determined for each valve, in order to relate choked flow for that particular valve to the basic liquid sizing equation. K_m is normally published with other valve capacity coefficients. Figures 5 and 6 show these flow vs. pressure drop relationships.

Valve Sizing Calculations (Traditional Method)



USE THIS CURVE FOR WATER. ENTER ON THE ABSCISSA AT THE WATER VAPOR PRESSURE AT THE VALVE INLET. PROCEED VERTICALLY TO INTERSECT THE CURVE. MOVE HORIZONTALLY TO THE LEFT TO READ THE CRITICAL PRESSURE RATIO, R_c, ON THE ORDINATE.

Figure 7. *Critical Pressure Ratios for Water*



USE THIS CURVE FOR LIQUIDS OTHER THAN WATER. DETERMINE THE VAPOR PRESSURE/CRITICAL PRESSURE RATIO BY DIVIDING THE LIQUID VAPOR PRESSURE AT THE VALVE INLET BY THE CRITICAL PRESSURE OF THE LIQUID. ENTER ON THE ABSCISSA AT THE RATIO JUST CALCULATED AND PROCEED VERTICALLY TO INTERSECT THE CURVE. MOVE HORIZONTALLY TO THE LEFT AND READ THE CRITICAL PRESSURE RATIO, R_c, ON THE ORDINATE.

Figure 8. *Critical Pressure Ratios for Liquid Other than Water*

Use the following equation to determine maximum allowable pressure drop that is effective in producing flow. Keep in mind, however, that the limitation on the sizing pressure drop, ΔP_{allow}, does not imply a maximum pressure drop that may be controlled y the valve.

$$\Delta P_{allow} = K_m (P_1 - r_c P_v) \quad (8)$$

where:

ΔP_{allow} = maximum allowable differential pressure for sizing purposes, psi

K_m = valve recovery coefficient from manufacturer's literature

P_1 = body inlet pressure, psia

r_c = critical pressure ratio determined from Figures 7 and 8

P_v = vapor pressure of the liquid at body inlet temperature, psia (vapor pressures and critical pressures for many common liquids are provided in the Physical Constants of Hydrocarbons and Physical Constants of Fluids tables; refer to the Table of Contents for the page number).

After calculating ΔP_{allow}, substitute it into the basic liquid sizing equation $Q = C_V \sqrt{\Delta P / G}$ to determine either Q or C_v. If the actual ΔP is less the ΔP_{allow}, then the actual ΔP should be used in the equation.

The equation used to determine ΔP_{allow} should also be used to calculate the valve body differential pressure at which significant cavitation can occur. Minor cavitation will occur at a slightly lower pressure differential than that predicted by the equation, but should produce negligible damage in most globe-style control valves.

Consequently, initial cavitation and choked flow occur nearly simultaneously in globe-style or low-recovery valves.

However, in high-recovery valves such as ball or butterfly valves, significant cavitation can occur at pressure drops below that which produces choked flow. So although ΔP_{allow} and K_m are useful in predicting choked flow capacity, a separate cavitation index (K_c) is needed to determine the pressure drop at which cavitation damage will begin (ΔP_c) in high-recovery valves.

The equation can e expressed:

$$\Delta P_C = K_C (P_1 - P_V) \quad (9)$$

This equation can be used anytime outlet pressure is greater than the vapor pressure of the liquid.

Addition of anti-cavitation trim tends to increase the value of K_m. In other words, choked flow and incipient cavitation will occur at substantially higher pressure drops than was the case without the anti-cavitation accessory.

Valve Sizing Calculations (Traditional Method)

Liquid Sizing Equation Application		
EQUATION		APPLICATION
1	$Q = C_v \sqrt{\Delta P / G}$	Basic liquid sizing equation. Use to determine proper valve size for a given set of service conditions. (Remember that viscosity effects and valve recovery capabilities are not considered in this basic equation.)
2	$C_V = Q \sqrt{\frac{G}{\Delta P}}$	Use to calculate expected C_v for valve controlling water or other liquids that behave like water.
3	$C_{vr} = F_V C_V$	Use to find actual required C_v for equation (2) after including viscosity correction factor.
4	$Q_{max} = C_{vr} \sqrt{\Delta P / G}$	Use to find maximum flow rate assuming no viscosity correction is necessary.
5	$Q_{pred} = \frac{Q_{max}}{F_V}$	Use to predict actual flow rate based on equation (4) and viscosity factor correction.
6	$C_{VC} = \frac{C_{vr}}{F_v}$	Use to calculate corrected sizing coefficient for use in equation (7).
7	$\Delta P_{pred} = G\,(Q/C_{vc})^2$	Use to predict pressure drop for viscous liquids.
8	$\Delta P_{allow} = K_m\,(P_1 - r_c P_v)$	Use to determine maximum allowable pressure drop that is effective in producing flow.
9	$\Delta P_C = K_C\,(P_1 - P_V)$	Use to predict pressure drop at which cavitation will begin in a valve with high recovery characteristics.

Liquid Sizing Summary

The most common use of the basic liquid sizing equation is to determine the proper valve size for a given set of service conditions. The first step is to calculate the required C_v by using the sizing equation. The ΔP used in the equation must be the actual valve pressure drop or ΔP_{allow}, whichever is smaller. The second step is to select a valve, from the manufacturer's literature, with a C_v equal to or greater than the calculated value.

Accurate valve sizing for liquids requires use of the dual coefficients of C_v and K_m. A single coefficient is not sufficient to describe both the capacity and the recovery characteristics of the valve. Also, use of the additional cavitation index factor K_c is appropriate in sizing high recovery valves, which may develop damaging cavitation at pressure drops well below the level of the choked flow.

Liquid Sizing Nomenclature

C_v = valve sizing coefficient for liquid determined experimentally for each size and style of valve, using water at standard conditions as the test fluid

C_{vc} = calculated C_v coefficient including correction for viscosity

C_{vr} = corrected sizing coefficient required for viscous applications

ΔP = differential pressure, psi

ΔP_{allow} = maximum allowable differential pressure for sizing purposes, psi

ΔP_c = pressure differential at which cavitation damage begins, psi

F_v = viscosity correction factor

G = specific gravity of fluid (water at 60°F = 1.0000)

K_c = dimensionless cavitation index used in determining ΔP_c

K_m = valve recovery coefficient from manufacturer's literature

P_1 = body inlet pressure, psia

P_v = vapor pressure of liquid at body inlet temperature, psia

Q = flow rate capacity, gallons per minute

Q_{max} = designation for maximum flow rate, assuming no viscosity correction required, gallons per minute

Q_{pred} = predicted flow rate after incorporating viscosity correction, gallons per minute

r_c = critical pressure ratio

Valve Sizing Calculations (Traditional Method)

Sizing for Gas or Steam Service

A sizing procedure for gases can be established based on adaptions of the basic liquid sizing equation. By introducing conversion factors to change flow units from gallons per minute to cubic feet per hour and to relate specific gravity in meaningful terms of pressure, an equation can be derived for the flow of air at 60°F. Because 60°F corresponds to 520° on the Rankine absolute temperature scale, and because the specific gravity of air at 60°F is 1.0, an additional factor can be included to compare air at 60°F with specific gravity (G) and absolute temperature (T) of any other gas. The resulting equation an be written:

$$Q_{SCFH} = 59.64\, C_V P_1 \sqrt{\frac{\Delta P}{P_1}} \sqrt{\frac{520}{GT}} \qquad \text{(A)}$$

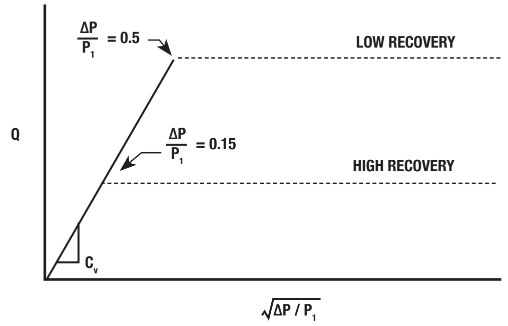


Figure 9. *Critical Flow for High and Low Recovery Valves with Equal C_v*

The equation shown above, while valid at very low pressure drop ratios, has been found to be very misleading when the ratio of pressure drop (ΔP) to inlet pressure (P_1) exceeds 0.02. The deviation of actual flow capacity from the calculated flow capacity is indicated in Figure 8 and results from compressibility effects and critical flow limitations at increased pressure drops.

Critical flow limitation is the more significant of the two problems mentioned. Critical flow is a choked flow condition caused by increased gas velocity at the vena contracta. When velocity at the vena contracta reaches sonic velocity, additional increases in ΔP by reducing downstream pressure produce no increase in flow. So, after critical flow condition is reached (whether at a pressure drop/inlet pressure ratio of about 0.5 for glove valves or at much lower ratios for high recovery valves) the equation above becomes completely useless. If applied, the C_v equation gives a much higher indicated capacity than actually will exist. And in the case of a high recovery valve which reaches critical flow at a low pressure drop ratio (as indicated in Figure 8), the critical flow capacity of the valve may be over-estimated by as much as 300 percent.

The problems in predicting critical flow with a C_v-based equation led to a separate gas sizing coefficient based on air flow tests. The coefficient (C_g) was developed experimentally for each type and size of valve to relate critical flow to absolute inlet pressure. By including the correction factor used in the previous equation to compare air at 60°F with other gases at other absolute temperatures, the critical flow equation an be written:

$$Q_{critical} = C_g P_1 \sqrt{520 / GT} \qquad \text{(B)}$$

Universal Gas Sizing Equation

To account for differences in flow geometry among valves, equations (A) and (B) were consolidated by the introduction of an additional factor (C_1). C_1 is defined as the ratio of the gas sizing coefficient and the liquid sizing coefficient and provides a numerical indicator of the valve's recovery capabilities. In general, C_1 values can range from about 16 to 37, based on the individual valve's recovery characteristics. As shown in the example, two valves with identical flow areas and identical critical flow (C_g) capacities can have widely differing C_1 values dependent on the effect internal flow geometry has on liquid flow capacity through each valve. Example:

High Recovery Valve

C_g = 4680
C_v = 254
C_1 = C_g/C_v
= 4680/254
= 18.4

Low Recovery Valve

C_g = 4680
C_v = 135
C_1 = C_g/C_v
= 4680/135
= 34.7

Valve Sizing Calculations (Traditional Method)

So we see that two sizing coefficients are needed to accurately size valves for gas flow—C_g to predict flow based on physical size or flow area, and C_1 to account for differences in valve recovery characteristics. A blending equation, called the Universal Gas Sizing Equation, combines equations (A) and (B) by means of a sinusoidal function, and is based on the "perfect gas" laws. It can be expressed in either of the following manners:

$$Q_{SCFH} = \sqrt{\frac{520}{GT}}\; C_g P_1 \,\mathrm{SIN}\left[\left(\frac{59.64}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{rad} \qquad \text{(C)}$$

OR

$$Q_{SCFH} = \sqrt{\frac{520}{GT}}\; C_g P_1 \,\mathrm{SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg} \qquad \text{(D)}$$

In either form, the equation indicates critical flow when the sine function of the angle designated within the brackets equals unity. The pressure drop ratio at which critical flow occurs is known as the critical pressure drop ratio. It occurs when the sine angle reaches $\pi/2$ radians in equation (C) or 90 degrees in equation (D). As pressure drop across the valve increases, the sine angle increases from zero up to $\pi/2$ radians (90°). If the angle were allowed to increase further, the equations would predict a decrease in flow. Because this is not a realistic situation, the angle must be limited to 90 degrees maximum.

Although "perfect gases," as such, do not exist in nature, there are a great many applications where the Universal Gas Sizing Equation, (C) or (D), provides a very useful and usable approximation.

General Adaptation for Steam and Vapors

The density form of the Universal Gas Sizing Equation is the most general form and can be used for both perfect and non-perfect gas applications. Applying the equation requires knowledge of one additional condition not included in previous equations, that being the inlet gas, steam, or vapor density (d_1) in pounds per cubic foot. (Steam density can be determined from tables.)

Then the following adaptation of the Universal Gas Sizing Equation can be applied:

$$Q_{lb/hr} = 1.06\sqrt{d_1 P_1}\; C_g \,\mathrm{SIN}\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right) \text{Deg} \qquad \text{(E)}$$

Special Equation Form for Steam Below 1000 psig

If steam applications do not exceed 1000 psig, density changes can be compensated for by using a special adaptation of the Universal Gas Sizing Equation. It incorporates a factor for amount of superheat in degrees Fahrenheit (T_{sh}) and also a sizing coefficient (C_s) for steam. Equation (F) eliminates the need for finding the density of superheated steam, which was required in Equation (E). At pressures below 1000 psig, a constant relationship exists between the gas sizing coefficient (C_g) and the steam coefficient (C_s). This relationship can be expressed: $C_s = C_g/20$. For higher steam pressure application, use Equation (E).

$$Q_{lb/hr} = \left[\left(\frac{C_S P_1}{1 + 0.00065T_{sh}}\right)\right] \mathrm{SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg} \qquad \text{(F)}$$

Gas and Steam Sizing Summary

The Universal Gas Sizing Equation can be used to determine the flow of gas through any style of valve. Absolute units of temperature and pressure must be used in the equation. When the critical pressure drop ratio causes the sine angle to be 90 degrees, the equation will predict the value of the critical flow. For service conditions that would result in an angle of greater than 90 degrees, the equation must be limited to 90 degrees in order to accurately determine the critical flow.

Most commonly, the Universal Gas Sizing Equation is used to determine proper valve size for a given set of service conditions. The first step is to calculate the required C_g by using the Universal Gas Sizing Equation. The second step is to select a valve from the manufacturer's literature. The valve selected should have a C_g which equals or exceeds the calculated value. Be certain that the assumed C_1 value for the valve is selected from the literature.

It is apparent that accurate valve sizing for gases that requires use of the dual coefficient is not sufficient to describe both the capacity and the recovery characteristics of the valve.

Proper selection of a control valve for gas service is a highly technical problem with many factors to be considered. Leading valve manufacturers provide technical information, test data, sizing catalogs, nomographs, sizing slide rules, and computer or calculator programs that make valve sizing a simple and accurate procedure.

Valve Sizing Calculations (Traditional Method)

Gas and Steam Sizing Equation Application		
	EQUATION	APPLICATION
A	$Q_{SCFH} = 59.64\, C_V P_1 \sqrt{\frac{\Delta P}{P_1}} \sqrt{\frac{520}{GT}}$	Use only at very low pressure drop (DP/P_1) ratios of 0.02 or less.
B	$Q_{critical} = C_g P_1 \sqrt{520 / GT}$	Use only to determine critical flow capacity at a given inlet pressure.
C	$Q_{SCFH} = \sqrt{\frac{520}{GT}}\ C_g P_1 \text{ SIN}\left[\left(\frac{59.64}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{rad}$ OR	Universal Gas Sizing Equation. Use to predict flow for either high or low recovery valves, for any gas adhering to the perfect gas laws, and under any service conditions.
D	$Q_{SCFH} = \sqrt{\frac{520}{GT}}\ C_g P_1 \text{ SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg}$	
E	$Q_{lb/hr} = 1.06 \sqrt{d_1 P_1}\ C_g \text{ SIN}\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right) \text{Deg}$	Use to predict flow for perfect or non-perfect gas sizing applications, for any vapor including steam, at any service condition when fluid density is known.
F	$Q_{lb/hr} = \left[\left(\frac{C_S P_1}{1 + 0.00065 T_{sh}}\right)\right] \text{SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg}$	Use only to determine steam flow when inlet pressure is 1000 psig or less.

Gas and Steam Sizing Nomenclature

C_1 = C_g/C_v

C_g = gas sizing coefficient

C_s = steam sizing coefficient, $C_g/20$

C_v = liquid sizing coefficient

d_1 = density of steam or vapor at inlet, pounds/cu. foot

G = gas specific gravity (air = 1.0)

P_1 = valve inlet pressure, psia

ΔP = pressure drop across valve, psi

$Q_{critical}$ = critical flow rate, SCFH

Q_{SCFH} = gas flow rate, SCFH

$Q_{lb/hr}$ = steam or vapor flow rate, pounds per hour

T = absolute temperature of gas at inlet, degrees Rankine

T_{sh} = degrees of superheat, °F

Valve Sizing (Standardized Method)

Introduction

Fisher® regulators and valves have traditionally been sized using equations derived by the company. There are now standardized calculations that are becoming accepted world wide. Some product literature continues to demonstrate the traditional method, but the trend is to adopt the standardized method. Therefore, both methods are covered in this application guide.

Liquid Valve Sizing

Standardization activities for control valve sizing can be traced back to the early 1960s when a trade association, the Fluids Control Institute, published sizing equations for use with both compressible and incompressible fluids. The range of service conditions that could be accommodated accurately by these equations was quite narrow, and the standard did not achieve a high degree of acceptance. In 1967, the ISA established a committee to develop and publish standard equations. The efforts of this committee culminated in a valve sizing procedure that has achieved the status of American National Standard. Later, a committee of the International Electrotechnical Commission (IEC) used the ISA works as a basis to formulate international standards for sizing control valves. (Some information in this introductory material has been extracted from ANSI/ISA S75.01 standard with the permission of the publisher, the ISA.) Except for some slight differences in nomenclature and procedures, the ISA and IEC standards have been harmonized. ANSI/ISA Standard S75.01 is harmonized with IEC Standards 534-2-1 and 534-2-2. (IEC Publications 534-2, Sections One and Two for incompressible and compressible fluids, respectively.)

In the following sections, the nomenclature and procedures are explained, and sample problems are solved to illustrate their use.

Sizing Valves for Liquids

Following is a step-by-step procedure for the sizing of control valves for liquid flow using the IEC procedure. Each of these steps is important and must be considered during any valve sizing procedure. Steps 3 and 4 concern the determination of certain sizing factors that may or may not be required in the sizing equation depending on the service conditions of the sizing problem. If one, two, or all three of these sizing factors are to be included in the equation for a particular sizing problem, refer to the appropriate factor determination section(s) located in the text after the sixth step.

1. *Specify the variables required to size the valve as follows:*
   - Desired design
   - Process fluid (water, oil, etc.), and
   - Appropriate service conditions q or w, P_1, P_2, or ΔP, T_1, G_f, P_v, P_c, and υ.

   The ability to recognize which terms are appropriate for a specific sizing procedure can only be acquired through experience with different valve sizing problems. If any of the above terms appears to be new or unfamiliar, refer to the Abbreviations and Terminology Table 3-1 for a complete definition.

2. *Determine the equation constant, N.*

   N is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. Values for these various constants and their applicable units are given in the Equation Constants Table 3-2.

   Use N_1, if sizing the valve for a flow rate in volumetric units (GPM or Nm^3/h).

   Use N_6, if sizing the valve for a flow rate in mass units (pound/hr or kg/hr).

3. *Determine F_p, the piping geometry factor.*

   F_p is a correction factor that accounts for pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valve to be sized. If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_p has a value of 1.0 and simply drops out of the sizing equation.

   For rotary valves with reducers (swaged installations), and other valve designs and fitting styles, determine the F_p factors by using the procedure for determining F_p, the Piping Geometry Factor, page 637.

4. *Determine q_{max} (the maximum flow rate at given upstream conditions) or ΔP_{max} (the allowable sizing pressure drop).*

   The maximum or limiting flow rate (q_{max}), commonly called choked flow, is manifested by no additional increase in flow rate with increasing pressure differential with fixed upstream conditions. In liquids, choking occurs as a result of vaporization of the liquid when the static pressure within the valve drops below the vapor pressure of the liquid.

   The IEC standard requires the calculation of an allowable sizing pressure drop (ΔP_{max}), to account for the possibility of choked flow conditions within the valve. The calculated ΔP_{max} value is compared with the actual pressure drop specified in the service conditions, and the lesser of these two values is used in the sizing equation. If it is desired to use ΔP_{max} to account for the possibility of choked flow conditions, it can be calculated using the procedure for determining q_{max}, the Maximum Flow Rate, or ΔP_{max}, the Allowable Sizing Pressure Drop. If it can be recognized that choked flow conditions will not develop within the valve, ΔP_{max} need not be calculated.

5. *Solve for required C_v, using the appropriate equation:*
   - For volumetric flow rate units:

   $$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

   - For mass flow rate units:

   $$C_v = \frac{w}{N_6 F_p \sqrt{(P_1 - P_2)\,\gamma}}$$

   In addition to C_v, two other flow coefficients, K_v and A_v, are used, particularly outside of North America. The following relationships exist:

   $K_v = (0.865)\,(C_v)$

   $A_v = (2.40 \times 10^{-5})\,(C_v)$

6. *Select the valve size using the appropriate flow coefficient table and the calculated C_v value.*

Valve Sizing (Standardized Method)

Table 3-1. Abbreviations and Terminology

SYMBOL		SYMBOL	
C_v	Valve sizing coefficient	P_1	Upstream absolute static pressure
d	Nominal valve size	P_2	Downstream absolute static pressure
D	Internal diameter of the piping	P_c	Absolute thermodynamic critical pressure
F_d	Valve style modifier, dimensionless	P_v	Vapor pressure absolute of liquid at inlet temperature
F_F	Liquid critical pressure ratio factor, dimensionless	ΔP	Pressure drop (P_1-P_2) across the valve
F_k	Ratio of specific heats factor, dimensionless	$\Delta P_{max(L)}$	Maximum allowable liquid sizing pressure drop
F_L	Rated liquid pressure recovery factor, dimensionless	$\Delta P_{max(LP)}$	Maximum allowable sizing pressure drop with attached fittings
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of valve with attached fittings (when there are no attached fittings, F_{LP} equals F_L), dimensionless	q	Volume rate of flow
F_P	Piping geometry factor, dimensionless	q_{max}	Maximum flow rate (choked flow conditions) at given upstream conditions
G_f	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 60°F), dimensionless	T_1	Absolute upstream temperature (deg Kelvin or deg Rankine)
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions[1], i.e., ratio of molecular weight of gas to molecular weight of air), dimensionless	w	Mass rate of flow
k	Ratio of specific heats, dimensionless	x	Ratio of pressure drop to upstream absolute static pressure ($\Delta P/P_1$), dimensionless
K	Head loss coefficient of a device, dimensionless	x_T	Rated pressure drop ratio factor, dimensionless
M	Molecular weight, dimensionless	Y	Expansion factor (ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number), dimensionless
N	Numerical constant	Z	Compressibility factor, dimensionless
		γ^1	Specific weight at inlet conditions
		υ	Kinematic viscosity, centistokes

1. Standard conditions are defined as 60°F and 14.7 psia.

Table 3-2. Equation Constants[1]

		N	w	q	p[2]	γ	T	d, D
N_1		0.0865 0.865 1.00	- - - - - - - - - - - -	Nm^3/h Nm^3/h GPM	kPa bar psia	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - -
N_2		0.00214 890	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	mm inch
N_5		0.00241 1000	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	mm inch
N_6		2.73 27.3 63.3	kg/hr kg/hr pound/hr	- - - - - - - - - - - -	kPa bar psia	kg/m^3 kg/m^3 $pound/ft^3$	- - - - - - - - - - - -	- - - - - - - - - - - -
N_7[3]	Normal Conditions T_N = 0°C	3.94 394	- - - - - - - -	Nm^3/h Nm^3/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_s = 16°C	4.17 417	- - - - - - - -	Nm^3/h Nm^3/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_s = 60°F	1360	- - - -	SCFH	psia	- - - -	deg Rankine	- - - -
N_8		0.948 94.8 19.3	kg/hr kg/hr pound/hr	- - - - - - - - - - - -	kPa bar psia	- - - - - - - - - - - -	deg Kelvin deg Kelvin deg Rankine	- - - - - - - - - - - -
N_9[3]	Normal Conditions T_N = 0°C	21.2 2120	- - - - - - - -	Nm^3/h Nm^3/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_S = 16°C	22.4 2240	- - - - - - - -	Nm^3/h Nm^3/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_S = 60°F	7320	- - - -	SCFH	psia	- - - -	deg Rankine	- - - -

1. Many of the equations used in these sizing procedures contain a numerical constant, N, along with a numerical subscript. These numerical constants provide a means for using different units in the equations. Values for the various constants and the applicable units are given in the above table. For example, if the flow rate is given in U.S. GPM and the pressures are psia, N_1 has a value of 1.00. If the flow rate is Nm^3/h and the pressures are kPa, the N_1 constant becomes 0.0865.
2. All pressures are absolute.
3. Pressure base is 101.3 kPa (1,01 bar) (14.7 psia).

Valve Sizing (Standardized Method)

Determining Piping Geometry Factor (F_p)

Determine an F_p factor if any fittings such as reducers, elbows, or tees will be directly attached to the inlet and outlet connections of the control valve that is to be sized. When possible, it is recommended that F_p factors be determined experimentally by using the specified valve in actual tests.

Calculate the F_p factor using the following equation:

$$F_p = \left[1 + \frac{\sum K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N_2 = Numerical constant found in the Equation Constants table
d = Assumed nominal valve size
C_v = Valve sizing coefficient at 100% travel for the assumed valve size

In the above equation, the $\sum K$ term is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve.

$$\sum K = K_1 + K_2 + K_{B1} - K_{B2}$$

where,

K_1 = Resistance coefficient of upstream fittings
K_2 = Resistance coefficient of downstream fittings
K_{B1} = Inlet Bernoulli coefficient
K_{B2} = Outlet Bernoulli coefficient

The Bernoulli coefficients, K_{B1} and K_{B2}, are used only when the diameter of the piping approaching the valve is different from the diameter of the piping leaving the valve, whereby:

$$K_{B1} \text{ or } K_{B2} = 1 - \left(\frac{d}{D}\right)^4$$

where,

d = Nominal valve size
D = Internal diameter of piping

If the inlet and outlet piping are of equal size, then the Bernoulli coefficients are also equal, $K_{B1} = K_{B2}$, and therefore they are dropped from the equation.

The most commonly used fitting in control valve installations is the short-length concentric reducer. The equations for this fitting are as follows:

- For an inlet reducer:

$$K_1 = 0.5\left(1 - \frac{d^2}{D^2}\right)^2$$

- For an outlet reducer:

$$K_2 = 1.0\left(1 - \frac{d^2}{D^2}\right)^2$$

- For a valve installed between identical reducers:

$$K_1 + K_2 = 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

Determining Maximum Flow Rate (q_{max})

Determine either q_{max} or ΔP_{max} if it is possible for choked flow to develop within the control valve that is to be sized. The values can be determined by using the following procedures.

$$q_{max} = N_1 F_L C_V \sqrt{\frac{P_1 - F_F P_V}{G_f}}$$

Values for F_F, the liquid critical pressure ratio factor, can be obtained from Figure 3-1, or from the following equation:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_V}{P_C}}$$

Values of F_L, the recovery factor for rotary valves installed without fittings attached, can be found in published coefficient tables. If the given valve is to be installed with fittings such as reducer attached to it, F_L in the equation must be replaced by the quotient F_{LP}/F_P, where:

$$F_{LP} = \left[\frac{K_1}{N_2}\left(\frac{C_V}{d^2}\right)^2 + \frac{1}{F_L^2}\right]^{-1/2}$$

and

$$K_1 = K_1 + K_{B1}$$

where,

K_1 = Resistance coefficient of upstream fittings

K_{B1} = Inlet Bernoulli coefficient

(See the procedure for Determining F_p, the Piping Geometry Factor, for definitions of the other constants and coefficients used in the above equations.)

Valve Sizing (Standardized Method)

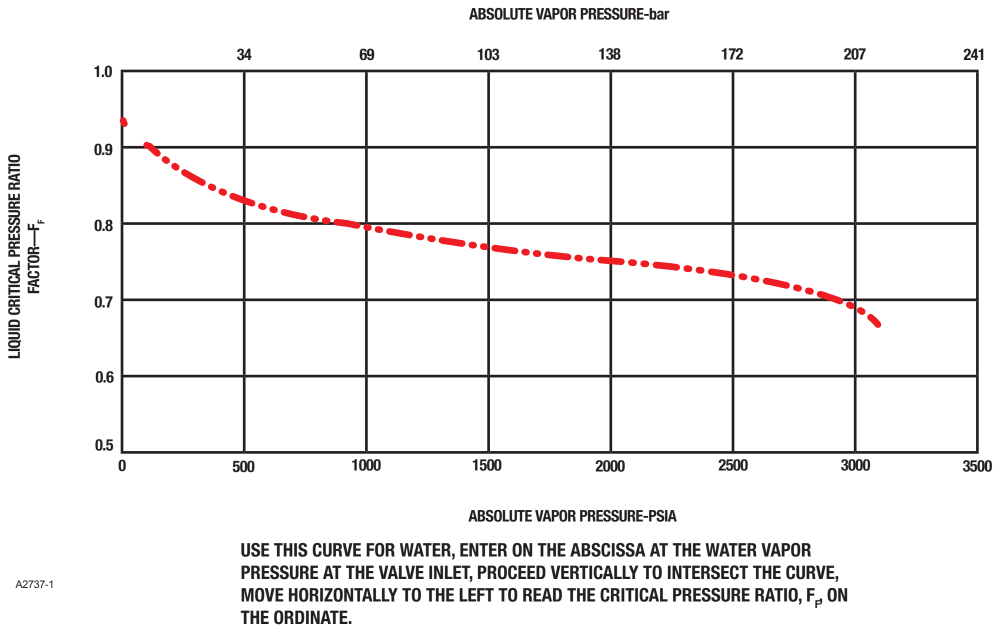


Figure 3-1. *Liquid Critical Pressure Ratio Factor for Water*

Determining Allowable Sizing Pressure Drop (ΔP_{max})

ΔP_{max} (the allowable sizing pressure drop) can be determined from the following relationships:

For valves installed without fittings:

$$\Delta P_{max(L)} = F_L^2 (P_1 - F_F P_V)$$

For valves installed with fittings attached:

$$\Delta P_{max(LP)} = \left(\frac{F_{LP}}{F_P}\right)^2 (P_1 - F_F P_V)$$

where,

P_1 = Upstream absolute static pressure

P_2 = Downstream absolute static pressure

P_v = Absolute vapor pressure at inlet temperature

Values of F_F, the liquid critical pressure ratio factor, can be obtained from Figure 3-1 or from the following equation:

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_V}{P_c}}$$

An explanation of how to calculate values of F_{LP}, the recovery factor for valves installed with fittings attached, is presented in the preceding procedure Determining q_{max} (the Maximum Flow Rate).

Once the ΔP_{max} value has been obtained from the appropriate equation, it should be compared with the actual service pressure differential ($\Delta P = P_1 - P_2$). If ΔP_{max} is less than ΔP, this is an indication that choked flow conditions will exist under the service conditions specified. If choked flow conditions do exist ($\Delta P_{max} < P_1 - P_2$), then step 5 of the procedure for Sizing Valves for Liquids must be modified by replacing the actual service pressure differential ($P_1 - P_2$) in the appropriate valve sizing equation with the calculated ΔP_{max} value.

Note

Once it is known that choked flow conditions will develop within the specified valve design (ΔP_{max} is calculated to be less than ΔP), a further distinction can be made to determine whether the choked flow is caused by cavitation or flashing. The choked flow conditions are caused by flashing if the outlet pressure of the given valve is less than the vapor pressure of the flowing liquid. The choked flow conditions are caused by cavitation if the outlet pressure of the valve is greater than the vapor pressure of the flowing liquid.

Liquid Sizing Sample Problem

Assume an installation that, at initial plant startup, will not be operating at maximum design capability. The lines are sized for the ultimate system capacity, but there is a desire to install a control valve now which is sized only for currently anticipated requirements. The line size is 8-inch (DN 200) and an ASME CL300 globe valve with an equal percentage cage has been specified. Standard concentric reducers will be used to install the valve into the line. Determine the appropriate valve size.

Valve Sizing (Standardized Method)

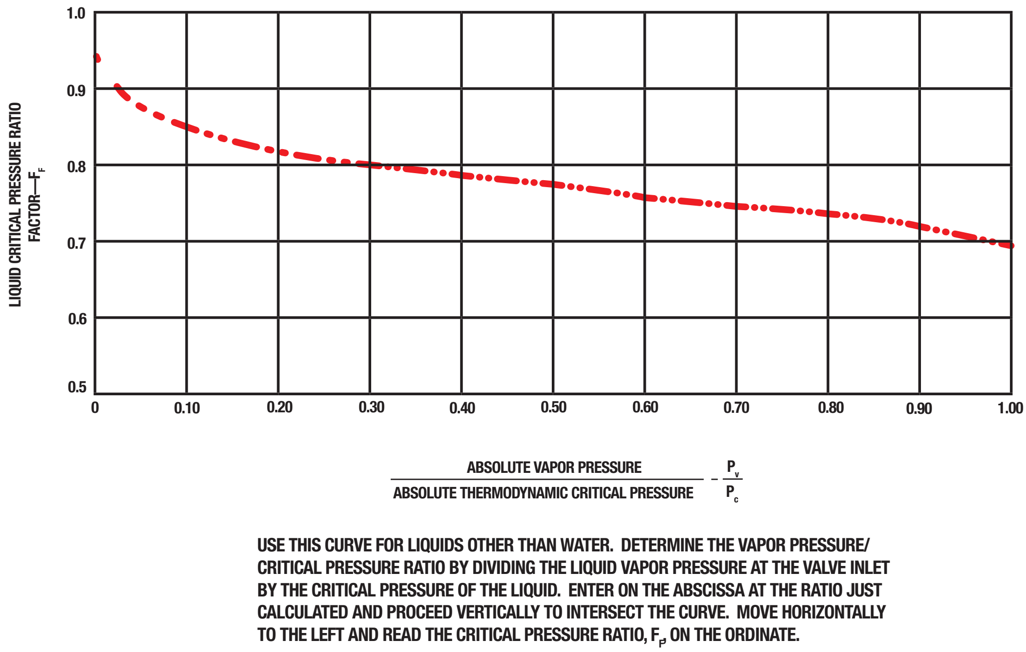


Figure 3-2. *Liquid Critical Pressure Ratio Factor for Liquids Other Than Water*

1. *Specify the necessary variables required to size the valve:*
   - Desired Valve Design—ASME CL300 globe valve with equal percentage cage and an assumed valve size of 3-inches.
   - Process Fluid—liquid propane
   - Service Conditions—q = 800 GPM (3028 l/min)

     P_1 = 300 psig (20,7 bar) = 314.7 psia (21,7 bar a)

     P_2 = 275 psig (19,0 bar) = 289.7 psia (20,0 bar a)

     ΔP = 25 psi (1,7 bar)

     T_1 = 70°F (21°C)

     G_f = 0.50

     P_v = 124.3 psia (8,6 bar a)

     P_c = 616.3 psia (42,5 bar a)
2. *Use an N_1 value of 1.0 from the Equation Constants table.*
3. *Determine F_p, the piping geometry factor.*

   Because it is proposed to install a 3-inch valve in an 8-inch (DN 200) line, it will be necessary to determine the piping geometry factor, F_p, which corrects for losses caused by fittings attached to the valve.

$$F_p = \left[1 + \frac{\sum K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N_2 = 890, from the Equation Constants table

d = 3-inch (76 mm), from step 1

C_v = 121, from the flow coefficient table for an ASME CL300, 3-inch globe valve with equal percentage cage

To compute $\sum K$ for a valve installed between identical concentric reducers:

$$\sum K = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{(3)^2}{(8)^2}\right)^2$$

$$= 1.11$$

Valve Sizing (Standardized Method)

where,

D = 8-inch (203 mm), the internal diameter of the piping so,

$$F_p = \left[1 + \frac{1.11}{890}\left(\frac{121}{3^2}\right)^2\right]^{-1/2}$$

$= 0.90$

4. *Determine ΔP_{max} (the Allowable Sizing Pressure Drop.)*

   Based on the small required pressure drop, the flow will not be choked ($\Delta P_{max} > \Delta P$).

5. *Solve for C_v, using the appropriate equation.*

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)\,(0.90)\sqrt{\frac{25}{0.5}}}$$

$= 125.7$

6. *Select the valve size using the flow coefficient table and the calculated C_v value.*

   The required C_v of 125.7 exceeds the capacity of the assumed valve, which has a C_v of 121. Although for this example it may be obvious that the next larger size (4-inch) would be the correct valve size, this may not always be true, and a repeat of the above procedure should be carried out.

   Assuming a 4-inches valve, $C_v = 203$. This value was determined from the flow coefficient table for an ASME CL300, 4-inch globe valve with an equal percentage cage.

   Recalculate the required C_v using an assumed C_v value of 203 in the F_p calculation.

where,

$$\sum K = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{16}{64}\right)^2$$

$= 0.84$

and

$$F_p = \left[1.0 + \frac{\sum K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

$$= \left[1.0 + \frac{0.84}{890}\left(\frac{203}{4^2}\right)^2\right]^{-1/2}$$

$= 0.93$

and

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)\,(0.93)\sqrt{\frac{25}{0.5}}}$$

$= 121.7$

This solution indicates only that the 4-inch valve is large enough to satisfy the service conditions given. There may be cases, however, where a more accurate prediction of the C_v is required. In such cases, the required C_v should be redetermined using a new F_p value based on the C_v value obtained above. In this example, C_v is 121.7, which leads to the following result:

$$F_p = \left[1.0 + \frac{\sum K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

$$= \left[1.0 + \frac{0.84}{890}\left(\frac{121.7}{4^2}\right)^2\right]^{-1/2}$$

$= 0.97$

The required C_v then becomes:

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)\,(0.97)\sqrt{\frac{25}{0.5}}}$$

$= 116.2$

Because this newly determined C_v is very close to the C_v used initially for this recalculation (116.2 versus 121.7), the valve sizing procedure is complete, and the conclusion is that a 4-inch valve opened to about 75% of total travel should be adequate for the required specifications.

Valve Sizing (Standardized Method)

Gas and Steam Valve Sizing

Sizing Valves for Compressible Fluids

Following is a six-step procedure for the sizing of control valves for compressible flow using the ISA standardized procedure. Each of these steps is important and must be considered during any valve sizing procedure. Steps 3 and 4 concern the determination of certain sizing factors that may or may not be required in the sizing equation depending on the service conditions of the sizing problem. If it is necessary for one or both of these sizing factors to be included in the sizing equation for a particular sizing problem, refer to the appropriate factor determination section(s), which is referenced and located in the following text.

1. *Specify the necessary variables required to size the valve as follows:*
   - Desired valve design (e.g. balanced globe with linear cage)
   - Process fluid (air, natural gas, steam, etc.) and
   - Appropriate service conditions— q, or w, P_1, P_2 or ΔP, T_1, G_g, M, k, Z, and γ_1

   The ability to recognize which terms are appropriate for a specific sizing procedure can only be acquired through experience with different valve sizing problems. If any of the above terms appear to be new or unfamiliar, refer to the Abbreviations and Terminology Table 3-1 in Liquid Valve Sizing Section for a complete definition.

2. *Determine the equation constant, N.*

   N is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. Values for these various constants and their applicable units are given in the Equation Constants Table 3-2 in Liquid Valve Sizing Section.

   Use either N_7 or N_9 if sizing the valve for a flow rate in volumetric units (SCFH or Nm^3/h). Which of the two constants to use depends upon the specified service conditions. N_7 can be used only if the specific gravity, G_g, of the following gas has been specified along with the other required service conditions. N_9 can be used only if the molecular weight, M, of the gas has been specified.

   Use either N_6 or N_8 if sizing the valve for a flow rate in mass units (pound/hr or kg/hr). Which of the two constants to use depends upon the specified service conditions. N_6 can be used only if the specific weight, γ_1, of the flowing gas has been specified along with the other required service conditions. N_8 can be used only if the molecular weight, M, of the gas has been specified.

3. *Determine F_p, the piping geometry factor.*

   F_p is a correction factor that accounts for any pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valves to be sized. If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_p has a value of 1.0 and simply drops out of the sizing equation.

   Also, for rotary valves with reducers and other valve designs and fitting styles, determine the F_p factors by using the procedure for Determining F_p, the Piping Geometry Factor, which is located in Liquid Valve Sizing Section.

4. *Determine Y, the expansion factor, as follows:*

$$Y = 1 - \frac{x}{3F_k x_T}$$

where,

F_k = k/1.4, the ratio of specific heats factor

k = Ratio of specific heats

x = $\Delta P/P_1$, the pressure drop ratio

x_T = The pressure drop ratio factor for valves installed without attached fittings. More definitively, x_T is the pressure drop ratio required to produce critical, or maximum, flow through the valve when F_k = 1.0

If the control valve to be installed has fittings such as reducers or elbows attached to it, then their effect is accounted for in the expansion factor equation by replacing the x_T term with a new factor x_{TP}. A procedure for determining the x_{TP} factor is described in the following section for Determining x_{TP}, the Pressure Drop Ratio Factor.

Note

Conditions of critical pressure drop are realized when the value of x becomes equal to or exceeds the appropriate value of the product of either $F_k x_T$ or $F_k x_{TP}$ at which point:

$$y = 1 - \frac{x}{3F_k x_T} = 1 - 1/3 = 0.667$$

Although in actual service, pressure drop ratios can, and often will, exceed the indicated critical values, this is the point where critical flow conditions develop. Thus, for a constant P_1, decreasing P_2 (i.e., increasing ΔP) will not result in an increase in the flow rate through the valve. Values of x, therefore, greater than the product of either $F_k x_T$ or $F_k x_{TP}$ must never be substituted in the expression for Y. This means that Y can never be less than 0.667. This same limit on values of x also applies to the flow equations that are introduced in the next section.

5. *Solve for the required C_v using the appropriate equation:*

   For volumetric flow rate units—

   - If the specific gravity, G_g, of the gas has been specified:

$$C_v = \frac{q}{N_7 F_p P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}}$$

Valve Sizing (Standardized Method)

- If the molecular weight, M, of the gas has been specified:

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{M T_1 Z}}}$$

For mass flow rate units—

- If the specific weight, γ_1, of the gas has been specified:

$$C_v = \frac{w}{N_6 F_P Y \sqrt{x P_1 \gamma_1}}$$

- If the molecular weight, M, of the gas has been specified:

$$C_v = \frac{w}{N_8 F_P P_1 Y \sqrt{\dfrac{x M}{T_1 Z}}}$$

In addition to C_v, two other flow coefficients, K_v and A_v, are used, particularly outside of North America. The following relationships exist:

$K_v = (0.865)(C_v)$

$A_v = (2.40 \times 10^{-5})(C_v)$

6. *Select the valve size using the appropriate flow coefficient table and the calculated C_v value.*

Determining x_{TP}, the Pressure Drop Ratio Factor

If the control valve is to be installed with attached fittings such as reducers or elbows, then their effect is accounted for in the expansion factor equation by replacing the x_T term with a new factor, x_{TP}.

$$x_{TP} = \frac{x_T}{F_p^{\,2}}\left[1 + \frac{x_T K_i}{N_5}\left(\frac{C_v}{d^2}\right)^2\right]^{-1}$$

where,

N_5 = Numerical constant found in the Equation Constants table

d = Assumed nominal valve size

C_v = Valve sizing coefficient from flow coefficient table at 100% travel for the assumed valve size

F_p = Piping geometry factor

x_T = Pressure drop ratio for valves installed without fittings attached. x_T values are included in the flow coefficient tables

In the above equation, K_i, is the inlet head loss coefficient, which is defined as:

$K_i = K_1 + K_{B1}$

where,

K_1 = Resistance coefficient of upstream fittings (see the procedure for Determining F_p, the Piping Geometry Factor, which is contained in the section for Sizing Valves for Liquids).

K_{B1} = Inlet Bernoulli coefficient (see the procedure for Determining F_p, the Piping Geometry Factor, which is contained in the section for Sizing Valves for Liquids).

Compressible Fluid Sizing Sample Problem No. 1

Determine the size and percent opening for a Fisher® Design V250 ball valve operating with the following service conditions. Assume that the valve and line size are equal.

1. *Specify the necessary variables required to size the valve:*

- Desired valve design—Design V250 valve
- Process fluid—Natural gas
- Service conditions—

P_1 = 200 psig (13,8 bar) = 214.7 psia (14,8 bar)

P_2 = 50 psig (3,4 bar) = 64.7 psia (4,5 bar)

ΔP = 150 psi (10,3 bar)

$x = \Delta P/P_1 = 150/214.7 = 0.70$

T_1 = 60°F (16°C) = 520°R

M = 17.38

$G_g = 0.60$

k = 1.31

$q = 6.0 \times 10^6$ SCFH

2. *Determine the appropriate equation constant, N, from the Equation Constants Table 3-2 in Liquid Valve Sizing Section.*

Because both G_g and M have been given in the service conditions, it is possible to use an equation containing either N_7 or N_9. In either case, the end result will be the same. Assume that the equation containing G_g has been arbitrarily selected for this problem. Therefore, $N_7 = 1360$.

3. *Determine F_p, the piping geometry factor.*

Since valve and line size are assumed equal, $F_p = 1.0$.

4. *Determine Y, the expansion factor.*

$$F_k = \frac{k}{1.40}$$

$$= \frac{1.31}{1.40}$$

$$= 0.94$$

It is assumed that an 8-inch Design V250 valve will be adequate for the specified service conditions. From the flow coefficient Table 4-2, x_T for an 8-inch Design V250 valve at 100% travel is 0.137.

x = 0.70 (This was calculated in step 1.)

Valve Sizing (Standardized Method)

Since conditions of critical pressure drop are realized when the calculated value of x becomes equal to or exceeds the appropriate value of $F_k x_T$, these values should be compared.

$$F_k x_T = (0.94)(0.137) = 0.129$$

Because the pressure drop ratio, x = 0.70 exceeds the calculated critical value, $F_k x_T = 0.129$, choked flow conditions are indicated. Therefore, Y = 0.667, and $x = F_k x_T = 0.129$.

5. *Solve for required C_v using the appropriate equation.*

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}}$$

The compressibility factor, Z, can be assumed to be 1.0 for the gas pressure and temperature given and $F_p = 1$ because valve size and line size are equal.

So,

$$C_v = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.129}{(0.6)(520)(1.0)}}} = 1515$$

6. *Select the valve size using the flow coefficient table and the calculated C_v value.*

The above result indicates that the valve is adequately sized (rated $C_v = 2190$). To determine the percent valve opening, note that the required C_v occurs at approximately 83 degrees for the 8-inch Design V250 valve. Note also that, at 83 degrees opening, the x_T value is 0.252, which is substantially different from the rated value of 0.137 used initially in the problem. The next step is to rework the problem using the x_T value for 83 degrees travel.

The $F_k x_T$ product must now be recalculated.

$$x = F_k x_T = (0.94)(0.252) = 0.237$$

The required C_v now becomes:

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}} = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.237}{(0.6)(520)(1.0)}}} = 1118$$

The reason that the required C_v has dropped so dramatically is attributable solely to the difference in the x_T values at rated and 83 degrees travel. A C_v of 1118 occurs between 75 and 80 degrees travel.

The appropriate flow coefficient table indicates that x_T is higher at 75 degrees travel than at 80 degrees travel. Therefore, if the problem were to be reworked using a higher x_T value, this should result in a further decline in the calculated required C_v.

Reworking the problem using the x_T value corresponding to 78 degrees travel (i.e., $x_T = 0.328$) leaves:

$$x = F_k x_T = (0.94)(0.328) = 0.308$$

and,

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}} = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.308}{(0.6)(520)(1.0)}}} = 980$$

The above C_v of 980 is quite close to the 75 degree travel C_v. The problem could be reworked further to obtain a more precise predicted opening; however, for the service conditions given, an 8-inch Design V250 valve installed in an 8-inch (203 mm) line will be approximately 75 degrees open.

Compressible Fluid Sizing Sample Problem No. 2

Assume steam is to be supplied to a process designed to operate at 250 psig (17 bar). The supply source is a header maintained at 500 psig (34,5 bar) and 500°F (260°C). A 6-inch (DN 150) line from the steam main to the process is being planned. Also, make the assumption that if the required valve size is less than 6-inch (DN 150), it will be installed using concentric reducers. Determine the appropriate Design ED valve with a linear cage.

1. *Specify the necessary variables required to size the valve:*

   a. Desired valve design—ASME CL300 Design ED valve with a linear cage. Assume valve size is 4 inches.

   b. Process fluid—superheated steam

   c. Service conditions—

   w = 125 000 pounds/hr (56 700 kg/hr)

   P_1 = 500 psig (34,5 bar) = 514.7 psia (35,5 bar)

   P_2 = 250 psig (17 bar) = 264.7 psia (18,3 bar)

   P = 250 psi (17 bar)

   $x = \Delta P/P_1 = 250/514.7 = 0.49$

   T_1 = 500°F (260°C)

   γ_1 = 1.0434 pound/ft³ (16,71 kg/m³)
   (from Properties of Saturated Steam Table)

   k = 1.28 (from Properties of Saturated Steam Table)

Valve Sizing (Standardized Method)

2. *Determine the appropriate equation constant, N, from the Equation Constants Table 3-2 in Liquid Valve Sizing Section.*

Because the specified flow rate is in mass units, (pound/hr), and the specific weight of the steam is also specified, the only sizing equation that can be used is that which contains the N_6 constant. Therefore,

$N_6 = 63.3$

3. *Determine F_p, the piping geometry factor.*

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

$N_2 = 890$, determined from the Equation Constants Table

$d = 4$ inches

$C_v = 236$, which is the value listed in the flow coefficient Table 4-3 for a 4-inch Design ED valve at 100% total travel.

$$\Sigma K = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{4^2}{6^2}\right)^2$$

$$= 0.463$$

Finally,

$$F_p = \left[1 + \frac{0.463}{890}\left(\frac{(1.0)(236)}{(4)^2}\right)^2\right]^{-1/2}$$

$$= 0.95$$

4. *Determine Y, the expansion factor.*

$$Y = 1 - \frac{x}{3F_k x_{TP}}$$

where,

$$F_k = \frac{k}{1.40}$$

$$= \frac{1.28}{1.40}$$

$$= 0.91$$

$x = 0.49$ (As calculated in step 1.)

Because the 4-inch valve is to be installed in a 6-inch line, the x_T term must be replaced by x_{TP}.

$$x_{TP} = \frac{x_T}{F_p^{\,2}}\left[1 + \frac{x_T K_i}{N_5}\left(\frac{C_v}{d^2}\right)^2\right]^{-1}$$

where,

$N_5 = 1000$, from the Equation Constants Table

$d = 4$ inches

$F_p = 0.95$, determined in step 3

$x_T = 0.688$, a value determined from the appropriate listing in the flow coefficient table

$C_v = 236$, from step 3

and

$$K_i = K_1 + K_{B1}$$

$$= 0.5\left(1 - \frac{d^2}{D^2}\right)^2 + \left[1 - \left(\frac{d}{D}\right)^4\right]$$

$$= 0.5\left(1 - \frac{4^2}{6^2}\right)^2 + \left[1 - \left(\frac{4}{6}\right)^4\right]$$

$$= 0.96$$

where D = 6-inch

so:

$$x_{TP} = \frac{0.69}{0.95^2}\left[1 + \frac{(0.69)(0.96)}{1000}\left(\frac{236}{4^2}\right)^2\right]^{-1} = 0.67$$

Finally:

$$Y = 1 - \frac{x}{3\,F_k\,x_{TP}}$$

$$= 1 - \frac{0.49}{(3)\,(0.91)\,(0.67)}$$

$$= 0.73$$

5. *Solve for required C_v using the appropriate equation.*

$$C_v = \frac{w}{N_6\,F_P\,Y\sqrt{x\,P_1\,\gamma_1}}$$

$$= \frac{125{,}000}{(63.3)(0.95)(0.73)\sqrt{(0.49)(514.7)(1.0434)}}$$

$$= 176$$

Valve Sizing (Standardized Method)

Table 4-1. Representative Sizing Coefficients for Type 1098-EGR Regulator

BODY SIZE, INCHES (DN)	LINEAR CAGE						
	Line Size Equals Body Size		2:1 Line Size to Body Size		X_T	F_D	F_L
	C_v		C_v				
	Regulating	Wide-Open	Regulating	Wide-Open			
1 (25)	16.8	17.7	17.2	18.1	0.806	0.43	0.84
2 (50)	63.3	66.7	59.6	62.8	0.820	0.35	
3 (80)	132	139	128	135	0.779	0.30	
4 (100)	202	213	198	209	0.829	0.28	
6 (150)	397	418	381	404	0.668	0.28	
BODY SIZE, INCHES (DN)	WHISPER TRIM™ CAGE						
	Line Size Equals Body Size Piping		2:1 Line Size to Body Size Piping		X_T	F_D	F_L
	C_v		C_v				
	Regulating	Wide-Open	Regulating	Wide-Open			
1 (25)	16.7	17.6	15.6	16.4	0.753	0.10	0.89
2 (50)	54	57	52	55	0.820	0.07	
3 (80)	107	113	106	110	0.775	0.05	
4 (100)	180	190	171	180	0.766	0.04	
6 (150)	295	310	291	306	0.648	0.03	

Table 4-2. Representative Sizing Coefficients for Rotary Shaft Valves

VALVE SIZE, INCHES	VALVE STYLE	DEGREES OF VALVE OPENING	C_v	F_L	X_T	F_D
1	V-Notch Ball Valve	60	15.6	0.86	0.53	- - - -
		90	34.0	0.86	0.42	- - - -
1-1/2	V-Notch Ball Valve	60	28.5	0.85	0.50	- - - -
		90	77.3	0.74	0.27	- - - -
2	V-Notch Ball Valve	60	59.2	0.81	0.53	- - - -
		90	132	0.77	0.41	- - - -
	High Performance Butterfly Valve	60	58.9	0.76	0.50	0.49
		90	80.2	0.71	0.44	0.70
3	V-Notch Ball Valve	60	120	0.80	0.50	0.92
		90	321	0.74	0.30	0.99
	High Performance Butterfly Valve	60	115	0.81	0.46	0.49
		90	237	0.64	0.28	0.70
4	V-Notch Ball Valve	60	195	0.80	0.52	0.92
		90	596	0.62	0.22	0.99
	High Performance Butterfly Valve	60	270	0.69	0.32	0.49
		90	499	0.53	0.19	0.70
6	V-Notch Ball Valve	60	340	0.80	0.52	0.91
		90	1100	0.58	0.20	0.99
	High Performance Butterfly Valve	60	664	0.66	0.33	0.49
		90	1260	0.55	0.20	0.70
8	V-Notch Ball Valve	60	518	0.82	0.54	0.91
		90	1820	0.54	0.18	0.99
	High Performance Butterfly Valve	60	1160	0.66	0.31	0.49
		90	2180	0.48	0.19	0.70
10	V-Notch Ball Valve	60	1000	0.80	0.47	0.91
		90	3000	0.56	0.19	0.99
	High Performance Butterfly Valve	60	1670	0.66	0.38	0.49
		90	3600	0.48	0.17	0.70
12	V-Notch Ball Valve	60	1530	0.78	0.49	0.92
		90	3980	0.63	0.25	0.99
	High Performance Butterfly Valve	60	2500	- - - -	- - - -	0.49
		90	5400	- - - -	- - - -	0.70
16	V-Notch Ball Valve	60	2380	0.80	0.45	0.92
		90	8270	0.37	0.13	1.00
	High Performance Butterfly Valve	60	3870	0.69	0.40	- - - -
		90	8600	0.52	0.23	- - - -

Valve Sizing (Standardized Method)

Table 4-3. Representative Sizing Coefficients for Design ED Single-Ported Globe Style Valve Bodies

VALVE SIZE, INCHES	VALVE PLUG STYLE	FLOW CHARACTERISTICS	PORT DIAMETER, INCHES (mm)	RATED TRAVEL, INCHES (mm)	C_v	F_L	X_T	F_D
1/2	Post Guided	Equal Percentage	0.38 (9,7)	0.50 (12,7)	2.41	0.90	0.54	0.61
3/4	Post Guided	Equal Percentage	0.56 (14,2)	0.50 (12,7)	5.92	0.84	0.61	0.61
1	Micro-Form™	Equal Percentage	3/8 (9,5)	3/4 (19,1)	3.07	0.89	0.66	0.72
			1/2 (12,7)	3/4 (19,1)	4.91	0.93	0.80	0.67
			3/4 (19,1)	3/4 (19,1)	8.84	0.97	0.92	0.62
	Cage Guided	Linear	1-5/16 (33,3)	3/4 (19,1)	20.6	0.84	0.64	0.34
		Equal Percentage	1-5/16 (33,3)	3/4 (19,1)	17.2	0.88	0.67	0.38
1-1/2	Micro-Form™	Equal Percentage	3/8 (9,5)	3/4 (19,1)	3.20	0.84	0.65	0.72
			1/2 (12,7)	3/4 (19,1)	5.18	0.91	0.71	0.67
			3/4 (19,1)	3/4 (19,1)	10.2	0.92	0.80	0.62
	Cage Guided	Linear	1-7/8 (47,6)	3/4 (19,1)	39.2	0.82	0.66	0.34
		Equal Percentage	1-7/8 (47,6)	3/4 (19,1)	35.8	0.84	0.68	0.38
2	Cage Guided	Linear	2-5/16 (58,7)	1-1/8 (28,6)	72.9	0.77	0.64	0.33
		Equal Percentage	2-5/16 (58,7)	1-1/8 (28,6)	59.7	0.85	0.69	0.31
3	Cage Guided	Linear	3-7/16 (87,3)	1-1/2 (38,1)	148	0.82	0.62	0.30
		Equal Percentage	- - - -	- - - -	136	0.82	0.68	0.32
4	Cage Guided	Linear	4-3/8 (111)	2 (50,8)	236	0.82	0.69	0.28
		Equal Percentage	- - - -	- - - -	224	0.82	0.72	0.28
6	Cage Guided	Linear	7 (178)	2 (50,8)	433	0.84	0.74	0.28
		Equal Percentage	- - - -	- - - -	394	0.85	0.78	0.26
8	Cage Guided	Linear	8 (203)	3 (76,2)	846	0.87	0.81	0.31
		Equal Percentage	- - - -	- - - -	818	0.86	0.81	0.26

6. *Select the valve size using flow coefficient tables and the calculated C_v value.*

Refer to the flow coefficient Table 4-3 for Design ED valves with linear cage. Because the assumed 4-inch valve has a C_v of 236 at 100% travel and the next smaller size (3-inch) has a C_v of only 148, it can be surmised that the assumed size is correct. In the event that the calculated required C_v had been small enough to have been handled by the next smaller size, or if it had been larger than the rated C_v for the assumed size, it would have been necessary to rework the problem again using values for the new assumed size.

7. *Sizing equations for compressible fluids.*

The equations listed below identify the relationships between flow rates, flow coefficients, related installation factors, and pertinent service conditions for control valves handling compressible fluids. Flow rates for compressible fluids may be encountered in either mass or volume units and thus equations are necessary to handle both situations. Flow coefficients may be calculated using the appropriate equations selected from the following. A sizing flow chart for compressible fluids is given in Annex B.

The flow rate of a compressible fluid varies as a function of the ratio of the pressure differential to the absolute inlet pressure ($\Delta P/P_1$), designated by the symbol x. At values of x near zero, the equations in this section can be traced to the basic Bernoulli equation for Newtonian incompressible fluids. However, increasing values of x result in expansion and compressibility effects that require the use of appropriate factors (see Buresh, Schuder, and Driskell references).

7.1 Turbulent flow

7.1.1 Non-choked turbulent flow

7.1.1.1 Non-choked turbulent flow without attached fittings

[*Applicable if* $x < F_\gamma x_T$]

The flow coefficient shall be calculated using one of the following equations:

Eq. 6

$$C = \frac{W}{N_6 Y \sqrt{x P_1 \rho_1}}$$

Eq. 7

$$C = \frac{W}{N_8 P_1 Y}\sqrt{\frac{T_1 Z}{xM}}$$

Eq. 8a

$$C = \frac{Q}{N_9 P_1 Y}\sqrt{\frac{M T_1 Z}{x}}$$

Eq. 8b

$$C = \frac{Q}{N_7 P_1 Y}\sqrt{\frac{G_g T_1 Z}{x}}$$

NOTE 1 Refer to 8.5 for details of the expansion factor *Y*.

NOTE 2 See Annex C for values of *M*.

7.1.1.2 Non-choked turbulent flow with attached fittings

[*Applicable if* $x < F_\gamma x_{TP}$]

Cold Temperature Considerations

Regulators Rated for Low Temperatures

In some areas of the world, regulators periodically operate in temperatures below -20°F (-29°C). These cold temperatures require special construction materials to prevent regulator failure. Emerson Process Management offers regulator constructions that are RATED for use in service temperatures below -20°F (-29°C).

Selection Criteria

When selecting a regulator for extreme cold temperature service, the following guidelines should be considered:

- The body material should be 300 Series stainless steel, LCC, or LCB due to low carbon content in the material makeup.
- Give attention to the bolts used. Generally, special stainless steel bolting is required.
- Gaskets and O-rings may need to be addressed if providing a seal between two parts exposed to the cold.
- Special springs may be required in order to prevent fracture when exposed to extreme cold.
- Soft parts in the regulator that are also being used as a seal gasket between two metal parts (such as a diaphragm) may need special consideration. Alternate diaphragm materials should be used to prevent leakage caused by hardening and stiffening of the standard materials.

Freezing

Introduction

Freezing has been a problem since the birth of the gas industry. This problem will likely continue, but there are ways to minimize the effects of the phenomenon.

There are two areas of freezing. The first is the formation of ice from water travelling within the gas stream. Ice will form when temperatures drop below 32°F (0°C).

The second is hydrate formation. Hydrate is a frozen mixture of water and hydrocarbons. This bonding of water around the hydrocarbon molecule forms a compound which can freeze above 32°F (0°C). Hydrates can be found in pipelines that are saturated with water vapor. It is also common to have hydrate formation in natural gas of high BTU content. Hydrate formation is dependent upon operating conditions and gas composition.

Reducing Freezing Problems

To minimize problems, we have several options.

1. Keep the fluid temperature above the freezing point by applying heat.
2. Feed an antifreeze solution into the flow stream.
3. Select equipment that is designed to be ice-free in the regions where there are moving parts.
4. Design systems that minimize freezing effects.
5. Remove the water from the flow stream.

Heat the Gas

Obviously, warm water does not freeze. What we need to know is when is it necessary to provide additional heat.

Gas temperature is reduced whenever pressure is reduced. This temperature drop is about 1°F (-17°C) for each 15 psi (1,03 bar) pressure drop. Potential problems can be identified by calculating the temperature drop and subtracting from the initial temperature. Usually ground temperature, about 50°F (10°C) is the initial temperature. If a pressure reducing station dropped the pressure from 400 to 250 psi (28 to 17 bar) and the initial temperature is 50°F (10°C), the final temperature would be 40°F (4°C).

50°F - (400 to 250 psi) (1°F/15 psi) = 40°F

(10°C - (28 to 17 bar) (-17°C/1,03 bar) = 5°C)

In this case, a freezing problem is not expected. However, if the final pressure was 25 psi (1,7 bar) instead of 250 psi (17 bar), the final temperature would be 25°F (-4°C). We should expect freezing in this example if there is any moisture in the gas stream.

We can heat the entire gas stream with line heaters where the situation warrants. However, this does involve some large equipment and considerable fuel requirements.

Many different types of large heaters are on the market today. Some involve boilers that heat a water/glycol solution which is circulated through a heat exchanger in the main gas line. Two important considerations are: (1) fuel efficiencies, and (2) noise generation.

In many cases, it is more practical to build a box around the pressure reducing regulator and install a small catalytic heater to warm the regulator. When pilot-operated regulators are used, we may find that the ice passes through the regulator without difficulty but plugs the small ports in the pilot. A small heater can be used to heat the pilot supply gas or the pilot itself. A word of caution is appropriate. When a heater remains in use when it is not needed, it can overheat the rubber parts of the regulator. They are usually designed for 180°F (82°C) maximum. Using an automatic temperature control thermostat can prevent overheating.

Antifreeze Solution

An antifreeze solution can be introduced into the flow stream where it will combine with the water. The mixture can pass through the pressure reducing station without freezing. The antifreeze is dripped into the pipeline from a pressurized reservoir through a needle valve. This system is quite effective if one remembers to replenish the reservoir. There is a system that allows the antifreeze to enter the pipeline only when needed. We can install a small pressure regulator between the reservoir and the pipeline with the control line of the small regulator connected downstream of the pressure reducing regulator in the pipeline. The small regulator is set at a lower pressure than the regulator in the pipeline. When the controlled pressure is normal, the small regulator remains closed and conserves the antifreeze. When ice begins to block the regulator in the pipeline, downstream pressure will fall below the setpoint of the small regulator which causes it to open, admitting antifreeze into the pipeline as it is needed. When the ice is removed, the downstream pressure returns to normal and the small regulator closes until ice begins to re-form. This system is quite reliable as long as the supply of the antifreeze solution is maintained. It is usually used at low volume pressure reducing stations.

Equipment Selection

We can select equipment that is somewhat tolerant of freezing if we know how ice forms in a pressure reducing regulator. Since the pressure drop occurs at the orifice, this is the spot where we might expect the ice formation. However, this is not necessarily the case. Metal regulator bodies are good heat conductors. As a result, the body, not just the port, is cooled by the pressure drop. The moisture in the incoming gas strikes the cooled surface as it enters the body and freezes to the body wall before it reaches the orifice. If the valve plug is located upstream of the orifice, there is a good chance that it will become trapped in the ice and remain in the last position. This ice often contains worm holes which allow

Freezing

gas to continue to flow. In this case, the regulator will be unable to control downstream pressure when the flow requirement changes. If the valve plug is located downstream of the port, it is operating in an area that is frequently ice-free. It must be recognized that any regulator can be disabled by ice if there is sufficient moisture in the flow stream.

System Design

We can arrange station piping to reduce freezing if we know when to expect freezing. Many have noted that there are few reported instances of freezing when the weather is very cold (0°F (-18°C)). They have observed that most freezing occurs when the atmospheric temperature is between 35° and 45°F (2° and 7°C). When the atmospheric temperature is quite low, the moisture within the gas stream freezes to the pipe wall before it reaches the pressure reducing valve which leaves only dry gas to pass through the valve. We can take advantage of this concept by increasing the amount of piping that is exposed above ground upstream of the pressure reducing valve. This will assure ample opportunity for the moisture to contact the pipe wall and freeze to the wall.

When the atmospheric temperature rises enough to melt the ice from the pipe wall, it is found that the operating conditions are not favorable to ice formation in the pressure reducing valve. There may be sufficient solar heat gain to warm the regulator body or lower flow rates which reduces the refrigeration effect of the pressure drop.

Parallel pressure reducing valves make a practical antifreeze system for low flow stations such as farm taps. The two parallel regulators are set at slightly different pressures (maybe one at 50 psi (3 bar) and one at 60 psi (4 bar)). The flow will automatically go through the regulator with the higher setpoint. When this regulator freezes closed, the pressure will drop and the second regulator will open and carry the load. Since most freezing instances occur when the atmospheric temperature is between 35° and 45°F (2° and 7°C), we expect the ice in the first regulator to begin thawing as soon as the flow stops. When the ice melts from the first regulator, it will resume flowing gas. These two regulators will continue to alternate between flowing and freezing until the atmospheric temperature decreases or increases, which will get the equipment out of the ice formation temperature range.

Water Removal

Removing the moisture from the flow stream solves the problem of freezing. However, this can be a difficult task. Where moisture is a significant problem, it may be beneficial to use a method of dehydration. Dehydration is a process that removes the water from the gas stream. Effective dehydration removes enough water to prevent reaching the dew point at the lowest temperature and highest pressure.

Two common methods of dehydration involve glycol absorption and desiccants. The glycol absorption process requires the gas stream to pass through glycol inside a contactor. Water vapor is absorbed by the glycol which in turn is passed through a regenerator that removes the water by distillation. The glycol is reused after being stripped of the water. The glycol system is continuous and fairly low in cost. It is important, however, that glycol is not pushed downstream with the dried gas.

The second method, solid absorption or desiccant, has the ability to produce much drier gas than glycol absorption. The solid process has the gas stream passing through a tower filled with desiccant. The water vapor clings to the desiccant, until it reaches saturation. Regeneration of the desiccant is done by passing hot gas through the tower to dry the absorption medium. After cooling, the system is ready to perform again. This is more of a batch process and will require two or more towers to keep a continuous flow of dry gas. The desiccant system is more expensive to install and operate than the glycol units.

Most pipeline gas does not have water content high enough to require these measures. Sometimes a desiccant dryer installed in the pilot gas supply lines of a pilot-operated regulator is quite effective. This is primarily true where water is present on an occasional basis.

Summary

It is ideal to design a pressure reducing station that will never freeze, but anyone who has spent time working on this problem will acknowledge that no system is foolproof. We can design systems that minimize the freezing potential by being aware of the conditions that favor freezing.

Sulfide Stress Cracking --NACE MR0175-2002, MR0175/ISO 15156

The Details

NACE MR0175, “Sulfide Stress Corrosion Cracking Resistant Metallic Materials for Oil Field Equipment” is widely used throughout the world. In late 2003, it became NACE MR0175/ISO 15156, “Petroleum and Natural Gas Industries - Materials for Use in H_2S-Containing Environments in Oil and Gas Production.” These standards specify the proper materials, heat treat conditions and strength levels required to provide good service life in sour gas and oil environments.

NACE International (formerly the National Association of Corrosion Engineers) is a worldwide technical organization which studies various aspects of corrosion and the damage that may result in refineries, chemical plants, water systems and other types of industrial equipment. MR0175 was first issued in 1975, but the origin of the document dates to 1959 when a group of engineers in Western Canada pooled their experience in successful handling of sour gas. The group organized as a NACE committee and in 1963 issued specification 1B163, “Recommendations of Materials for Sour Service.” In 1965, NACE organized a nationwide committee, which issued 1F166 in 1966 and MR0175 in 1975. Revisions were issued on an annual basis as new materials and processes were added. Revisions had to receive unanimous approval from the responsible NACE committee.

In the mid-1990’s, the European Federation of Corrosion (EFC) issued 2 reports closely related to MR0175; Publication 16, “Guidelines on Materials Requirements for Carbon and Low Alloy Steels for H_2S-Containing Environments in Oil and Gas Production” and Publication 17, “Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H_2S Service.” EFC is located in London, England.

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from more than 140 countries. One organization from each country acts as the representative for all organizations in that country. The American National Standards Institute (ANSI) is the USA representative in ISO. Technical Committee 67, “Materials, Equipment and Offshore Structures for Petroleum, Petrochemical and Natural Gas Industries,” requested that NACE blend the different sour service documents into a single global standard.

This task was completed in late 2003 and the document was issued as ISO standard, NACE MR0175/ISO 15156. It is now maintained by ISO/TC 67, Work Group 7, a 12-member “Maintenance Panel” and a 40-member Oversight Committee under combined NACE/ISO control. The three committees are an international group of users, manufacturers and service providers. Membership is approved by NACE and ISO based on technical knowledge and experience. Terms are limited. Previously, some members on the NACE Task Group had served for over 25 years.

NACE MR0175/ISO 15156 is published in 3 volumes.

Part 1: General Principles for Selection of Cracking-Resistant Materials

Part 2: Cracking-Resistant Carbon and Low Alloy Steels, and the Use of Cast Irons

Part 3: Cracking-Resistant CRA’s (Corrosion-Resistant Alloys) and Other Alloys

NACE MR0175/ISO 15156 applies only to petroleum production, drilling, gathering and flow line equipment and field processing facilities to be used in H_2S bearing hydrocarbon service. In the past, MR0175 only addressed sulfide stress cracking (SSC). In NACE MR0175/ISO 15156, however, but both SSC and chloride stress corrosion cracking (SCC) are considered. While clearly intended to be used only for oil field equipment, industry has applied MR0175 in to many other areas including refineries, LNG plants, pipelines and natural gas systems. The judicious use of the document in these applications is constructive and can help prevent SSC failures wherever H_2S is present. Saltwater wells and saltwater handling facilities are not covered by NACE MR0175/ISO 15156. These are covered by NACE Standard RP0475, “Selection of Metallic Materials to Be Used in All Phases of Water Handling for Injection into Oil-Bearing Formations.”

When new restrictions are placed on materials in NACE MR0175/ISO 15156 or when materials are deleted from this standard, materials in use at that time are in compliance. This includes materials listed in MR0175-2002, but not listed in NACE MR0175/ISO 15156. However, if this equipment is moved to a different location and exposed to different conditions, the materials must be listed in the current revision. Alternatively, successful use of materials outside the limitations of NACE MR0175/ISO 15156 may be perpetuated by qualification testing per the standard. The user may replace materials in kind for existing wells or for new wells within a given field if the environmental conditions of the field have not changed.

Sulfide Stress Cracking --NACE MR0175-2002, MR0175/ISO 15156

New Sulfide Stress Cracking Standard for Refineries

Don Bush, Principal Engineer - Materials, at Emerson Process Management Fisher Valves, is a member and former chair of a NACE task group that has written a document for refinery applications, NACE MR0103. The title is “Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments.” The requirements of this standard are very similar to the pre-2003 MR0175 for many materials. When applying this standard, there are changes to certain key materials compared with NACE MR0175-2002.

Responsibility

It has always been the responsibility of the end user to determine the operating conditions and to specify when NACE MR0175 applies. This is now emphasized more strongly than ever in NACE MR0175/ISO 15156. The manufacturer is responsible for meeting the metallurgical requirements of NACE MR0175/ISO 15156. It is the end user’s responsibility to ensure that a material will be satisfactory in the intended environment. Some of the operating conditions which must be considered include pressure, temperature, corrosiveness, fluid properties, etc. When bolting components are selected, the pressure rating of flanges could be affected. It is always the responsibility of the equipment user to convey the environmental conditions to the equipment supplier, particularly if the equipment will be used in sour service.

The various sections of NACE MR0175/ISO 15156 cover the commonly available forms of materials and alloy systems. The requirements for heat treatment, hardness levels, conditions of mechanical work and post-weld heat treatment are addressed for each form of material. Fabrication techniques, bolting, platings and coatings are also addressed.

Applicability of NACE MR0175/ISO 15156

Low concentrations of H_2S (<0.05 psi (0,3 kPa) H_2S partial pressure) and low pressures (<65 psia or 450 kPa) are considered outside the scope of NACE MR0175/ISO 15156. The low stress levels at low pressures or the inhibitive effects of oil may give satisfactory performance with standard commercial equipment. Many users, however, have elected to take a conservative approach and specify compliance to either NACE MR0175 or NACE MR0175/ISO 15156 any time a measurable amount of H_2S is present. The decision to follow these specifications must be made by the user based on economic impact, the safety aspects should a failure occur and past field experience. Legislation can impact the decision as well. Such jurisdictions include; the Texas Railroad Commission and the U.S. Minerals Management Service (offshore). The Alberta, Canada Energy Conservation Board recommends use of the specifications.

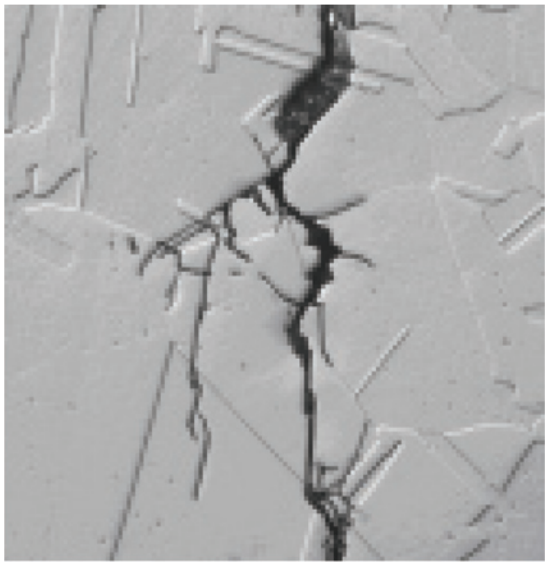


Figure 1. *Photomicrograph Showing Stress Corrosion Cracking*

Basics of Sulfide Stress Cracking (SSC) and Stress Corrosion Cracking (SCC)

SSC and SCC are cracking processes that develop in the presence of water, corrosion and surface tensile stress. It is a progressive type of failure that produces cracking at stress levels that are well below the material’s tensile strength. The break or fracture appears brittle, with no localized yielding, plastic deformation or elongation. Rather than a single crack, a network of fine, feathery, branched cracks will form (see Figure 1). Pitting is frequently seen, and will serve as a stress concentrator to initiate cracking.

With SSC, hydrogen ions are a product of the corrosion process (Figure 2). These ions pick up electrons from the base material producing hydrogen atoms. At that point, two hydrogen atoms may combine to form a hydrogen molecule. Most molecules will eventually collect, form hydrogen bubbles and float away harmlessly. However, some percentage of the hydrogen atoms will diffuse into the base metal and embrittle the crystalline structure. When a certain critical concentration of hydrogen is reached and combined with a tensile stress exceeding a threshold level, SSC will occur. H_2S does not actively participate in the SSC reaction; however, sulfides act to promote the entry of the hydrogen atoms into the base material.

As little as 0.05 psi (0,3 kPa) H_2S partial pressure in 65 psia (450 kPa) hydrocarbon gas can cause SSC of carbon and low alloy steels. Sulfide stress cracking is most severe at ambient temperature, particularly in the range of 20° to 120°F (-6° to 49°C). Below 20°F (-6°C) the diffusion rate of the hydrogen is

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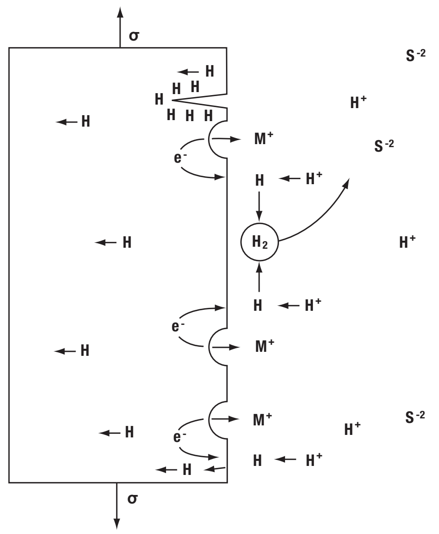

Figure 2. *Schematic Showing the Generation of Hydrogen Producing SSC*

so slow that the critical concentration is never reached. Above 120°F (49°C), the diffusion rate is so fast that the hydrogen atoms pass through the material in such a rapid manner that the critical concentration is not reached.

Chloride SCC is widely encountered and has been extensively studied. Much is still unknown, however, about its mechanism. One theory says that hydrogen, generated by the corrosion process, diffuses into the base metal in the atomic form and embrittles the lattice structure. A second, more widely accepted theory proposes an electrochemical mechanism. Stainless steels are covered with a protective, chromium oxide film. The chloride ions rupture the film at weak spots, resulting in anodic (bare) and cathodic (film covered) sites. The galvanic cell produces accelerated attack at the anodic sites, which when combined with tensile stresses produces cracking. A minimum ion concentration is required to produce SCC. As the concentration increases, the environment becomes more severe, reducing the time to failure.

Temperature also is a factor in SCC. In general, the likelihood of SCC increases with increasing temperature. A minimum threshold temperature exists for most systems, below which SCC is rare. Across industry, the generally accepted minimum temperature for chloride SCC of the 300 SST's is about 160°F (71°C). NACE MR0175/ISO 15156 has set a very conservative limit of 140°F (60°C) due to the synergistic effects of the chlorides, H_2S and low pH values. As the temperature increases above these values, the time to failure will typically decrease.

Resistance to chloride SCC increases with higher alloy materials. This is reflected in the environmental limits set by NACE MR0175/ISO 15156. Environmental limits progressively increase from 400 Series SST and ferritic SST to 300 Series, highly alloy austenitic SST, duplex SST, nickel and cobalt base alloys.

Carbon Steel

Carbon and low-alloy steels have acceptable resistance to SSC and SCC however; their application is often limited by their low resistance to general corrosion. The processing of carbon and low alloy steels must be carefully controlled for good resistance to SSC and SCC. The hardness must be less than 22 HRC. If welding or significant cold working is done, stress relief is required. Although the base metal hardness of a carbon or alloy steel is less than 22 HRC, areas of the heat affected zone (HAZ) will be harder. PWHT will eliminate these excessively hard areas.

ASME SA216 Grades WCB and WCC and SAME SA105 are the most commonly used body materials. It is Fisher's policy to stress relieve all welded carbon steels that are supplied to NACE MR0175/ISO 15156.

All carbon steel castings sold to NACE MR0175/ISO 15156 requirements are produced using one of the following processes:

1. In particular product lines where a large percentage of carbon steel assemblies are sold as NACE MR0175/ISO 15156 compliant, castings are ordered from the foundry with a requirement that the castings be either normalized or stress relieved following all weld repairs, major or minor. Any weld repairs performed, either major or minor, are subsequently stress relieved.

2. In product lines where only a small percentage of carbon steel products are ordered NACE MR0175/ISO 15156 compliant, stock castings are stress relieved whether they are weld repaired by Emerson Process Management or not. This eliminates the chance of a minor foundry weld repair going undetected and not being stress relieved.

ASME SA352 grades LCB and LCC have the same composition as WCB and WCC, respectively. They are heat treated differently and impact tested at -50°F (-46°C) to ensure good toughness in low temperature service. LCB and LCC are used in locations where temperatures commonly drop below the -20°F (-29°C) permitted for WCB and WCC. LCB and LCC castings are processed in the same manner as WCB and WCC when required to meet NACE MR0175/ ISO 15156.

For carbon and low-alloy steels NACE MR0175/ISO 15156 imposes some changes in the requirements for the weld procedure qualification report (PQR). All new PQR's will meet these requirements; however, it will take several years for Emerson Process Management and our suppliers to complete this work. At this time, we will require user approval to use HRC.

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Carbon and Low-Alloy Steel Welding Hardness Requirements

- HV-10, HV-5 or Rockwell 15N.
- HRC testing is acceptable if the design stresses are less than 67% of the minimum specified yield strength and the PQR includes PWHT.
- Other methods require user approval.
- 250 HV or 70.6 HR15N maximum.
- 22 HRC maximum if approved by user.

Low-Alloy Steel Welding Hardness Requirements

- All of the above apply with the additional requirement of stress relieve at 1150°F (621°C) minimum after welding.

All new PQR's at Emerson Process Management and our foundries will require hardness testing with HV-10, HV-5 or Rockwell 15N and HRC. The acceptable maximum hardness values will be 250 HV or 70.6 HR15N and 22 HRC. Hardness traverse locations are specified in NACE MR0175/ISO 15156 part 2 as a function of thickness and weld configuration. The number and locations of production hardness tests are still outside the scope of the standard. The maximum allowable nickel content for carbon and low-alloy steels and their weld deposits is 1%.

Low alloy steels like WC6, WC9, and C5 are acceptable to NACE MR0175/ISO 15156 to a maximum hardness of 22 HRC. These castings must all be stress relieved to FMS 20B52.

The compositions of C12, C12a, F9 and F91 materials do not fall within the definition of "low alloy steel" in NACE MR0175/ISO 15156, therefore, these materials are not acceptable.

A few customers have specified a maximum carbon equivalent (CE) for carbon steel. The primary driver for this requirement is to improve the SSC resistance in the as-welded condition. Fisher's practice of stress relieving all carbon steel negates this need. Decreasing the CE reduces the hardenability of the steel and presumably improves resistance to sulfide stress cracking (SSC). Because reducing the CE decreases the strength of the steel, there is a limit to how far the CE can be reduced.

Cast Iron

Gray, austenitic and white cast irons cannot be used for any pressure-retaining parts, due to low ductility. Ferritic ductile iron to ASTM A395 is acceptable when permitted by ANSI, API or other industry standards.

Stainless Steel

400 Series Stainless Steel

UNS 410 (410 SST), CA15 (cast 410), 420 (420 SST) and several other martensitic grades must be double tempered to a maximum hardness of 22 HRC. PWHT is also required. An environmental limit now applies to the martensitic grades; 1.5 psi (10 kPa) H_2S partial pressure and pH greater than or equal to 3.5, 416 (416 SST) is similar to 410 (410) with the exception of a sulfur addition to produce free machining characteristics. Use of 416 and other free machining steels is not permitted by NACE MR0175/ISO 15156.

CA6NM is a modified version of the cast 410 stainless steel. NACE MR0175/ISO 15156 allows its use, but specifies the exact heat treatment required. Generally, the carbon content must be restricted to 0.03% maximum to meet the 23 HRC maximum hardness. PWHT is required for CA6NM. The same environmental limit applies; 1.5 psi (10 kPa) H_2S partial pressure and pH greater than or equal to 3.5.

300 Series Stainless Steel

Several changes have been made with the requirements of the austenitic (300 Series) stainless steels. Individual alloys are no longer listed. All alloys with the following elemental ranges are acceptable: C 0.08% maximum, Cr 16% minimum, Ni 8% minimum, P 0.045% maximum, S 0.04% maximum, Mn 2.0% maximum, and Si 2.0% maximum. Other alloying elements are permitted. The other requirements remain; solution heat treated condition, 22 HRC maximum and free of cold work designed to improve mechanical properties. The cast and wrought equivalents of 302, 304 (CF8), S30403 (CF3), 310 (CK20), 316 (CF8M), S31603 (CF3M), 317 (CG8M), S31703 (CG3M), 321, 347 (CF8C) and N08020 (CN7M) are all acceptable per NACE MR0175/ISO 15156.

Environmental restrictions now apply to the 300 Series SST. The limits are 15 psia (100 kPa) H_2S partial pressure, a maximum temperature of 140°F (60°C), and no elemental sulfur. If the chloride content is less than 50 mg/L (50 ppm), the H_2S partial pressure must be less than 50 psia (350 kPa) but there is no temperature limit.

There is less of a restriction on 300 Series SST in oil and gas processing and injection facilities. If the chloride content in aqueous solutions is low (typically less than 50 mg/L or 50 ppm chloride) in operations after separation, there are no limits for austenitic stainless steels, highly alloyed austenitic stainless steels, duplex stainless steels, or nickel-based alloys.

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Post-weld heat treatment of the 300 Series SST is not required. Although the corrosion resistance may be affected by poorly controlled welding, this can be minimized by using the low carbon filler material grades, low heat input levels and low interpass temperatures. We impose all these controls as standard practice. NACE MR0175/ISO 15156 now requires the use of "L" grade consumables with 0.03% carbon maximum.

S20910

S20910 (Nitronic® 50) is acceptable in both the annealed and high strength conditions with environmental restrictions; H_2S partial pressure limit of 15 psia (100 kPa), a maximum temperature of 150°F (66°C), and no elemental sulfur. This would apply to components such as bolting, plugs, cages, seat rings and other internal parts. Strain hardened (cold-worked) S20910 is acceptable for shafts, stems, and pins without any environmental restrictions. Because of the environmental restrictions and poor availability on the high strength condition, use of S20910 will eventually be discontinued except for shafts, stems and pins where unrestricted application is acceptable for these components.

CK3MCuN

The cast equivalent of S31254 (Avesta 254SMO®), CK3MCuN (UNS J93254), is included in this category. The same elemental limits apply. It is acceptable in the cast, solution heat-treated condition at a hardness level of 100 HRB maximum in the absence of elemental sulfur.

S17400

The use of S17400 (17-4PH) is now prohibited for pressure-retaining components including bolting, shafts and stems. Prior to 2003, S17400 was listed as an acceptable material in the general section (Section 3) of NACE MR0175. Starting with the 2003 revision, however, it is no longer listed in the general section. Its use is restricted to internal, non-pressure containing components in valves, pressure regulators and level controllers. This includes cages and other trim parts. 17-4 bolting will no longer be supplied in any NACE MR0175/ISO 15156 construction. The 17-4 and 15-5 must be heat-treated to the H1150 DBL condition or the H1150M condition. The maximum hardness of 33 HRC is the same for both conditions.

CB7Cu-1 and CB7Cu-2 (cast 17-4PH and 15-5 respectively) in the H1150 DBL condition are also acceptable for internal valve and regulator components. The maximum hardness is 30 HRC or 310 HB for both alloys.

Duplex Stainless Steel

Wrought and cast duplex SST alloys with 35-65% ferrite are acceptable based on the composition of the alloy, but there are environmental restrictions. There is no differentiation between cast and wrought, therefore, cast CD3MN is now acceptable. There are two categories of duplex SST. The "standard" alloys with a $30 \leq PREN \leq 40$ and $\geq 1.5\%$ Mo, and the "super" duplex alloys with PREN>40. The PREN is calculated from the composition of the material. The chromium, molybdenum, tungsten and nitrogen contents are used in the calculation. NACE MR0175/ISO 15156 uses this number for several classes of materials.

$$PREN = Cr\% + 3.3(Mo\% + 0.5W\%) + 16N\%$$

The "standard" duplex SST grades have environmental limits of 450°F (232°C) maximum and H_2S partial pressure of 1.5 psia (10 kPa) maximum. The acceptable alloys include S31803, CD3MN, S32550 and CD7MCuN (Ferralium® 255). The alloys must be in the solution heat-treated and quenched condition. There are no hardness restrictions in NACE MR0175/ISO 15156, however, 28 HRC remains as the limit in the refinery document MR0103.

The "super" duplex SST with PREN>40 have environmental limits of 450°F (232°C) maximum and H_2S partial pressure of 3 psia (20 kPa) maximum. The acceptable "super" duplex SST's include S32760 and CD3MWCuN (Zeron® 100).

The cast duplex SST Z 6CNDU20.08M to the French National Standard NF A 320-55 is no longer acceptable for NACE MR0175/ ISO 15156 applications. The composition fails to meet the requirements set for either the duplex SST or the austenitic SST.

Highly Alloyed Austenitic Stainless Steels

There are two categories of highly alloyed austenitic SST's that are acceptable in the solution heat-treated condition. There are different compositional and environmental requirements for the two categories. The first category includes alloys S31254 (Avesta 254SMO®) and N08904 (904L); Ni% + 2Mo%>30 and Mo=2% minimum.

Alloy S31254 and N08904 Environmetal Limits

MAXIMUM TEMPERATURE	MAXIMUM H_2S PARTIAL PRESSURE	MAXIMUM CHLORIDES	ELEMENTAL SULFUR
140°F (60°C)	1.5 psia (10 kPa)	No restriction	No
140°F (60°C)	50 psia (345 kPa)	50 mg/L Chloride	No

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The second category of highly alloyed austenitic stainless steels are those having a PREN >40. This includes S31654 (Avesta 654SMO®), N08926 (Inco 25-6Mo), N08367 (AL-6XN), S31266 (UR B66) and S34565. The environmental restrictions for these alloys are as follows:

Alloy S31654, N08926, N08367, S31266, and S34565 Environmental Limits			
MAXIMUM TEMPERATURE	MAXIMUM H_2S PARTIAL PRESSURE	MAXIMUM CHLORIDES	ELEMENTAL SULFUR
250°F (121°C)	100 psia (700 kPa)	5,000 mg/L chloride	No
300°F (149°C)	45 psia (310 kPa)	5,000 mg/L chloride	No
340°F (171°C)	15 psia (100 kPa)	5,000 mg/L chloride	No

Nonferrous Alloys

Nickel-Base Alloys

Nickel base alloys have very good resistance to cracking in sour, chloride containing environments. There are 2 different categories of nickel base alloys in NACE MR0175/ISO 15156:

- Solid-solution nickel-based alloys
- Precipitation hardenable alloys

The solid solution alloys are the Hastelloy® C, Inconel® 625 and Incoloy® 825 type alloys. Both the wrought and cast alloys are acceptable in the solution heat-treated condition with no hardness limits or environmental restrictions. The chemical composition of these alloys is as follows:

- 19.0% Cr minimum, 29.5% Ni minimum, and 2.5% Mo minimum. Includes N06625, CW6MC, N08825, CU5MCuC.

- 14.5% Cr minimum, 52% Ni minimum, and 12% Mo minimum. Includes N10276, N06022, CW2M.

N08020 and CN7M (alloy 20 Cb3) are not included in this category. They must follow the restrictions placed on the austenitic SST's like 304, 316 and 317.

Although originally excluded from NACE MR0175/ISO 15156, N04400 (Monel® 400) in the wrought and cast forms are now included in this category.

The precipitation hardenable alloys are Incoloy® 925, Inconel® 718 and X750 type alloys. They are listed in the specification as individual alloys. Each has specific hardness and environmental restrictions.

N07718 is acceptable in the solution heat-treated and precipitation hardened condition to 40 HRC maximum. N09925 is acceptable in the cold-worked condition to 35 HRC maximum, solution-annealed and aged to 38 HRC maximum and cold-worked and aged to 40 HRC maximum.

The restrictions are as follows:

Cast N07718 Environmental Limits		
MAXIMUM TEMPERATURE	MAXIMUM H_2S PARTIAL PRESSURE	ELEMENTAL SULFUR
450°F (232°C)	30 psia (0,2 MPa)	No
400°F (204°C)	200 psia (1,4 MPa)	No
300°F (149°C)	400 psia (2,8 MPa)	No
275°F (135°C)	No limit	Yes

Cast N07718 is acceptable in the solution heat-treated and precipitation hardened condition to 35 HRC maximum. The restrictions are as follows:

Alloy N07718 and N09925 Environmental Limits		
MAXIMUM TEMPERATURE	MAXIMUM H_2S PARTIAL PRESSURE	ELEMENTAL SULFUR
450°F (232°C)	30 psia (0,2 MPa)	No
400°F (204°C)	200 psia (1,4 MPa)	No
390°F (199°C)	330 psia (2,3 MPa)	No
375°F (191°C)	360 psia (2,5 MPa)	No
300°F (149°C)	400 psia (2,8 MPa)	No
275°F (135°C)	No limit	Yes

Monel® K500 and Inconel® X750

N05500 and N07750 are now prohibited for use in pressure-retaining components including bolting, shafts and stems. They can still be used for internal parts such as cages, other trim parts and torque tubes. There are no environmental restrictions, however, for either alloy. They must be in the solution heat-treated condition with a maximum hardness of 35 HRC. N07750 is still acceptable for springs to 50 HRC maximum.

Cobalt-Base Alloys

Alloy 6 castings and hardfacing are still acceptable. There are no environmental limits with respect to partial pressures of H_2S or elemental sulfur. All other cobalt-chromium-tungsten, nickel-chromium-boron (Colmonoy) and tungsten-carbide castings are also acceptable without restrictions.

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All cobalt based, nickel based and tungsten-carbide weld overlays are acceptable without environmental restrictions. This includes CoCr-A, NiCr-A (Colmonoy® 4), NiCr-C (Colmonoy® 6) and Haynes Ultimet® hardfacing.

Wrought UNS R31233 (Haynes Ultimet®) is acceptable in the solution heat-treated condition to 22 HRC maximum, however, all production barstock exceeds this hardness limit. Therefore, Ultimet® barstock cannot be used for NACE MR0175/ISO 15156 applications. Cast Ultimet is not listed in NACE MR0175/ISO 15156.

R30003 (Elgiloy®) springs are acceptable to 60 HRC in the cold worked and aged condition. There are no environmental restrictions.

Aluminum and Copper Alloys

Per NACE MR0175/ISO 15156, environmental limits have not been established for aluminum base and copper alloys. This means that they could be used in sour applications per the requirements of NACE MR0175/ISO 15156, however, they should not be used because severe corrosion attack will likely occur. They are seldom used in direct contact with H_2S.

Titanium

Environmental limits have not been established for the wrought titanium grades. Fisher® has no experience in using titanium in sour applications. The only common industrial alloy is wrought R50400 (grade 2). Cast titanium is not included in NACE MR0175/ISO 15156.

Zirconium

Zirconium is not listed in NACE MR0175/ISO 15156.

Springs

Springs in compliance with NACE represent a difficult problem. To function properly, springs must have very high strength (hardness) levels. Normal steel and stainless steel springs would be very susceptible to SSC and fail to meet NACE MR0175/ISO 15156. In general, relatively soft, low strength materials must be used. Of course, these materials produce poor springs. The two exceptions allowed are the cobalt based alloys, such as R30003 (Elgiloy®), which may be cold worked and hardened to a maximum hardness of 60 HRC and alloy N07750 (alloy X750) which is permitted to 50 HRC. There are no environmental restrictions for these alloys.

Coatings

Coatings, platings and overlays may be used provided the base metal is in a condition which is acceptable per NACE MR0175/ISO 15156. The coatings may not be used to protect a base material which is susceptible to SSC. Coatings commonly used in sour service are chromium plating, electroless nickel (ENC) and nitriding. Overlays and castings commonly used include CoCr-A (Stellite® or alloy 6), R30006 (alloy 6B), NiCr-A and NiCr-C (Colmonoy® 4 and 6) nickel-chromium-boron alloys. Tungsten carbide alloys are acceptable in the cast, cemented or thermally sprayed conditions. Ceramic coatings such as plasma sprayed chromium oxide are also acceptable. As is true with all materials in NACE MR0175/ISO 15156, the general corrosion resistance in the intended application must always be considered.

NACE MR0175/ISO 15156 permits the uses of weld overlay cladding to protect an unacceptable base material from cracking. Fisher does not recommend this practice, however, as hydrogen could diffuse through the cladding and produce cracking of a susceptible basemetal such as carbon or low alloy steel.

Stress Relieving

Many people have the misunderstanding that stress relieving following machining is required by NACE MR0175/ISO 15156. Provided good machining practices are followed using sharp tools and proper lubrication, the amount of cold work produced is negligible. SSC and SCC resistance will not be affected. NACE MR0175/ISO 15156 actually permits the cold rolling of threads, provided the component will meet the heat treat conditions and hardness requirements specified for the given parent material. Cold deformation processes such as burnishing are also acceptable.

Bolting

Bolting materials must meet the requirements of NACE MR0175/ISO 15156 when directly exposed to the process environment (“exposed” applications). Standard ASTM A193 and ASME SA193 grade B7 bolts or ASTM A194 and ASME SA194 grade 2H nuts can and should be used provided they are outside of the process environment (“non-exposed” applications). If the bolting will be deprived atmospheric contact by burial, insulation or flange protectors and the customer specifies that the bolting will be “exposed”, then grades of bolting such as B7 and 2H are unacceptable. The most commonly used fasteners listed for “exposed” applications are grade B7M bolts (99 HRB maximum) and grade 2HM nuts (22 HRC maximum). If 300 Series SST fasteners are needed, the bolting grades B8A Class 1A and B8MA Class 1A are acceptable. The corresponding nut grades are 8A and 8MA.

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It must be remembered, however, that the use of lower strength bolting materials such as B7M may require pressure vessel derating. The special S17400 double H1150 bolting previously offered on E body valves to maintain the full B7 rating is no longer acceptable to NACE MR0175/ISO 15156. Prior to the 2003, S17400 was listed as an acceptable material in the general section (Section 3) of NACE MR0175. Following the 2003 revision, it is no longer listed in the general section. Its use is now restricted to internal, non-pressure containing components in valves, pressure regulators and level controllers. The use of S17400 for bolting is specifically prohibited. N07718 (alloy 718) bolting with 2HM nuts is one alternative.

Two different types of packing box studs and nuts are commonly used by Fisher®. The stainless steel type is B8M S31600 class 2 (strain hardened) and 316 nuts per FMS 20B86. The steel type is B7 studs with 2H nuts. If the customer specifies that the packing box studs and nuts are "exposed" then grade B7M studs and grade 2HM nuts or B8MA Class 1A studs and 8MA nuts are commonly used.

Bolting Coatings

NFC (Non-Corroding Finish) and ENC (Electroless Nickel Coating) coatings are acceptable on pressure-retaining and non-pressure-retaining fasteners. For some reason, there is often confusion regarding the acceptability of zinc plated fasteners per NACE MR0175/ISO 15156. NACE MR0175/ISO 15156 does not preclude the use of any coating, provided it is not used in an attempt to prevent SSC or SCC of an otherwise unacceptable base material. However, zinc plating of pressure-retaining bolting is not recommended due to liquid metal induced embrittlement concerns.

Composition Materials

NACE MR0175/ISO 15156 does not address elastomer and polymer materials although ISO/TC 67, Work Group 7 is now working on a Part 4 to address these materials. The importance of these materials in critical sealing functions, however, cannot be overlooked. User experience has been successful with elastomers such as Nitrile (NBR), Neoprene and the Fluoroelastomers (FKM) and Perfluoroelastomers (FFKM). In general, fluoropolymers such as Polytetrafluoroethylene (PTFE), TCM Plus, TCM Ultra and TCM III can be applied without reservation within their normal temperature range.

Elastomer use is as follows:

1. If possible, use HNBR for sour natural gas, oil, or water at temperatures below 250°F (121°C). It covers the widest range of sour applications at a lower cost than PTFE or Fluoroelastomer (FKM). Unfortunately, the material is relatively new, and only a handful of parts are currently set up. Check availability before specifying.
2. Use PTFE for sour natural gas, oil, or water applications at temperatures between 250°F (121°C) and 400°F (204°C).
3. Fluoroelastomer (FKM) can be used for sour natural gas, oil, or water applications with less than 10% H_2S and temperatures below 250°F (121°C).
4. Conventional Nitrile (NBR) can be used for sour natural gas, oil, or water applications with less than 1% H_2S and temperatures below 150°F (66°C).
5. CR can be used for sour natural gas or water applications involving temperatures below 150°F (66°C). Its resistance to oil is not as good.
6. IIR and Ethylenepropylene (EPDM) (or EPR) can be used for H_2S applications that don't involve hydrocarbons (H_2S gas, sour water, etc.).

Tubulars

A separate section has been established for downhole tubulars and couplings. This section contains provisions for using materials in the cold-drawn condition to higher hardness levels (cold-worked to 35 HRC maximum). In some cases, the environmental limits are also different. This has no affect on Fisher as we do not make products for these applications. Nickel-based components used for downhole casing, tubing, and the related equipment (hangers and downhole component bodies; components that are internal to the downhole component bodies) are subject to the requirements.

Expanded Limits and Materials

With documented laboratory testing and/or field experience, it is possible to expand the environmental limits of materials in NACE MR0175/ISO 15156 or use materials not listed in NACE MR0175/ISO 15156. This includes increasing the H_2S partial pressure limit or temperature limitations. Supporting documentation must be submitted to NACE International Headquarters, which will make the data available to the public. NACE International will neither review nor approve this documentation. It is the user's responsibility to evaluate and determine the applicability of the documented data for the intended application.

It is the user's responsibility to ensure that the testing cited is relevant for the intended applications. Choice of appropriate temperatures and environments for evaluating susceptibility to both SCC and SSC is required. NACE Standard TM0177 and EFC Publication #1739 provide guidelines for laboratory testing.

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Field-based documentation for expanded alloy use requires exposure of a component for sufficient time to demonstrate its resistance to SCC/SSC. Sufficient information on factors that affect SCC/SSC (e.g., stress levels, fluid and gas composition, operating conditions, galvanic coupling, etc.) must be documented.

Codes and Standards

Applicable ASTM, ANSI, ASME and API standards are used along with NACE MR0175/ISO 15156 as they would normally be used for other applications. The NACE MR0175/ISO 15156 requires that all weld procedures be qualified to these same standards. Welders must be familiar with the procedures and capable of making welds which comply.

Certification

Fisher® Certification Form 7508 is worded as follows for NACE MR0175-2002 and MR0175/ISO 15156:

"NACE MR0175/ISO 15156 OR NACE MR0175-2002: This unit meets the metallurgical requirements of NACE MR0175 or ISO 15156 (revision and materials of construction as specified by the customer). Environmental restrictions may apply to wetted parts and/or bolting."

Chemical Compatibility of Elastomers and Metals

Introduction

This section explains the uses and compatibilities of elastomers commonly used in Fisher® regulators. The following tables provide the compatibility of the most common elastomers and metals to a variety of chemicals and/or compounds.

The information contained herein is extracted from data we believe to be reliable. However, because of variable service conditions over which we have no control, we do not in any way make any warranty, either express or implied, as to the properties of any materials or as to the performance of any such materials in any particular application, and we hereby expressly disclaim any responsibility for the accuracy of any of the information set forth herein.

Refer to the applicable process gas service code or standard to determine if a specific material found in the Process Gases Application Guide is allowed to be used in that service.

Elastomers: Chemical Names and Uses

NBR - Nitrile Rubber, also called Buna-N, is a copolymer of butadiene and acrylonitrile. Nitrile is recommended for: general purpose sealing, petroleum oils and fluids, water, silicone greases and oils, di-ester based lubricants (such as MIL-L-7808), and ethylene glycol based fluids (Hydrolubes). It is not recommended for: halogenated hydrocarbons, nitro hydrocarbons (such as nitrobenzene and aniline), phosphate ester hydraulic fluids (Skydrol, Cellulube, Pydraul), ketones (MEK, acetone), strong acids, ozone, and automotive brake fluid. Its temperature range is -60° to 225°F (-51° to 107°C), although this would involve more than one compound and would depend upon the stress state of the component in service.

EPDM, EPM - Ethylenepropylene rubber is an elastomer prepared from ethylene and propylene monomers. EPM is a copolymer of ethylene and propylene, while EPDM contains a small amount of a third monomer (a diene) to aid in the curing process. EP is recommended for: phosphate ester based hydraulic fluids, steam to 400°F (204°C), water, silicone oils and greases, dilute acids, dilute alkalis, ketones, alcohols, and automotive brake fluids. It is not recommended for: petroleum oils, and di-ester based lubricants. Its temperature range is -60° to 500°F (-51° to 260°C) (The high limit would make use of a special high temperature formulation developed for geothermal applications).

FKM - This is a fluoroelastomer of the polymethylene type having substituent fluoro and perfluoroalkyl or perfluoroalkoxy groups on the polymer chain. Viton® and Fluorel® are the most common trade names. FKM is recommended for: petroleum oils, di-ester based lubricants, silicate ester based lubricants (such as MLO 8200, MLO 8515, OS-45), silicone fluids and greases, halogenated hydrocarbons, selected phosphate ester fluids, and some acids. It is not recommended for: ketones, Skydrol 500, amines (UDMH), anhydrous ammonia, low molecular weight esters and ethers, and hot hydrofluoric and chlorosulfonic acids. Its temperature range is -20° to 450°F (-29° to 232°C) (This extended range would require special grades and would limit use on each end of the range.).

CR - This is chloroprene, commonly know as neoprene, which is a homopolymer of chloroprene (chlorobutadiene). CR is recommended for: refrigerants (Freons, ammonia), high aniline point petroleum oils, mild acids, and silicate ester fluids. It is not recommended for: phosphate ester fluids and ketones. Its temperature range is -60° to 200°F (-51° to 93°C), although this would involve more than one compound.

NR - This is natural rubber which is a natural polyisoprene, primarily from the tree, Hevea Brasiliensis. The synthetics have all but completely replaced natural rubber for seal use. NR is recommended for automotive brake fluid, and it is not recommended for petroleum products. Its temperature range is -80° to 180°F (-62° to 82°C).

FXM - This is a copolymer of tetrafluoroethylene and propylene; hence, it is sometimes called PTFE/P rubber. Common trade names are Aflas® (Asahi Glass Co., Ltd) and Fluoraz® (Greene, Tweed & Co.). It is generally used where resistance to both hydrocarbons and hot water are required. Its temperature range is 20° to 400°F (-7° to 204°C).

ECO - This is commonly called Hydrin® rubber, although that is a trade name for a series of rubber materials by B.F. Goodrich. CO is the designation for the homopolymer of epichlorohydrin, ECO is the designation for a copolymer of ethylene oxide and chloromethyl oxirane (epichlorohydrin copolymer), and ETER is the designation for the terpolymer of epichlorohydrin, ethylene oxide, and an unsaturated monomer. All the epichlorohydrin rubbers exhibit better heat resistance than nitrile rubbers, but corrosion with aluminum may limit applications. Normal temperature range is (-40° to 250°F (-40° to 121°C), while maximum temperature ranges are -40° to 275°F (-40° to 135°C) (for homopolymer CO) and -65° to 275°F (-54° to 135°C) (for copolymer ECO and terpolymer ETER).

FFKM - This is a perfluoroelastomer generally better known as Kalrez® (DuPont) and Chemraz® (Greene, Tweed). Perfluoro rubbers of the polymethylene type have all substituent groups on the polymer chain of fluoro, perfluoroalkyl, or perfluoroalkoxy groups. The resulting polymer has superior chemical resistance and heat temperature resistance. This elastomer is extremely expensive and should be used only when all else fails. Its temperature range is 0° to 480°F (-18° to 249°C). Some materials, such as Kalrez® 1050LF is usable to 550°F (288°C) and Kalrez® 4079 can be used to 600°F (316°C).

FVMQ - This is fluorosilicone rubber which is an elastomer that should be used for static seals because it has poor mechanical properties. It has good low and high temperature resistance and is reasonably resistant to oils and fuels because of its fluorination. Because of the cost, it only finds specialty use. Its temperature range is -80° to 400°F (-62° to 204°C).

VMQ - This is the most general term for silicone rubber. Silicone rubber can be designated MQ, PMQ, and PVMQ, where the Q designates any rubber with silicon and oxygen in the polymer chain, and M, P, and V represent methyl, phenyl, and vinyl substituent groups on the polymer chain. This elastomer is used only for static seals due to its poor mechanical properties. Its temperature range is -175° to 600°F (-115° to 316°C) (Extended temperature ranges require special compounds for high or low temperatures).

Chemical Compatibility of Elastomers and Metals

General Properties of Elastomers													
PROPERTY		NATURAL RUBBER	BUNA-S	NITRILE (NBR)	NEO-PRENE (CR)	BUTYL	THIOKOL®	SILICONE	HYPALON®	FLUORO-ELASTOMER[1,2] (FKM)	POLY-URETHANE[2]	POLY-ACRYLIC[1]	ETHYLENE-PROPYLENE[3] (EPDM)
Tensile Strength, Psi (bar)	Pure Gum	3000 (207)	400 (28)	600 (41)	3500 (241)	3000 (207)	300 (21)	200 to 450 (14 to 31)	4000 (276)	- - - -	- - - -	100 (7)	- - - -
	Reinforced	4500 (310)	3000 (207)	4000 (276)	3500 (241)	3000 (207)	1500 (103)	1100 (76)	4400 (303)	2300 (159)	6500 (448)	1800 (124)	2500 (172)
Tear Resistance		Excellent	Poor-Fair	Fair	Good	Good	Fair	Poor-Fair	Excellent	Good	Excellent	Fair	Poor
Abrasion Resistance		Excellent	Good	Good	Excellent	Fair	Poor	Poor	Excellent	Very Good	Excellent	Good	Good
Aging: Sunlight Oxidation		Poor Good	Poor Fair	Poor Fair	Excellent Good	Excellent Good	Good Good	Good Very Good	Excellent Very Good	Excellent Excellent	Excellent Excellent	Excellent Excellent	Good
Heat (Maximum Temperature)		200°F (93°C)	200°F (93°C)	250°F (121°C)	200°F (93°C)	200°F (93°C)	140°F (60°C)	450°F (232°C)	300°F (149°C)	400°F (204°C)	200°F (93°C)	350°F (177°C)	350°F (177°C)
Static (Shelf)		Good	Good	Good	Very Good	Good	Fair	Good	Good	- - - -	- - - -	Good	Good
Flex Cracking Resistance		Excellent	Good	Good	Excellent	Excellent	Fair	Fair	Excellent	- - - -	Excellent	Good	- - - -
Compression Set Resistance		Good	Good	Very Good	Excellent	Fair	Poor	Good	Poor	Poor	Good	Good	Fair
Solvent Resistance: Aliphatic Hydrocarbon Aromatic Hydrocarbon Oxygenated Solvent Halogenated Solvent		Very Poor Very Poor Good Very Poor	Very Poor Very Poor Good Very Poor	Good Fair Poor Very Poor	Fair Poor Fair Very Poor	Poor Very Poor Good Poor	Excellent Good Fair Poor	Poor Very Poor Poor Very Poor	Fair Poor Poor Very Poor	Excellent Very Good Good - - - -	Very Good Fair Poor - - - -	Good Poor Poor Poor	Poor Fair - - - - Poor
Oil Resistance: Low Aniline Mineral Oil High Aniline Mineral Oil Synthetic Lubricants Organic Phosphates		Very Poor Very Poor Very Poor Very Poor	Very Poor Very Poor Very Poor Very Poor	Excellent Excellent Fair Very Poor	Fair Good Very Poor Very Poor	Very Poor Very Poor Poor Good	Excellent Excellent Poor Poor	Poor Good Fair Poor	Fair Good Poor Poor	Excellent Excellent - - - - Poor	- - - - - - - - - - - - Poor	Excellent Excellent Fair Poor	Poor Poor Poor Very Good
Gasoline Resistance: Aromatic Non-Aromatic		Very Poor Very Poor	Very Poor Very Poor	Good Excellent	Poor Good	Very Poor Very Poor	Excellent Excellent	Poor Good	Poor Fair	Good Very Good	Fair Good	Fair Poor	Fair Poor
Acid Resistance: Diluted (Under 10%) Concentrated		Good Fair	Good Poor	Good Poor	Fair Fair	Good Fair	Poor Very Poor	Fair Poor	Good Good	Excellent Very Good	Fair Poor	Poor Poor	Very Good Good
Low Temperature Flexibility (Maximum)		-65°F (-54°C)	-50°F (-46°C)	-40°F (-40°C)	-40°F (-40°C)	-40°F (-40°C)	-40°F (-40°C)	-100°F (-73°C)	-20°F (-29°C)	-30°F (-34°C)	-40°F (-40°C)	-10°F (-23°C)	-50°F (-45°C)
Permeability to Gases		Fair	Fair	Fair	Very Good	Very Good	Good	Fair	Very Good	Good	Good	Good	Good
Water Resistance		Good	Very Good	Very Good	Fair	Very Good	Fair	Fair	Fair	Excellent	Fair	Fair	Very Good
Alkali Resistance: Diluted (Under 10%) Concentrated		Good Fair	Good Fair	Good Fair	Good Good	Very Good Very Good	Poor Poor	Fair Poor	Good Good	Excellent Very Good	Fair Poor	Poor Poor	Excellent Good
Resilience		Very Good	Fair	Fair	Very Good	Very Good	Poor	Good	Good	Good	Fair	Very Poor	Very Good
Elongation (Maximum)		700%	500%	500%	500%	700%	400%	300%	300%	425%	625%	200%	500%

1. Do not use with steam.
2. Do not use with ammonia.
3. Do not use with petroleum based fluids. Use with ester based non-flammable hydraulic oils and low pressure steam applications to 300°F (149°C).
4. Except for nitric and sulfuric acid.

Chemical Compatibility of Elastomers and Metals

Fluid Compatibility of Elastomers

FLUID	MATERIAL				
	Neoprene (CR)	Nitrile (NBR)	Fluoroelastomer (FKM)	Ethylenepropylene (EPDM)	Perfluoroelastomer (FFKM)
Acetic Acid (30%)	B	C	C	A	A
Acetone	C	C	C	A	A
Air, Ambient	A	A	A	A	A
Air, Hot (200°F (93°C))	C	B	A	A	A
Alcohol (Ethyl)	A	C	C	A	A
Alcohol (Methyl)	A	A	C	A	A
Ammonia (Anhydrous) (Cold)	A	A	C	A	A
Ammonia (Gas, Hot)	B	C	C	B	A
Beer	A	A	A	A	A
Benzene	C	C	B	C	A
Brine (Calcium Chloride)	A	A	B	A	A
Butadiene Gas	C	C	B	C	A
Butane (Gas)	A	A	A	C	A
Butane (Liquid)	C	A	A	C	A
Carbon Tetrachloride	C	C	A	C	A
Chlorine (Dry)	C	C	A	C	A
Chlorine (Wet)	C	C	B	C	A
Coke Oven Gas	C	C	A	C	A
Ethyl Acetate	C	C	C	B	A
Ethylene Glycol	A	A	A	A	A
Freon 11	C	B	A	C	A
Freon 12	A	A	B	B	A
Freon 22	A	C	C	A	A
Freon 114	A	A	B	A	A
Gasoline (Automotive)	C	B	A	C	A
Hydrogen Gas	A	A	A	A	A
Hydrogen Sulfide (Dry)	A	A[(1)]	C	A	A
Hydrogen Sulfide (Wet)	B	C	C	A	A
Jet Fuel (JP-4)	B	A	A	C	A
Methyl Ethyl Ketone (MEK)	C	C	C	A	A
MTBE	C	C	C	C	A
Natural Gas	A	A	A	C	A
Nitric Acid (50 to 100%)	C	C	B	C	A
Nitrogen	A	A	A	A	A
Oil (Fuel)	C	A	A	C	A
Propane	B	A	A	C	A
Sulfur Dioxide	A	C	A	A	A
Sulfuric Acid (up to 50%)	B	C	A	B	A
Sulfuric Acid (50 to 100%)	C	C	A	B	A
Water (Ambient)	A	A	A	A	A
Water (at 200°F (93°C))	C	B	B	A	A

1. Performance worsens with hot temperatures.
A - Recommended
B - Minor to moderate effect. Proceed with caution.
C - Unsatisfactory
N/A - Information not available

Chemical Compatibility of Elastomers and Metals

Compatibility of Metals

CORROSION INFORMATION

Fluid	Carbon Steel	Cast Iron	S302 or S304 Stainless Steel	S316 Stainless Steel	Bronze	Monel®	Hastelloy® B	Hastelloy® C	Durimet® 20	Titanium	Cobalt-Base Alloy 6	S416 Stainless Steel	440C Stainless Steel	17-4PH Stainless Steel
Acetaldehyde	A	A	A	A	A	A	IL	A	A	IL	IL	A	A	A
Acetic Acid, Air Free	C	C	B	B	B	B	A	A	A	A	A	C	C	B
Acetic Acid, Aerated	C	C	A	A	A	A	A	A	A	A	A	C	C	B
Acetic Acid Vapors	C	C	A	A	B	B	IL	A	B	A	A	C	C	B
Acetone	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acetylene	A	A	A	A	IL	A	A	A	A	IL	A	A	A	A
Alcohols	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Aluminum Sulfate	C	C	A	A	B	B	A	A	A	A	IL	C	C	IL
Ammonia	A	A	A	A	C	A	A	A	A	A	A	A	A	IL
Ammonium Chloride	C	C	B	B	B	B	A	A	A	A	B	C	C	IL
Ammonium Nitrate	A	C	A	A	C	C	A	A	A	A	A	C	B	IL
Ammonium Phosphate (Mono Basic)	C	C	A	A	B	B	A	A	B	A	A	B	B	IL
Ammonium Sulfate	C	C	B	A	B	A	A	A	A	A	A	C	C	IL
Ammonium Sulfite	C	C	A	A	C	C	IL	A	A	A	A	B	B	IL
Aniline	C	C	A	A	C	B	A	A	A	A	A	C	C	IL
Asphalt	A	A	A	A	A	A	A	A	A	IL	A	A	A	A
Beer	B	B	A	A	B	A	A	A	A	A	A	B	B	A
Benzene (Benzol)	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Benzoic Acid	C	C	A	A	A	A	IL	A	A	A	IL	A	A	A
Boric Acid	C	C	A	A	A	A	A	A	A	A	A	B	B	IL
Butane	A	A	A	A	A	A	A	A	A	IL	A	A	A	A
Calcium Chloride (Alkaline)	B	B	C	B	C	A	A	A	A	A	IL	C	C	IL
Calcium Hypochlorite	C	C	B	B	B	B	C	A	A	A	IL	C	C	IL
Carbolic Acid	B	B	A	A	A	A	A	A	A	A	A	IL	IL	IL
Carbon Dioxide, Dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Carbon Dioxide, Wet	C	C	A	A	B	A	A	A	A	A	A	A	A	A
Carbon Disulfide	A	A	A	A	C	B	A	A	A	A	A	B	B	IL
Carbon Tetrachloride	B	B	B	B	A	A	B	A	A	A	IL	C	A	IL
Carbonic Acid	C	C	B	B	B	A	A	A	A	IL	IL	A	A	A
Chlorine Gas, Dry	A	A	B	B	B	A	A	A	A	C	B	C	C	C
Chlorine Gas, Wet	C	C	C	C	C	C	C	B	C	A	B	C	C	C
Chlorine, Liquid	C	C	C	C	B	C	C	A	B	C	B	C	C	C
Chromic Acid	C	C	C	B	C	A	C	A	C	A	B	C	C	C
Citric Acid	IL	C	B	A	A	B	A	A	A	A	IL	B	B	B
Coke Oven Gas	A	A	A	A	B	B	A	A	A	A	A	A	A	A
Copper Sulfate	C	C	B	B	B	C	IL	A	A	A	IL	A	A	A
Cottonseed Oil	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Creosote	A	A	A	A	C	A	A	A	A	IL	A	A	A	A
Ethane	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ether	B	B	A	A	A	A	A	A	A	A	A	A	A	A
Ethyl Chloride	C	C	A	A	A	A	A	A	A	A	A	B	B	IL
Ethylene	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethylene Glycol	A	A	A	A	A	A	IL	IL	A	IL	A	A	A	A
Ferric Chloride	C	C	C	C	C	C	C	B	C	A	B	C	C	IL
Formaldehyde	B	B	A	A	A	A	A	A	A	A	A	A	A	A
Formic Acid	IL	C	B	B	A	A	A	A	A	C	B	C	C	B
Freon, Wet	B	B	B	A	A	A	A	A	A	A	A	IL	IL	IL
Freon, Dry	B	B	A	A	A	A	A	A	A	A	A	IL	IL	IL
Furfural	A	A	A	A	A	A	A	A	A	A	A	B	B	IL
Gasoline, Refine	A	A	A	A	A	A	A	A	A	A	A	A	A	A

A - Recommended
B - Minor to moderate effect. Proceed with caution.
C - Unsatisfactory
IL - Information lacking

- continued -

Chemical Compatibility of Elastomers and Metals

Compatibility of Metals (continued)

CORROSION INFORMATION

Fluid	Material													
	Carbon Steel	Cast Iron	S302 or S304 Stainless Steel	S316 Stainless Steel	Bronze	Monel®	Hastelloy® B	Hastelloy® C	Durimet® 20	Titanium	Cobalt-Base Alloy 6	S416 Stainless Steel	440C Stainless Steel	17-4PH Stainless Steel
Glucose	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrochloric Acid, Aerated	C	C	C	C	C	C	A	B	C	C	B	C	C	C
Hydrochloric Acid, Air free	C	C	C	C	C	C	A	B	C	C	B	C	C	C
Hydrofluoric Acid, Aerated	B	C	C	B	C	C	A	A	B	C	B	C	C	C
Hydrofluoric Acid, Air free	A	C	C	B	C	A	A	A	B	C	IL	C	C	IL
Hydrogen	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrogen Peroxide	IL	A	A	A	C	A	B	B	A	A	IL	B	B	IL
Hydrogen Sufide, Liquid	C	C	A	A	C	C	A	A	B	A	A	C	C	IL
Magnesium Hydroxide	A	A	A	A	B	A	A	A	A	A	A	A	A	IL
Mercury	A	A	A	A	C	B	A	A	A	A	A	A	A	B
Methanol	A	A	A	A	A	A	A	A	A	A	A	A	B	A
Methyl Ethyl Ketone	A	A	A	A	A	A	A	A	A	IL	A	A	A	A
Milk	C	C	A	A	A	A	A	A	A	A	A	C	C	C
Natural Gas	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Nitric Acid	C	C	A	B	C	C	C	B	A	A	C	C	C	B
Oleic Acid	C	C	A	A	B	A	A	A	A	A	A	A	A	IL
Oxalic Acid	C	C	B	B	B	B	A	A	A	B	B	B	B	IL
Oxygen	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Petroleum Oils, Refined	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Phosphoric Acid, Aerated	C	C	A	A	C	C	A	A	A	B	A	C	C	IL
Phosphoric Acid, Air Free	C	C	A	A	C	B	A	A	A	B	A	C	C	IL
Phosphoric Acid Vapors	C	C	B	B	C	C	A	IL	A	B	C	C	C	IL
Picric Acid	C	C	A	A	C	C	A	A	A	IL	IL	B	B	IL
Potassium Chloride	B	B	A	A	B	B	A	A	A	A	IL	C	C	IL
Potassium Hydroxide	B	B	A	A	B	A	A	A	A	A	IL	B	B	IL
Propane	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Rosin	B	B	A	A	A	A	A	A	A	IL	A	A	A	A
Silver Nitrate	C	C	A	A	C	C	A	A	A	A	B	B	B	IL
Sodium Acetate	A	A	B	A	A	A	A	A	A	A	A	A	A	A
Sodium Carbonate	A	A	A	A	A	A	A	A	A	A	A	B	B	A
Sodium Chloride	C	C	B	B	A	A	A	A	A	A	A	B	B	B
Sodium Chromate	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sodium Hydroxide	A	A	A	A	C	A	A	A	A	A	A	B	B	A
Sodium Hypochloride	C	C	C	C	B-C	B-C	C	A	B	A	IL	C	C	IL
Sodium Thiosulfate	C	C	A	A	C	C	A	A	A	A	IL	B	B	IL
Stannous Chloride	B	B	C	A	C	B	A	A	A	A	IL	C	C	IL
Stearic Acid	A	C	A	A	B	B	A	A	A	A	B	B	B	IL
Sulfate Liquor (Black)	A	A	A	A	C	A	A	A	A	A	A	IL	IL	IL
Sulfur	A	A	A	A	C	A	A	A	A	A	A	A	A	A
Sulfur Dioxide, Dry	A	A	A	A	A	A	B	A	A	A	A	B	B	IL
Sulfur Trioxide, Dry	A	A	A	A	A	A	B	A	A	A	A	B	B	IL
Sufuric Acid (Aerated)	C	C	C	C	C	C	A	A	A	B	B	C	C	C
Sufuric Acid (Air Free)	C	C	C	C	B	B	A	A	A	B	B	C	C	C
Sulfurous Acid	C	C	B	B	B	C	A	A	A	A	B	C	C	IL
Tar	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Trichloroethylene	B	B	B	A	A	A	A	A	A	A	A	B	B	IL
Turpentine	B	B	A	A	A	B	A	A	A	A	A	A	A	A
Vinegar	C	C	A	A	B	A	A	A	A	IL	A	C	C	A
Water, Boiler Feed	B	C	A	A	C	A	A	A	A	A	A	B	A	A
Water, Distilled	A	A	A	A	A	A	A	A	A	A	A	B	B	IL
Water, Sea	B	B	B	B	A	A	A	A	A	A	A	C	C	A
Whiskey and Wines	C	C	A	A	A	B	A	A	A	A	A	C	C	IL
Zinc Chloride	C	C	C	C	C	C	A	A	A	A	B	C	C	IL
Zinc Sulfate	C	C	A	A	B	A	A	A	A	A	A	B	B	IL

A - Recommended
B - Minor to moderate effect. Proceed with caution.
C - Unsatisfactory
IL - Information lacking

Regulator Tips

1. All regulators should be installed and used in accordance with federal, state, and local codes and regulations.

2. Adequate overpressure protection should be installed to protect the regulator from overpressure. Adequate overpressure protection should also be installed to protect all downstream equipment in the event of regulator failure.

3. Downstream pressures significantly higher than the regulator's pressure setting may damage soft seats and other internal parts.

4. If two or more available springs have published pressure ranges that include the desired pressure setting, use the spring with the lower range for better accuracy.

5. The recommended selection for orifice diameters is the smallest orifice that will handle the flow.

6. Most regulators shown in this application guide are generally suitable for temperatures to 180°F (82°C). With high temperature fluoroelastomers (if available), the regulators can be used for temperatures to 300°F (149°C). Check the temperature capabilities to determine materials and temperature ranges available. Use stainless steel diaphragms and seats for higher temperatures, such as steam service.

7. The full advertised range of a spring can be utilized without sacrificing performance or spring life.

8. Regulator body size should not be larger than the pipe size. In many cases, the regulator body is one size smaller than the pipe size.

9. Do not oversize regulators. Pick the smallest orifice size or regulator that will work. Keep in mind when sizing a station that most restricted trims that do not reduce the main port size do not help with improved low flow control.

10. Speed of regulator response, in order:
    - Direct-operated
    - Two-path pilot-operated
    - Unloading pilot-operated
    - Control valve

    Note: Although direct-operated regulators give the fastest response, all types provide quick response.

11. When a regulator appears unable to pass the published flow rate, be sure to check the inlet pressure measured at the regulator body inlet connection. Piping up to and away from regulators can cause significant flowing pressure losses.

12. When adjusting setpoint, the regulator should be flowing at least five percent of the normal operating flow.

13. Direct-operated regulators generally have faster response to quick flow changes than pilot-operated regulators.

14. Droop is the reduction of outlet pressure experienced by pressure-reducing regulators as the flow rate increases. It is stated as a percent, in inches of water column (mbar) or in pounds per square inch (bar) and indicates the difference between the outlet pressure setting made at low flow rates and the actual outlet pressure at the published maximum flow rate. Droop is also called offset or proportional band.

15. Downstream pressure always changes to some extent when inlet pressure changes.

16. Most soft-seated regulators will maintain the pressure within reasonable limits down to zero flow. Therefore, a regulator sized for a high flow rate will usually have a turndown ratio sufficient to handle pilot-light loads during off cycles.

17. Do not undersize the monitor set. It is important to realize that the monitor regulator, even though it is wide-open, will require pressure drop for flow. Using two identical regulators in a monitor set will yield approximately 70 percent of the capacity of a single regulator.

18. Diaphragms leak a small amount due to migration of gas through the diaphragm material. To allow escape of this gas, be sure casing vents (where provided) remain open.

19. Use control lines of equal or greater size than the control tap on the regulator. If a long control line is required, make it bigger. A rule of thumb is to use the next nominal pipe size for every 20 feet (6,1 m) of control line. Small control lines cause a delayed response of the regulator, leading to increased chance of instability. 3/8-inch (9,5 mm) OD tubing is the minimum recommended control line size.

20. For every 15 psid (1,0 bar d) pressure differential across the regulator, expect approximately a one degree drop in gas temperature due to the natural refrigeration effect. Freezing is often a problem when the ambient temperature is between 30° and 45°F (-1° and 7°C).

21. A disk with a cookie cut appearance probably means you had an overpressure situation. Thus, investigate further.

22. When using relief valves, be sure to remember that the reseat point is lower than the start-to-bubble point. To avoid seepage, keep the relief valve setpoint far enough above the regulator setpoint.

Regulator Tips

23. Vents should be pointed down to help avoid the accumulation of water condensation or other materials in the spring case.

24. Make control line connections in a straight run of pipe about 10 pipe diameters downstream of any area of turbulence, such as elbows, pipe swages, or block valves.

25. When installing a working monitor station, get as much volume between the two regulators as possible. This will give the upstream regulator more room to control intermediate pressure.

26. Cutting the supply pressure to a pilot-operated regulator reduces the regulator gain or sensitivity and, thus, may improve regulator stability. (This can only be used with two path control.)

27. Regulators with high flows and large pressure drops generate noise. Noise can wear parts which can cause failure and/or inaccurate control. Keep regulator noise below 110 dBA.

28. Do not place control lines immediately downstream of rotary or turbine meters.

29. Keep vents open. Do not use small diameter, long vent lines. Use the rule of thumb of the next nominal pipe size every 10 feet (3,1 m) of vent line and 3 feet (0,9 m) of vent line for every elbow in the line.

30. Fixed factor measurement (or PFM) requires the regulator to maintain outlet pressure within ±1% of absolute pressure. For example: Setpoint of 2 psig + 14.7 psia = 16.7 psia x 0.01 = ±0.167 psi. (Setpoint of 0,14 bar + 1,01 bar = 1,15 bar x 0,01 = ±0,0115 bar.)

31. Regulating C_g (coefficient of flow) can only be used for calculating flow capacities on pilot-operated regulators. Use capacity tables or flow charts for determining a direct-operated regulator's capacity.

32. Do not make the setpoints of the regulator/monitor too close together. The monitor can try to take over if the setpoints are too close, causing instability and reduction of capacity. Set them at least one proportional band apart.

33. Consider a butt-weld end regulator where available to lower costs and minimize flange leakages.

34. Do not use needle valves in control lines; use full-open valves. Needle valves can cause instability.

35. Burying regulators is not recommended. However, if you must, the vent should be protected from ground moisture and plugging.

Conversions, Equivalents, and Physical Data

Pressure Equivalents

TO OBTAIN / BY / MULTIPLY NUMBER OF	KG PER SQUARE CENTIMETER	POUNDS PER SQUARE INCH	ATMOSPHERE	BAR	INCHES OF MERCURY	KILOPASCALS	INCHES OF WATER COLUMN	FEET OF WATER COLUMN
Kg per square cm	1	14.22	0.9678	0,98067	28.96	98,067	394.05	32.84
Pounds per square inch	0,07031	1	0.06804	0,06895	2.036	6,895	27.7	2.309
Atmosphere	1,0332	14.696	1	1,01325	29.92	101,325	407.14	33.93
Bar	1,01972	14.5038	0.98692	1	29.53	100	402.156	33.513
Inches of Mercury	0,03453	0.4912	0.03342	0,033864	1	3,3864	13.61	1.134
Kilopascals	0,0101972	0.145038	0.0098696	0,01	0.2953	1	4.02156	0.33513
Inches of Water	0,002538	0.0361	0.002456	0,00249	0.07349	0,249	1	0.0833
Feet of Water	0,3045	0.4332	0.02947	0,029839	0.8819	2,9839	12	1

1 ounce per square inch = 0.0625 pounds per square inch

Pressure Conversion - Pounds per Square Inch to Bar(1)

POUNDS PER SQUARE INCH	0	1	2	3	4	5	6	7	8	9
	Bar									
0	0,000	0,069	0,138	0,207	0,276	0,345	0,414	0,482	0,552	0,621
10	0,689	0,758	0,827	0,896	0,965	1,034	1,103	1,172	1,241	1,310
20	1,379	1,448	1,517	1,586	1,655	1,724*	1,793	1,862	1,931	1,999
30	2,068	2,137	2,206	2,275	2,344	2,413	2,482	2,551	2,620	2,689
40	2,758	2,827	2,896	2,965	3,034	3,103	3,172	3,241	3,309	3,378
50	3,447	3,516	3,585	3,654	3,723	3,792	3,861	3,930	3,999	4,068
60	4,137	4,275	4,275	4,344	4,413	4,482	4,551	4,619	4,688	4,758
70	4,826	4,964	4,964	5,033	5,102	5,171	5,240	5,309	5,378	5,447
80	5,516	5,585	5,654	5,723	5,792	5,861	5,929	5,998	6,067	6,136
90	6,205	6,274	6,343	6,412	6,481	6,550	6,619	6,688	6,757	6,826
100	6,895	6,964	7,033	7,102	7,171	7,239	7,308	7,377	7,446	7,515

1. To convert to kilopascals, move decimal point two positions to the right; to convert to megapascals, move decimal point one position to the left.
   *Note: Round off decimal points to provide no more than the desired degree of accuracy.
   To use this table, see the shaded example.
   25 psig (20 from the left column plus five from the top row) = 1,724 bar

Volume Equivalents

TO OBTAIN / BY / MULTIPLY NUMBER OF	CUBIC DECIMETERS (LITERS)	CUBIC INCHES	CUBIC FEET	U.S. QUART	U.S. GALLON	IMPERIAL GALLON	U.S. BARREL (PETROLEUM)
Cubic Decimeters (Liters)	1	61.0234	0.03531	1.05668	0.264178	0,220083	0.00629
Cubic Inches	0,01639	1	5.787×10^{-4}	1.01732	0.004329	0,003606	0.000103
Cubic Feet	28,317	1728	1	29.9221	7.48055	6,22888	0.1781
U.S. Quart	0,94636	57.75	0.03342	1	0.25	0,2082	0.00595
U.S. Gallon	3,78543	231	0.13368	4	1	0,833	0.02381
Imperial Gallon	4,54374	277.274	0.16054	4.80128	1.20032	1	0.02877
U.S. Barrel (Petroleum)	158,98	9702	5.6146	168	42	34,973	1

1 cubic meter = 1,000,000 cubic centimeters
1 liter = 1000 milliliters = 1000 cubic centimeters

Conversions, Equivalents, and Physical Data

Volume Rate Equivalents

TO OBTAIN / BY / MULTIPLY NUMBER OF	LITERS PER MINUTE	CUBIC METERS PER HOUR	CUBIC FEET PER HOUR	LITERS PER HOUR	U.S. GALLONS PER MINUTE	U.S. BARRELS PER DAY
Liters per Minute	1	0,06	2.1189	60	0.264178	9.057
Cubic Meters per Hour	16,667	1	35.314	1000	4.403	151
Cubic Feet per Hour	0,4719	0,028317	1	28.317	0.1247	4.2746
Liters per Hour	0,016667	0,001	0.035314	1	0.004403	0.151
U.S. Gallons per Minute	3,785	0,2273	8.0208	227.3	1	34.28
U.S. Barrels per Day	0,1104	0,006624	0.23394	6.624	0.02917	1

Mass Conversion - Pounds to Kilograms

POUNDS	0	1	2	3	4	5	6	7	8	9
	Kilograms									
0	0,00	0,45	0,91	1,36	1,81	2,27	2,72	3,18	3,63	4,08
10	4,54	4,99	5,44	5,90	6,35	6,80	7,26	7,71	8,16	8,62
20	9,07	9,53	9,98	10,43	10,89	11,34*	11,79	12,25	12,70	13,15
30	13,61	14,06	14,52	14,97	15,42	15,88	16,33	16,78	17,24	17,69
40	18,14	18,60	19,05	19,50	19,96	20,41	20,87	21,32	21,77	22,23
50	22,68	23,13	23,59	24,04	24,49	24,95	25,40	25,86	26,31	26,76
60	27,22	27,67	28,12	28,58	29,03	29,48	29,94	30,39	30,84	31,30
70	31,75	32,21	32,66	33,11	33,57	34,02	34,47	34,93	35,38	35,83
80	36,29	36,74	37,20	37,65	38,10	38,56	39,01	39,46	39,92	40,37
90	40,82	41,28	41,73	42,18	42,64	43,09	43,55	44,00	44,45	44,91

1 pound = 0,4536 kilograms
*NOTE: To use this table, see the shaded example.
25 pounds (20 from the left column plus five from the top row) = 11,34 kilograms

Area Equivalents

TO OBTAIN / BY / MULTIPLY NUMBER OF	SQUARE METERS	SQUARE INCHES	SQUARE FEET	SQUARE MILES	SQUARE KILOMETERS
Square Meters	1	1549.99	10.7639	3.861×10^{-7}	1×10^{-6}
Square Inches	0,0006452	1	6.944×10^{-3}	2.491×10^{-10}	$6,452 \times 10^{-10}$
Square Feet	0,0929	144	1	3.587×10^{-8}	$9,29 \times 10^{-8}$
Square Miles	2 589 999	- - - -	27,878,400	1	2,59
Square Kilometers	1 000 000	- - - -	10,763,867	0.3861	1

1 square meter = 10 000 square centimeters
1 square millimeter = 0,01 square centimeter = 0.00155 square inches

Temperature Conversion Formulas

TO CONVERT FROM	TO	SUBSTITUTE IN FORMULA
Degrees Celsius	Degrees Fahrenheit	(°C x 9/5) + 32
Degrees Celsius	Kelvin	(°C + 273.16)
Degrees Fahrenheit	Degrees Celsius	(°F - 32) x 5/9
Degrees Fahrenheit	Degrees Rankine	(°F + 459.69)

Kinematic-Viscosity Conversion Formulas

VISCOSITY SCALE	RANGE OF t, SEC	KINEMATIC VISCOSITY, STROKES
Saybolt Universal	$32 < t < 100$ $t > 100$	$0.00226t - 1.95/t$ $0.00220t - 1.35/t$
Saybolt Furol	$25 < t < 40$ $t > 40$	$0.0224t - 1.84/t$ $0.0216t - 0.60/t$
Redwood No. 1	$34 < t < 100$ $t > 100$	$0.00226t - 1.79/t$ $0.00247t - 0.50/t$
Redwood Admiralty	- - - -	$0.027t - 20/t$
Engler	- - - -	$0.00147t - 3.74/t$

Conversions, Equivalents, and Physical Data

Conversion Units

MULTIPLY	BY	TO OBTAIN
	Volume	
Cubic centimeter	0.06103	Cubic inches
Cubic feet	7.4805	Gallons (US)
Cubic feet	28.316	Liters
Cubic feet	1728	Cubic inches
Gallons (US)	0.1337	Cubic feet
Gallons (US)	3.785	Liters
Gallons (US)	231	Cubic inches
Liters	1.057	Quarts (US)
Liters	2.113	Pints (US)
	Miscellaneous	
BTU	0.252	Calories
Decitherm	10,000	BTU
Kilogram	2.205	Pounds
Kilowatt Hour	3412	BTU
Ounces	28.35	Grams
Pounds	0.4536	Kilograms
Pounds	453.5924	Grams
Pounds	21,591	LPG BTU
Therm	100,000	BTU
API Bbls	42	Gallons (US)
Gallons of Propane	26.9	KWH
HP	746	KWH
HP (Steam)	42,418	BTU
	Pressure	
Grams per square centimeter	0.0142	Pounds per square inch
Inches of mercury	0.4912	Pounds per square inch
Inches of mercury	1.133	Feet of water
Inches of water	0.0361	Pounds per square inch
Inches of water	0.0735	Inches of mercury
Inches of water	0.5781	Ounces per square inch
Inches of water	5.204	Pounds per foot
kPa	100	Bar
Kilograms per square centimeter	14.22	Pounds per square inch
Kilograms per square meter	0.2048	Pounds per square foot
Pounds per square inch	0.06804	Atmospheres
Pounds per square inch	0.07031	Kilograms per square centimeter
Pounds per square inch	0.145	KPa
Pounds per square inch	2.036	Inches of mercury
Pounds per square inch	2.307	Feet of water
Pounds per square inch	14.5	Bar
Pounds per square inch	27.67	Inches of water
	Length	
Centimeters	0.3937	Inches
Feet	0.3048	Meters
Feet	30.48	Centimeters
Feet	304.8	Millimeters
Inches	2.540	Centimeters
Inches	25.40	Millimeters
Kilometer	0.6214	Miles
Meters	1.094	Yards
Meters	3.281	Feet
Meters	39.37	Inches
Miles (nautical)	1853	Meters
Miles (statute)	1609	Meters
Yards	0.9144	Meters
Yards	91.44	Centimeters

Other Useful Conversions

TO CONVERT FROM	TO	MULTIPLY BY
Cubic feet of methane	BTU	1000 (approximate)
Cubic feet of water	Pounds of water	62.4
Degrees	Radians	0,01745
Gallons	Pounds of water	8.336
Grams	Ounces	0.0352
Horsepower (mechanical)	Foot pounds per minute	33,000
Horsepower (electrical)	Watts	746
Kg	Pounds	2.205
Kg per cubic meter	Pounds per cubic feet	0.06243
Kilowatts	Horsepower	1.341
Pounds	Kg	0,4536
Pounds of Air (14.7 psia and 60°F)	Cubic feet of air	13.1
Pounds per cubic feet	Kg per cubic meter	16,0184
Pounds per hour (gas)	SCFH	13.1 ÷ Specific Gravity
Pounds per hour (water)	Gallons per minute	0.002
Pounds per second (gas)	SCFH	46,160 ÷ Specific Gravity
Radians	Degrees	57.3
SCFH Air	SCFH Propane	0.81
SCFH Air	SCFH Butane	0.71
SCFH Air	SCFH 0.6 Natural Gas	1.29
SCFH	Cubic meters per hour	0.028317

Converting Volumes of Gas

CFH TO CFH OR CFM TO CFM		
Multiply Flow of	**By**	**To Obtain Flow of**
Air	0.707	Butane
	1.290	Natural Gas
	0.808	Propane
Butane	1.414	Air
	1.826	Natural Gas
	1.140	Propane
Natural Gas	0.775	Air
	0.547	Butane
	0.625	Propane
Propane	1.237	Air
	0.874	Butane
	1.598	Natural Gas

Conversions, Equivalents, and Physical Data

Fractional Inches to Millimeters

INCH	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
	mm															
0	0,0	1,6	3,2	4,8	6,4	7,9	9,5	11,1	12,7	14,3	15,9	17,5	19,1	20,6	22,2	23,8
1	25,4	27,0	28,6	30,2	31,8	33,3	34,9	36,5	38,1	39,7	41,3	42,9	44,5	46,0	47,6	49,2
2	50,8	52,4	54,0	55,6	57,2	58,7	60,3	61,9	63,5	65,1	66,7	68,3	69,9	71,4	73,0	74,6
3	76,2	77,8	79,4	81,0	82,6	84,1	85,7	87,3	88,9	90,5	92,1	93,7	95,3	96,8	98,4	100,0
4	101,6	103,2	104,8	106,4	108,0	109,5	111,1	112,7	114,3	115,9	117,5	119,1	120,7	122,2	123,8	125,4
5	127,0	128,6	130,2	131,8	133,4	134,9	136,5	138,1	139,7	141,3	142,9	144,5	146,1	147,6	149,2	150,8
6	152,4	154,0	155,6	157,2	158,8	160,3	161,9	163,5	165,1	166,7	168,3	169,9	171,5	173,0	174,6	176,2
7	177,8	179,4	181,0	182,6	184,2	185,7	187,3	188,9	190,5	192,1	193,7	195,3	196,9	198,4	200,0	201,6
8	203,2	204,8	206,4	208,0	209,6	211,1	212,7	214,3	215,9	217,5	219,1	220,7	222,3	223,8	225,4	227,0
9	228,6	230,2	231,8	233,4	235,0	236,5	238,1	239,7	241,3	242,9	244,5	246,1	247,7	249,2	250,8	252,4
10	254,0	255,6	257,2	258,8	260,4	261,9	263,5	265,1	266,7	268,3	269,9	271,5	273,1	274,6	276,2	277,8

1-inch = 25,4 millimeters
NOTE: To use this table, see the shaded example.
2-1/2-inches (2 from the left column plus 1/2 from the top row) = 63,5 millimeters

Length Equivalents

TO OBTAIN / BY / MULTIPLY NUMBER OF	METERS	INCHES	FEET	MILLIMETERS	MILES	KILOMETERS
Meters	1	39.37	3.2808	1000	0.0006214	0,001
Inches	0,0254	1	0.0833	25,4	0.00001578	0,0000254
Feet	0,3048	12	1	304,8	0.0001894	0,0003048
Millimeters	0,001	0.03937	0.0032808	1	0.0000006214	0,000001
Miles	1609,35	63,360	5,280	1 609 350	1	1,60935
Kilometers	1000	39,370	3280.83	1 000 000	0.62137	1

1 meter = 100 cm = 1000 mm = 0,001 km = 1,000,000 micrometers

Whole Inch-Millimeter Equivalents

INCH	0	1	2	3	4	5	6	7	8	9
	mm									
0	0,00	25,4	50,8	76,2	101,6	127,0	152,4	177,8	203,2	228,6
10	254,0	279,4	304,8	330,2	355,6	381,0	406,4	431,8	457,2	482,6
20	508,0	533,4	558,8	584,2	609,6	635,0	660,4	685,8	711,2	736,6
30	762,0	787,4	812,8	838,2	863,6	889,0	914,4	939,8	965,2	990,6
40	1016,0	1041,4	1066,8	1092,2	1117,6	1143,0	1168,4	1193,8	1219,2	1244,6
50	1270,0	1295,4	1320,8	1346,2	1371,6	1397,0	1422,4	1447,8	1473,2	1498,6
60	1524,0	1549,4	1574,8	1600,2	1625,6	1651,0	1676,4	1701,8	1727,2	1752,6
70	1778,0	1803,4	1828,8	1854,2	1879,6	1905,0	1930,4	1955,8	1981,2	2006,6
80	2032,0	2057,4	2082,8	2108,2	2133,6	2159,0	2184,4	2209,8	2235,2	2260,6
90	2286,0	2311,4	2336,8	2362,2	2387,6	2413,0	2438,4	2463,8	2489,2	2514,6
100	2540,0	2565,4	2590,8	2616,2	2641,6	2667,0	2692,4	2717,8	2743,2	2768,6

Note: All values in this table are exact, based on the relation 1-inch = 25,4 mm.
To use this table, see the shaded example.
25-inches (20 from the left column plus five from the top row) = 635 millimeters

Metric Prefixes and Symbols

MULTIPLICATION FACTOR	PREFIX	SYMBOL
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 01 = 10^{-6}	micro	m
0.000 001 = 10^{-9}	nano	n
0.000 000 001 = 10^{-12}	pico	p
0.000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 001 = 10^{-18}	atto	a

Greek Alphabet

CAPS	LOWER CASE	GREEK NAME	CAPS	LOWER CASE	GREEK NAME	CAPS	LOWER CASE	GREEK NAME
Α	α	Alpha	Ι	ι	Iota	Ρ	ρ	Rho
Β	β	Beta	Κ	κ	Kappa	Σ	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	Τ	τ	Tau
Δ	δ	Delta	Μ	μ	Mu	Υ	υ	Upsilon
Ε	ε	Epsilon	Ν	ν	Nu	Φ	φ	Phi
Ζ	ζ	Zeta	Ξ	ξ	Xi	Χ	χ	Chi
Η	η	Eta	Ο	ο	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

Conversions, Equivalents, and Physical Data

Length Equivalents - Fractional and Decimal Inches to Millimeters

INCHES		mm	INCHES		mm	INCHES		mm	INCHES		mm
Fractions	Decimals		Fractions	Decimals		Fractions	Decimals		Fractions	Decimals	
	0.00394	0.1		0.23	5.842	1/2	0.50	12.7		0.77	19.558
	0.00787	0.2	15/64	0.234375	5.9531		0.51	12.954		0.78	19.812
	0.01	0.254		0.23622	6.0		0.51181	13.0	25/32	0.78125	19.8438
	0.01181	0.3		0.24	6.096	33/64	0.515625	13.0969		0.78740	20.0
1/64	0.015625	0.3969	1/4	0.25	6.35		0.52	13.208		0.79	20.066
	0.01575	0.4		0.26	6.604		0.53	13.462	51/64	0.796875	20.2406
	0.01969	0.5	17/64	0.265625	6.7469	17/32	0.53125	13.4938		0.80	20.320
	0.02	0.508		0.27	6.858		0.54	13.716		0.81	20.574
	0.02362	0.6		0.27559	7.0	35/64	0.546875	13.8906	13/64	0.8125	20.6375
	0.02756	0.7		0.28	7.112		0.55	13.970		0.82	20.828
	0.03	0.762	9/32	0.28125	7.1438		0.55118	14.0		0.82677	21.0
1/32	0.03125	0.7938		0.29	7.366		0.56	14.224	53/64	0.828125	21.0344
	0.0315	0.8	19/64	0.296875	7.5406	9/16	0.5625	14.2875		0.83	21.082
	0.13543	0.9		0.30	7.62		0.57	14.478		0.84	21.336
	0.03937	1.0		0.31	7.874	37/64	0.578125	14.6844	27/32	0.84375	21.4312
	0.04	1.016	5/16	0.3125	7.9375		0.58	14.732		0.85	21.590
3/64	0.046875	1.1906		0.31496	8.0		0.59	14.986	55/64	0.859375	21.8281
	0.05	1.27		0.32	8.128		0.5905	15.0		0.86	21.844
	0.06	1.524	21/64	0.328125	8.3344	19/32	0.59375	15.0812		0.86614	22.0
1/16	0.0625	1.5875		0.33	8.382		0.60	15.24		0.87	22.098
	0.07	1.778		0.34	8.636	39/64	0.609375	15.4781	7/8	0.875	22.225
5/64	0.078125	1.9844	11/32	0.34375	8.7312		0.61	15.494		0.88	22.352
	0.07874	2.0		0.35	8.89		0.62	15.748		0.89	22.606
	0.08	2.032		0.35433	9.0	5/8	0.625	15.875	57/64	0.890625	22.6219
	0.09	2.286	23/64	0.359375	9.1281		0.62992	16.0		0.90	22.860
3/32	0.09375	2.3812		0.36	9.144		0.63	16.002		0.90551	23.0
	0.1	2.54		0.37	9.398		0.64	16.256	29/32	0.90625	23.0188
7/64	0.109375	2.7781	3/8	0.375	9.525	41/64	0.640625	16.2719		0.91	23.114
	0.11	2.794		0.38	9.652		0.65	16.510		0.92	23.368
	0.11811	3.0		0.39	9.906	21/32	0.65625	16.6688	59/64	0.921875	23.1456
	0.12	3.048	25/64	0.390625	9.9219		0.66	16.764		0.93	23.622
1/8	0.125	3.175		0.39370	10.0		0.66929	17.0	15/16	0.9375	23.8125
	0.13	3.302		0.40	10.16		0.67	17.018		0.94	23.876
	0.14	3.556	13/32	0.40625	10.3188	43/64	0.671875	17.0656		0.94488	24.0
9/64	0.140625	3.5719		0.41	10.414		0.68	17.272		0.95	24.130
	0.15	3.810		0.42	10.668	11/16	0.6875	17.4625	61/64	0.953125	24.2094
5/32	0.15625	3.9688	27/64	0.421875	10.7156		0.69	17.526		0.96	24.384
	0.15748	4.0		0.43	10.922		0.70	17.78	31/32	0.96875	24.6062
	0.16	4.064		0.43307	11.0	45/64	0.703125	17.8594		0.97	24.638
	0.17	4.318	7/16	0.4375	11.1125		0.70866	18.0		0.98	24.892
11/64	0.171875	4.3656		0.44	11.176		0.71	18.034		0.98425	25.0
	0.18	4.572		0.45	11.430	23/32	0.71875	18.2562	63/64	0.984375	25.0031
3/16	0.1875	4.7625	29/64	0.453125	11.5094		0.72	18.288		0.99	25.146
	0.19	4.826		0.46	11.684		0.73	18.542	1	1.00000	25.4000
	0.19685	5.0	15/32	0.46875	11.9062	47/64	0.734375	18.6531			
	0.2	5.08		0.47	11.938		0.74	18.796			
13/64	0.203125	5.1594		0.47244	12.0		0.74803	19.0			
	0.21	5.334		0.48	12.192	3/4	0.75	19.050			
7/32	0.21875	5.5562	31/64	0.484375	12.3031		0.76	19.304			
	0.22	5.588		0.49	12.446	49/64	0.765625	19.4469			

Note: Round off decimal points to provide no more than the desired degree of accuracy.

Conversions, Equivalents, and Physical Data

Temperature Conversions											
°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F
-273,16	-460	-796	-90,00	-130	-202.0	-17,8	0	32.0	21,1	70	158.0
-267,78	-450	-778	-84,44	-120	-184.0	-16,7	2	35.6	22,2	72	161.6
-262,22	-440	-760	-78,89	-110	-166.0	-15,6	4	39.2	23,3	74	165.2
-256,67	-430	-742	-73,33	-100	-148.0	-14,4	6	42.8	24,4	76	168.8
-251,11	-420	-724	-70,56	-95	-139.0	-13,3	8	46.4	25,6	78	172.4
-245,56	-410	-706	-67,78	-90	-130.0	-12,2	10	50.0	26,7	80	176.0
-240,00	-400	-688	-65,00	-85	-121.0	-11,1	12	53.6	27,8	82	179.6
-234,44	-390	-670	-62,22	-80	-112.0	-10,0	14	57.2	28,9	84	183.2
-228,89	-380	-652	-59,45	-75	-103.0	-8,89	16	60.8	30,0	86	186.8
-223,33	-370	-634	-56,67	-70	-94.0	-7,78	18	64.4	31,1	88	190.4
-217,78	-360	-616	-53,89	-65	-85	-6,67	20	68.0	32,2	90	194.0
-212,22	-350	-598	-51,11	-60	-76.0	-5,56	22	71.6	33,3	92	197.6
-206,67	-340	-580	-48,34	-55	-67.0	-4,44	24	75.2	34,4	94	201.2
-201,11	-330	-562	-45,56	-50	-58.0	-3,33	26	78.8	35,6	96	204.8
-195,56	-320	-544	-42,78	-45	-49.0	-2,22	28	82.4	36,7	98	208.4
-190,00	-310	-526	-40,00	-40	-40.0	-1,11	30	86.0	37,8	100	212.0
-184,44	-300	-508	-38,89	-38	-36.4	0	32	89.6	43,3	110	230.0
-178,89	-290	-490	-37,78	-36	-32.8	1,11	34	93.2	48,9	120	248.0
-173,33	-280	-472	-36,67	-34	-29.2	2,22	36	96.8	54,4	130	266.0
-169,53	-273	-459.4	-35,56	-32	-25.6	3,33	38	100.4	60,0	140	284.0
-168,89	-272	-457.6	-34,44	-30	-22.0	4,44	40	104.0	65,6	150	302.0
-167,78	-270	-454.0	-33,33	-28	-18.4	5,56	42	107.6	71,1	160	320.0
-162,22	-260	-436.0	-32,22	-26	-14.8	6,67	44	111.2	76,7	170	338.0
-156,67	-250	-418.0	-31,11	-24	-11.2	7,78	46	114.8	82,2	180	356.0
-151,11	-240	-400.0	-30,00	-22	-7.6	8,89	48	118.4	87,8	190	374.0
-145,56	-230	-382.0	-28,89	-20	-4.0	10,0	50	122.0	93,3	200	392.0
-140,00	-220	-364.0	-27,78	-18	-0.4	11,1	52	125.6	98,9	210	410.0
-134,44	-210	-356.0	-26,67	-16	3.2	12,2	54	129.2	104,4	220	428.0
-128,89	-200	-328.0	-25,56	-14	6.8	13,3	56	132.8	110,0	230	446.0
-123,33	-190	-310.0	-24,44	-12	10.4	14,4	58	136.4	115,6	240	464.0
-117,78	-180	-292.0	-23,33	-10	14.0	15,6	60	140.0	121,1	250	482.0
-112,22	-170	-274.0	-22,22	-8	17.6	16,7	62	143.6	126,7	260	500.0
-106,67	-160	-256.0	-21,11	-6	21.2	17,8	64	147.2	132,2	270	518.0
-101,11	-150	-238.0	-20,00	-4	24.8	18,9	66	150.8	137,8	280	536.0
-95,56	-140	-220.0	-18,89	-2	28.4	20,0	68	154.4	143,3	290	665.0

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Conversions, Equivalents, and Physical Data

Temperature Conversions (continued)								
°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F
21,1	70	158.0	204,4	400	752.0	454,0	850	1562.0
22,2	72	161.6	210,0	410	770.0	460,0	860	1580.0
23,3	74	165.2	215,6	420	788.0	465,6	870	1598.0
24,4	76	168.8	221,1	430	806.0	471,1	880	1616.0
25,6	78	172.4	226,7	440	824.0	476,7	890	1634.0
26,7	80	176.0	232,2	450	842.0	482,2	900	1652.0
27,8	82	179.6	237,8	460	860.0	487,8	910	1670.0
28,9	84	183.2	243,3	470	878.0	493,3	920	1688.0
30,0	86	186.8	248,9	480	896.0	498,9	930	1706.0
31,1	88	190.4	254,4	490	914.0	504,4	940	1724.0
32,2	90	194.0	260,0	500	932.0	510,0	950	1742.0
33,3	92	197.6	265,6	510	950.0	515,6	960	1760.0
34,4	94	201.2	271,1	520	968.0	521,1	970	1778.0
35,6	96	204.8	276,7	530	986.0	526,7	980	1796.0
36,7	98	208.4	282,2	540	1004.0	532,2	990	1814.0
37,8	100	212.0	287,8	550	1022.0	537,8	1000	1832.0
43,3	110	230.0	293,3	560	1040.0	543,3	1010	1850.0
48,9	120	248.0	298,9	570	1058.0	548,9	1020	1868.0
54,4	130	266.0	304,4	580	1076.0	554,4	1030	1886.0
60,0	140	284.0	310,0	590	1094.0	560,0	1040	1904.0
65,6	150	302.0	315,6	600	1112.0	565,6	1050	1922.0
71,1	160	320.0	321,1	610	1130.0	571,1	1060	1940.0
76,7	170	338.0	326,7	620	1148.0	576,7	1070	1958.0
82,2	180	356.0	332,2	630	1166.0	582,2	1080	1976.0
87,8	190	374.0	337,8	640	1184.0	587,8	1090	1994.0
93,3	200	392.0	343,3	650	1202.0	593,3	1100	2012.0
98,9	210	410.0	348,9	660	1220.0	598,9	1110	2030.0
104,4	220	428.0	354,4	670	1238.0	604,4	1120	2048.0
110,0	230	446.0	360,0	680	1256.0	610,0	1130	2066.0
115,6	240	464.0	365,6	690	1274.0	615,6	1140	2084.0
121,1	250	482.0	371,1	700	1292.0	621,1	1150	2102.0
126,7	260	500.0	376,7	710	1310.0	626,7	1160	2120.0
132,2	270	518.0	382,2	720	1328.0	632,2	1170	2138.0
137,8	280	536.0	287,8	730	1346.0	637,8	1180	2156.0
143,3	290	665.0	393,3	740	1364.0	643,3	1190	2174.0

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Conversions, Equivalents, and Physical Data

Temperature Conversions (continued)											
°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F	°C	TEMP. IN °C OR °F TO BE CONVERTED	°F
148,9	300	572.0	315,6	600	1112.0	482,2	900	1652.0	648,9	1200	2192.0
154,4	310	590.0	321,1	610	1130.0	487,8	910	1670.0	654,4	1210	2210.0
160,0	320	608.0	326,7	620	1148.0	493,3	920	1688.0	660,0	1220	2228.0
165,6	330	626.0	332,2	630	1166.0	498,9	930	1706.0	665,6	1230	2246.0
171,1	340	644.0	337,8	640	1184.0	504,4	940	1724.0	671,1	1240	2264.0
176,7	350	662.0	343,3	650	1202.0	510,0	950	1742.0	676,7	1250	2282.0
182,2	360	680.0	348,9	660	1220.0	515,6	960	1760.0	682,2	1260	2300.0
187,8	370	698.0	354,4	670	1238.0	521,1	970	1778.0	687,8	1270	2318.0
189,9	380	716.0	360,0	680	1256.0	526,7	980	1796.0	693,3	1280	2336.0
193,3	390	734.0	365,6	690	1274.0	532,2	990	1814.0	698,9	1290	2354.0
204,4	400	752.0	371,1	700	1292.0	537,8	1000	1832.0	704,4	1300	2372.0
210,0	410	770.0	376,7	710	1310.0	543,3	1010	1850.0	710,0	1310	2390.0
215,6	420	788.0	382,2	720	1328.0	548,9	1020	1868.0	715,6	1320	2408.0
221,1	430	806.0	287,8	730	1346.0	554,4	1030	1886.0	721,1	1330	2426.0
226,7	440	824.0	393,3	740	1364.0	560,0	1040	1904.0	726,7	1340	2444.0
232,2	450	842.0	398,9	750	1382.0	565,6	1050	1922.0	732,2	1350	2462.0
237,8	460	860.0	404,4	760	1400.0	571,1	1060	1940.0	737,8	1360	2480.0
243,3	470	878.0	410,0	770	1418.0	576,7	1070	1958.0	743,3	1370	2498.0
248,9	480	896.0	415,6	780	1436.0	582,2	1080	1976.0	748,9	1380	2516.0
254,4	490	914.0	421,1	790	1454.0	587,8	1090	1994.0	754,4	1390	2534.0
260,0	500	932.0	426,7	800	1472.0	593,3	1100	2012.0	760,0	1400	2552.0
265,6	510	950.0	432,2	810	1490.0	598,9	1110	2030.0	765,6	1410	2570.0
271,1	520	968.0	437,8	820	1508.0	604,4	1120	2048.0	771,1	1420	2588.0
276,7	530	986.0	443,3	830	1526.0	610,0	1130	2066.0	776,7	1430	2606.0
282,2	540	1004.0	448,9	840	1544.0	615,6	1140	2084.0	782,2	1440	2624.0
287,8	550	1022.0	454,4	850	1562.0	621,1	1150	2102.0	787,0	1450	2642.0
293,3	560	1040.0	460,0	860	1580.0	626,7	1160	2120.0	793,3	1460	2660.0
298,9	570	1058.0	465,6	870	1598.0	632,2	1170	2138.0	798,9	1470	2678.0
304,4	580	1076.0	471,1	880	1616.0	637,8	1180	2156.0	804,4	1480	2696.0
310,0	590	1094.0	476,7	890	1634.0	643,3	1190	2174.0	810,0	1490	2714.0

Conversions, Equivalents, and Physical Data

A.P.I. and Baumé Gravity Tables and Weight Factors

A.P.I. Gravity	Baumé Gravity	Specific Gravity	Lbs/U.S. Gallons	U.S. Gallons-/Lb	A.P.I. Gravity	Baumé Gravity	Specific Gravity	Lbs/U.S. Gallons	U.S. Gallons-/Lb	A.P.I. Gravity	Baumé Gravity	Specific Gravity	Lbs/U.S. Gallons	U.S. Gallons-/Lb	A.P.I. Gravity	Baumé Gravity	Specific Gravity	Lbs/U.S. Gallons	U.S. Gallons-/Lb
0	10.247	1.0760	8.962	0.1116	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
1	9.223	1.0679	8.895	0.1124	31	30.78	0.9808	7.251	0.1379	61	60.46	0.7351	6.119	0.1634	81	80.25	0.6659	5.542	0.1804
2	8.198	1.0599	8.828	0.1133	32	31.77	0.8654	7.206	0.1388	62	61.45	0.7313	6.087	0.1643	82	81.24	0.6628	5.516	0.1813
3	7.173	1.0520	8.762	0.1141	33	32.76	0.8602	7.163	0.1396	63	62.44	0.7275	6.056	0.1651	83	82.23	0.6597	5.491	0.1821
4	6.148	1.0443	8.698	0.1150	34	33.75	0.8550	7.119	0.1405	64	63.43	0.7238	6.025	0.1660	84	83.22	0.6566	5.465	0.1830
5	5.124	1.0366	8.634	0.1158	35	34.73	0.8498	7.075	0.1413	65	64.42	0.7201	6.994	0.1668	85	84.20	0.6536	5.440	0.1838
6	4.099	1.0291	8.571	0.1167	36	35.72	0.8448	7.034	0.1422	66	65.41	0.7165	5.964	0.1677	86	85.19	0.6506	5.415	0.1847
7	3.074	1.0217	8.509	0.1175	37	36.71	0.8398	6.993	0.1430	67	66.40	0.7128	5.934	0.1685	87	86.18	0.6476	5.390	0.1855
8	2.049	1.0143	8.448	0.1184	38	37.70	0.8348	6.951	0.1439	68	67.39	0.7093	5.904	0.1694	88	87.17	0.6446	5.365	0.1864
9	1.025	1.0071	8.388	0.1192	39	38.69	0.8299	6.910	0.1447	69	68.37	0.7057	5.874	0.1702	89	88.16	0.6417	5.341	0.1872
10	10.00	1.0000	8.328	0.1201	40	39.68	0.8251	6.870	0.1456	70	69.36	0.7022	5.845	0.1711	90	89.15	0.6388	5.316	0.1881
11	10.99	0.9930	8.270	0.1209	41	40.67	0.8203	6.830	0.1464	71	70.35	0.6988	5.817	0.1719	91	90.14	0.6360	5.293	0.1889
12	11.98	0.9861	8.212	0.1218	42	41.66	0.8155	6.790	0.1473	72	71.34	0.6953	5.788	0.1728	92	91.13	0.6331	5.269	0.1898
13	12.97	0.9792	8.155	0.1226	43	42.65	0.8109	6.752	0.1481	73	72.33	0.6919	5.759	0.1736	93	92.12	0.6303	5.246	0.1906
14	13.96	0.9725	8.099	0.1235	44	43.64	0.8063	6.713	0.1490	74	73.32	0.6886	5.731	0.1745	94	93.11	0.6275	5.222	0.1915
15	14.95	0.9659	8.044	0.1243	45	44.63	0.8017	6.675	0.1498	75	74.31	0.6852	5.703	0.1753	95	94.10	0.6247	5.199	0.1924
16	15.94	0.9593	7.989	0.1252	46	45.62	0.7972	6.637	0.1507	76	75.30	0.6819	5.676	0.1762	96	95.09	0.6220	5.176	0.1932
17	16.93	0.9529	7.935	0.1260	47	50.61	0.7927	6.600	0.1515	77	76.29	0.6787	5.649	0.1770	97	96.08	0.6193	5.154	0.1940
18	17.92	0.9465	7.882	0.1269	48	50.60	0.7883	6.563	0.1524	78	77.28	0.6754	5.622	0.1779	98	97.07	0.6166	5.131	0.1949
19	18.90	0.9402	7.930	0.1277	49	50.59	0.7839	6.526	0.1532	79	78.27	0.6722	5.595	0.1787	99	98.06	0.6139	5.109	0.1957
20	19.89	0.9340	7.778	0.1286	50	50.58	0.7796	6.490	0.1541	80	79.26	0.6690	5.568	0.1796	100	99.05	0.6112	5.086	0.1966
21	20.88	0.9279	7.727	0.1294	51	50.57	0.7753	6.455	0.1549										
22	21.87	0.9218	7.676	0.1303	52	51.55	0.7711	6.420	0.1558										
23	22.86	0.9159	7.627	0.1311	53	52.54	0.7669	6.385	0.1566										
24	23.85	0.9100	7.578	0.1320	54	53.53	0.7628	6.350	0.1575										
25	24.84	0.9042	7.529	0.1328	55	54.52	0.7587	6.136	0.1583										
26	25.83	0.8984	7.481	0.1337	56	55.51	0.7547	6.283	0.1592										
27	26.82	0.8927	7.434	0.1345	57	56.50	0.7507	6.249	0.1600										
28	27.81	0.8871	7.387	0.1354	58	57.49	0.7467	6.216	0.1609										
29	28.80	0.8816	7.341	0.1362	59	58.48	0.7428	6.184	0.1617										
30	29.79	0.8762	7.296	0.1371	60	59.47	0.7389	6.151	0.1626										

The relation of degrees Baume or A.P.I. to Specific Gravity is expressed by these formulas:

For liquids lighter than water:

Degrees Baume = $\frac{140}{G} - 130$ $G = \frac{140}{130 + \text{Degrees Baume}}$

Degrees A.P.I. = $\frac{141}{5} - 131.5$ $G = \frac{141.5}{131.5 + \text{Degrees A.P.I.}}$

For liquids heavier than water:

Degrees Baume = $145 - \frac{145}{5}$ $G = \frac{145}{145 - \text{Degrees Baume}}$

G = Specific Gravity = ratio of weight of a given volume of oil at 60°F to the weight of the same volume of water at 60°F.

The above tables are based on the weight of 1 gallon (U.S.) of oil with a volume of 231 cubic inches at 60°F in air at 760 mm pressure and 50% relative humidity. Assumed weight of 1 gallon of water at 60°F in air is 8.32828 pounds.

To determine the resulting gravity by mixing oils of different gravities:

$$D = \frac{md_1+md_2}{m+n}$$

D = Density or Specific Gravity of mixture
m = Proportion of oil of d_1 density
n = Proportion of oil of d_2 density
d_1 = Specific gravity of m oil
d_2 = Specific gravity of n oil

Conversions, Equivalents, and Physical Data

Characteristics of the Elements

ELEMENT	SYMBOL	ATOMIC NUMBER	MASS NUMBER[1]	MELTING POINT (°C)	BOILING POINT (°C)	ELEMENT	SYMBOL	ATOMIC NUMBER	MASS NUMBER[1]	MELTING POINT (°C)	BOILING POINT (°C)
Actinium	Ac	89	(227)	1600†		Neon	Ne	10	20	-248.67	-245.9
Aluminum	Al	13	27	659.7	2057	Neptunium	Np	93	(237)		
Americum	Am	95	(243)			Nickel	Ni	28	58	1455	2900
Antimony (Stibium)	Sb	51	121	630.5	1380	Niobium	Nb	41	93	2500±50	3700
Argon	Ar	18	40	-189.2	-185.7	Nitrogen	N	7	14	-209.86	-195.8
Arsenic	As	33	75	sublimes at 615	sublimes at 615	Nobelium	No	102	(253)		
Astatine	At	85	(210)			Osmium	Os	76	192	2700	>5300
Barium	Ba	56	138	850	1140	Oxygen	O	8	16	-218.4	-182.86
Berkelium	Bk	97	(247)			Palladium	Pd	46	106	1549.4	2000
Beryllium	Be	4	9	1278±5	2970	Phosphorus	P	15	31		
Bismuth	Bi	83	209	271.3	1560±5	Platinum	Pt	78	195	1773.5	4300
Boron	B	5	11	2300	2550	Plutonium	Pu	94	(242)		
Bromine	Br	35	79	-7.2	58.78	Polonium	Po	84	(209)		
Cadmium	Cd	48	114	320.9	767±2	Potassium	K	19	39	53.3	760
Calcium	Ca	20	40	842±8	1240	Praseodymium	Pr	59	141	940	
Californium	Cf	98	(249)			Promethium	Pm	61	(145)		
Carbon	C	6	12	>3550	4200	Protactinium	Pa	91	(231)		
Cerium	Ce	58	140	804	1400	Radium	Ra	88	(226)	700	
Cesium	Cs	55	133	28.5	670	Radon	Rn	86	(222)	-71	1140
Chlorine	Cl	17	35	-103±5	-34.6	Rhenium	Re	75	187	3167±60	-61.8
Chromium	Cr	24	52	1890	2480	Rhodium	Rh	45	103	1966±3	>2500
Cobalt	Co	27	59	1495	2900	Rubidium	Rb	37	85	38.5	700
Copper	Cu	29	63	1083	2336	Ruthenium	Ru	44	102	2450	2700
Curium	Cm	96	(248)			Samarium	Sm	62	152	>1300	
Dysprosium	Dy	66	164			Scandium	Sc	21	45	1200	2400
Einsteinium	Es	99	(254)			Selenium	Se	34	80	217	688
Erbium	Er	68	166			Silicon	Si	14	28	1420	2355
Europium	Eu	63	153	1150±50		Silver	Ag	47	107	960.8	1950
Fermium	Fm	100	(252)			Sodium	Na	11	23	97.5	880
Fluourine	F	9	19	-223	-188	Strontium	Sr	38	88	800	1150
Francium	Fr	87	(223)			Sulfur	S	16	32		
Gadolinium	Gd	64	158			Tantalum	Ta	73	180	2996±50	c.4100
Gallium	Ga	31	69	29.78	1983	Technetium	Tc	43	(99)		
Germanium	Ge	32	74	958.5	2700	Tellurium	Te	52	130	452	1390
Gold	Au	79	197	1063	2600	Terbium	Tb	65	159	327±5	
Hafnium	Hf	72	180	1700[2]	>3200	Thallium	Tl	81	205	302	1457±10
Helium	He	2	4	-272	-268.9	Thorium	Th	90	232	1845	4500
Holmium	Ho	67	165			Thulium	Tm	69	169		
Hydrogen	H	1	1	-259.14	-252.8	Tin	Sn	50	120	231.89	2270
Indium	In	49	115	156.4	2000±10	Titanium	Ti	22	48	1800	>3000
Iodine	I	53	127	113.7	184.35	Tungsten (Wolfram)	W	74	184	3370	5900
Iridium	Ir	77	193	2454	>4800	Uranium	U	92	238	c.1133	
Iron	Fe	26	56	1535	3000	Vanadium	V	23	51	1710	3000
Krypton	Kr	36	84	-156.6	-152.9	Xenon	Xe	54	132	-112	-107.1
Lanthanum	La	57	139	826		Ytterbium	Yb	70	174	1800	
Lawrencium	Lw	103	(257)			Yttrium	Y	39	89	1490	2500
Lead	Pb	82	208	327.43	1620	Zinc	Zn	30	64	419.47	907
Lithium	Li	3	7	186	1336±5	Zirconium	Zr	40	90	1857	>2900
Lutetium	Lu	71	175								
Magnesium	Mg	12	24	651	1107						
Manganese	Mn	25	55	1260	1900						
Mendelevium	Mv	101	(256)								
Mercury	Hg	80	202	-38.87	356.58						
Molybdenum	Mo	42	98	2620±10	4800						
Neodymium	Nd	60	142	840							

1. Mass number shown is that of stable isotope most common in nature. Mass numbers shown in parentheses designate the isotope with the longest half-life (slowest rate of radioactive decay) for those elements having an unstable isotope.
2. Calculated

> Greater than

Conversions, Equivalents, and Physical Data

Recommended Standard Specifications for Valve Materials Pressure-Containing Castings			
1 Carbon Steel ASTM A216 Grade WCC Temperature Range = -20° to 800°F Composition (Percent) C 0.25 maximum Mn 1.20 maximum P 0.04 maximum S 0.04 maximum Si 0.60 maximum	2 Carbon Steel ASTM A216 Grade WCB Temperature Range = -20° to 1000°F Composition (Percent) C 0.30 maximum Mn 1.00 maximum P 0.05 maximum S 0.06 maximum Si 0.60 maximum	11 Type 304 Stainless Steel ASTM A351 Grade CF-8 Temperature Range = -425° to 1500°F Composition (Percent) C 0.08 maximum Mn 1.50 maximum Si 2.00 maximum S 0.04 maximum P 0.04 maximum Cr 18.00 to 21.00 Ni 8.00 to 11.00	12 Type 316 Stainless Steel ASTM A351 Grade CF-8M Temperature Range = -425° to 1500°F Composition (Percent) C 0.08 maximum Mn 1.50 maximum Si 2.00 maximum P 0.04 maximum S 0.04 maximum Cr 18.00 to 21.00 Ni 9.00 to 12.00 Mo 2.00 to 3.00
3 Carbon Steel ASTM A352 Grade LCC Temperature Range = -50° to 650°F Composition: same as ASTM A216 Grade WCC	4 Carbon Steel ASTM A352 Grade LCB Temperature Range = -50° to 650°F Composition: same as ASTM A216 Grade WCB	13 Cast Iron ASTM A126 Class B Temperature Range = -150° to 450°F Composition (Percent) P 0.75 maximum S 0.12 maximum	14 Cast Iron ASTM A126 Class C Temperature Range = -150° to 450°F Composition (Percent) P 0.75 maximum S 0.12 maximum
5 Chrome Moly Steel ASTM A217 Grade C5 Temperature Range = -20° to 1100°F Composition (Percent) C 0.20 maximum Mn 0.40 to 0.70 P 0.05 maximum S 0.06 maximum Si 0.75 maximum Cr 4.00 to 6.50 Mo 0.45 to 0.65	6 Carbon Moly Steel ASTM A217 Grade WC1 Temperature Range = -20° to 850°F Composition (Percent) C 0.25 Mn 0.50 to 0.80 P 0.05 maximum S 0.06 maximum Si 0.60 maximum Mo 0.45 to 0.65	15 Ductile Iron ASTM A395 Type 60-45-15 Temperature Range = -20° to 650°F Composition (Percent) C 3.00 minimum Si 2.75 maximum P 0.80 maximum	16 Ductile Ni-Resist* Iron ASTM A439 Type D-2B Temperature Range = -20° to 750°F Composition (Percent) C 3.00 maximum Si 1.50 to 3.00 Mn 0.70 to 1.25 P 0.08 maximum Ni 18.00 to 22.00 Cr 2.75 to 4.00
7 Chrome Moly Steel ASTM A217 Grade WC6 Temperature Range = -20° to 1000°F Composition (Percent) C 0.20 maximum Mn 0.50 to 0.80 P 0.05 maximum S 0.06 maximum Si 0.60 maximum Cr 1.00 to 1.50 Mo 0.45 to 0.65	8 Chrome Moly Steel ASTM A217 Grade WC9 Temperature Range = -20° to 1050°F Composition (Percent) C 0.18 maximum Mn 0.40 to 0.70 P 0.05 maximum Si 0.60 maximum Cr 2.00 to 2.75 Mo 0.90 to 1.20	17 Standard Valve Bronze ASTM B62 Temperature Range = -325° to 450°F Composition (Percent) Cu 84.00 to 86.00 Sn 4.00 to 6.00 Pb 4.00 to 6.00 Zn 4.00 to 6.00 Ni 1.00 maximum Fe 0.30 maximum P 0.05 maximum	18 Tin Bronze ASTM B143 Alloy 1A Temperature Range = -325° to 400°F Composition (Percent) Cu 86.00 to 89.00 Sn 9.00 to 11.00 Pb 0.30 maximum Zn 1.00 to 3.00 Ni 1.00 maximum Fe 0.15 maximum P 0.05 maximum
9 3.5% Nickel Steel ASTM A352 Grade LC3 Temperature Range = -150° to 650°F Composition (Percent) C 0.15 maximum Mn 0.50 to 0.80 P 0.05 maximum S 0.05 maximum Si 0.60 maximum Ni 3.00 to 4.00	10 Chrome Moly Steel ASTM A217 Grade C12 Temperature Range = -20° to 1100°F Composition (Percent) C 0.20 maximum Si 1.00 maximum Mn 0.35 to 0.65 Cr 8.00 to 10.00 Mo 0.90 to 1.20 P 0.05 maximum S 0.06 maximum	19 Manganese Bronze ASTM B147 Alloy 8A Temperature Range = -325° to 350°F Composition (Percent) Cu 55.00 to 60.00 Sn 1.00 maximum Pb 0.40 maximum Ni 0.50 maximum Fe 0.40 to 2.00 Al 0.50 to 1.50 Mn 1.50 maximum Zn Remainder	20 Aluminum Bronze ASTM B148 Alloy 9C Temperature Range = -325° to 500°F Composition (Percent) Cu 83.00 minimum Al 10.00 to 11.50 Fe 3.00 to 5.00 Mn 0.50 Ni 2.50 maximum Minimum total named elements = 99.5

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Conversions, Equivalents, and Physical Data

Recommended Standard Specifications for Valve Materials Pressure-Containing Castings (continued)			
21 Mondel* Alloy 411 (Weldable Grade) Temperature Range = -325° to 900°F Composition (Percent) Ni 60.00 minimum Cu 26.00 to 33.00 C 0.30 maximum Mn 1.50 maximum Fe 3.50 maximum S 0.015 maximum Si 1.00 to 2.00 Nb 1.00 to 3.00	22 Nickel-Moly Alloy "B" ASTM A494 (Hastelloy® "B" †) Temperature Range = -325° to 700°F Composition (Percent) Cr 1.00 maximum Fe 4.00 to 6.00 C 0.12 maximum Si 1.00 maximum Co 2.50 maximum Mn 1.00 maximum V 0.20 to 0.60 Mo 26.00 to 30.00 P 0.04 maximum S 0.03 maximum Ni Remainder	31 Type 302 Stainless Steel ASTM A276 Type 302 Composition (Percent) C 0.15 maximum Mn 2.00 maximum P 0.045 maximum S 0.030 maximum Si 1.00 maximum Cr 17.00 to 19.00 Ni 8.00 to 10.00	32 Type 304 Stainless Steel ASTM A276 Type 304 Composition (Percent) C 0.08 maximum Mn 2.00 maximum P 0.045 maximum S 0.030 maximum Si 1.00 maximum Cr 18.00 to 20.00 Ni 8.00 to 12.00
23 Nickel-Moly-Chrome Alloy "C" ASTM A494 (Hastelloy® "C" †) Temperature Range = -325° to 1000°F Composition (Percent) Cr 15.50 to 17.50 Fe 4.50 to 7.50 W 3.75 to 5.25 C 0.12 maximum Si 1.00 maximum Co 2.50 maximum Mn 1.00 maximum V 0.20 to 0.40 Mo 16.00 to 18.00 P 0.04 S 0.03 Ni Remainder	24 Cobalt-based Alloy No.6 Stellite † No. 6 Composition (Percent) C 0.90 to 1.40 Mn 1.00 W 3.00 to 6.00 Ni 3.00 Cr 26.00 to 32.00 Mo 1.00 Fe 3.00 Se 0.40 to 2.00 Co Remainder	33 Type 316 Stainless Steel ASTM A276 Type 316 Composition (Percent) C 0.08 maximum Mn 2.00 maximum P 0.045 maximum S 0.030 maximum Si 1.00 maximum Cr 16.00 to 18.00 Ni 10.00 to 14.00 Mo 2.00 to 3.00	34 Type 316L Stainless Steel ASTM A276 Type 316L Composition (Percent) C 0.03 maximum Mn 2.00 maximum P 0.045 maximum S 0.030 maximum Si 1.00 maximum Cr 16.00 to 18.00 Ni 10.00 to 14.00 Mo 2.00 to 3.00
25 Aluminum Bar ASTM B211 Alloy 20911-T3 Composition (Percent) Si 0.40 maximum Fe 0.70 maximum Cu 5.00 to 6.00 Zn 0.30 maximum Bi 0.20 to 0.60 Pb 0.20 to 0.60 Other Elements 0.15 maximum Al Remainder	26 Yellow Brass Bar ASTM B16 1/2 Hard Composition (Percent) Cu 60.00 to 63.00 Pb 2.50 to 3.70 Fe 0.35 maximum Zn Remainder	35 Type 410 Stainless Steel ASTM A276 Type 410 Composition (Percent) C 0.15 maximum Mn 1.00 maximum P 0.040 maximum S 0.030 maximum Si 1.00 maximum Cr 11.50 to 13.50 Al 0.10 to 0.30	36 Type 17-4PH Stainless Steel ASTM A461 Grade 630 Composition (Percent) C 0.07 maximum Mn 1.00 maximum Si 1.00 maximum P 0.04 maximum S 0.03 maximum Cr 15.50 to 17.50 Nb 0.05 to 0.45 Cu 3.00 to 5.00 Ni 3.00 to 5.00 Fe Remainder
27 Naval Brass Bar ASTM B21 Allow 464 Composition (Percent) Cu 59.00 to 62.00 Sn 0.50 to 1.00 Pb 0.20 maximum Zn Remainder	28 Leaded Steel Bar AISI 12L14 Composition (Percent) C 0.15 maximum Mn 0.80 to 1.20 P 0.04 to 0.09 S 0.25 to 0.35 Pb 0.15 to 0.35	37 Nickel-Copper Alloy Bar Alloy K500 (K Monel®*) Composition (Percent) Ni 63.00 to 70.00 Fe 2.00 maximum Mn 1.50 maximum Si 1.00 maximum C 0.25 maximum S 0.01 maximum Al 2.00 to 4.00 Ti 0.25 to 1.00 Cu Remainder	38 Nickel-Moly Alloy "B" Bar ASTM B335 (Hastelloy® "B" †) Composition (Percent) Cr 1.00 maximum Fe 4.00 to 6.00 C 0.04 maximum Si 1.00 maximum Co 2.50 maximum Mn 1.00 maximum V 0.20 to 0.40 Mo 26.00 to 30.00 P 0.025 maximum S 0.030 maximum Ni Remainder
29 Carbon Steel Bar ASTM A108 Grade 1018 Composition (Percent) C 0.15 to 0.20 Mn 0.60 to 0.90 P 0.04 maximum S 0.05 maximum	30 AISI 4140 Chrome-Moly Steel (Suitable for ASTM A193 Grade B7 bolt material) Composition (Percent) C 0.38 to 0.43 Mn 0.75 to 1.00 P 0.035 maximum S 0.04 maximum Si 0.20 to 0.35 Cr 0.80 to 1.10 Mo 0.15 to 0.25 Fe Remainder	39 Nickel-Moly-Chrome Alloy "C" Bar ASTM B336 (Hastelloy® "C" †) Composition (Percent) Cr 14.50 to 16.50 Fe 4.00 to 7.00 W 3.00 to 4.50 C 0.08 maximum Si 1.00 maximum Co 2.50 maximum Mn 1.00 maximum Va 0.35 maximum Mo 15.00 to 17.00 P 0.04 S 0.03 Ni Remainder	

Conversions, Equivalents, and Physical Data

Recommended Standard Specifications for Valve Materials Pressure-Containing Castings									
MATERIAL CODE AND DESCRIPTION			MINIMUM PHYSICAL PROPERTIES				MODULUS OF ELASTICITY AT 70°F (PSI x 10^6)	APPROXIMATE BRINELL HARDNESS
			Tensile (Psi)	Yield Point (Psi)	Elong. in 2-inches (%)	Reduction of Area (%)		
1	Carbon Steel	ASTM A 216 Grade WCC	70,000	40,000	22	35	30.4	137 to 187
2	Carbon Steel	ASTM A 216 Grade WCB	70,000	36,000	22	35	27.9	137 to 187
3	Carbon Steel	ASTM A 352 Grade LCC	70,000	40,000	22	35	29.9	137 to 187
4	Carbon Steel	ASTM A 352 Grade LCB	65,000	35,000	24	35	27.9	137 to 187
5	Chrome Moly Steel	ASTM A217 Grade C5	90,000	60,000	18	35	27.4	241 Maximum
6	Carbon Moly Steel	ASTM A217 Grade WC1	65,000	35,000	24	35	29.9	215 Maximum
7	Chrome Moly Steel	ASTM A217 Grade WC6	70,000	40,000	20	35	29.9	215 Maximum
8	Chrome Moly Steel	ASTM A217 Grade WC9	70,000	40,000	20	35	29.9	241 Maximum
9	3.5% Nickel Steel	ASTM A352 Grade LC3	65,000	40,000	24	35	27.9	137
10	Chrome Moly Steel	ASTM A217 Grade C12	90,000	60,000	18	35	27.4	180 to 240
11	Type 304 Stainless Steel	ASTM A351 Grade CF8	65,000	28,000	35	- - - -	28.0	140
12	Type 316 Stainless Steel	ASTM A351 Grade CF8M	70,000	30,000	30	- - - -	28.3	156 to 170
13	Cast Iron	ASTM A126 Class B	31,000	- - - -	- - - -	- - - -	- - - -	160 to 220
14	Cast Iron	ASTM A126 Class C	41,000	- - - -	- - - -	- - - -	- - - -	160 to 220
15	Ductile Iron	ASTM A395 Type 60-45-15	60,000	45,000	15	- - - -	23-26	143 to 207
16	Ductile Ni-Resist Iron(1)	ASTM A439 Type D-2B	58,000	30,000	7	- - - -	- - - -	148 to 211
17	Standard Valve Bronze	ASTM B62	30,000	14,000	20	17	13.5	55 to 65*
18	Tin Bronze	ASTM B143 Alloy 1A	40,000	18,000	20	20	15	75 to 85*
19	Manganese Bronze	ASTM B147 Alloy 8A	65,000	25,000	20	20	15.4	98*
20	Aluminum Bronze	ASTM B148 Alloy 9C	75,000	30,000	12 minimum	12	17	150
21	Mondel Alloy 411	(Weldable Grade)	65,000	32,500	25	- - - -	23	120 to 170
22	Nickel-Moly Alloy "B"	ASTM A494 (Hastelloy® "B")	72,000	46,000	6	- - - -	- - - -	- - - -
23	Nickel-Moly-Chrome Alloy "C"	ASTM A494 (Hastelloy® "C")	72,000	46,000	4	- - - -	- - - -	- - - -
24	Cobalt-base Alloy No.6	Stellite No. 6	121,000	64,000	1 to 2	- - - -	30.4	- - - -
25	Aluminum Bar	ASTM B211 Alloy 20911-T3	44,000	36,000	15	- - - -	10.2	95
26	Yellow Brass Bar	ASTM B16-1/2 Hard	45,000	15,000	7	50	14	- - - -
27	Naval Brass Bar	ASTM B21 Alloy 464	60,000	27,000	22	55	- - - -	- - - -
28	Leaded Steel Bar	AISI 12L14	79,000	71,000	16	52	- - - -	163
29	Carbon Steel Bar	ASTM A108 Grade 1018	69,000	48,000	38	62	- - - -	143
30	AISI 4140 Chrome-Moly Steel	(Suitable for ASTM A193 Grade B7 bolt material)	135,000	115,000	22	63	29.9	255
31	Type 302 Stainless Steel	ASTM A276 Type 302	85,000	35,000	60	70	28	150
32	Type 304 Stainless Steel	ASTM A276 Type 304	85,000	35,000	60	70	- - - -	149
33	Type 316 Stainless Steel	ASTM A276 Type 316	80,000	30,000	60	70	28	149
34	Type 316L Stainless Steel	ASTM A276 Type 316L	81,000	34,000	55	- - - -	- - - -	146
35	Type 410 Stainless Steel	ASTM A276 Type 410	75,000	40,000	35	70	29	155
36	Type 17-4PH Stainless Steel	ASTM A461 Grade 630	135,000	105,000	16	50	29	275 to 345
37	Nickel-Copper Alloy Bar	Alloy K500 (K Monel®)	100,000	70,000	35	- - - -	26	175 to 260
38	Nickel-Moly Alloy "B" Bar	ASTM B335 (Hastelloy® "B")	100,000	46,000	30	- - - -	- - - -	- - - -
39	Nickel-Moly Alloy "C" Bar	ASTM B336 (Hastelloy® "C")	100,000	46,000	20	- - - -	- - - -	- - - -

1. 500 kg load.

Conversions, Equivalents, and Physical Data

Physical Constants of Hydrocarbons

NO.	COMPOUND	FORMULA	MOLECULAR WEIGHT	BOILING POINT AT 14.696 PSIA (°F)	VAPOR PRESSURE AT 100°F (PSIA)	FREEZING POINT AT 14.696 PSIA (°F)	CRITICAL CONSTANTS		SPECIFIC GRAVITY AT 14.696 PSIA	
							Critical Temperature (°F)	Critical Pressure (psia)	Liquid[3, 4], 60°F/60°F	Gas at 60°F (Air = 1)[1]
1	Methane	CH_4	16.043	-258.69	(5000)[2]	-296.46[5]	-116.63	667.8	0.3000[8]	0.5539
2	Ethane	C_2H_6	30.070	-127.48	(800)[2]	-297.89[5]	90.09	707.8	0.3564[7]	1.0382
3	Propane	C_3H_8	44.097	-43.67	190	-305.84[5]	206.01	616.3	0.5077[7]	1.5225
4	n-Butane	C_4H_{10}	58.124	31.10	51.6	-217.05	305.65	550.7	0.5844[7]	2.0068
5	Isobutane	C_4H_{10}	58.124	10.90	72.2	-255.29	274.98	529.1	0.5631[7]	2.0068
6	n-Pentane	C_5H_{12}	72.151	96.92	15.570	-201.51	385.7	488.6	0.6310	2.4911
7	Isopentane	C_5H_{12}	72.151	82.12	20.44	-255.83	369.10	490.4	0.6247	2.4911
8	Neopentane	C_5H_{12}	72.151	49.10	35.9	2.17	321.13	464.0	0.5967[7]	2.4911
9	n-Hexane	C_6H_{14}	86.178	155.72	4.956	-139.58	453.7	436.9	0.6640	2.9753
10	2-Methylpentane	C_6H_{14}	86.178	140.47	6.767	-244.63	435.83	436.6	0.6579	2.9753
11	3-Methylpentane	C_6H_{14}	86.178	145.89	6.098	- - - -	448.3	453.1	0.6689	2.9753
12	Neohexane	C_6H_{14}	86.178	121.52	9.856	-147.72	420.13	446.8	0.6540	2.9753
13	2,3-Dimethylbutane	C_6H_{14}	86.178	136.36	7.404	-199.38	440.29	453.5	0.6664	2.9753
14	n-Heptane	C_7H_{16}	100.205	209.17	1.620	-131.05	512.8	396.8	0.6882	3.4596
15	2-Methylhexane	C_7H_{16}	100.205	194.09	2.271	-180.89	495.00	396.5	0.6830	3.4596
16	3-Methylhexane	C_7H_{16}	100.205	197.32	2.130	- - - -	503.78	408.1	0.6917	3.4596
17	3-Ethylpentane	C_7H_{16}	100.205	200.25	2.012	-181.48	513.48	419.3	0.7028	3.4596
18	2,2-Dimethylpentane	C_7H_{16}	100.205	174.54	3.492	-190.86	477.23	402.2	0.6782	3.4596
19	2,4-Dimethylpentane	C_7H_{16}	100.205	176.89	3.292	-182.63	475.95	396.9	0.6773	3.4596
20	3,3-Dimethylpentane	C_7H_{16}	100.205	186.91	2.773	-210.01	505.85	427.2	0.6976	3.4596
21	Triptane	C_7H_{16}	100.205	177.58	3.374	-12.82	496.44	428.4	0.6946	3.4596
22	n-Octane	C_8H_{18}	114.232	258.22	0.537	-70.18	564.22	360.6	0.7068	3.9439
23	Disobutyl	C_8H_{18}	114.232	228.39	1.101	-132.07	530.44	360.6	0.6979	3.9439
24	Isooctane	C_8H_{18}	114.232	210.63	1.708	-161.27	519.46	372.4	0.6962	3.9439
25	n-Nonane	C_9H_{20}	128.259	303.47	0.179	-64.28	610.68	332	0.7217	4.4282
26	n-Decane	$C_{10}H_{22}$	142.286	345.48	0.0597	-21.36	652.1	304	0.7342	4.9125
27	Cyclopentane	C_5H_{10}	70.135	120.65	9.914	-136.91	461.5	653.8	0.7504	2.4215
28	Methylcyclopentane	C_6H_{12}	84.162	161.25	4.503	-224.44	499.35	548.9	0.7536	2.9057
29	Cyclohexane	C_6H_{12}	84.162	177.29	3.264	43.77	536.7	591	0.7834	2.9057
30	Methylcyclohexane	C_7H_{14}	98.189	213.68	1.609	-195.98	570.27	503.5	0.7740	3.3900
31	Ethylene	C_2H_4	28.054	-154.62	- - - -	-272.45[5]	48.58	729.8	- - - -	0.9686
32	Propene	C_3H_6	42.081	-53.90	226.4	-301.45[5]	196.9	669	0.5220[7]	1.4529
33	1-Butene	C_4H_8	56.108	20.75	63.05	-301.63[5]	295.6	583	0.6013[7]	1.9372
34	Cis-2-Butene	C_4H_8	56.108	38.69	45.54	-218.06	324.37	610	0.6271[7]	1.9372
35	Trans-2-Butene	C_4H_8	56.108	33.58	49.80	-157.96	311.86	595	0.6100[7]	1.9372
36	Isobutene	C_4H_8	56.108	19.59	63.40	-220.61	292.55	580	0.6004[7]	1.9372
37	1-Pentene	C_5H_{10}	70.135	85.93	19.115	-265.39	376.93	590	0.645[7]	2.4215
38	1,2-Butadiene	C_4H_6	54.092	51.56	(20)[2]	-213.16	(339)[2]	(653)[2]	0.658[7]	1.8676
39	1,3-Butadiene	C_4H_6	54.092	24.06	(60)[2]	-164.02	306	628	0.6272[7]	1.8676
40	Isoprene	C_5H_8	68.119	93.30	16.672	-230.74	(412)[2]	(558.4)[2]	0.6861	2.3519
41	Acetylene	C_2H_2	26.038	-119[6]	- - - -	-114[5]	95.31	890.4	0.615[9]	0.8990
42	Benzene	C_6H_6	78.114	176.17	3.224	41.96	552.22	710.4	0.8844	2.6969
43	Toluene	C_7H_8	92.141	231.13	1.032	-138.94	605.55	595.9	0.8718	3.1812
44	Ethylbenzene	C_8H_{10}	106.168	277.16	0.371	-138.91	651.24	523.5	0.8718	3.6655
45	o-Xylene	C_8H_{10}	106.168	291.97	0.264	-13.30	675.0	541.4	0.8848	3.6655
46	m-Xylene	C_8H_{10}	106.168	282.41	0.326	-54.12	651.02	513.6	0.8687	3.6655
47	p-Xylene	C_8H_{10}	106.168	281.05	0.342	55.86	649.6	509.2	0.8657	3.6655
48	Styrene	C_8H_8	104.152	293.29	(0.24)[2]	-23.10	706.0	580	0.9110	3.5959
49	Isopropylbenzane	C_9H_{12}	120.195	306.34	0.188	-140.82	676.4	465.4	0.8663	4.1498

1. Calculated values.
2. ( ) - Estimated values.
3. Air saturated hydrocarbons.
4. Absolute values from weights in vacuum.
5. At saturation pressure (- - - -).
6. Sublimation point.
7. Saturation pressure at 60°F.
8. Apparent value for methane at 60°F.
9. Specific gravity, 119°F/60°F (sublimation point).

Conversions, Equivalents, and Physical Data

Physical Constants of Various Fluids								
FLUID	FORMULA	MOLECULAR WEIGHT	BOILING POINT (°F AT 14.696 PSIA)	VAPOR PRESSURE AT 70°F (PSIG)	CRITICAL TEMPERATURE (°F)	CRITICAL PRESSURE (PSIA)	SPECIFIC GRAVITY	
							Liquid 60°F/60°F	Gas
Acetic Acid	$HC_2H_3O_3$	60.06	245	- - - -	- - - -	- - - -	1.05	- - - -
Acetone	C_3H_6O	58.08	133	- - - -	455	691	0.79	2.01
Air	N_2O_2	28.97	-317	- - - -	-221	547	0.86‡	1.0
Alcohol, Ethyl	C_2H_6O	46.07	173	2.3(2)	470	925	0.794	1.59
Alcohol, Methyl	CH_4O	32.04	148	4.63(2)	463	1174	0.796	1.11
Ammonia	NH_3	17.03	-28	114	270	1636	0.62	0.59
Ammonium Chloride(1)	NH_4Cl	- - - -	- - - -	- - - -	- - - -	- - - -	1.07	- - - -
Ammonium Hydroxide(1)	NH_4OH	- - - -	- - - -	- - - -	- - - -	- - - -	0.91	- - - -
Ammonium Sulfate(1)	$(NH_4)_2SO_4$	- - - -	- - - -	- - - -	- - - -	- - - -	1.15	- - - -
Aniline	C_6H_7N	93.12	365	- - - -	798	770	1.02	- - - -
Argon	A	39.94	-302	- - - -	-188	705	1.65	1.38
Bromine	Br_2	159.84	138	- - - -	575	- - - -	2.93	5.52
Calcium Chloride(1)	$CaCl_2$	- - - -	- - - -	- - - -	- - - -	- - - -	1.23	- - - -
Carbon Dioxide	CO_2	44.01	-109	839	88	1072	0.801(3)	1.52
Carbon Disulfide	CS_2	76.1	115	- - - -	- - - -	- - - -	1.29	2.63
Carbon Monoxide	CO	28.01	-314	- - - -	-220	507	0.80	0.97
Carbon Tetrachloride	CCl_4	153.84	170	- - - -	542	661	1.59	5.31
Chlorine	Cl_2	70.91	-30	85	291	1119	1.42	2.45
Chromic Acid	H_2CrO_4	118.03	- - - -	- - - -	- - - -	- - - -	1.21	- - - -
Citric Acid	$C_6H_8O_7$	192.12	- - - -	- - - -	- - - -	- - - -	1.54	- - - -
Copper Sulfate(1)	$CuSO_4$	- - - -	- - - -	- - - -	- - - -	- - - -	1.17	- - - -
Ether	$(C_2H_5)_2O$	74.12	34	- - - -	- - - -	- - - -	0.74	2.55
Ferric Chloride(1)	$FeCl_3$	- - - -	- - - -	- - - -	- - - -	- - - -	1.23	- - - -
Fluorine	F_2	38.00	-305	300	-200	809	1.11	1.31
Formaldehyde	H_2CO	30.03	-6	- - - -	- - - -	- - - -	0.82	1.08
Formic Acid	HCO_2H	46.03	214	- - - -	- - - -	- - - -	1.23	- - - -
Furfural	$C_5H_4O_2$	96.08	324	- - - -	- - - -	- - - -	1.16	- - - -
Glycerine	$C_3H_8O_3$	92.09	554	- - - -	- - - -	- - - -	1.26	- - - -
Glycol	$C_2H_6O_2$	62.07	387	- - - -	- - - -	- - - -	1.11	- - - -
Helium	He	4.003	-454	- - - -	-450	33	0.18	0.14
Hydrochloric Acid	HCl	36.47	-115	- - - -	- - - -	- - - -	1.64	- - - -
Hydrofluoric Acid	HF	20.01	66	0.9	446	- - - -	0.92	- - - -
Hydrogen	H_2	2.016	-422	- - - -	-400	188	0.07(3)	0.07
Hydrogen Chloride	HCl	36.47	-115	613	125	1198	0.86	1.26
Hydrogen Sulfide	H_2S	34.07	-76	252	213	1307	0.79	1.17
Isopropyl Alcohol	C_3H_8O	60.09	180	- - - -	- - - -	- - - -	0.78	2.08
Linseed Oil	- - - -	- - - -	538	- - - -	- - - -	- - - -	0.93	- - - -

1. Aqueous Solution - 25% by weight of compound.
2. Vapor pressure in psia at 100°F.
3. Density of liquid, gm/ml at normal boiling point.

Conversions, Equivalents, and Physical Data

Physical Constants of Various Fluids (continued)

FLUID	FORMULA	MOLECULAR WEIGHT	BOILING POINT (°F AT 14.696 PSIA)	VAPOR PRESSURE AT 70°F (PSIG)	CRITICAL TEMPERATURE (°F)	CRITICAL PRESSURE (PSIA)	SPECIFIC GRAVITY	
							Liquid 60°F/60°F	Gas
Magnesium Chloride(1)	$MgCl_2$	- - - -	- - - -	- - - -	- - - -	- - - -	1.22	- - - -
Mercury	Hg	200.61	670	- - - -	- - - -	- - - -	13.6	6.93
Methyl Bromide	CH_3Br	94.95	38	13	376	- - - -	1.73	3.27
Methyl Chloride	CH_3Cl	50.49	-11	59	290	969	0.99	1.74
Naphthalene	$C_{10}H_8$	128.16	424	- - - -	- - - -	- - - -	1.14	4.43
Nitric Acid	HNO_3	63.02	187	- - - -	- - - -	- - - -	1.5	- - - -
Nitrogen	N_2	28.02	-320	- - - -	-233	493	0.81(3)	0.97
Oil, Vegetable	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	0.91 to 0.94	- - - -
Oxygen	O_2	32	-297	- - - -	-181	737	1.14(3)	1.105
Phosgene	$COCl_2$	98.92	47	10.7	360	823	1.39	3.42
Phosphoric Acid	H_3PO_4	98.00	415	- - - -	- - - -	- - - -	1.83	- - - -
Potassium Carbonate(1)	K_2CO_3	- - - -	- - - -	- - - -	- - - -	- - - -	1.24	- - - -
Potassium Chloride(1)	KCl	- - - -	- - - -	- - - -	- - - -	- - - -	1.16	- - - -
Potassium Hydroxide(1)	KOH	- - - -	- - - -	- - - -	- - - -	- - - -	1.24	- - - -
Refrigerant 11	CCl_3F	137.38	75	13.4	388	635	- - - -	5.04
Refrigerant 12	CCl_2F_2	120.93	-22	70.2	234	597	- - - -	4.2
Refrigerant 13	$CClF_3$	104.47	-115	458.7	84	561	- - - -	- - - -
Refrigerant 21	$CHCl_2F$	102.93	48	8.4	353	750	- - - -	3.82
Refrigerant 22	$CHClF_2$	86.48	-41	122.5	205	716	- - - -	- - - -
Refrigerant 23	CHF_3	70.02	-119	635	91	691	- - - -	- - - -
Sodium Chloride(1)	NaCl	- - - -	- - - -	- - - -	- - - -	- - - -	1.19	- - - -
Sodium Hydroxide(1)	NaOH	- - - -	- - - -	- - - -	- - - -	- - - -	1.27	- - - -
Sodium Sulfate(1)	Na_2SO_4	- - - -	- - - -	- - - -	- - - -	- - - -	1.24	- - - -
Sodium Thiosulfate(1)	Na_2SO_3	- - - -	- - - -	- - - -	- - - -	- - - -	1.23	- - - -
Starch	$(C_6H_{10}O_5)x$	- - - -	- - - -	- - - -	- - - -	- - - -	1.50	- - - -
Sugar Solutions(1)	$C_{12}H_{22}O_{11}$	- - - -	- - - -	- - - -	- - - -	- - - -	1.10	- - - -
Sulfuric Acid	H_2SO_4	98.08	626	- - - -	- - - -	- - - -	1.83	- - - -
Sulfer Dioxide	SO_2	64.6	14	34.4	316	1145	1.39	2.21
Turpentine	- - - -	- - - -	320	- - - -	- - - -	- - - -	0.87	- - - -
Water	H_2O	18.016	212	0.9492(2)	706	3208	1.00	0.62
Zinc Chloride(1)	$ZnCl_2$	- - - -	- - - -	- - - -	- - - -	- - - -	1.24	- - - -
Zinc Sulfate(1)	$ZnSO_4$	- - - -	- - - -	- - - -	- - - -	- - - -	1.31	- - - -

1. Aqueous Solution - 25% by weight of compound.
2. Vapor pressure in psia at 100°F.
3. Density of liquid, gm/ml at normal boiling point.

Conversions, Equivalents, and Physical Data

Properties of Water

TEMPERATURE OF WATER (°F)	SATURATION PRESSURE (POUNDS PER SQUARE INCH ABSOLUTE)	WEIGHT (POUNDS PER GALLON)	SPECIFIC GRAVITY 60°F/60°F	CONVERSION FACTOR[1], LBS/HR TO GPM
32	0.0885	8.345	1.0013	0.00199
40	0.1217	8.345	1.0013	0.00199
50	0.1781	8.340	1.0007	0.00199
60	0.2653	8.334	1.0000	0.00199
70	0.3631	8.325	0.9989	0.00200
80	0.5069	8.314	0.9976	0.00200
90	0.6982	8.303	0.9963	0.00200
100	0.9492	8.289	0.9946	0.00201
110	1.2748	8.267	0.9919	0.00201
120	1.6924	8.253	0.9901	0.00200
130	2.2225	8.227	0.9872	0.00202
140	2.8886	8.207	0.9848	0.00203
150	3.718	8.182	0.9818	0.00203
160	4.741	8.156	0.9786	0.00204
170	5.992	8.127	0.9752	0.00205
180	7.510	8.098	0.9717	0.00205
190	9.339	8.068	0.9681	0.00206
200	11.526	8.039	0.9646	0.00207
210	14.123	8.005	0.9605	0.00208
212	14.696	7.996	0.9594	0.00208
220	17.186	7.972	0.9566	0.00209
240	24.969	7.901	0.9480	0.00210
260	35.429	7.822	0.9386	0.00211
280	49.203	7.746	0.9294	0.00215
300	67.013	7.662	0.9194	0.00217
350	134.63	7.432	0.8918	0.00224
400	247.31	7.172	0.8606	0.00232
450	422.6	6.892	0.8270	0.00241
500	680.8	6.553	0.7863	0.00254
550	1045.2	6.132	0.7358	0.00271
600	1542.9	5.664	0.6796	0.00294
700	3093.7	3.623	0.4347	0.00460

1. Multiply flow in pounds per hour by the factor to get equivalent flow in gallons per minute. Weight per gallon is based on 7.48 gallons per cubic foot.

Properties of Saturated Steam

ABSOLUTE PRESSURE		VACUUM (INCHES OF HG)	TEMP. (°F)	HEAT OF THE LIQUID (BTU/LB.)	LATENT HEAT OF EVAPORATION (BTU/LB.)	TOTAL HEAT OF STEAM HG (BTU/LB.)	SPECIFIC VOLUME (CUBIC FT./LB.)
PSIA	Inches of Hg						
0.20	0.41	29.51	53.14	21.21	1063.8	1085.0	1526.0
0.25	0.51	29.41	59.30	27.36	1060.3	1087.7	1235.3
0.30	0.61	29.31	64.47	32.52	1057.4	1090.0	1039.5
0.35	0.71	29.21	68.93	36.97	1054.9	1091.9	898.5
0.40	0.81	29.11	72.86	40.89	1052.7	1093.6	791.9
0.45	0.92	29.00	76.38	44.41	1050.7	1095.1	708.5
0.50	1.02	28.90	79.58	47.60	1048.8	1096.4	641.4
0.60	1.22	28.70	85.21	53.21	1045.7	1098.9	540.0
0.70	1.43	28.49	90.08	58.07	1042.9	1101.0	466.9
0.80	1.63	28.29	94.38	62.36	1040.4	1102.8	411.7
0.90	1.83	28.09	98.24	66.21	1038.3	1104.5	368.4
1.0	2.04	27.88	101.74	69.70	1036.3	1106.0	333.6
1.2	2.44	27.48	107.92	75.87	1032.7	1108.6	280.9
1.4	2.85	27.07	113.26	81.20	1029.6	1110.8	243.0
1.6	3.26	26.66	117.99	85.91	1026.9	1112.8	214.3
1.8	3.66	26.26	122.23	90.14	1024.5	1114.6	191.8
2.0	4.07	25.85	126.08	93.99	1022.2	1116.2	173.73
2.2	4.48	25.44	129.62	97.52	1020.2	1117.7	158.85
2.4	4.89	25.03	132.89	100.79	1018.3	1119.1	146.38
2.6	5.29	24.63	135.94	103.83	1016.5	1120.3	135.78
2.8	5.70	24.22	138.79	106.68	1014.8	1121.5	126.65
3.0	6.11	23.81	141.48	109.37	1013.2	1122.6	67.24
3.5	7.13	22.79	147.57	115.46	1009.6	1125.1	61.98
4.0	8.14	21.78	152.97	120.86	1006.4	1127.3	57.50
4.5	9.16	20.76	157.83	125.71	1003.6	1129.3	53.64
5.0	10.18	19.74	162.24	130.13	1001.0	1131.1	50.29
5.5	11.20	18.72	166.30	134.19	998.5	1132.7	67.24
6.0	12.22	17.70	170.06	137.96	996.2	1134.2	61.98
6.5	13.23	16.69	173.56	141.47	994.1	1135.6	57.50
7.0	14.25	15.67	176.85	144.76	992.1	1136.9	53.64
7.5	15.27	14.65	179.94	147.86	990.2	1138.1	50.29
8.0	16.29	13.63	182.86	150.79	988.5	1139.3	47.34
8.5	17.31	12.61	185.64	153.57	986.8	1140.4	44.73
9.0	18.32	11.60	188.28	156.22	985.2	1141.4	42.40
9.5	19.34	10.58	190.80	158.75	983.6	1142.3	40.31
10.0	20.36	9.56	193.21	161.17	982.1	1143.3	38.42
11.0	22.40	7.52	197.75	165.73	979.3	1145.0	35.14
12.0	24.43	5.49	201.96	169.96	976.6	1146.6	32.40
13.0	26.47	3.45	205.88	173.91	974.2	1148.1	30.06
14.0	28.50	1.42	209.56	177.61	971.9	1149.5	28.04

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Conversions, Equivalents, and Physical Data

Properties of Saturated Steam (continued)

PRESSURE (PSI)		TEMP. (°F)	HEAT OF THE LIQUID (BTU/LB)	LATENT HEAT OF EVAPORATION (BTU/LB)	TOTAL HEAT OF STEAM H_g (BTU/LB)	SPECIFIC VOLUME ∇ (FT^3/LB)	PRESSURE (PSI)		TEMP. (°F)	HEAT OF THE LIQUID (BTU/LB)	LATENT HEAT OF EVAPORATION (BTU/LB)	TOTAL HEAT OF STEAM H_g (BTU/LB)	SPECIFIC VOLUME ∇ (FT^3/LB)
Absolute P'	Gauge P						Absolute P'	Gauge P					
14.696	0.0	212.00	180.07	970.3	1150.4	26.80	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
15.0	0.3	213.03	181.11	969.7	1150.8	26.29	75.0	60.3	307.60	277.43	904.5	1181.9	5.816
16.0	1.3	216.32	184.42	967.6	1152.0	24.72	76.0	61.3	308.50	278.37	903.7	1182.1	5.743
17.0	2.3	219.44	187.56	965.5	1153.1	23.39	77.0	62.3	309.40	279.30	903.1	1182.4	5.673
18.0	3.3	222.41	190.56	963.6	1154.2	22.17	78.0	63.3	310.29	280.21	902.4	1182.6	5.604
19.0	4.3	225.24	193.42	961.9	1155.3	21.08	79.0	64.3	311.16	281.12	901.7	1182.8	5.537
20.0	5.3	227.96	196.16	960.1	1156.3	20.089	80.0	65.3	312.03	282.02	901.1	1183.1	5.472
21.0	6.3	230.57	198.79	958.4	1157.2	19.192	81.0	66.3	312.89	282.91	900.4	1183.3	5.408
22.0	7.3	233.07	201.33	956.8	1158.1	18.375	82.0	67.3	313.74	283.79	899.7	1183.5	5.346
23.0	8.3	235.49	203.78	955.2	1159.0	17.627	83.0	68.3	314.59	284.66	899.1	1183.8	5.285
24.0	9.3	237.82	206.14	953.7	1159.8	16.938	84.0	69.3	315.42	285.53	898.5	1184.0	5.226
25.0	10.3	240.07	208.42	952.1	1160.6	16.303	85.0	70.3	316.25	286.39	897.8	1184.2	5.168
26.0	11.3	242.25	210.62	950.7	1161.3	15.715	86.0	71.3	317.07	287.24	897.2	1184.4	5.111
27.0	12.3	244.36	212.75	949.3	1162.0	15.170	87.0	72.3	317.88	288.08	896.5	1184.6	5.055
28.0	13.3	246.41	214.83	947.9	1162.7	14.663	88.0	73.3	318.68	288.91	895.9	1184.8	5.001
29.0	14.3	248.40	216.86	946.5	1163.4	14.189	89.0	74.3	319.48	289.74	895.3	1185.1	4.948
30.0	15.3	250.33	218.82	945.3	1164.1	13.746	90.0	75.3	320.27	290.56	894.7	1185.3	4.896
31.0	16.3	252.22	220.73	944.0	1164.7	13.330	91.0	76.3	321.06	291.38	894.1	1185.5	4.845
32.0	17.3	254.05	222.59	942.8	1165.4	12.940	92.0	77.3	321.83	292.18	893.5	1185.7	4.796
33.0	18.3	255.84	224.41	941.6	1166.0	12.572	93.0	78.3	322.60	292.98	892.9	1185.9	4.747
34.0	19.3	257.58	226.18	940.3	1166.5	12.226	94.0	79.3	323.36	293.78	892.3	1186.1	4.699
35.0	20.3	259.28	227.91	939.2	1167.1	11.898	95.0	80.3	324.12	294.56	891.7	1186.2	4.652
36.0	21.3	260.95	229.60	938.0	1167.6	11.588	96.0	81.3	324.87	295.34	891.1	1186.4	4.606
37.0	22.3	262.57	231.26	936.9	1168.2	11.294	97.0	82.3	325.61	296.12	890.5	1186.6	4.561
38.0	23.3	264.16	232.89	935.8	1168.7	11.150	98.0	83.3	326.35	296.89	889.9	1186.8	4.517
39.0	24.3	265.72	234.48	934.7	1169.2	10.750	99.0	84.3	327.08	297.65	889.4	1187.0	4.474
40.0	25.3	267.25	236.03	933.7	1169.7	10.498	100.0	85.3	327.81	298.40	888.8	1187.2	4.432
41.0	26.3	268.74	237.55	932.6	1170.2	10.258	101.0	86.3	328.53	299.15	888.2	1187.4	4.391
42.0	27.3	270.21	239.04	931.6	1170.7	10.029	102.0	87.3	329.25	299.90	887.6	1187.5	4.350
43.0	28.3	271.64	240.51	930.6	1171.1	9.810	103.0	88.3	329.96	300.64	887.1	1187.7	4.310
44.0	29.3	273.05	241.95	929.6	1171.6	9.601	104.0	89.3	330.66	301.37	886.5	1187.9	4.271
45.0	30.3	274.44	243.36	928.6	1172.0	9.401	105.0	90.3	331.36	302.10	886.0	1188.1	4.232
46.0	31.3	275.80	244.75	927.7	1172.4	9.209	106.0	91.3	332.05	302.82	885.4	1188.2	4.194
47.0	32.3	277.13	246.12	926.7	1172.9	9.025	107.0	92.3	332.74	303.54	884.9	1188.4	4.157
48.0	33.3	278.45	247.47	925.8	1173.3	8.848	108.0	93.3	333.42	304.26	884.3	1188.6	4.120
49.0	34.3	279.74	248.79	924.9	1173.7	8.678	109.0	94.3	334.10	304.97	883.7	1188.7	4.084
50.0	35.3	281.01	250.09	924.0	1174.1	8.515	110.0	95.3	334.77	305.66	883.2	1188.9	4.049
51.0	36.3	282.26	251.37	923.0	1174.4	8.359	111.0	96.3	335.44	306.37	882.6	1189.0	4.015
52.0	37.3	283.49	252.63	922.2	1174.8	8.208	112.0	97.3	336.11	307.06	882.1	1189.2	3.981
53.0	38.3	284.70	253.87	921.3	1175.2	8.062	113.0	98.3	336.77	307.75	881.6	1189.4	3.947
54.0	39.3	285.90	255.09	920.5	1175.6	7.922	114.0	99.3	337.42	308.43	881.1	1189.5	3.914
55.0	40.3	287.07	256.30	919.6	1175.9	7.787	115.0	100.3	338.07	309.11	880.6	1189.7	3.882
56.0	41.3	288.28	257.50	918.8	1176.3	7.656	116.0	101.3	338.72	309.79	880.0	1189.8	3.850
57.0	42.3	289.37	258.67	917.9	1176.6	7.529	117.0	102.3	339.36	310.46	879.5	1190.0	3.819
58.0	43.3	290.50	259.82	917.1	1176.9	7.407	118.0	103.3	339.99	311.12	879.0	1190.1	3.788
59.0	44.3	291.61	260.96	916.3	1177.3	7.289	119.0	104.3	340.62	311.78	878.4	1190.2	3.758
60.0	45.3	292.71	262.09	915.5	1177.6	7.175	120.0	105.3	341.25	312.44	877.9	1190.4	3.728
61.0	46.3	293.79	263.20	914.7	1177.9	7.064	121.0	106.3	341.88	313.10	877.4	1190.5	3.699
62.0	47.3	294.85	264.30	913.9	1178.2	6.957	122.0	107.3	342.50	313.75	876.9	1190.7	3.670
63.0	48.3	295.90	265.38	913.1	1178.5	6.853	123.0	108.3	343.11	314.40	876.4	1190.8	3.642
64.0	49.3	296.94	266.45	912.3	1178.8	6.752	124.0	109.3	343.72	315.04	875.9	1190.9	3.614
65.0	50.3	297.97	267.50	911.6	1179.1	6.655	125.0	110.3	344.33	315.68	875.4	1191.1	3.587
66.0	51.3	298.99	268.55	910.8	1179.4	6.560	126.0	111.3	344.94	316.31	874.9	1191.2	3.560
67.0	52.3	299.99	269.58	910.1	1179.7	6.468	127.0	112.3	345.54	316.94	874.4	1191.3	3.533
68.0	53.3	300.98	270.60	909.4	1180.0	6.378	128.0	113.3	346.13	317.57	873.9	1191.5	3.507
69.0	54.3	301.96	291.61	908.7	1180.3	6.291	129.0	114.3	346.73	318.19	873.4	1191.6	3.481
70.0	55.3	302.92	272.61	907.9	1180.6	6.206	130.0	115.3	347.32	318.81	872.9	1191.7	3.455
71.0	56.3	303.88	273.60	907.2	1180.8	6.124	131.0	116.3	347.90	319.43	872.5	1191.9	3.430
72.0	57.3	304.83	274.57	906.5	1181.1	6.044	132.0	117.3	348.48	320.04	872.0	1192.0	3.405
73.0	58.3	305.76	275.54	905.8	1181.3	5.966	133.0	118.3	349.06	320.65	871.5	1192.1	3.381
74.0	59.3	306.68	276.49	905.1	1181.6	5.890	134.0	119.3	349.64	321.25	871.0	1192.2	3.357

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Conversions, Equivalents, and Physical Data

Properties of Saturated Steam (continued)

PRESSURE (PSI) Absolute P'	PRESSURE (PSI) Gauge P	TEMP. (°F)	HEAT OF THE LIQUID (BTU/LB)	LATENT HEAT OF EVAPORATION (BTU/LB)	TOTAL HEAT OF STEAM H_g (BTU/LB)	SPECIFIC VOLUME ∇ (FT^3/LB)	PRESSURE (PSI) Absolute P'	PRESSURE (PSI) Gauge P	TEMP. (°F)	HEAT OF THE LIQUID (BTU/LB)	LATENT HEAT OF EVAPORATION (BTU/LB)	TOTAL HEAT OF STEAM H_g (BTU/LB.)	SPECIFIC VOLUME ∇ (CU. FT./LB.)
135.0	120.3	350.21	321.85	870.6	1192.4	3.333	400.0	385.3	444.59	424.0	780.5	1204.5	1.1613
136.0	121.3	350.78	322.45	870.1	1192.5	3.310	420.0	405.3	449.39	429.4	775.2	1204.6	1.1061
137.0	122.3	351.35	323.05	869.6	1192.6	3.287	440.0	425.3	454.02	434.6	770.0	1204.6	1.0556
138.0	123.3	351.91	323.64	869.1	1192.7	3.264	460.0	445.3	458.50	439.7	764.9	1204.6	1.0094
139.0	124.3	352.47	324.23	868.7	1192.9	3.242	480.0	465.3	462.82	444.6	759.9	1204.5	0.9670
140.0	125.3	353.02	324.82	868.2	1193.0	3.220	500.0	485.3	467.01	449.4	755.0	1204.4	0.9278
141.0	126.3	353.57	325.40	867.7	1193.1	3.198	520.0	505.3	471.07	454.1	750.1	1204.2	0.7815
142.0	127.3	354.12	325.98	867.2	1193.2	3.177	540.0	525.3	475.01	458.6	745.4	1204.0	0.8578
143.0	128.3	354.67	326.56	866.7	1193.3	3.155	560.0	545.3	478.85	463.0	740.8	1203.8	0.8265
144.0	129.3	355.21	327.13	866.3	1193.4	3.134	580.0	565.3	482.58	467.4	736.1	1203.5	0.7973
145.0	130.3	355.76	327.70	865.8	1193.5	3.114	600.0	585.3	486.21	471.6	731.6	1203.2	0.7698
146.0	131.3	356.29	328.27	865.3	1193.6	3.094	620.0	605.3	489.75	475.7	727.2	1202.9	0.7440
147.0	132.3	356.83	328.83	864.9	1193.8	3.074	640.0	625.3	493.21	479.8	722.7	1202.5	0.7198
148.0	133.3	357.36	329.39	864.5	1193.9	3.054	660.0	645.3	496.58	483.8	718.3	1202.1	0.6971
149.0	134.3	357.89	329.95	864.0	1194.0	3.034	680.0	665.3	499.88	487.7	714.0	1201.7	0.6757
150.0	135.3	358.42	330.51	863.6	1194.1	3.015	700.0	685.3	503.10	491.5	709.7	1201.2	0.6554
152.0	137.3	359.46	331.61	862.7	1194.3	2.977	720.0	705.3	506.25	495.3	705.4	1200.7	0.6362
154.0	139.3	360.49	332.70	851.8	1194.5	2.940	740.0	725.3	509.34	499.0	701.2	1200.2	0.6180
156.0	141.3	361.52	333.79	860.9	1194.7	2.904	760.0	745.3	512.36	502.6	697.1	1199.7	0.6007
158.0	143.3	362.53	334.86	860.0	1194.9	2.869	780.0	765.3	505.33	506.2	692.9	1199.1	0.5843
160.0	145.3	363.53	335.93	859.2	1195.1	2.834	800.0	785.3	518.23	509.7	688.9	1198.6	0.5687
162.0	147.3	364.53	336.98	858.3	1195.3	2.801	820.0	805.3	521.08	513.2	684.8	1198.0	0.5538
164.0	149.3	365.51	338.02	857.5	1195.5	2.768	840.0	825.3	523.88	516.6	680.8	1197.4	0.5396
166.0	151.3	366.48	339.05	856.6	1195.7	2.736	860.0	845.3	526.63	520.0	676.8	1196.8	0.5260
168.0	153.3	367.45	340.07	855.7	1195.8	2.705	880.0	865.3	529.33	523.3	672.8	1196.1	0.5130
170.0	155.3	368.41	341.09	854.9	1196.0	2.675	900.0	885.3	531.98	526.6	668.8	1195.4	0.5006
172.0	157.3	369.35	342.10	854.1	1196.2	2.645	920.0	905.3	534.59	529.8	664.9	1194.7	0.4886
174.0	159.3	370.29	343.10	853.3	1196.4	2.616	940.0	925.3	537.16	533.0	661.0	1194.0	0.4772
176.0	161.3	371.22	344.09	852.4	1196.5	2.587	960.0	945.3	539.68	536.2	657.1	1193.3	0.4663
178.0	163.3	372.14	345.06	851.6	1196.7	2.559	980.0	965.3	542.17	539.3	653.3	1192.6	0.4557
180.0	165.3	373.06	346.03	850.8	1196.9	2.532	1000.0	985.3	544.61	542.4	649.4	1191.8	0.4456
182.0	167.3	373.96	347.00	850.0	1197.0	2.505	1050.0	1035.3	550.57	550.0	639.9	1189.9	0.4218
184.0	169.3	374.86	347.96	849.2	1197.2	2.479	1100.0	1085.3	556.31	557.4	630.4	1187.8	0.4001
186.0	171.3	375.75	348.92	848.4	1197.3	2.454	1150.0	1135.3	561.86	565.6	621.0	1185.6	0.3802
188.0	173.3	376.64	349.86	847.6	1197.5	2.429	1200.0	1185.3	567.22	571.7	611.7	1183.4	0.619
190.0	175.3	377.51	350.79	846.8	1197.6	2.404	1250.0	1235.3	572.42	578.6	602.4	1181.0	0.3450
192.0	177.3	378.38	351.72	846.1	1197.8	2.380	1300.0	1285.3	577.46	585.4	593.2	1178.6	0.3293
194.0	179.3	379.24	352.64	845.3	1197.9	2.356	1350.0	1335.3	582.35	592.1	584.0	1176.1	0.3148
196.0	181.3	380.10	353.55	844.5	1198.1	2.333	1400.0	1385.3	587.10	598.7	574.7	1173.4	0.3012
198.0	183.3	380.95	354.46	843.7	1198.2	2.310	1450.0	1435.3	591.73	605.2	565.5	1170.7	0.2884
200.0	185.3	381.79	355.36	843.0	1198.4	2.288	1500.0	1485.3	596.23	611.6	556.3	1167.9	0.2765
205.0	190.3	383.86	357.58	841.0	1198.7	2.234	1600.0	1585.3	604.90	624.1	538.0	1162.1	0.2548
210.0	195.3	385.90	359.77	839.2	1199.0	2.183	1700.0	1685.3	613.15	636.3	519.6	1155.9	0.2354
215.0	200.3	387.89	361.91	837.4	1199.3	2.134	1800.0	1785.3	621.03	648.3	501.1	1149.4	0.2179
220.0	205.3	389.86	364.02	835.6	1199.6	2.087	1900.0	1885.3	628.58	660.1	482.4	1142.4	0.2021
225.0	210.3	391.79	366.09	833.8	1199.9	2.0422	2000.0	1985.3	635.82	671.7	463.4	1135.1	0.1878
230.0	215.3	393.68	368.13	832.0	1200.1	1.9992	2100.0	2085.3	642.77	683.3	444.1	1127.4	0.1746
235.0	220.3	395.54	370.14	830.3	1200.4	1.9579	2200.0	2185.3	649.46	694.8	424.4	1119.2	0.1625
240.0	225.3	397.37	372.12	828.5	1200.6	1.9183	2300.0	2285.3	655.91	706.5	403.9	1110.4	0.1513
245.0	230.3	399.18	374.08	826.8	1200.9	1.8803	2400.0	2385.3	662.12	718.4	382.7	1101.1	0.1407
250.0	235.3	400.95	376.00	825.1	1201.1	1.8438	2500.0	2485.3	668.13	730.6	360.5	1091.1	0.1307
255.0	240.3	402.70	377.89	823.4	1201.3	1.8086	2600.0	2585.3	673.94	743.0	337.2	1080.2	0.1213
260.0	245.3	404.42	379.76	821.8	1201.5	1.7748	2700.0	2685.3	679.55	756.2	312.1	1068.3	0.1123
265.0	250.3	406.11	381.60	820.1	1201.7	1.7422	2800.0	2785.3	684.99	770.1	284.7	1054.8	0.1035
270.0	255.3	407.78	383.42	818.5	1201.9	1.7107	2900.0	2885.3	690.26	785.4	253.6	1039.0	0.0947
275.0	260.3	409.43	385.21	816.9	1202.1	1.6804	3000.0	2985.3	695.36	802.5	217.8	1020.3	0.0858
280.0	265.3	411.05	386.98	815.3	1202.3	1.6511	3100.0	3085.3	700.31	825.0	168.1	993.1	0.0753
285.0	270.3	412.65	388.73	813.7	1202.4	1.6228	3200.0	3185.3	705.11	872.4	62.0	934.4	0.0580
290.0	275.3	414.23	390.46	812.1	1202.6	1.5954	3206.2	3191.5	705.40	902.7	0.0	902.7	0.0503
295.0	280.3	415.79	392.16	810.5	1202.7	1.5689	----	----	----	----	----	----	----
300.0	285.3	417.33	393.84	809.0	1202.8	1.5433	----	----	----	----	----	----	----
320.0	305.3	423.29	400.39	803.0	1203.4	1.4485	----	----	----	----	----	----	----
340.0	325.3	428.97	406.66	797.1	1203.7	1.3645	----	----	----	----	----	----	----
360.0	345.3	434.40	412.67	797.4	1204.1	1.2895	----	----	----	----	----	----	----
380.0	365.3	439.60	418.45	785.8	1204.3	1.2222	----	----	----	----	----	----	----

Conversions, Equivalents, and Physical Data

Properties of Saturated Steam (Metric)							
TEMPERATURE, °K	PRESSURE, BAR	VOLUME, m/kg		ENTHALPY, kJ/kg		ENTROPY, kJ/(kg x °K)	
		Condensed	Vapor	Condensed	Vapor	Condensed	Vapor
150	6.30 to 11	1.073 to 3	9.55 + 9	- 539.6	2273	- 2.187	16.54
160	7.72 to 10	1.074 to 3	9.62 + 8	- 525.7	2291	- 2.106	15.49
170	7.29 to 9	1.076 to 3	1.08 + 8	- 511.7	2310	- 2.026	14.57
180	5.38 to 8	1.077 to 3	1.55 + 7	- 497.8	2328	- 1.947	13.76
190	3.23 to 7	1.078 to 3	2.72 + 6	- 483.8	2347	- 1.868	16.03
200	1.62 to 6	1.079 to 3	5.69 + 5	- 467.5	2366	- 1.789	12.38
210	7.01 to 6	1.081 to 3	1.39 + 5	- 451.2	2384	- 1.711	11.79
220	2.65 to 5	1.082 to 3	3.83 + 4	- 435.0	2403	- 1.633	11.20
230	8.91 to 5	1.084 to 3	1.18 + 4	- 416.3	2421	- 1.555	10.79
240	3.72 to 4	1.085 to 3	4.07 + 3	- 400.1	2440	- 1.478	10.35
250	7.59 to 4	1.087 to 3	1.52 + 3	- 318.5	2459	- 1.400	9.954
255	1.23 to 3	1.087 to 3	956.4	- 369.8	2468	- 1.361	9.768
260	1.96 to 3	1.088 to 3	612.2	- 360.5	2477	- 1.323	9.590
265	3.06 to 3	1.089 to 3	400.4	- 351.2	2486	- 1.281	9.461
270	4.69 to 3	1.090 to 3	265.4	- 339.6	2496	- 1.296	9.255
273.15	6.11 to 3	1.091 to 3	206.3	- 333.5	2502	- 1.221	9.158
273.15	0.00611	1.000 to 3	206.3	0.00	2502	0.000	9.158
275	0.00697	1.000 to 3	181.7	7.80	2505	0.028	9.109
280	0.00990	1.000 to 3	130.4	28.8	2514	0.104	8.890
285	0.01387	1.000 to 3	99.4	49.8	2523	0.178	8.857
290	0.01917	1.001 to 3	69.7	70.7	2532	0.251	8.740
295	0.02617	1.002 to 3	51.94	91.6	2541	0.323	8.627
300	0.03531	1.003 to 3	39.13	112.5	2550	0.393	8.520
305	0.04712	1.005 to 3	27.90	133.4	2559	0.462	8.417
310	0.06221	1.007 to 3	22.93	154.3	2568	0.530	8.318
315	0.08132	1.009 to 3	17.82	175.2	2577	0.597	8.224
320	0.01053	1.011 to 3	13.98	196.1	2586	0.649	8.151
325	0.01351	1.013 to 3	11.06	217.0	2595	0.727	8.046
330	0.01719	1.016 to 3	8.82	237.9	2604	0.791	7.962
335	0.02167	1.018 to 3	7.09	258.8	2613	0.854	7.881
340	0.02713	1.021 to 3	5.74	279.8	2622	0.916	7.804
345	0.3372	1.024 to 3	4.683	300.7	2630	0.977	7.729
350	0.4163	1.027 to 3	3.846	321.7	2639	1.038	7.657
355	0.5100	1.030 to 3	3.180	342.7	2647	1.097	7.588
360	0.6209	1.034 to 3	2.645	363.7	2655	1.156	7.521
365	0.7514	1.038 to 3	2.212	384.7	2663	1.214	7.456
370	0.9040	1.041 to 3	1.861	405.8	2671	1.271	7.394
373.15	1.0133	1.044 to 3	1.679	419.1	2676	1.307	7.356
375	1.0815	1.045 to 3	1.574	426.8	2679	1.328	7.333
380	1.2869	1.049 to 3	1.337	448.0	2687	1.384	7.275
385	1.5233	1.053 to 3	1.142	469.2	2694	1.439	7.210
390	1.794	1.058 to 3	0.980	490.4	2702	1.494	7.163
400	2.455	1.067 to 3	0.731	532.9	2716	1.605	7.058
410	3.302	1.077 to 3	0.553	575.6	2729	1.708	6.959
420	4.370	1.088 to 3	0.425	618.6	2742	1.810	6.865
430	5.699	1.099 to 3	0.331	661.8	2753	1.911	6.775
440	7.333	1.110 to 3	0.261	705.3	2764	2.011	6.689
450	9.319	1.123 to 3	0.208	749.2	2773	2.109	6.607
460	11.71	1.137 to 3	0.167	793.5	2782	2.205	6.528
470	14.55	1.152 to 3	0.136	838.2	2789	2.301	6.451
480	17.90	1.167 to 3	0.111	883.4	2795	2.395	6.377
490	21.83	1.184 to 3	0.0922	929.1	2799	2.479	6.312
500	26.40	1.203 to 3	0.0776	975.6	2801	2.581	6.233
510	31.66	1.222 to 3	0.0631	1023	2802	2.673	6.163
520	37.70	1.244 to 3	0.0525	1071	2801	2.765	6.093
530	44.58	1.268 to 3	0.0445	1119	2798	2.856	6.023
540	52.38	1.294 to 3	0.0375	1170	2792	2.948	5.953
550	61.19	1.323 to 3	0.0317	1220	2784	3.039	5.882
560	71.08	1.355 to 3	0.0269	1273	2772	3.132	5.808
570	82.16	1.392 to 3	0.0228	1328	2757	3.225	5.733
580	94.51	1.433 to 3	0.0193	1384	2737	3.321	5.654
590	108.3	1.482 to 3	0.0163	1443	2717	3.419	5.569
600	123.5	1.541 to 3	0.0137	1506	2682	3.520	5.480
610	137.3	1.612 to 3	0.0115	1573	2641	3.627	5.318
620	159.1	1.705 to 3	0.0094	1647	2588	3.741	5.259
625	169.1	1.778 to 3	0.0085	1697	2555	3.805	5.191
630	179.1	1.856 to 3	0.0075	1734	2515	3.875	5.115
635	190.9	1.935 to 3	0.0066	1783	2466	3.950	5.025
640	202.7	2.075 to 3	0.0057	1841	2401	4.037	4.912
645	215.2	2.351 to 3	0.0045	1931	2292	4.223	4.732
647.31	221.2	3.170 to 3	0.0032	2107	2107	4.443	4.443

Conversions, Equivalents, and Physical Data

Properties of Superheated Steam														
PRESSURE (PSI)		SAT. TEMP. (°F)		TOTAL TEMPERATURE — °F										
Absolute P'	Gauge P			360°	400°	440°	480°	500°	600°	700°	800°	900°	1000°	1200°
14.696	0.0	212.00	∇	33.03	34.68	36.32	37.96	38.78	42.86	46.94	51.00	55.07	59.13	67.25
			h_g	1221.1	1239.9	1258.8	1277.6	1287.1	1334.8	1383.2	1432.3	1482.3	1533.1	1637.5
20.0	5.3	227.96	∇	24.21	25.43	26.65	27.86	28.46	31.47	34.47	37.46	40.45	43.44	49.41
			h_g	1220.3	1239.2	1258.2	1277.1	1286.6	1334.4	1382.9	1432.1	1482.1	1533.0	1637.4
30.0	15.3	250.33	∇	16.072	16.897	17.714	18.528	18.933	20.95	22.96	24.96	26.95	28.95	32.93
			h_g	1218.6	1237.9	1257.0	1276.2	1285.7	1333.8	1382.4	1431.17	1481.8	1532.7	1637.2
40.0	25.3	267.25	∇	12.001	12.628	13.247	13.962	14.168	15.688	17.198	18.702	20.20	21.70	24.69
			h_g	1216.9	1236.5	1255.9	1275.2	1284.8	1333.1	1381.9	1431.3	1481.4	1532.4	1637.0
50.0	35.3	281.01	∇	9.557	10.065	10.567	11.062	11.309	12.532	13.744	14.950	16.152	17.352	19.747
			h_g	1215.2	1235.1	1254.7	1274.2	1283.9	1332.5	1381.4	1430.9	1481.1	1532.1	1636.8
60.0	45.3	292.71	∇	7.927	8.357	8.779	9.196	9.403	10.427	11.441	12.449	13.452	14.454	16.451
			h_g	1213.4	1233.6	1253.5	1273.2	1283.0	1331.8	1380.9	1430.5	1480.8	1531.9	1636.6
70.0	55.3	302.92	∇	6.762	7.136	7.502	7.863	8.041	8.924	9.796	10.662	11.524	12.383	14.097
			h_g	1211.5	1232.1	1252.3	1272.2	1282.0	1331.1	1380.4	1430.1	1480.5	1531.6	1636.3
80.0	65.3	312.03	∇	5.888	6.220	6.544	6.862	7.020	7.797	8.562	9.322	10.077	10.830	12.332
			h_g	1209.7	1230.7	1251.1	1271.1	1281.1	1330.5	1379.9	1429.7	1480.1	1531.3	1636.2
90.0	75.3	320.27	∇	5.208	5.508	5.799	6.084	6.225	6.920	7.603	8.279	8.952	9.623	10.959
			h_g	1207.7	1229.1	1249.8	1270.1	1280.1	1329.8	1379.4	1429.3	1479.8	1531.0	1635.9
100.0	85.3	327.81	∇	4.663	4.937	5.202	5.462	5.589	6.218	6.835	7.446	8.052	8.656	9.860
			h_g	1205.7	1227.6	1248.6	1269.0	1279.1	1329.1	1378.9	1428.9	1479.5	1530.8	1635.7
120.0	105.3	341.25	∇	3.844	4.081	4.307	4.527	4.636	5.165	5.683	6.195	6.702	7.207	8.212
			h_g	1201.6	1224.4	1246.0	1266.9	1277.2	1327.7	1377.8	1428.1	1478.8	1530.2	1635.3
140.0	125.3	353.02	∇	3.258	3.468	3.667	3.860	3.954	4.413	4.861	5.301	5.738	6.172	7.035
			h_g	1197.3	1221.1	1243.3	1264.7	1275.2	1326.4	1376.8	1427.2	1478.2	1529.7	1634.9
160.0	145.3	363.53	∇	- - - -	3.008	3.187	3.359	3.443	3.849	4.244	4.631	5.015	5.396	6.152
			h_g	- - - -	1217.6	1240.6	1262.4	1273.1	1325.0	1375.7	1426.4	1477.5	1529.1	1634.5
180.0	165.3	373.06	∇	- - - -	2.649	2.813	2.969	3.044	3.411	3.964	4.110	4.452	4.792	5.466
			h_g	- - - -	1214.0	1237.8	1260.2	1271.0	1323.5	1374.7	1425.6	1476.8	1528.6	1634.1
200.0	185.3	381.79	∇	- - - -	2.361	2.513	2.656	2.726	3.060	3.380	3.693	4.002	4.309	4.917
			h_g	- - - -	1210.3	1234.9	1257.8	1268.9	1322.1	1373.6	1424.8	1476.2	1528.0	1633.7
220.0	205.3	389.86	∇	- - - -	2.125	2.267	2.400	2.465	2.772	3.066	3.352	3.634	3.913	4.467
			h_g	- - - -	1206.5	1231.9	1255.4	1266.7	1320.7	1372.6	1424.0	1475.5	1527.5	1633.3
240.0	225.3	397.37	∇	- - - -	1.9276	2.062	2.187	2.247	2.533	2.804	3.068	3.327	3.584	4.093
			h_g	- - - -	1202.5	1228.8	1253.0	1264.5	1319.2	1371.5	1432.2	1474.8	1526.9	1632.9
260.0	245.3	404.42	∇	- - - -	- - - -	1.8882	2.006	2.063	2.330	2.582	2.827	3.067	3.305	3.776
			h_g	- - - -	- - - -	1225.7	1250.5	1262.3	1317.7	1370.4	1422.3	1474.2	1526.3	1632.5
280.0	265.3	411.05	∇	- - - -	- - - -	1.7388	1.8512	1.9047	2.156	2.392	2.621	2.845	3.066	3.504
			h_g	- - - -	- - - -	1222.4	1247.9	1260.0	1316.2	1369.4	1421.5	1473.5	1525.8	1632.1
300.0	285.3	417.33	∇	- - - -	- - - -	1.6090	1.7165	1.7675	2.005	2.227	2.442	2.652	2.859	3.269
			h_g	- - - -	- - - -	1219.1	1245.3	1257.6	1314.7	1368.3	1420.6	1472.8	1525.2	1631.7
320.0	305.3	423.29	∇	- - - -	- - - -	1.4950	1.5985	1.6472	1.8734	2.083	2.285	2.483	2.678	3.063
			h_g	- - - -	- - - -	1215.6	1242.6	1255.2	1313.2	1367.2	1419.8	1472.1	1524.7	1631.3
340.0	325.3	428.97	∇	- - - -	- - - -	1.3941	1.4941	1.5410	1.7569	1.9562	2.147	2.334	2.518	2.881
			h_g	- - - -	- - - -	1212.1	1239.9	1252.8	1311.6	1366.1	1419.0	1471.5	1524.1	1630.9
360.0	345.3	343.40	∇	- - - -	- - - -	1.3041	1.4012	1.4464	1.6533	1.8431	2.025	2.202	2.376	2.719
			h_g	- - - -	- - - -	1208.4	1237.1	1250.3	1310.1	1365.0	1418.1	1470.8	1523.5	1630.5

∇ = specific volume, cubic feet per pound
h_g = total heat of steam, BTU per pound

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EMERSON

Conversions, Equivalents, and Physical Data

Properties of Superheated Steam (continued)

PRESSURE (PSI) Absolute P'	PRESSURE (PSI) Gauge P	SAT. TEMP. °F		TOTAL TEMPERATURE — °F 500°	540°	600°	640°	660°	700°	740°	800°	900°	1000°	1200°
380.0	365.3	439.60	∇	1.3616	1.4444	1.5605	1.6345	1.6707	1.7419	1.8118	1.9149	2.083	2.249	2.575
			ηγ	1247.7	1273.1	1308.5	1331.0	1342.0	1363.8	1385.3	1417.3	1470.1	1523.0	1630.0
400.0	385.3	444.59	∇	1.2851	1.3652	1.4770	1.5480	1.5827	1.6508	1.7177	1.8161	1.9767	2.134	2.445
			h_g	1245.1	1271.0	1306.9	1329.6	1340.8	1362.7	1384.3	1416.4	1469.4	1522.4	1629.6
420.0	405.3	449.39	∇	1.2158	1.2935	1.4014	1.4697	1.5030	1.5684	1.6324	1.7267	1.8802	2.031	2.327
			h_g	1242.5	1268.9	1305.3	1328.3	1339.5	1361.6	1383.3	1415.5	1468.7	1521.9	1629.2
440.0	425.3	454.02	∇	1.1526	1.2282	1.3327	1.3984	1.4306	1.4934	1.5549	1.6454	1.7925	1.9368	2.220
			h_g	1239.8	1266.7	1303.6	1326.9	1338.2	1360.4	1382.3	1414.7	1468.1	1521.3	1628.8
460.0	445.3	458.5	∇	1.0948	1.1685	1.2698	1.3334	1.3644	1.4250	1.4842	1.5711	1.7124	1.8508	2.122
			h_g	1237.0	1264.5	1302.0	1325.4	1336.9	1359.3	1381.3	1413.8	1467.4	1520.7	1628.4
480.0	465.3	462.82	∇	1.0417	1.1138	1.2122	1.2737	1.3038	1.3622	1.4193	1.5031	1.6390	1.7720	2.033
			h_g	1234.2	1262.3	1300.3	1324.0	1335.6	1358.2	1380.3	1412.9	1466.7	1520.2	1628.0
500.0	485.3	467.01	∇	0.9927	1.0633	1.1591	1.2188	1.2478	1.3044	1.3596	1.4405	1.5715	1.6996	1.9504
			h_g	1231.3	1260.0	1298.6	1322.6	1334.2	1357.0	1379.3	1412.1	1466.0	1519.6	1627.6
520.0	505.3	471.07	∇	0.9473	1.0166	1.1101	1.1681	1.1962	1.2511	1.3045	1.3826	1.5091	1.636	1.8743
			h_g	1228.3	1257.7	1296.9	1321.1	1332.9	1355.8	1378.2	1411.2	1465.3	1519.0	1627.2
540.0	525.3	475.01	∇	0.9052	0.9733	1.0646	1.1211	1.1485	1.2017	1.2535	1.3291	1.4514	1.5707	1.8039
			h_g	1225.3	1255.4	1295.2	1319.7	1331.5	1354.6	1377.2	1410.3	1464.6	1518.5	1626.8
560.0	545.3	478.85	∇	0.8659	0.9330	1.0224	1.0775	1.1041	1.1558	1.2060	1.2794	1.3978	1.5132	1.7385
			h_g	1222.2	1253.0	1293.4	1318.2	1330.2	1353.5	1376.1	1409.4	1463.9	1517.9	1626.4
580.0	565.3	482.58	∇	0.8291	0.8954	0.9830	1.0368	1.0627	1.1331	1.1619	1.2331	1.3479	1.4596	1.6776
			h_g	1219.0	1250.5	1291.7	1316.7	1328.8	1352.3	1375.1	1408.6	1463.2	1517.3	1626.0
600.0	585.3	486.21	∇	0.7947	0.8602	0.9463	0.9988	1.0241	1.0732	1.1207	1.1899	1.3013	1.4096	1.6208
			h_g	1215.7	1248.1	1289.9	1315.2	1327.4	1351.1	1374.0	1407.7	1462.5	1516.7	1625.5
620.0	605.0	489.75	∇	0.7624	0.8272	0.9118	0.9633	0.9880	1.0358	1.0821	1.1494	1.2577	1.3628	1.5676
			h_g	1212.4	1245.5	1288.1	1313.7	1326.0	1349.9	1373.0	1406.8	1461.8	1516.2	1625.1
640.0	625.3	493.21	∇	0.7319	0.7963	0.8795	0.9299	0.9541	1.0008	1.0459	1.1115	1.2168	1.3190	1.5178
			h_g	1209.0	1243.0	1296.2	1312.2	1324.6	1348.6	1371.9	1405.9	1461.1	1515.6	1624.7
660.0	645.3	496.58	∇	0.7032	0.7670	0.8491	0.8985	0.9222	0.9679	1.0119	1.0759	1.1784	1.2778	1.4709
			h_g	1205.4	1240.4	1284.4	1310.6	1323.2	1347.4	1370.8	1405.0	1460.4	1515.0	1624.3
680.0	665.3	499.88	∇	0.6759	0.7395	0.8205	0.8690	0.8922	0.9369	0.9800	1.0424	1.1423	1.2390	1.4269
			h_g	1201.8	1237.7	1282.5	1309.1	1321.7	1346.2	1369.8	1404.1	1459.7	1514.5	1623.9
700.0	685.3	503.10	∇	- - -	0.7134	0.7934	0.8411	0.8639	0.9077	0.9498	1.0108	1.1082	1.2024	1.3853
			h_g	- - -	1235.0	1280.6	1307.5	1320.3	1345.0	1368.7	1403.2	1459.0	1513.9	1623.5
750.	735.3	510.86	∇	- - -	0.6540	0.7319	0.7778	0.7996	0.8414	0.8813	0.9391	1.0310	1.1196	1.2912
			h_g	- - -	1227.9	1275.7	1303.5	1316.6	1341.8	1366.0	1400.9	1457.2	1512.4	1622.4
800.0	785.3	518.23	∇	- - -	0.6015	0.6779	0.7223	0.7433	0.7833	0.8215	0.8763	0.9633	1.0470	1.2088
			h_g	- - -	1220.5	1270.7	1299.4	1312.9	1338.6	1363.2	1398.6	1455.4	1511.0	1621.4
850.0	835.3	525.26	∇	- - -	0.5546	0.6301	0.6732	0.6934	0.7320	0.7685	0.8209	0.9037	0.9830	1.1360
			h_g	- - -	1212.7	1265.5	1295.2	1309.0	1335.4	1360.4	1396.3	1453.6	1509.5	1620.4
90.0	885.3	531.98	∇	- - -	0.5124	0.5873	0.6294	0.6491	0.6863	0.7215	0.7716	0.8506	0.9262	1.0714
			h_g	- - -	1204.4	1260.1	1290.9	1305.1	1332.1	1357.5	1393.9	1451.8	1508.1	1619.3
950.0	935.3	538.42	∇	- - -	0.4740	0.5489	0.5901	0.6092	0.6453	0.6793	0.7275	0.8031	0.8753	1.0136
			h_g	- - -	1195.5	1254.6	1286.4	1301.1	1328.7	1354.7	1391.6	1450.0	1506.6	1618.3
1000.0	985.3	544.61	∇	- - -	- - -	0.5140	0.5546	0.5733	0.6084	0.6413	0.6878	0.7604	0.8294	0.9615
			h_g	- - -	- -	1248.8	1281.9	1297.0	1325.3	1351.7	1389.2	1448.2	1505.1	1617.3

∇ = specific volume, cubic feet per pound
h_g = total heat of steam, BTU per pound

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Conversions, Equivalents, and Physical Data

Properties of Superheated Steam (continued)														
PRESSURE (PSI)		SAT. TEMP. °F	TOTAL TEMPERATURE — °F (t)											
Absolute P'	Gauge			660°	700°	740°	760°	780°	800°	860°	900°	1000°	1100°	1200°
1100.0	1085.3	556.31	∇	0.5110	0.5445	0.5755	0.5904	0.6049	0.6191	0.6601	0.6866	0.7503	0.8117	0.8716
			h_g	1288.5	1318.3	1345.8	1358.9	1371.7	1384.3	1420.8	1444.5	1502.2	1558.8	1615.2
1200.0	1185.3	567.22	∇	0.4586	0.4909	0.5206	0.5347	0.5484	0.5617	0.6003	0.6250	0.6843	0.7412	0.7967
			h_g	1279.6	1311.0	1339.6	1353.2	1366.4	1379.3	1416.7	1440.7	1499.2	1556.4	1613.1
1300.0	1285.3	577.46	∇	0.4139	0.4454	0.4739	0.4874	0.5004	0.5131	0.5496	0.5728	0.6284	0.6816	0.7333
			h_g	1270.2	1303.4	1333.3	1347.3	1361.0	1374.3	1412.5	1437.0	1496.2	1553.9	1611.0
1400.0	1385.3	587.10	∇	0.3753	0.4062	0.4338	0.4468	0.4593	0.4714	0.5061	0.5281	0.5805	0.6305	0.6789
			h_g	1260.3	1295.5	1326.7	1341.3	1355.4	1369.1	1408.2	1433.1	1493.2	1551.4	1608.9
1500.0	1485.3	596.23	∇	0.3413	0.3719	0.3989	0.4114	0.4235	0.4352	0.4684	0.4893	0.5390	0.5862	0.6318
			h_g	1249.8	1287.2	1320.0	1335.2	1349.7	1363.8	1403.9	1429.3	1490.1	1548.9	1606.8
1600.0	1585.3	604.90	∇	0.3112	0.3417	0.3682	0.3804	0.3921	0.4034	0.4353	0.4553	0.5027	0.5474	0.5906
			h_g	1238.7	1278.7	1313.0	1328.8	1343.9	1358.4	1399.5	1425.3	1487.0	1546.4	1604.6
1700.0	1685.3	613.15	∇	0.2842	0.3148	0.3410	0.3529	0.3643	0.3753	0.4061	0.4253	0.4706	0.5132	0.5542
			h_g	1226.8	1269.7	1305.8	1322.3	1337.9	1352.9	1395.0	1421.4	1484.0	1543.8	1602.5
1800.0	1785.3	621.03	∇	0.2597	0.2907	0.3166	0.3284	0.3395	0.3502	0.3801	0.3986	0.4421	0.4828	0.5218
			h_g	1214.0	1260.3	1298.4	1315.5	1331.8	1347.2	1390.4	1417.4	1480.8	1541.3	1600.4
1900.0	1885.3	628.58	∇	0.2371	0.2688	0.2947	0.3063	0.3171	0.3277	0.3568	0.3747	0.4165	0.4556	0.4929
			h_g	1200.2	1250.4	1290.6	1308.6	1325.4	1341.5	1385.8	1413.3	1477.7	1538.8	1598.2
2000.0	1985.3	635.82	∇	0.2161	0.2489	0.2748	0.2863	0.2972	0.3074	0.3358	0.3532	0.3935	0.4311	0.4668
			h_g	1184.9	1240.0	1282.6	1301.4	1319.0	1335.5	1381.2	1409.2	1474.5	1536.2	1596.1
2100.0	2085.3	642.77	∇	0.1962	0.2306	0.2567	0.2682	0.2789	0.2890	0.3167	0.3337	0.3727	0.4089	0.4433
			h_g	1167.7	1229.0	1274.3	1294.0	1312.3	1329.5	1376.4	1405.0	1471.4	1533.6	1593.9
2200.0	2185.3	649.46	∇	0.1768	0.2135	0.2400	0.2514	0.2621	0.2721	0.2994	0.3159	0.3538	0.3887	0.4218
			h_g	1147.8	1217.4	1265.7	1286.3	1305.4	1323.3	1371.5	1400.8	1468.2	1531.1	1591.8
2300.0	2285.3	655.91	∇	0.1575	0.1978	0.2247	0.2362	0.2468	0.2567	0.2835	0.2997	0.3365	0.3703	0.4023
			h_g	1123.8	1204.9	1256.7	1278.4	1298.4	1316.9	1366.6	1396.5	1464.9	1528.5	1589.6
2400.0	2385.3	662.12	∇	- - - -	0.1828	0.2105	0.2221	0.2327	0.2425	0.2689	0.2848	0.3207	0.3534	0.3843
			h_g	- - - -	1191.5	1247.3	1270.2	1291.1	1310.3	1361.6	1392.2	1461.7	1525.9	1587.4
2500.0	2485.3	668.13	∇	- - -	0.1686	0.1973	0.2090	0.2196	0.2294	0.2555	0.2710	0.3061	0.3379	0.3678
			h_g	- - -	1176.8	1207.6	1261.8	1283.6	1303.6	1356.5	1387.8	1458.4	1523.2	1585.3
2600.0	2585.3	673.94	∇	- - - -	0.1549	0.1849	0.1967	0.2074	0.2172	0.2431	0.2584	0.2926	0.3236	0.3526
			h_g	- - - -	1160.6	1227.3	1252.9	1275.8	1296.8	1351.4	1383.4	1455.1	1520.6	1583.1
2700.0	2685.3	679.55	∇	- - -	0.1415	0.1732	0.1853	0.1960	0.2059	0.2315	0.2466	0.2801	0.3103	0.3385
			h_g	- - -	1142.5	1216.5	1243.8	1267.9	1289.7	1346.1	1378.9	1451.8	1518.0	1580.9
2800.0	2785.3	684.99	∇	- - - -	0.1281	0.1622	0.1745	0.1854	0.1953	0.2208	0.2356	0.2685	0.2979	0.3254
			h_g	- - - -	1121.4	1205.1	1234.2	1259.6	1282.4	1340.8	1374.3	1448.5	1515.4	1578.7
2900.0	2885.3	690.26	∇	- - -	0.1143	0.1517	0.1644	0.1754	0.1853	0.2108	0.2254	0.2577	0.2864	0.3132
			h_g	- - -	1095.9	1193.0	1224.3	1251.1	1274.9	1335.3	1369.7	1445.1	1512.7	1576.5
3000.0	2985.3	695.36	∇	- - - -	0.0984	0.1416	0.1548	0.1660	0.1760	0.2014	0.2159	0.2476	0.2757	0.3018
			h_g	- - - -	1060.7	1180.1	1213.8	1242.2	1267.2	1329.7	1365.0	1441.8	1510.0	1574.3
3100.0	3085.3	700.31	∇	- - -	- - - -	0.1320	0.1456	0.1571	0.1672	0.1926	0.2070	0.2382	0.2657	0.2911
			h_g	- - -	- - - -	1166.2	1202.9	1233.0	1259.3	1324.1	1360.3	1438.4	1507.4	1572.1
3200.0	3185.3	705.11	∇	- - - -	- - -	0.1226	0.1369	0.1486	0.1589	0.1843	0.1986	0.2293	0.2563	0.2811
			h_g	- - - -	- - -	1151.1	1191.4	1223.5	1251.1	1318.3	1355.5	1434.9	1504.7	1569.9
3206.2	3191.5	705.40	∇	- - -	- - -	0.1220	0.1363	0.1480	0.1583	0.1838	0.1981	0.2288	0.2557	0.2806
			h_g	- - -	- - -	1150.2	1190.6	1222.9	1250.5	1317.9	1355.2	1434.7	1504.5	1569.8

∇ = specific volume, cubic feet per pound
h_g = total heat of steam, BTU per pound

EMERSON.

Conversions, Equivalents, and Physical Data

Determine Velocity of Steam in Pipes:

$$\text{Velocity (ft/s)} = \frac{(25)\,(A)}{(V)}$$

Where: A = Nominal pipe section area = $\frac{\pi\,(d)^2}{4}$
d = Diameter
V = Specific volume from steam tables in ft^3/lb (m^3/kg)

Note: Specific volume changes with steam pressure and temperature. Make sure to calculate velocities of inlet and outlet piping of the regulator.

Recommended Steam Pipe Line Velocities

STEAM CONDITION	VELOCITY, FEET/SECOND (METERS/SECOND)
0 to 15 psig (0 to 1,0 bar), Dry and saturated	100 (30,5)
15 psig (1,0 bar), Dry and saturated and up	175 (53,3)
200 psig (13,8 bar), Superheated and up	250 (76,2)

Typical Condensation Rates In Insulated Steam Pipes

PRESSURE, PSIG (bar)	RATES IN POUNDS/HOUR (KG/HOUR) PER FOOT OF PIPE WITH 2-INCHES OF INSULATION					
	Pipe Diameter in Inches					
	3/4	1	1-1/2	2	3	4
1 (0,069)	0.02 (0,009)	0.03 (0,014)	0.03 (0,014)	0.04 (0,018)	0.05 (0,023)	0.06 (0,027)
5 (0,34)	0.03 (0,014)	0.03 (0,014)	0.04 (0,018)	0.04 (0,018)	0.05 (0,023)	0.06 (0,027)
10 (0,69)	0.03 (0,014)	0.03 (0,014)	0.04 (0,018)	0.04 (0,018)	0.05 (0,023)	0.07 (0,032)
25 (1,7)	0.03 (0,014)	0.04 (0,018)	0.05 (0,023)	0.05 (0,023)	0.06 (0,027)	0.08 (0,036)
50 (3,4)	0.04 (0,018)	0.04 (0,018)	0.05 (0,023)	0.06 (0,027)	0.09 (0,041)	0.11 (0,05)
75 (5,2)	0.04 (0,018)	0.05 (0,023)	0.06 (0,027)	0.07 (0,032)	0.11 (0,05)	0.14 (0,064)
100 (6,9)	0.05 (0,023)	0.05 (0,023)	0.07 (0,032)	0.08 (0,036)	0.12 (0,054)	0.15 (0,068)
125 (8,6)	0.05 (0,023)	0.06 (0,027)	0.07 (0,032)	0.08 (0,036)	0.13 (0,059)	0.16 (0,073)
150 (10,3)	0.06 (0,027)	0.06 (0,027)	0.08 (0,036)	0.09 (0,041)	0.14 (0,064)	0.17 (0,077)
200 (13,8)	0.06 (0,027)	0.07 (0,032)	0.08 (0,036)	0.09 (0,041)	0.15 (0,068)	0.19 (0,086)

Typical Condensation Rates In Steam Pipes Without Insulation

PRESSURE, PSIG (bar)	RATES IN POUNDS/HOUR (KG/HOUR) PER FOOT OF BARE PIPE AT 72°F (22°C) AMBIENT AIR					
	Pipe Diameter in Inches					
	3/4	1	1-1/2	2	3	4
1 (0,069)	0.11 (0,05)	0.15 (0,068)	0.21 (0,095)	0.25 (0,113)	0.38 (0,172)	0.46 (0,209)
5 (0,34)	0.14 (0,064)	0.16 (0,073)	0.22 (0,1)	0.26 (0,118)	0.41 (0,186)	0.50 (0,227)
10 (0,69)	0.15 (0,068)	0.18 (0,082)	0.24 (0,109)	0.29 (0,132)	0.44 (0,2)	0.53 (0,24)
25 (1,7)	0.17 (0,077)	0.22 (0,1)	0.31 (0,141)	0.36 (0,163)	0.53 (0,24)	0.65 (0,295)
50 (3,4)	0.22 (0,1)	0.27 (0,122)	0.39 (0,177)	0.46 (0,209)	0.66 (0,299)	0.83 (0,376)
75 (5,2)	0.26 (0,118)	0.31 (0,141)	0.45 (0,204)	0.54 (0,245)	0.77 (0,349)	1.04 (0,472)
100 (6,9)	0.29 (0,132)	0.35 (0,159)	0.50 (0,227)	0.61 (0,277)	0.86 (0,39)	1.11 (0,503)
125 (8,6)	0.32 (0,145)	0.39 (0,177)	0.55 (0,249)	0.68 (0,308)	0.94 (0,426)	1.23 (0,558)
150 (10,3)	0.35 (0,159)	0.42 (0,191)	0.60 (0,272)	0.74 (0,336)	1.03 (0,467)	1.33 (0,603)
200 (13,8)	0.40 (0,181)	0.49 (0,222)	0.69 (0,313)	0.81 (0,367)	1.19 (0,54)	1.50 (0,68)

Conversions, Equivalents, and Physical Data

Flow of Water Through Schedule 40 Steel Pipes

DISCHARGE		PRESSURE DROP PER 100 FEET AND VELOCITY IN SCHEDULE 40 PIPE FOR WATER AT 60°F															
Gallons per Minute	Cubic Ft. per Second	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)
		1/8-Inch		1/4-Inch													
0.2	0.000446	1.13	1.86	0.616	0.359	3/8-Inch		1/2-Inch									
0.3	0.000668	1.69	4.22	0.924	0.903	0.504	0.159	0.317	0.061	3/4-Inch							
0.4	0.000891	2.26	6.98	1.23	1.61	0.672	0.345	0.422	0.086								
0.5	0.00111	2.82	10.5	1.54	2.39	0.840	0.539	0.528	0.167	0.301	0.033						
0.6	0.00134	3.39	14.7	1.85	3.29	1.01	0.751	0.633	0.240	0.361	0.041						
0.8	0.00178	4.52	25.0	2.46	5.44	1.34	1.25	0.844	0.408	0.481	0.102	1-inch					
1	0.00223	5.65	37.2	3.08	8.28	1.68	1.85	1.06	0.600	0.602	0.155	0.371	0.048	1-1/4-Inch			
2	0.00446	11.29	134.4	6.16	30.1	3.36	6.58	2.11	2.10	1.20	0.526	0.743	0.164	0.429	0.044	1-1/2-Inch	
3	0.00668			9.25	64.1	5.04	13.9	3.17	4.33	1.81	1.09	1.114	0.336	0.644	0.090	0.473	0.043
4	0.00891			12.33	111.2	6.72	23.9	4.22	7.42	2.41	1.83	1.49	0.565	0.858	0.150	0.630	0.071
5	0.01114	2-Inch				8.40	36.7	5.28	11.2	3.01	2.75	1.86	0.835	1.073	0.223	0.788	0.104
6	0.01337	0.574	0.044	2-1/2-Inch		10.08	51.9	6.33	15.8	3.61	3.84	2.23	1.17	1.29	0.309	0.943	0.145
8	0.01782	0.765	0.073			13.44	91.1	8.45	27.7	4.81	6.60	2.97	1.99	1.72	0.518	1.26	0.241
10	0.02228	0.956	0.108	0.670	0.046	3-Inch		10.56	42.4	6.02	9.99	3.71	2.99	2.15	0.774	1.58	0.361
15	0.03342	1.43	0.224	1.01	0.094					9.03	21.6	5.57	6.36	3.22	1.63	2.37	0.755
20	0.04456	1.91	3.375	1.34	0.158	0.868	0.056	3-1/2-Inch		12.03	37.8	7.43	10.9	4.29	2.78	3.16	1.28
25	0.05570	2.39	0.561	1.68	0.234	1.09	0.083	0.812	0.041	4-Inch		9.28	16.7	5.37	4.22	3.94	1.93
30	0.06684	2.87	0.786	2.01	0.327	1.30	0.114	0.974	0.056			11.14	23.8	6.44	5.92	4.73	2.72
35	0.07798	3.35	1.05	2.35	0.436	1.52	0.151	1.14	0.071	0.882	0.041	12.99	32.2	7.51	7.90	5.52	3.64
40	0.08912	3.83	1.35	2.68	0.556	1.74	0.192	1.30	0.095	1.01	0.052	14.85	41.5	8.59	10.24	6.30	4.65
45	0.1003	4.30	1.67	3.02	0.668	1.95	0.239	1.46	0.117	1.13	0.064			9.67	12.80	7.09	5.85
50	0.1114	4.78	2.03	3.35	0.839	2.17	0.288	1.62	0.142	1.26	0.076			10.74	15.66	7.88	7.15
60	0.1337	5.74	2.87	4.02	1.18	2.60	0.46	1.95	0.204	1.51	0.107	5-Inch		12.89	22.2	9.47	10.21
70	0.1560	6.70	3.84	4.69	1.59	3.04	0.540	2.27	0.261	1.76	0.143	1.12	0.047			11.05	13.71
80	0.1782	7.65	4.97	5.36	2.03	3.47	0.687	2.60	0.334	2.02	0.180	1.28	0.060			12.62	17.59
90	0.2005	8.60	6.20	6.03	2.53	3.91	0.861	2.92	0.416	2.27	0.224	1.44	0.074	6-Inch		14.20	22.0
100	0.2228	9.56	7.59	6.70	3.09	4.34	1.05	3.25	0.509	2.52	0.272	1.60	0.090	1.11	0.036	15.778	26.9
125	0.2785	11.97	11.76	8.38	4.71	5.43	1.61	4.06	0.769	3.15	0.415	2.01	0.135	1.39	0.055	19.72	41.4
150	0.3342	14.36	16.70	10.05	6.69	6.51	2.24	4.87	1.08	3.78	0.580	2.41	0.190	1.67	0.077		
175	0.3899	16.75	22.3	11.73	8.97	7.60	3.00	5.68	1.44	4.41	0.774	2.81	0.253	1.94	0.102		
200	0.4456	19.14	28.8	13.42	11.68	8.68	3.87	6.49	1.85	5.04	0.985	3.21	0.323	2.22	0.130	8-Inch	
225	0.5013	- - - -	- - - -	15.09	14.63	9.77	4.83	7.30	2.32	5.67	1.23	3.61	0.401	2.50	0.162	1.44	0.043
250	0.557	- - - -	- - - -	- - - -	- - - -	10.85	5.93	8.12	2.84	6.30	1.46	4.01	0.495	2.78	0.195	1.60	0.051
275	0.6127	- - - -	- - - -	- - - -	- - - -	11.94	7.14	8.93	3.40	6.93	1.79	4.41	0.583	3.05	0.234	1.76	0.061
300	0.6684	- - - -	- - - -	- - - -	- - - -	13.00	8.36	9.74	4.02	7.56	2.11	4.81	0.683	3.33	0.275	1.92	0.072
325	0.7241	- - - -	- - - -	- - - -	- - - -	14.12	9.89	10.53	4.09	8.19	2.47	5.21	0.797	3.61	0.320	2.08	0.083
350	0.7798			- - - -	- - - -	- - - -	- - - -	11.36	5.51	8.82	2.84	5.62	0.919	3.89	0.367	2.24	0.095
375	0.8355			- - - -	- - - -	- - - -	- - - -	12.17	6.18	9.45	3.25	6.02	10.5	4.16	0.416	2.40	0.108
400	0.8912			- - - -	- - - -	- - - -	- - - -	12.98	7.03	10.08	3.68	6.42	1.19	4.44	0.471	2.56	0.121
425	0.9469			- - - -	- - - -	- - - -	- - - -	13.80	7.89	10.71	4.12	6.82	1.33	4.72	0.529	2.73	0.136
450	1.003	10-Inch		- - - -	- - - -	- - - -	- - - -	14.61	8.80	11.34	4.60	7.22	1.48	5.00	0.590	2.89	0.151
475	1.059	1.93	0.054			- - - -	- - - -	- - - -	- - - -	11.97	5.12	7.62	1.64	5.27	0.653	3.04	0.166
500	1.114	2.03	0.059			- - - -	- - - -	- - - -	- - - -	12.60	5.65	8.02	1.81	5.55	0.720	3.21	0.182
550	1.225	2.24	0.071			- - - -	- - - -	- - - -	- - - -	13.85	6.79	8.82	2.17	6.11	0.861	3.53	0.219
600	1.337	2.44	0.083			- - - -	- - - -	- - - -	- - - -	15.12	8.04	9.63	2.55	6.66	1.02	3.85	0.258
650	1.448	2.64	0.097			- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	10.43	2.98	7.22	1.18	4.17	0.301

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EMERSON

Conversions, Equivalents, and Physical Data

Flow of Water Through Schedule 40 Steel Pipes (continued)

DISCHARGE		PRESSURE DROP PER 100 FEET AND VELOCITY IN SCHEDULE 40 PIPE FOR WATER AT 60°F															
Gallons per Minute	Cubic Ft. per Second	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)	Velocity (Ft. per Second)	Pressure Drop (PSI)
		10-Inch		12-Inch								5-Inch		6-Inch		8-Inch	
700	1.560	2.85	0.112	2.01	0.047			- - - -	- - - -	- - - -	- - - -	11.23	3.43	7.78	1.35	4.49	0.343
750	1.671	3.05	0.127	2.15	0.054			- - - -	- - - -	- - - -	- - - -	12.03	3.92	8.33	1.55	4.81	0.392
800	1.782	3.25	0.143	2.29	0.061	14-Inch		- - - -	- - - -	- - - -	- - - -	12.83	4.43	8.88	1.75	5.13	0.443
850	1.894	3.46	0.160	2.44	0.068	2.02	0.042	- - - -	- - - -	- - - -	- - - -	13.64	5.00	9.44	1.96	5.45	0.497
900	2.005	3.66	0.179	2.58	0.075	2.13	0.047	- - - -	- - - -	- - - -	- - - -	14.44	5.58	9.99	2.18	5.77	0.554
950	2.117	3.86	0.198	2.72	0.083	2.25	0.052	- - - -	- - - -	- - - -	- - - -	15.24	6.21	10.55	2.42	6.09	0.613
1000	2.228	4.07	0.218	2.87	0.091	2.37	0.057	16-Inch		- - - -	- - - -	16.04	6.84	11.10	2.68	6.41	0.675
1100	2.451	4.48	0.260	3.15	0.110	2.61	0.068			- - - -	- - - -	17.65	8.23	12.22	3.22	7.05	0.807
1200	2.674	4.88	0.306	3.44	0.128	2.85	0.800	2.18	0.042	- - - -	- - - -	- - - -	- - - -	13.33	3.81	7.70	0.948
1300	2.896	5.29	0.355	3.73	0.150	3.08	0.093	2.36	0.048	- - - -	- - - -	- - - -	- - - -	14.43	4.45	8.33	1.11
1400	3.119	5.70	0.409	4.01	0.171	3.32	0.107	2.54	0.055	- - - -	- - - -	- - - -	- - - -	15.55	5.13	8.98	1.28
1500	3.342	6.10	0.466	4.30	0.195	3.56	0.122	2.72	0.063	18-Inch				16.66	5.85	9.62	1.46
1600	3.565	6.51	0.527	4.59	0.219	3.79	0.138	2.90	0.071					17.77	6.61	10.26	1.65
1800	4.010	7.32	0.663	5.16	0.276	4.27	0.172	3.27	0.088	2.58	0.050			19.99	8.37	11.54	2.08
2000	4.456	8.14	0.808	5.73	0.339	4.74	0.209	3.63	0.107	2.87	0.060			22.21	10.3	12.82	2.55
2500	5.570	10.17	1.24	7.17	0.515	5.93	0.321	4.54	0.163	3.59	0.091	20-Inch				16.03	3.94
3000	6.684	12.20	1.76	8.60	0.731	7.11	0.451	5.45	0.232	4.30	0.129	3.46	0.075	24-Inch		19.24	5.59
3500	7.798	14.24	2.38	10.03	0.982	8.30	0.607	6.35	0.312	5.02	0.173	4.04	0.101			22.44	7.56
4000	8.912	16.27	3.08	11.47	1.27	9.48	0.787	7.26	0.401	5.74	0.222	4.62	0.129	3.19	0.052	25.65	9.80
4500	10.03	18.31	3.87	12.90	1.60	10.67	0.990	8.17	0.503	6.46	0.280	5.20	0.162	3.59	0.065	28.87	12.2
5000	11.14	20.35	7.71	14.33	1.95	11.85	1.21	9.08	0.617	7.17	0.340	5.77	0.199	3.99	0.079	- - - -	- - - -
6000	13.37	24.41	6.74	17.20	2.77	14.23	1.71	10.89	0.877	8.61	0.483	6.93	0.280	4.79	0.111	- - - -	- - - -
7000	15.60	28.49	9.11	20.07	3.74	16.60	2.31	12.71	1.18	10.04	0.652	8.08	0.376	5.59	0.150	- - - -	- - - -
8000	17.82	- - - -	- - - -	22.93	4.84	18.96	2.99	14.52	1.51	11.47	0.839	9.23	0.488	6.38	0.192	- - - -	- - - -
9000	20.05	- - - -	- - - -	25.79	6.09	21.34	3.76	16.34	1.90	12.91	1.05	10.39	0.608	7.18	0.242	- - - -	- - - -
10,000	22.28	- - - -	- - - -	28.66	7.46	23.71	4.61	18.15	2.34	14.34	1.28	11.54	0.739	7.98	0.294	- - - -	- - - -
12,000	26.74	- - - -	- - - -	34.40	10.7	28.45	6.59	21.79	3.33	17.21	1.83	13.85	1.06	9.58	0.416	- - - -	- - - -
14,000	31.19	- - - -	- - - -	- - - -	- - - -	33.19	8.89	25.42	4.49	20.08	2.45	16.16	1.43	11.17	0.562	- - - -	- - - -
16,000	35.65	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	29.05	5.83	22.95	3.18	18.47	1.85	12.77	0.723	- - - -	- - - -
18,000	40.10	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	32.68	7.31	25.82	4.03	20.77	2.32	14.36	0.907	- - - -	- - - -
20,000	44.56	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	36.31	9.03	28.69	4.93	23.08	2.86	15.96	1.12	- - - -	- - - -

For pipe lengths other than 100 feet, the pressure drop is proportional to the length. Thus, for 50 feet of pipe, the pressure drop is approximately one half the value given in the table or 300 feet, three times the given value, etc.
Velocity is a function of the cross sectional flow area; thus, it is constant for a given flow rate and is independent of pipe length.
Extracted from Technical Paper No. 410, Flow of Fluids, with permission of Crane Co.

Conversions, Equivalents, and Physical Data

Flow of Air Through Schedule 40 Steel Pipes

FREE AIR Q^{TM}	COMPRESSED AIR	PRESSURE DROP OF AIR IN POUNDS PER SQUARE INCH PER 100 FEET OF SCHEDULE 40 PIPE FOR AIR AT 100 POUNDS PER SQUARE INCH GAUGE PRESSURE AND 60°F TEMPERATURE								
Cubic Feet per Minute at 60°F and 14.7 psia	Cubic Feet per Minute at 60°F and 100 psig	1/8-Inch	1/4-Inch	3/8-Inch	1/2-Inch	3/4-Inch	1-Inch	1-1/4-Inch	1-1/2-Inch	2-Inch
1	0.128	0.361	0.083	0.018						
2	0.256	1.31	0.285	0.064	0.020					
3	0.384	3.06	0.605	0.133	0.042					
4	0.513	4.83	1.04	0.226	0.071					
5	0.641	7.45	1.58	0.343	0.106	0.027				
6	0.769	10.6	2.23	0.408	0.148	0.037				
8	1.025	18.6	3.89	0.848	0.255	0.062	0.019			
10	0.282	28.7	5.96	1.26	0.356	0.094	0.029			
15	1.922	- - - -	13.0	2.73	0.834	0.201	0.062			
20	2.563	- - - -	22.8	4.76	1.43	0.345	0.102	0.026		
25	3.204	- - - -	35.6	7.34	2.21	0.526	0.156	0.039	0.019	
30	3.845	- - - -	- - - -	10.5	3.15	0.748	0.219	0.055	0.026	
35	4.486	- - - -	- - - -	14.2	4.24	1.00	0.293	0.073	0.035	
40	5.126	- - - -	- - - -	18.4	5.49	1.30	0.379	0.095	0.044	
45	5.767	- - - -	- - - -	23.1	6.90	1.62	0.474	0.116	0.055	
50	6.408			28.5	8.49	1.99	0.578	0.149	0.067	0.019
60	7.690	**2-1/2-Inch**		40.7	12.2	2.85	0.819	0.200	0.094	0.027
70	8.971			- - - -	16.5	3.83	1.10	0.270	0.126	0.036
80	10.25	0.019		- - - -	21.4	4.96	1.43	0.350	0.162	0.046
90	11.53	0.023		- - - -	27.0	6.25	1.80	0.437	0.203	0.058
100	12.82	0.029	**3-Inch**		33.2	7.69	2.21	0.534	0.247	0.070
125	16.02	0.044			- - - -	11.9	3.39	0.825	0.380	0.107
150	19.22	0.062	0.021		- - - -	17.0	4.87	1.17	0.537	0.151
175	22.43	0.083	0.028	**3-1/2-Inch**	- - - -	23.1	6.60	1.58	0.727	0.205
200	25.63	0.107	0.036		- - - -	30.0	8.54	2.05	0.937	0.264
225	28.84	0.134	0.045	0.022		37.9	10.8	2.59	1.19	0.331
250	32.04	0.164	0.055	0.027		- - - -	13.3	3.18	1.45	0.404
275	35.24	0.191	0.066	0.032		- - - -	16.0	3.83	1.75	0.484
300	38.45	0.232	0.078	0.037		- - - -	19.0	4.56	2.07	0.573
325	41.65	0.270	0.090	0.043	**4-Inch**	- - - -	22.3	5.32	2.42	0.673
350	44.87	0.313	0.104	0.050		- - - -	25.8	6.17	2.80	0.776
375	48.06	0.356	0.119	0.057	0.030	- - - -	29.6	7.05	3.20	0.887
400	51.26	0.402	0.134	0.064	0.034	- - - -	33.6	8.02	3.64	1.00
425	54.47	0.452	0.151	0.072	0.038	- - - -	37.9	9.01	4.09	1.13
450	57.67	0.507	0.168	0.081	0.042	- - - -	- - - -	10.2	4.59	1.26
475	60.88	0.562	0.187	0.089	0.047		- - - -	11.3	5.09	1.40
500	64.08	0.623	0.206	0.099	0.052		- - - -	12.5	5.61	1.55
550	70.49	0.749	0.248	0.118	0.062		- - - -	15.1	6.79	1.87
600	76.90	0.887	0.293	0.139	0.073	**5-Inch**	- - - -	18.0	8.04	2.21
650	83.30	1.04	0.342	0.163	0.086		- - - -	21.1	9.43	2.60
700	89.71	1.19	0.395	0.188	0.099	0.032		24.3	10.9	3.00
750	96.12	1.36	0.451	0.214	0.113	0.036		27.9	12.6	3.44
800	102.5	1.55	0.513	0.244	0.127	0.041		31.8	14.2	3.90
850	108.9	1.74	0.576	0.274	0.144	0.046	**6-Inch**	35.9	16.0	4.40
900	115.3	1.95	0.642	0.305	0.160	0.051		40.2	18.0	4.91
950	121.8	2.18	0.715	0.340	0.178	0.057	0.023	- - - -	20.0	5.47
1,000	128.2	2.40	0.788	0.375	0.197	0.063	0.025	- - - -	22.1	6.06
1,100	141.0	2.89	0.948	0.451	0.236	0.075	0.030	- - - -	26.7	7.29
1,200	153.8	3.44	1.13	0.533	0.279	0.089	0.035	- - - -	31.8	8.63
1,300	166.6	4.01	1.32	0.626	0.327	0.103	0.041	- - - -	37.3	10.1

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Conversions, Equivalents, and Physical Data

Flow of Air Through Schedule 40 Steel Pipes (continued)										
FREE AIR Q^{M}	COMPRESSED AIR	PRESSURE DROP OF AIR IN POUNDS PER SQUARE INCH PER 100 FEET OF SCHEDULE 40 PIPE FOR AIR AT 100 POUNDS PER SQUARE INCH GAUGE PRESSURE AND 60°F TEMPERATURE								
Cubic Feet per Minute at 60°F and 14.7 psia	Cubic Feet per Minute at 60°F and 100 psig	2-1/2-Inch	3-Inch	3-1/2-Inch	4-Inch	5-Inch	6-Inch	8-Inch	10-Inch	12-Inch
1,400	179.4	4.65	1.52	0.718	0.377	0.119	0.047			11.8
1,500	192.2	5.31	1.74	0.824	0.431	0.136	0.054			13.5
1,600	205.1	6.04	1.97	0.932	0.490	0.154	0.061			15.3
1,800	230.7	7.65	2.50	1.18	0.616	0.193	0.075			19.3
2,000	256.3	9.44	3.06	1.45	0.757	0.237	0.094	0.023		23.9
2,500	320.4	14.7	4.76	2.25	1.17	0.366	0.143	0.035		37.3
3,000	384.5	21.1	6.82	3.20	1.67	0.524	0.204	0.051	0.016	
3,500	448.6	28.8	9.23	4.33	2.26	0.709	0.276	0.068	0.022	
4,000	512.6	37.6	12.1	5.66	2.94	0.919	0.358	0.088	0.028	**12-Inch**
4,500	576.7	47.6	15.3	7.16	3.69	1.16	0.450	0.111	0.035	
5,000	640.8	- - - -	18.8	8.85	4.56	1.42	0.552	0.136	0.043	0.018
6,000	769.0	- - - -	27.1	12.7	6.57	2.03	0.794	0.195	0.061	0.025
7,000	897.1	- - - -	36.9	17.2	8.94	2.76	1.07	0.262	0.082	0.034
8,000	1025	- - - -	- - - -	22.5	11.7	3.59	1.39	0.339	0.107	0.044
9,000	1153	- - - -	- - - -	28.5	14.9	4.54	1.76	0.427	0.134	0.055
10,000	1282	- - - -	- - - -	35.2	18.4	5.60	2.16	0.526	0.164	0.067
11,000	1410	- - - -	- - - -	- - - -	22.2	6.78	2.62	0.633	0.197	0.081
12,000	1538	- - - -	- - - -	- - - -	26.4	8.07	3.09	0.753	0.234	0.096
13,000	1666	- - - -	- - - -	- - - -	31.0	9.47	3.63	0.884	0.273	0.112
14,000	1794	- - - -	- - - -	- - - -	36.0	11.0	4.21	1.02	0.316	0.129
15,000	1922	- - - -	- - - -	- - - -	- - - -	12.6	4.84	1.17	0.364	0.148
16,000	2051	- - - -	- - - -	- - - -	- - - -	14.3	5.50	1.33	0.411	0.167
18,000	2307	- - - -	- - - -	- - - -	- - - -	18.2	6.96	1.68	0.520	0.213
20,000	2563	- - - -	- - - -	- - - -	- - - -	22.4	8.60	2.01	0.642	0.260
22,000	2820	- - - -	- - - -	- - - -	- - - -	27.1	10.4	2.50	0.771	0.314
24,000	3076	- - - -	- - - -	- - - -	- - - -	32.3	12.4	2.97	0.918	0.371
26,000	3332	- - - -	- - - -	- - - -	- - - -	37.9	14.5	3.49	1.12	0.435
28,000	3588	- - - -	- - - -	- - - -	- - - -	- - - -	16.9	4.04	1.25	0.505
30,000	3845	- - - -	- - - -	- - - -	- - - -	- - - -	19.3	4.64	1.42	0.520
Extracted from Technical Paper No. 410, Flow of Fluids, with permission of Crane Co.										

Conversions, Equivalents, and Physical Data

Average Properties of Propane	
Formula	C_3H_8
Boiling Point, °F (°C)	-44 (-42)
Specific Gravity of Gas (Air = 1.00)	1.53
Pounds per Gallon of Liquid at 60°F (16°C)	4.24
BTU per Gallon of Gas at 60°F (16°C)	91,547
BTU per Pound of Gas	21,591
BTU per Cubic Foot of Gas at 60°F (16°)	2516
Cubic Feet of Vapor at 60°F (16°C) per Gallon of Liquid at 60°F (16°C)	36.39
Cubic Feet of Vapor at 60°F (16°C) per Pound of Liquid at 60°F (16°)	8.547
Latent Heat of Vaporization at Boiling Point, BTU per Gallon	785.0
Combustion Data	
Cubic Feet of Air Required to Burn 1 Cubic Foot of Gas	23.86
Flash Point, °F (°C)	-156 (-104)
Ignition Temperature in Air, °F (°C)	920 to 1020 (493 to 549)
Maximum Flame Temperature in Air, °F (°C)	3595 (1979)
Limits of Inflammability, Percentage of Gas in Air Mixture	
at Lower Limit	2.4%
at Upper Limit	9.6%
Octane Number (ISO Octane = 100)	Over 100

Standard Domestic Propane Tank Specifications

CAPACITY Gallons (Liters)	DIAMETER Inches (mm)	LENGTH Inches (mm)	TANK WEIGHT Pounds (kg)
120 (454)	24 (610)	68 (1727)	288 (131)
150 (568)	24 (610)	84 (2134)	352 (160)
200 (757)	30 (762)	79 (2007)	463 (210)
250 (946)	30 (762)	94 (2387)	542 (246)
325 (1230)	30 (762)	119 (3023)	672 (305)
500 (1893)	37 (940)	119 (3023)	1062 (482)
1000 (3785)	41 (1041)	192 (4877)	1983 (900)

Approximate Vaporization Capacities of Propane Tanks

BTU PER HOUR WITH 40% LIQUID IN DOMESTIC TANK SYSTEMS

Tank Size Water Capacity	Prevailing Air Temperature	
	20°F (-7°C)	60°F (16°)
120	235,008	417,792
150	290,304	516,096
200	341,280	606,720
250	406,080	721,920
325	514,100	937,900
500	634,032	1,127,168
1000	1,088,472	1,978,051

Orifice Capacities for Propane

ORIFICE OR DRILL SIZE	ORIFICE CAPACITY BTU PER HOUR, 11-INCHES W.C.	ORIFICE OR DRILL SIZE	ORIFICE CAPACITY BTU PER HOUR, 11-INCHES W.C
0.008	519	51	36531
0.009	656	50	39842
0.010	812	49	43361
0.011	981	48	46983
0.012	1169	47	50088
80	1480	46	53296
79	1708	45	54641
78	2080	44	60229
77	2629	43	64369
76	3249	42	71095
75	3581	41	74924
74	4119	40	78029
73	4678	39	80513
72	5081	38	83721
71	5495	37	87860
70	6375	36	92207
69	6934	35	98312
68	7813	34	100175
67	8320	33	103797
66	8848	32	109385
65	9955	31	117043
64	10535	30	134119
63	11125	29	150366
62	11735	28	160301
61	12367	27	168580
60	13008	26	175617
59	13660	25	181619
58	14333	24	187828
57	15026	23	192796
56	17572	22	200350
55	21939	21	205525
54	24630	20	210699
53	28769	19	223945
52	32805	18	233466

BTU per cubic foot = 2516
Specific Gravity = 1.52
Pressure at orifice, inches of water column = 11
Orifice Coefficient = 0.9

Conversions, Equivalents, and Physical Data

Pipe and Tubing Sizing

PROPANE PIPE AND TUBING SIZING BETWEEN SINGLE OR SECOND STAGE LOW PRESSURE REGULATORS AND APPLIANCES

Pipe or Tubing Length, Feet	Copper Tubing Size, Outside Diameter (Inside Diameter), Type L					Pipe or Tubing Length, Feet	Nominal Pipe Size, Outside Diameter (Inside Diameter), Schedule 40					
	3/8 (0.315)	1/2 (0.430)	5.8 (0.545)	3/4 (0.666)	7/8 (0.785)		1/2 (0.622)	3.4 (0.824)	1 (1.049)	1-1/4 (1.380)	1-1/2 (1.610)	2 (2.067)
10	49	110	206	348	536	10	291	608	1146	2353	3525	6789
20	34	76	151	239	368	20	200	418	788	1617	2423	4666
30	27	61	114	192	296	30	161	336	632	1299	1946	3747
40	23	52	97	164	253	40	137	282	541	1111	1665	3207
50	20	46	86	146	224	50	122	557	480	985	1476	2842
60	19	42	78	132	203	60	110	231	435	892	1337	2575
70	17	39	72	121	187	80	94	198	372	764	1144	2204
80	16	36	67	113	174	100	84	175	330	677	1014	1954
90	15	34	63	106	163	125	74	155	292	600	899	1731
100	14	32	59	100	154	150	67	141	265	544	815	1569
150	11	26	48	80								

To convert to capacities in cubic feet per hour, divide by 2.5
Note: Maximum undiluted propane capacities listed are based on 11-inches w.c. setting and a 0.5-inch w.c. pressure drop - Capacities in 1,000 BTU per hour.

Vapor Pressures of Propane

TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE
°F (°C)	Psig (Bar)	°F (°C)	Psig (Bar)	°F (°C)	Psig (Bar)	°F (°C)	Psig (Bar)
130 (54)	257 (18)	70 (21)	109 (8)	20 (-7)	40 (2,8)	-20 (-29)	10 (0,69)
120 (49)	225 (16)	65 (18)	100 (6,9)	10 (-12)	31 (2)	-25 (-32)	8 (0,55)
110 (43)	197 (14)	60 (16)	92 (6)	0 (-17)	23 (2)	-30 (-34)	5 (0,34)
100 (38)	172 (12)	50 (10)	77 (5)	-5 (-21)	20 (1,4)	-35 (-37)	3 (0,21)
90 (32)	149 (10)	40 (4)	63 (4)	-10 (-23)	16 (1)	-40 (-40)	1 (0,069)
80 (27)	128 (9)	30 (-1)	51 (4)	-15 (-26)	13 (1)	-44 (-42)	0 (0)

Converting Volumes of Gas

CFH TO CFH OR CFM TO CFM

Multiply Flow of	By	To Obtain Flow of
Air	0.707	Butane
	1.290	Natural Gas
	0.808	Propane
Butane	1.414	Air
	1.826	Natural Gas
	1.140	Propane
Natural Gas	0.775	Air
	0.547	Butane
	0.625	Propane
Propane	1.237	Air
	0.874	Butane
	1.598	Natural Gas

BTU Comparisons

COMMON FUELS	PER GALLON	PER POUND
Propane	91,547	21,591
Butane	102,032	21,221
Gasoline	110,250	20,930
Fuel Oil	134,425	16,960

Conversions, Equivalents, and Physical Data

Capacities of Spuds and Orifices

DRILL DESIGNATION	DIAMETER, INCHES	AREA, SQUARE INCHES	CAPACITIES IN CFH OF 0.6 GRAVITY HIGH PRESSURE NATURAL GAS AND AN ORIFICE COEFFICIENT OF 1.0																		
			Upstream Pressure, Psi Gauge																		
			1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50
80	0.0135	0.000143	1.61	2.26	2.76	3.17	3.52	3.84	4.13	4.40	4.65	4.88	5.31	5.65	6.05	6.44	6.84	7.82	8.80	10.8	12.8
79	0.0145	0.000163	1.85	2.61	3.18	3.65	4.06	4.43	4.77	5.07	5.36	5.63	6.12	6.52	6.98	7.43	7.89	9.02	10.2	12.5	14.7
1/64”	0.0156	0.000191	2.14	3.02	3.68	4.23	4.70	5.13	5.52	5.87	6.20	6.51	7.09	7.55	8.08	8.61	9.13	10.5	11.8	14.4	17.1
78	0.0160	0.000201	2.26	3.18	3.88	4.45	4.94	5.40	5.81	6.18	6.53	6.85	7.46	7.95	8.50	9.05	9.61	11.0	12.4	15.2	17.9
77	0.0180	0.000234	2.85	4.02	4.90	5.62	6.25	6.82	7.34	7.81	8.25	8.66	9.42	10.1	10.8	11.5	12.2	13.9	15.7	19.2	22.7
76	0.0200	0.000314	3.53	4.97	6.05	6.95	7.72	8.43	9.07	9.65	10.2	10.8	11.7	12.5	13.3	14.2	15.0	17.2	19.4	23.7	28.0
75	0.0210	0.000346	3.89	5.48	6.67	7.65	8.51	9.29	10.0	10.7	12.3	11.8	12.9	13.7	14.7	15.6	16.6	19.0	21.3	26.1	30.9
74	0.0225	0.000398	4.47	7.08	7.67	8.80	9.78	10.7	11.5	12.4	13.0	13.6	14.8	15.8	16.9	18.0	19.1	21.8	24.5	30.0	35.5
73	0.0240	0.000452	5.08	7.16	8.71	10.0	11.2	12.2	13.1	13.9	14.7	15.4	16.8	17.9	19.1	20.4	21.6	24.7	27.6	34.1	40.3
72	0.0250	0.000491	5.52	7.78	9.46	10.9	12.1	13.2	14.2	15.1	16.0	16.8	18.3	19.4	20.8	22.1	23.5	26.9	30.3	37.0	43.8
71	0.0260	0.000531	5.97	8.41	10.3	11.8	13.1	14.3	15.4	16.4	17.3	18.1	19.7	21.0	22.5	23.9	25.4	29.1	32.7	40.0	47.3
70	0.0280	0.000616	6.92	9.75	11.9	13.7	15.2	16.6	17.8	19.0	20.0	21.0	22.9	24.4	26.1	27.8	29.5	33.8	38.0	46.4	54.9
69	0.0292	0.000670	7.53	10.6	13.0	14.9	16.5	18.0	19.4	20.0	21.8	22.9	24.9	26.5	28.4	30.2	32.1	36.7	41.3	50.5	59.7
68	0.0310	0.000735	8.48	12.0	14.6	16.7	18.6	20.3	21.9	23.2	24.5	25.8	28.0	29.9	32.0	34.0	36.1	41.3	46.5	56.9	67.3
1/32”	0.0313	0.000765	8.59	12.2	14.8	17.0	18.8	20.6	22.1	23.5	24.9	26.1	28.4	30.3	32.4	34.5	36.6	41.9	47.1	57.7	68.2
67	0.0320	0.000804	9.03	12.8	15.5	17.8	19.8	21.6	23.3	24.7	26.1	27.4	29.9	31.8	34.0	36.2	38.5	44.0	49.5	60.6	71.7
66	0.0330	0.000855	9.60	13.6	16.5	18.9	21.1	23.0	24.7	26.3	27.6	29.2	31.8	33.8	36.2	38.5	40.9	46.8	52.7	64.4	76.2
65	0.0350	0.000962	10.8	15.3	18.6	21.3	23.7	25.9	27.8	29.6	31.3	32.8	35.7	38.1	40.7	43.4	46.0	52.6	59.2	72.5	85.7
64	0.0360	0.001018	11.5	16.2	19.7	22.6	25.1	27.4	29.4	31.3	33.1	34.7	37.8	40.3	42.4	45.9	48.7	55.7	62.7	76.7	90.7
63	0.0370	0.001075	12.1	17.1	20.8	23.8	26.5	28.9	31.1	33.1	34.9	36.7	39.9	42.5	45.5	48.4	51.4	58.8	66.2	81.0	95.8
62	0.0380	0.001134	12.8	18.0	21.9	25.1	27.9	30.5	32.8	34.9	36.8	38.7	42.1	44.8	48.0	51.1	54.2	62.0	69.8	85.4	101
61	0.0390	0.001195	13.5	19.0	23.1	26.5	29.4	32.1	34.6	36.8	38.8	40.8	44.4	47.3	50.6	53.8	57.1	65.4	73.6	90.0	107
60	0.0400	0.001257	14.2	19.9	24.3	27.8	30.9	33.8	36.4	38.7	40.8	42.9	46.7	49.7	53.2	56.6	60.1	68.7	77.4	94.7	112
59	0.0410	0.001320	14.9	20.9	25.5	29.2	32.5	35.5	38.2	40.6	42.9	45.0	49.0	52.2	55.8	59.5	63.1	72.2	81.3	99.5	118
58	0.0420	0.001385	15.6	22.0	26.7	30.7	34.1	37.2	40.0	42.6	45.0	41.2	51.4	54.8	58.6	62.4	66.2	75.7	85.3	105	124
57	0.0430	0.001452	16.3	23.0	28.0	32.1	35.7	39.0	42.0	44.7	47.2	49.5	53.9	57.4	61.4	65.4	69.4	79.4	89.4	110	130
56	0.0465	0.001698	19.1	26.9	32.8	37.6	41.8	45.6	49.1	52.2	55.1	57.9	63.0	67.1	71.8	76.5	81.2	92.8	105	128	152
3/64”	0.0469	0.00173	19.5	27.4	33.4	38.3	42.6	46.5	50.0	53.2	56.2	59.0	64.2	68.4	73.2	77.9	82.7	94.6	107	131	155
55	0.0520	0.00212	23.8	33.6	40.9	46.9	52.1	57.0	61.3	65.2	68.8	72.3	78.7	83.8	89.6	95.5	102	116	131	160	189
54	0.0550	0.00238	26.8	37.7	45.9	52.7	58.5	63.9	68.8	73.2	77.3	81.1	88.3	94.1	101	108	114	132	147	180	212
53	0.0595	0.00278	31.1	44.0	53.6	61.5	68.4	74.7	80.3	85.4	90.3	94.7	104	110	118	126	133	152	172	210	248
1/16”	0.0625	0.00307	34.5	48.6	59.2	67.9	75.5	82.5	88.8	94.4	99.7	105	114	122	130	139	147	168	189	232	274
52	0.0635	0.00317	35.6	50.2	61.1	70.1	78.0	85.1	91.6	97.4	103	108	118	126	134	143	152	174	196	239	283
51	0.0670	0.00353	39.7	55.9	68.0	78.1	86.8	94.8	102	109	115	121	131	140	150	159	169	193	218	266	315
50	0.0700	0.00385	43.3	61.0	74.2	85.2	94.7	104	112	119	125	132	143	153	163	174	184	211	237	290	343
49	0.0730	0.00419	47.1	66.4	80.8	92.7	103	113	121	129	136	143	156	166	178	189	201	229	258	316	374
48	0.0760	0.00454	51.0	71.9	87.5	101	112	122	132	140	148	155	169	180	192	205	217	249	280	342	405
5/64”	0.0781	0.00479	53.8	75.9	92.3	106	118	129	134	148	156	164	178	190	203	216	229	262	295	361	427
47	0.0785	0.00484	54.4	76.6	93.3	107	119	130	140	149	158	165	180	192	205	218	232	265	298	365	432
46	0.0810	0.00515	57.9	81.6	99.2	114	127	139	149	159	168	176	191	204	218	232	246	282	317	388	459
45	0.0820	0.00528	59.3	83.6	102	117	130	141	153	163	172	180	196	209	224	238	253	289	325	398	471
44	0.0860	0.00582	65.3	92.1	113	129	143	157	169	179	189	199	216	230	246	262	278	319	359	439	519
43	0.0890	0.00622	69.9	98.5	120	138	153	167	180	192	202	212	231	246	263	280	298	340	383	469	555
42	0.0935	0.00687	77.2	109	133	152	169	185	199	212	223	234	255	272	291	310	329	376	423	518	612
3/32”	0.0937	0.00690	77.5	110	133	153	170	186	200	212	224	235	256	273	292	311	350	378	425	520	615
41	0.0960	0.00724	81.3	115	140	161	178	195	210	223	235	247	269	287	306	326	346	396	446	546	645
40	0.0980	0.00754	84.7	120	146	167	186	203	218	232	245	257	280	298	319	340	361	413	464	568	672
39	0.0995	0.00778	87.4	124	150	172	192	209	225	239	253	265	289	308	329	351	372	426	479	585	693
38	0.1015	0.00809	90.9	128	156	179	199	218	234	249	263	276	300	320	342	365	387	443	498	610	721
37	0.1040	0.00849	95.4	135	164	188	209	228	246	261	276	290	315	336	359	383	406	464	523	640	757

- continued -

Conversions, Equivalents, and Physical Data

Capacities of Spuds and Orifices (continued)

DRILL DESIGNATION	DIAMETER, INCHES	AREA, SQUARE INCHES	CAPACITIES IN CFH OF 0.6 GRAVITY HIGH PRESSURE NATURAL GAS AND AN ORIFICE COEFFICIENT OF 1.0 — Upstream Pressure, Psi Gauge: 1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50
36	0.1065	0.00891	100	141	172	197	219	240	258	274	290	304	331	352	377	402	426	487	549	671	794
7/64"	0.1094	0.00940	106	149	182	208	231	253	272	289	305	321	349	372	398	424	449	514	579	708	838
35	0.1100	0.00950	107	151	183	210	234	255	275	292	309	324	353	376	402	428	454	520	585	716	847
34	0.1110	0.00968	109	154	187	214	238	260	280	298	315	330	359	383	410	436	463	530	596	729	863
33	0.1130	0.01003	113	159	194	222	247	270	290	309	326	342	372	396	424	452	480	549	618	756	894
32	0.1160	0.01057	119	168	204	234	260	284	306	325	343	360	392	418	447	476	505	578	651	796	942
31	0.1200	0.01131	127	179	218	250	278	304	327	348	367	386	420	447	478	510	541	619	696	852	1010
1/8"	0.1250	0.01227	138	195	237	272	302	330	355	377	399	418	456	485	519	553	587	671	756	924	1100
30	0.1285	0.01296	146	206	250	287	319	348	375	399	421	442	481	512	548	584	620	709	798	976	1160
29	0.1360	0.01433	164	230	280	322	357	390	420	447	472	495	539	575	615	655	695	795	893	1100	1300
28	0.1405	0.01549	174	246	299	343	381	416	448	476	503	528	575	612	655	698	740	847	954	1170	1380
9/64"	0.1406	0.01553	175	246	300	344	382	417	449	478	504	529	576	614	657	700	742	849	956	1170	1390
27	0.1440	0.01629	183	258	314	361	401	438	471	501	529	555	605	644	689	734	779	891	1010	1230	1460
26	0.1470	0.01697	191	269	327	376	417	456	491	522	551	579	630	671	718	764	811	928	1050	1280	1520
25	0.1495	0.01755	197	278	339	388	432	472	507	540	570	598	651	694	742	790	839	960	1080	1330	1570
24	0.1520	0.01815	204	288	350	402	446	490	525	558	589	619	674	718	768	818	867	992	1120	1370	1620
23	0.1540	0.01863	210	295	359	412	458	501	539	573	605	635	691	737	788	839	890	1020	1150	1410	1660
5/32"	0.1562	0.01917	216	304	370	424	472	515	554	589	623	653	711	758	811	863	916	1050	1180	1450	1710
22	0.1570	0.01936	218	307	373	428	476	520	560	595	629	660	713	765	819	872	925	1060	1200	1460	1730
21	0.1590	0.01986	223	315	383	440	488	534	574	611	645	677	737	785	840	894	949	1090	1230	1500	1770
20	0.1610	0.02036	229	323	393	451	501	547	589	626	661	694	756	805	861	917	973	1120	1260	1540	1820
19	0.1660	0.02164	243	343	417	479	532	581	625	665	703	738	803	855	915	975	1040	1190	1340	1630	1930
18	0.1695	0.02256	254	358	435	499	555	606	652	694	733	769	837	892	954	1020	1080	1240	1390	1700	2010
11/64"	0.1719	0.02320	261	368	447	513	571	623	671	713	753	790	861	917	981	1050	1110	1270	1430	1750	2070
17	0.1730	0.02351	264	373	453	520	578	632	680	723	763	801	872	929	994	1060	1130	1290	1450	1770	2100
16	0.1770	0.02461	277	390	475	545	605	661	711	756	799	839	913	973	1040	1110	1180	1350	1520	1860	2200
15	0.1800	0.02345	286	403	491	563	626	684	736	782	826	868	944	1010	1080	1150	1220	1400	1570	1920	2270
14	0.1820	0.02602	293	412	502	576	640	699	752	800	845	887	965	1030	1100	1180	1250	1430	1610	1960	2320
13	0.1850	0.02688	302	426	518	595	661	722	777	826	873	916	997	1060	1140	1210	1290	1470	1660	2030	2400
3/16"	0.1875	0.02761	310	437	532	611	679	742	798	849	896	941	1030	1100	1170	1250	1320	1510	1700	2080	2460
12	0.1890	0.02806	315	445	541	621	690	754	811	862	911	956	1050	1110	1190	1270	1340	1540	1730	2120	2500
11	0.1910	0.02865	322	454	552	634	704	770	828	881	930	976	1070	1140	1220	1290	1370	1570	1770	2160	2560
10	0.1930	0.02940	331	466	567	650	723	790	850	904	955	1010	1090	1170	1250	1330	1410	1610	1810	2220	2620
9	0.1960	0.03017	339	478	582	667	742	810	872	927	980	1030	1120	1200	1270	1360	1450	1650	1860	2280	2690
8	0.1990	0.03110	350	493	600	688	765	835	899	956	1010	1060	1160	1230	1320	1400	1490	1700	1920	2350	2770
7	0.2010	0.03173	357	503	612	702	780	852	917	975	1030	1090	1180	1260	1350	1430	1520	1740	1960	2390	2830
13/64"	0.2031	0.03241	364	513	625	717	797	870	937	996	1060	1110	1210	1290	1370	1460	1550	1780	2000	2450	2890
6	0.2040	0.03269	367	518	630	723	804	878	945	1010	1070	1120	1220	1300	1390	1480	1570	1790	2020	2470	2920
5	0.2055	0.03317	373	525	639	734	816	891	959	1020	1080	1130	1230	1320	1410	1500	1590	1820	2050	2500	2960
4	0.2090	0.03431	386	543	661	739	844	921	991	1060	1120	1170	1280	1360	1450	1550	1640	1880	2120	2590	2770
3	0.2130	0.03563	400	564	687	788	876	959	1030	1100	1160	1220	1330	1410	1510	1610	1710	1950	2200	2690	2830
7/32"	0.2187	0.03758	422	595	724	831	924	1010	1090	1160	1220	1280	1400	1490	1590	1700	1800	2060	2320	2830	2890
2	0.2210	0.03836	431	608	739	849	943	1030	1110	1180	1250	1310	1430	1520	1630	1730	1840	2100	2370	2890	2920
1	0.2280	0.04083	459	647	787	903	1010	1100	1180	1260	1330	1400	1520	1620	1730	1840	1950	2240	2520	3080	2960
A	0.2340	0.04301	483	681	829	951	1060	1160	1250	1330	1400	1470	1600	1700	1820	1940	2060	2360	2650	3240	3060
15/64"	0.2344	0.04314	485	683	831	954	1060	1160	1250	1330	1400	1470	1600	1710	1830	1950	2070	2360	2660	3250	3180
B	0.2380	0.04449	500	705	857	984	1100	1200	1290	1370	1450	1520	1650	1760	1880	2010	2130	2440	2740	3350	3350
C	0.2420	0.04600	517	725	916	1020	1130	1240	1330	1420	1500	1570	1710	1820	1950	2080	2200	2520	2840	3470	3420
D	0.2460	0.04733	534	733	975	1060	1170	1280	1370	1460	1550	1620	1770	1880	2010	2140	2280	2600	2930	3580	3640
E=1/4"	0.2500	0.04909	552	777	946	1090	1210	1320	1420	1510	1600	1680	1830	1940	2080	2210	2350	2690	3030	3700	4380
F	0.2570	0.05187	583	821	1000	1150	1280	1400	1500	1600	1690	1770	1930	2050	2200	2340	2480	2840	3200	3910	4620
G	0.2610	0.05350	601	847	1040	1190	1320	1440	1550	1650	1740	1830	1990	2120	2270	2410	2560	2930	3300	4030	4770
17/64"	0.2656	0.05542	623	878	1070	1230	1370	1490	1610	1710	1810	1890	2060	2190	2350	2500	2650	3030	3410	4180	4940
H	0.2660	0.05557	624	880	1070	1230	1370	1500	1610	1710	1810	1900	2070	2200	2350	2510	2660	3040	3420	4190	4950

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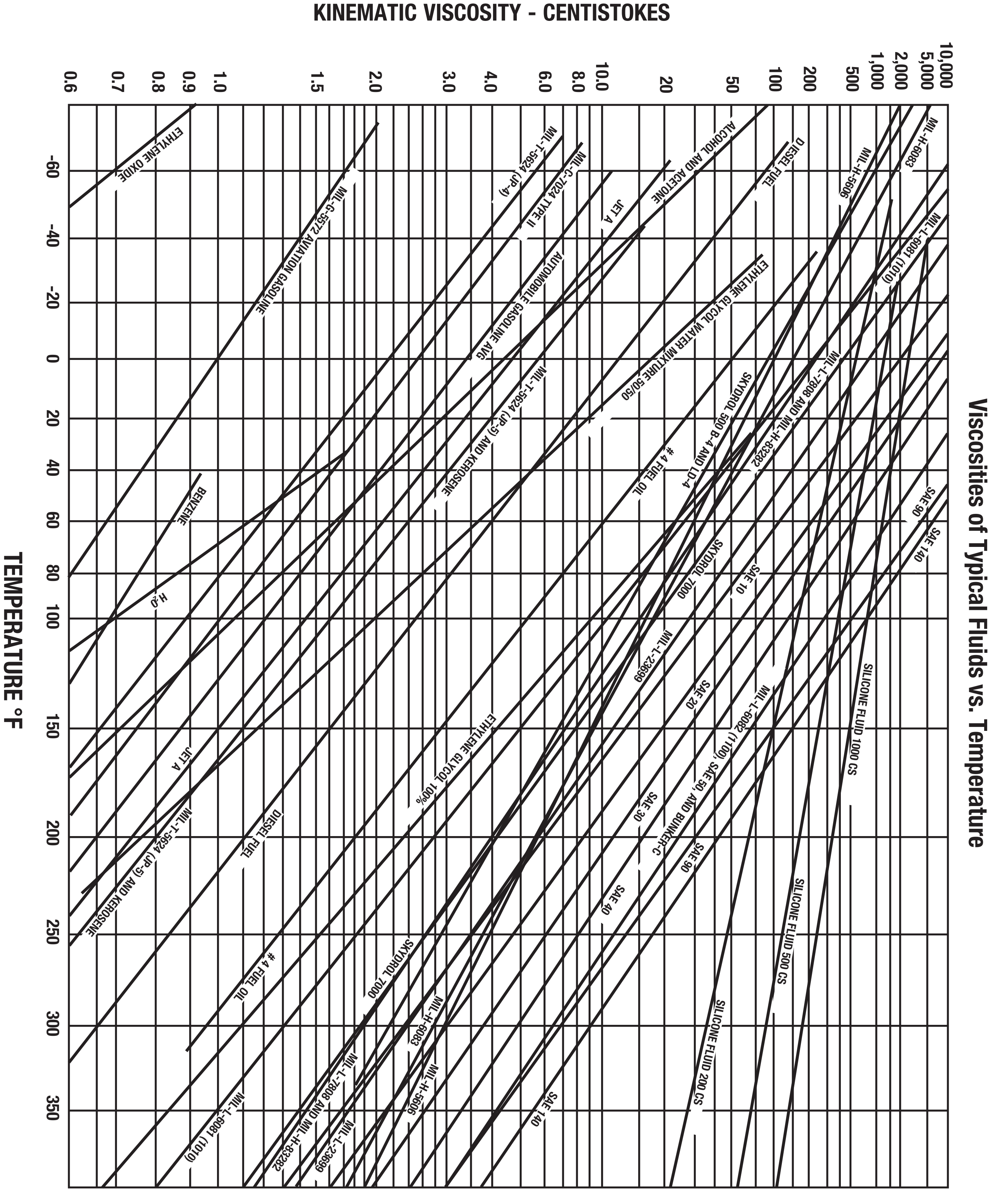
Conversions, Equivalents, and Physical Data

Capacities of Spuds and Orifices (continued)

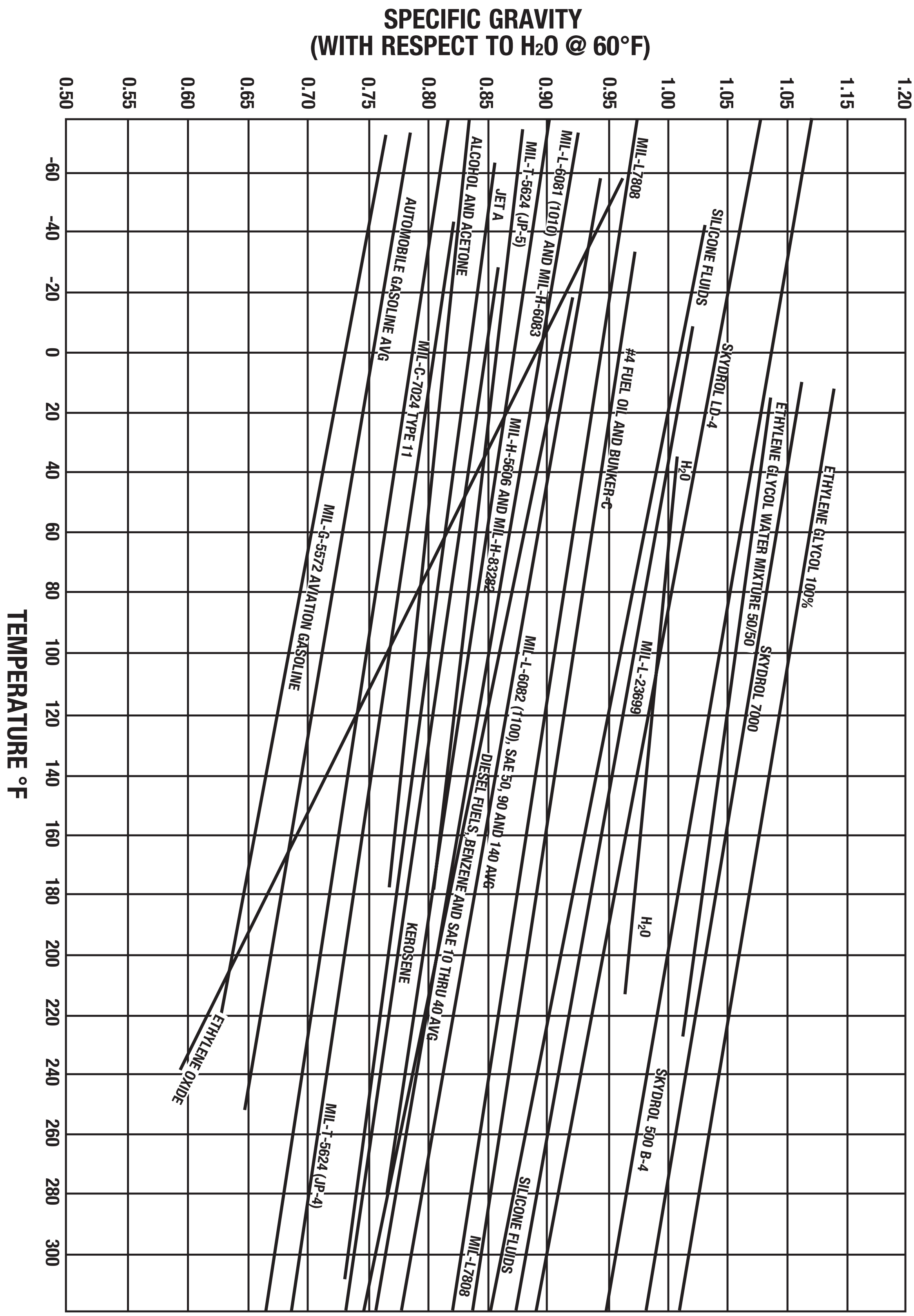
DRILL DESIGNATION	DIAMETER, INCHES	AREA, SQUARE INCHES	CAPACITIES IN CFH OF 0.6 GRAVITY HIGH PRESSURE NATURAL GAS AND AN ORIFICE COEFFICIENT OF 1.0																		
			Upstream Pressure, Psi Gauge																		
			1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	40	50
I	0.2720	0.005811	653	916	1120	1290	1430	1560	1680	1790	1890	1980	2160	2300	2460	2620	2780	3180	3580	4380	5180
J	0.2770	0.006026	677	957	1170	1340	1490	1620	1750	1860	1960	2060	2240	2390	2550	2720	2880	3300	3710	4540	5370
K	0.2810	0.006102	697	983	1200	1380	1530	1670	1800	1910	2020	2120	2300	2450	2630	2800	2970	3390	3820	4680	5530
9/32"	0.2812	0.006113	698	984	1200	1380	1530	1670	1800	1910	2020	2120	2310	2460	2630	2800	2970	3400	3830	4680	5540
L	0.2900	0.006605	742	1050	1280	1460	1630	1780	1910	2030	2150	2250	2450	2610	2800	2980	3160	3610	4070	4980	5890
M	0.2930	0.006835	768	1090	1320	1520	1680	1840	1980	2100	2220	2330	2540	2710	2890	3080	3270	3740	4210	5150	6090
19/64"	0.2969	0.006922	778	1100	1340	1530	1710	1860	2000	2130	2250	2360	2570	2740	2930	3120	3310	3790	4260	5220	6170
N	0.3020	0.007163	805	1140	1380	1590	1760	1930	2070	2210	2330	2440	2660	2830	3030	3230	3430	3920	4410	5400	6390
5/16"	0.3125	0.007670	862	1220	1480	1700	1890	2060	2220	2360	2490	2620	2850	3030	3250	3460	3670	4200	4720	5780	6840
O	0.3160	0.007843	881	1250	1520	1740	1930	2110	2270	2410	2550	2660	2910	3100	3320	3540	3750	4290	4830	5910	6990
P	0.3230	0.008194	920	1300	1580	1820	2020	2200	2370	2520	2660	2800	3040	3240	3470	3690	3920	4480	5050	6180	7300
21/64"	0.3281	0.008456	950	1340	1630	1870	2080	2270	2450	2600	2750	2890	3140	3350	3580	3810	4040	4630	5210	6370	7540
Q	0.3320	0.008657	972	1370	1670	1920	2130	2330	2500	2660	2810	2950	3210	3420	3660	3900	4140	4740	5330	6520	7720
R	0.3390	0.009026	1020	1430	1740	2000	2220	2430	2607	2780	2930	3080	3350	3570	3820	4070	4320	4940	5560	6800	8040
11/32"	0.3437	0.009281	1050	1470	1790	2060	2290	2500	2690	2860	3020	3170	3450	3670	3930	4180	4440	5080	5720	6990	8270
S	0.3480	0.09511	1070	1510	1840	2110	2340	2530	2750	2930	3090	3240	3530	3760	4020	4290	4550	5200	5860	7170	8480
T	0.3580	0.1006	1130	1600	1940	2230	2480	2710	2910	3100	3270	3430	3740	4000	4260	4530	4810	5500	6200	7580	8970
23/64"	0.3594	0.1014	1140	1610	1960	2250	2500	2730	2930	3120	3300	3460	3770	4010	4290	4570	4850	5550	6240	7640	9040
U	0.3680	0.1065	1200	1690	2050	2360	2620	2860	3080	3270	3460	3630	3950	4210	4500	4790	5050	5820	6550	8020	9480
3/8"	0.3750	0.1105	1240	1750	2130	2450	2720	2970	3200	3400	3590	3770	4100	4370	4670	4980	5280	6040	6800	8330	9850
V	0.3770	0.1116	1260	1770	2150	2470	2750	3000	3230	3430	3630	3810	4140	4410	4720	5030	5340	6100	6870	8410	9950
W	0.3860	0.1170	1320	1860	2260	2590	2900	3200	3380	3600	3800	3990	4340	4630	5000	5270	5590	6350	7200	8820	10 400
25/64"	0.3960	0.1198	1350	1900	2310	2650	2950	3220	3460	3680	3890	4090	4450	4740	5100	5400	5730	6550	7380	9030	10 700
X	0.3970	0.1238	1390	1960	2390	2740	3050	3330	3580	3810	4020	4220	4600	4900	5240	5580	5920	6770	7620	9330	11 100
Y	0.4040	0.1282	1440	2030	2470	2840	3150	3450	3710	3940	4160	4370	4760	5070	5420	5780	6130	7010	7890	9660	11 500
13/32"	0.4062	0.1295	1460	2060	2500	2870	3190	3480	3750	3990	4210	4420	4810	5120	5480	5840	6200	7090	7980	9760	11 600
Z	0.4130	0.1340	1510	2130	2590	2970	3300	3600	3870	4130	4350	4570	4970	5300	5670	6040	6400	7330	8250	10 100	12 000
27/64"	0.4219	0.1398	1570	2220	2700	3100	3440	3760	4040	4300	4540	4770	5190	5530	5910	6300	6680	7650	8610	10 600	12 500
7/16"	0.4375	0.1503	1690	2380	2900	3330	3700	4040	4350	4620	4880	5120	5580	5940	6360	6770	7200	8220	9250	11 400	13 400
29/64"	0.4531	0.1613	1820	2560	3110	3570	4000	4230	4660	5000	5140	5500	5990	6380	6820	7270	7700	8820	9930	12 200	14 400
15/32"	0.4687	0.1726	1940	2740	3330	3820	4250	4640	4990	5310	5610	5880	6410	6820	7300	7770	8300	9440	10 700	13 000	15 400
31/64"	0.4844	0.1843	2070	3280	3550	4080	4530	4950	5330	5670	5990	6280	6840	7280	7790	8300	8800	10 100	11 400	13 900	16 400
1/2"	0.5000	0.1964	2210	3110	3790	4350	4830	5280	5680	6340	6380	6690	7290	7760	8310	8850	9400	10 800	12 100	14 800	17 500
33/64"	0.5156	0.2088	2350	3310	4030	4620	5140	5610	6040	6420	6780	7120	7750	8250	8490	9400	10 000	11 500	12 900	15 800	18 600
17/32"	0.5313	0.2217	2490	3510	4280	4910	5450	5960	6410	6820	7200	7560	8230	8760	9370	9980	10 600	12 200	13 700	16 700	19 800
35/64"	0.5469	0.2349	2640	3720	4530	5200	5780	6310	6790	7220	7630	8010	8720	9290	9930	10 600	11 300	12 900	14 500	17 700	21 000
9/16"	0.5625	0.2485	2790	3940	4770	5500	6110	6680	7180	7640	8070	8470	9220	9820	10 500	11 200	11 900	13 600	15 300	18 800	22 000
37/64"	0.5781	0.2625	2950	4160	5060	5810	6450	7050	7590	8070	8520	8950	9740	10 370	11 100	11 900	12 600	14 400	16 200	19 800	23 400
19/32"	0.5938	0.2769	3110	4390	5340	6130	6810	7440	8000	8510	8990	9440	10 300	10 940	11 700	12 500	13 300	15 200	17 100	20 900	24 700
39/64"	0.6094	0.2917	3280	4620	5620	6450	7170	7830	8430	8970	9470	9940	10 900	11 600	12 400	13 200	14 000	16 000	18 000	22 000	26 000
5/8"	0.6250	0.3068	3450	4860	5910	6790	7540	8240	8870	9430	9960	10 500	11 400	12 200	12 700	13 900	14 700	16 800	18 900	23 100	27 400
41/64"	0.6406	0.3223	3620	5110	6210	7130	7920	8660	9310	9910	10 500	11 000	12 000	12 800	13 700	14 600	15 400	17 700	19 900	24 300	28 800
21/32"	0.6562	0.3382	3800	5360	6520	7480	8320	9080	9770	10 400	11 000	11 600	12 600	13 400	14 300	15 300	16 200	18 500	20 900	25 500	30 200
43/64"	0.6719	0.3545	3980	5620	6830	7840	8720	9520	10 300	10 900	11 500	12 100	13 200	14 000	15 000	16 000	17 000	19 400	21 900	26 700	31 600
11/16"	0.6875	0.3712	4170	5880	7150	8210	9130	9970	10 600	11 500	12 100	12 700	13 800	14 700	15 700	16 800	17 800	20 300	22 900	28 000	33 100
23/32"	0.7188	0.4057	4560	6430	7820	8970	9970	10 900	11 800	12 500	13 200	13 900	15 100	16 100	17 200	18 300	19 400	22 200	25 000	30 600	36 200
3/4"	0.7500	0.4418	4960	7000	8510	9770	10 900	11 900	12 800	13 600	14 400	15 100	16 400	17 500	18 700	19 900	21 200	24 200	27 200	33 300	39 400
25/32"	0.7812	0.4794	5390	7590	9240	10 600	11 800	12 900	13 900	14 800	15 600	16 400	17 800	19 000	20 300	21 600	22 900	26 200	29 500	36 100	42 800
13/16"	0.8125	0.5185	5830	8210	9990	11 500	12 800	14 000	15 000	16 000	16 900	17 700	19 300	20 500	22 000	23 400	24 800	28 400	32 000	39 100	46 200
27/32"	0.8438	0.5591	6280	8850	10 800	12 400	13 800	15 000	16 200	17 200	18 200	19 100	20 800	22 100	23 700	25 200	26 700	30 600	34 400	42 100	49 800
7/8"	0.8750	0.6013	6760	9520	11 600	13 300	14 800	16 200	17 400	18 500	19 600	20 500	22 300	23 800	25 500	27 100	28 800	32 900	37 000	45 300	53 600
29/32"	0.9062	0.6450	7250	10 200	12 400	14 300	15 900	17 400	18 700	19 000	21 000	22 000	24 000	25 500	26 400	29 100	30 900	35 300	39 700	48 600	57 500
15/16"	0.9375	0.6903	7750	10 900	13 300	15 300	17 000	18 600	20 000	21 200	22 400	23 600	25 600	27 500	29 200	31 100	33 000	37 800	42 500	52 000	61 500
31/32"	0.9688	0.7371	8280	11 700	14 200	16 300	18 200	19 800	21 300	22 700	24 000	25 100	27 400	29 200	31 200	33 200	35 300	40 300	45 400	55 600	65 700
1.0"	1.0000	0.7854	8820	12 400	15 100	17 400	19 300	21 100	22 700	24 200	25 500	26 800	29 200	31 100	33 200	35 400	37 600	43 000	48 400	59 200	70 000

Conversions, Equivalents, and Physical Data



Viscosities of Typical Fluids vs. Temperature

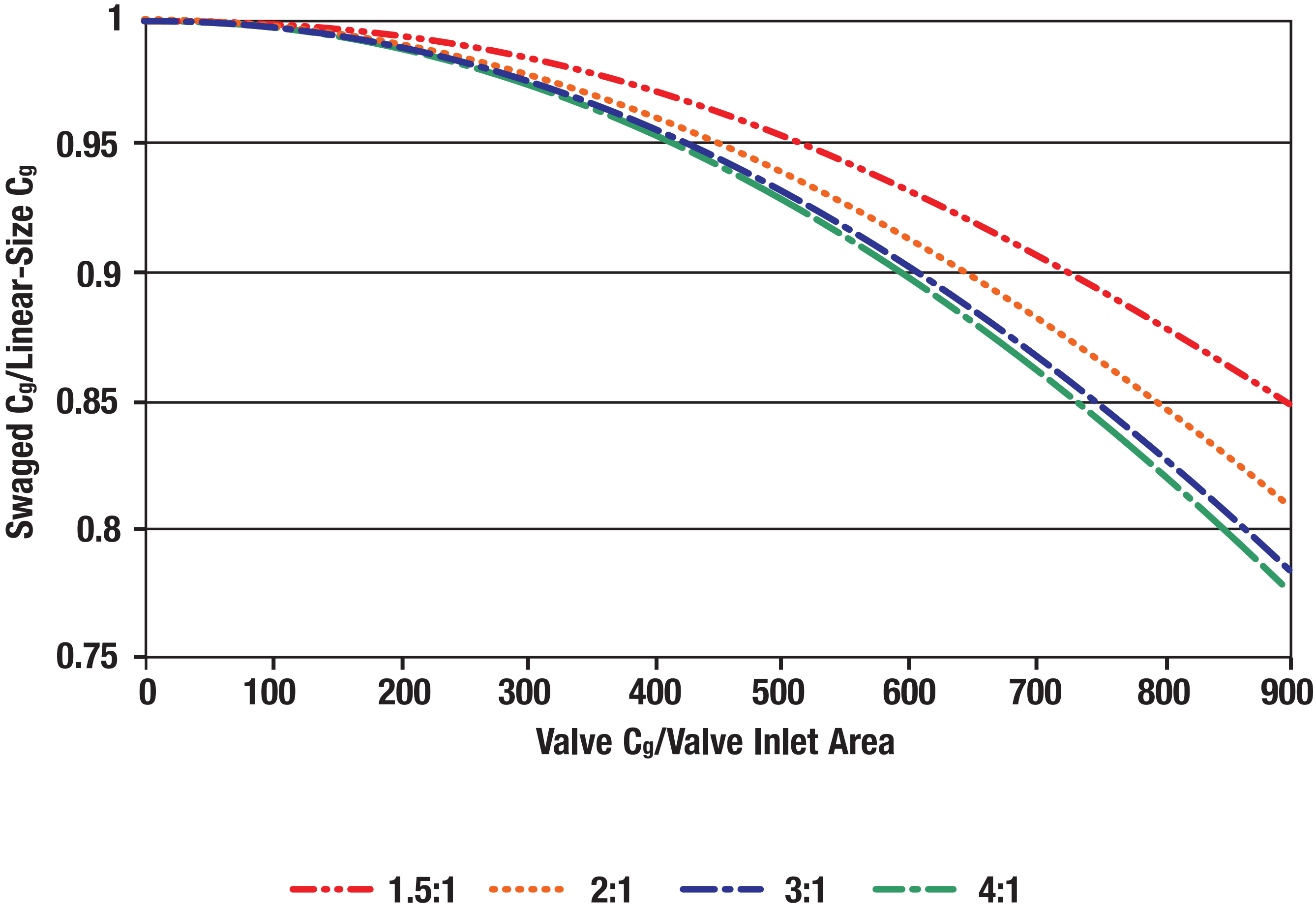
Conversions, Equivalents, and Physical Data



Specific Gravity of Typical Fluids vs. Temperature

Conversions, Equivalents, and Physical Data

Effect of Inlet Swage On Critical Flow C_g Requirements



Conversions, Equivalents, and Physical Data

Seat Leakage Classifications (In Accordance with ANSI/FCI 70-3-2004)		
LEAKAGE CLASS DESIGNATION	DESCRIPTION	MAXIMUM LEAKAGE ALLOWABLE
I	A modification of any Class II, III or IV regulator where the design intent is the same as the basic class, but by agreement between user and supplier, no test is required.	- - - -
II	This class establishes the maximum permissible leakage generally associated with commercial double-seat regulators with metal-to-metal seats.	0.5% of maximum Cv
III	This class establishes the maximum permissible leakage generally associated with Class II, but with a higher degree of seat and seal tightness.	0.1% of maximum Cv
IV	This class establishes the maximum permissible leakage generally associated with commercial unbalanced single-seat regulators with metal-to-metal seats.	0.01% of maximum Cv
VI	This class establishes the maximum permissible seat leakage generally associated with resilient seating regulators either balanced or unbalanced with O-rings or similar gapless seals.	Leakage per following table as expressed in ml per minute versus seat diameter.
VII	This class establishes the maximum permissible seat leakage generally associated with Class VI, but with test performed at the maximum operating differential pressure.	Leakage per following table as expressed in ml per minute versus seat diameter.

Nominal Port Diameter and Leak Rate		
NOMINAL PORT DIAMETER	LEAK RATE	
Millimeters (Inches)	Standard ml per Minute(3)	Bubbles per Minute(1)
≤25 (≤1)(2)	0,15	1(2)
38 (1.5)	0,30	2
51 (2)	0,45	3
64 (2.5)	0,60	4
76 (3)	0,90	6
102 (4)	1,70	11
152 (6)	4,00	27
203 (8)	6,75	45
250 (10)	11,1	- - - -
300 (12)	16,0	- - - -
350 (14)	21,6	- - - -
400 (16)	28,4	- - - -

1. Bubbles per minute as tabulated are an easily measured suggested alternative based on a suitable calibrated measuring device in this case a 0.24 inch (6 mm) O.D. x 0.04 inch (1 mm) wall tube submerged in water to a depth of from 0.12 to 0.24 inch (3 to 6 mm). The tube end shall be cut square and smooth with no chamfers or burrs and the tube axis shall be perpendicular to the surface of the water. Other apparatus may be constructed and the number of bubbles per minute may differ from those shown as long as they correctly indicate the flow in ml per minute.
2. If valve seat diameter differs by more than 0.08 inch (2 mm) from one of the valves listed, the leakage rate may be obtained by interpolation assuming that the leakage rate varies as the square of the seat diameter.
3. Standard millimeters based on 60 °F (16 °C) and 14.73 psia (1,016 bar a).

Conversions, Equivalents, and Physical Data

Flange, Valve Size, and Pressure-Temperature Rating Designations

Sizes of ASME flanges are designated as NPS (for "nominal pipe size"). The nominal size is based on inches, but the units are not required in the designation. For example: NPS 2 is the size. Pressure ratings are designated by class. For example, CL150 is the rating. ASME designations replace ANSI designations.

Sizes of EN and ISO flanges are designated with DN (for "nominal diameter"). The nominal diameter is based on millimeters, but the units are not included in the designation. For example: DN 50 is the size. Pressure ratings are designated by PN (for "nominal pressure"). For example PN 40 is the pressure rating. EN and ISO designations replace DIN designations through PN 100.

ASME B16.5 flanges will mate with EN 1759 flanges but not with EN 1092 flanges (formerly DIN flanges). ASME B16.5 flanges will mate with most ISO 7005 flanges.

Common size designations in wide use are shown in the table below.

A summary of flange terminology is shown in the table below, and equivalency of flanges is shown in the table on the following page.

Pipe Thread Standards

There are three pipe thread standards that are accepted globally:

- NPT, ASME B1.20.1: General-purpose pipe threads (inches).
- G Series, ISO 228-1: Pipe threads for use where pressure-tight joints are not made on the threads. The internal and external threads are not tapered but are parallel or straight.
- R Series, ISO 7/1: Pipe threads for use where pressure-tight joints are made on the threads. The internal thread is parallel (straight) or tapered; external is always tapered.

Notes

Japanese (JIS) valves and flanges are designated according to JIS standards.

European Norm flange types, such as flat-face and raised-face are designated Type A, Type B, Type C. These types do not correspond to the DIN 2526 Form A, Form D, etc., designations.

Common Size Designations

NPS	1/2	3/4	1	1-1/2	2	2-1/2	3	4	6	8	10	12	14	16	18	20	24
DN	15	20	25	40	50	65	80	100	150	200	250	300	350	400	450	500	600

Summary of Flange Terminology

	ASME	EUROPEAN NORM	EXAMPLE OF PRINTED PRESENTATION
Pressure Rating	CLASS	PN	CL300 or CL300, PN 40
Size	NPS	DN	NPS 2, DN 50
Pipe Threads (Internal or External)	NPT	NPT, G (Straight), R (Tapered)	G 1/4, 1/4 NPT, 1/4 NPT Internal (or External)

Conversions, Equivalents, and Physical Data

Equivalency Table

	ISO	ASME	DIN	EUROPEAN NORM	LIMITATIONS
ASME and European Norm Only	- - - -	Class Flanges ASME B16.5	- - - -	EN 1759-1	Specifies ASTM materials but also permits European materials per EN 1092-1.
European Norm Only	- - - -			EN 1092	Through PN 100(1)
DIN Only	- - - -		DIN(2)	- - - -	Above PN 100(1)
ISO and ASME Only	ISO 7005	Class Flanges ASME B16.5	- - - -		A few sizes are compatible to previous DIN standards. An older version contained flange designations that do not appear in the current standard.

1. DIN is no longer used except for pressure ratings above PN 100.
2. DIN standards 2628, 2629, 2638, 2548, 2549, 2550, and 2551.

Standard Pressure-Temperature Ratings for ASME CL150 Valve Bodies(1)

SERVICE TEMPERATURE, °F (°C)	WORKING PRESSURE, PSIG (bar)				
	LCB	LCC/WCC	WCB	CF8 or 304	CF8M/CF3M
-20 to 100 (-29 to 38) 200 (93)	265 (18,3) 255 (17,6)	290 (20,0) 260 (17,9)	285 (19,7) 260 (17,9)	275 (19,0) 230 (15,9)	275 (19,0) 235 (16,2)
300 (149) 400 (204)	230 (15,9) 200 (13,8)	230 (15,9) 200 (13,8)	230 (15,9) 200 (13,8)	205 (14,1) 190 (13,1)	215 (14,8) 195 (13,4)
500 (260) 600 (316)	170 (11,7) 140 (9,7)	170 (11,7) 140 (9,7)	170 (11,7) 140 (9,7)	170 (11,7) 140 (9,7)	170 (11,7) 140 (9,7)
650 (343) 700 (371)	125 (8,6) 110 (7,6)	125 (8,6) 110 (7,6)	125 (8,6) 110 (7,6)	125 (8,6) 110 (7,6)	125 (8,6) 110 (7,6)

1. Table information is extracted from the Valve-Flanged, Threaded, and Welding End, ASME Standard B16.34-2004. These tables must be used in accordance with the ASME standard.

Standard Pressure-Temperature Ratings for ASME CL300 Valve Bodies(1)

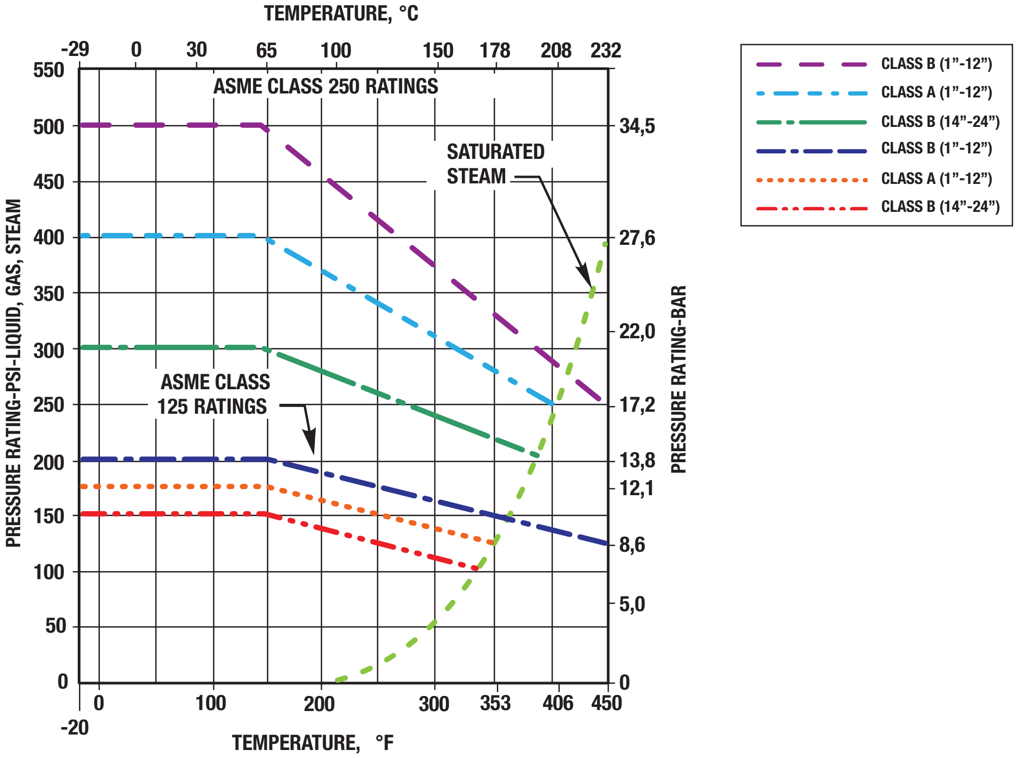
SERVICE TEMPERATURE, °F (°C)	WORKING PRESSURE, PSIG (bar)				
	LCB	LCC/WCC	WCB	CF8 or 304	CF8M/CF3M
-20 to 100 (-29 to 38) 200 (93)	695 (47,9) 660 (45,5)	750 (51,7) 750 (51,7)	740 (51,0) 680 (46,9)	720 (49,6) 600 (41,4)	720 (49,6) 620 (42,7)
300 (149) 400 (204)	640 (44,1) 615 (42,4)	730 (50,3) 705 (48,6)	655 (45,2) 635 (43,8)	540 (37,2) 495 (34,1)	560 (38,6) 515 (35,5)
500 (260) 600 (316)	585 (40,3) 550 (37,9)	665 (45,9) 605 (41,7)	605 (41,7) 570 (39.3)	465 (32,1) 440 (30.3)	480 (33,1) 450 (31,0)
650 (343) 700 (371)	535 (36,8) 510 (35,2)	590 (40,7) 555 (38,3)	550 (38,0) 530 (36,5)	430 (29,6) 420 (29,0)	440 (30,3) 435 (30,0)

1. Table information is extracted from the Valve-Flanged, Threaded, and Welding End, ASME Standard B16.34-2004. These tables must be used in accordance with the ASME standard.

Conversions, Equivalents, and Physical Data

Standard Pressure-Temperature Ratings for ASME CL600 Valve Bodies[1]					
SERVICE TEMPERATURE, °F (°C)	WORKING PRESSURE, PSIG (bar)				
	LCB	LCC/WCC	WCB	CF8 or 304	CF8M/CF3M
-20 to 100 (-29 to 38) 200 (93)	1395 (96,2) 1320 (91,0)	1500 (103) 1500 (103)	1480 (102) 1360 (93,7)	1440 (99,3) 1200 (82,7)	1440 (99,3) 1240 (85,5)
300 (149) 400 (204)	1275 (87,9) 1230 (84,8)	1455 (100) 1405 (97,0)	1310 (90,3) 1265 (87,2)	1075 (74,1) 995 (68,6)	1120 (77,2) 1025 (70,7)
500 (260) 600 (316)	1175 (81,0) 1105 (76,2)	1330 (91,7) 1210 (83,4)	1205 (83,1) 1135 (78,3)	930 (64,1) 885 (61,0)	955 (65,8) 900 (62,1)
650 (343) 700 (371)	1065 (73,4) 1025 (70,7)	1175 (81,0) 1110 (76,5)	1100 (75,8) 1060 (73,1)	865 (59,6) 845 (58,3)	885 (61,0) 870 (60,0)

1. Table information is extracted from the Valve-Flanged, Threaded, and Welding End, ASME Standard B16.34-2004. These tables must be used in accordance with the ASME standard.



Pressure/Temperature Ratings for ASTM A126 Cast Iron Valves

Conversions, Equivalents, and Physical Data

Diameter of Bolt Circles						
NOMINAL PIPE SIZE, INCHES	ASMECL125 (CAST IRON) OR CL150 (STEEL)(1)	ASME CL250 (CAST IRON) OR CL300 (STEEL)(2)	ASME CL600	ASME CL900	ASME CL1500	ASME CL2500
1	3.12	3.50	3.50	4.00	4.00	4.25
1-1/4	3.50	3.88	3.88	4.38	4.38	5.12
1-1/2	3.88	4.50	4.50	4.88	4.88	5.75
2	4.75	5.00	5.00	6.50	6.50	6.75
2-1/2	5.50	5.88	5.88	7.50	7.50	7.75
3	6.00	6.62	6.62	7.50	8.00	9.00
4	7.50	7.88	8.50	9.25	9.50	10.75
5	8.50	9.25	10.50	11.00	11.50	12.75
6	39.50	10.62	11.50	12.50	12.50	14.50
8	11.75	13.00	13.75	15.50	15.50	17.25
10	14.25	15.25	17.00	18.50	19.00	21.75
12	17.00	17.75	19.25	21.00	22.50	24.38
14	18.75	20.25	20.75	22.00	25.00	- - - -
16	21.25	22.50	23.75	24.25	27.75	- - - -
18	22.75	24.75	25.75	27.00	30.50	- - - -
20	25.00	27.00	28.50	29.50	32.75	- - - -
24	29.50	32.00	33.00	35.50	39.00	- - - -
30	36.00	39.25	- - - -	- - - -	- - - -	- - - -
36	42.75	46.00	- - - -	- - - -	- - - -	- - - -
42	49.50	52.75	- - - -	- - - -	- - - -	- - - -
48	56.00	60.75	- - - -	- - - -	- - - -	- - - -

1. Sizes 1 through 12-inches also apply to ASME Class 150 bronze flanges.
2. Sizes 1 through 8-inches also apply to ASME Class 300 bronze flanges.

ASME Face-To-Face Dimensions for Flanged Regulators						
BODY SIZE, INCHES	ASME CLASS AND END CONNECTIONS (INCH DIMENSIONS ARE IN ACCORDANCE WITH ISA S4.01.1-1997)					
	CL125 FF (Cast Iron) CL150 RF (Steel), Inches (mm)	CL250 RF (Cast Iron) CL300 RF (Steel), Inches (mm)	CL150 RJT (Steel), Inches (mm)	CL300 RJT (Steel), Inches (mm)	CL600 RF (Steel), Inches (mm)	CL600 RJT (Steel), Inches (mm)
1	7.25 (184)	7.75 (197)	7.75 (197)	8.25 (210)	8.25 (210)	8.25 (210)
1-1/4	7.88 (200)	8.38 (213)	8.38 (213)	8.88 (226)	9.00 (229)	9.00 (229)
1-1/2	8.75 (222)	9.25 (235)	9.25 (235)	9.75 (248)	9.88 (251)	9.88 (251)
2	10.00 (254)	10.50 (267)	10.50 (267)	11.12 (282)	11.25 (286)	11.38 (289)
2-1/2	10.88 (276)	11.50 (292)	11.38 (289)	12.12 (308)	12.25 (311)	12.38 (314)
3	11.75 (298)	12.50 (317)	12.25 (311)	13.12 (333)	13.25 (337)	13.38 (340)
4	13.88 (353)	14.50 (368)	14.38 (365)	15.12 (384)	15.50 (394)	15.62 (397)
6	17.75 (451)	18.62 (473)	18.25 (464)	19.25 (489)	20.00 (508)	20.12 (511)
8	21.38 (543)	22.38 (568)	21.88 (556)	23.00 (584)	24.00 (610)	24.12 (613)
10	26.50 (673)	27.88 (708)	27.00 (686)	28.50 (724)	29.62 (752)	29.75 (756)
12	29.00 (737)	30.50 (775)	29.50 (749)	31.12 (790)	32.25 (819)	32.38 (822)
16	40.00 (1016)	41.62 (1057)	40.50 (1029)	42.25 (1073)	43.62 (1108)	43.75 (1111)

FF—Flat-faced, RF—Raised-faced, and RTJ—Ring Type Joint

Conversions, Equivalents, and Physical Data

Wear and Galling Resistance Chart of Material Combinations

MATERIAL	304 STAINLESS STEEL	316 STAINLESS STEEL	BRONZE	INCONEL®	MONEL®	HASTELLOY® C	NICKEL
304 Stainless Steel	P	P	F	P	P	F	P
316 Stainless Steel	P	P	F	P	P	F	P
Bronze	F	F	S	S	S	S	S
Inconel®	P	P	S	P	P	F	F
Monel®	P	P	S	P	P	F	F
Hastelloy® C	F	F	S	F	F	F	F
Nickel	P	P	S	P	F	F	P
Alloy 20	P	P	S	F	F	F	P
Type 416 Hard	F	F	F	F	F	F	F
Type 440 Hard	F	F	F	F	F	F	F
17-4PH	F	F	F	F	F	F	F
ENC(1)	F	F	F	F	F	F	F
Cr Plate	F	F	F	F	F	S	S
Al Bronze	F	F	F	S	S	S	S

1. Electroless Nickel Coating
F - Fair
S - Satisfactory
P - Poor

- continued -

Wear and Galling Resistance Chart of Material Combinations (continued)

MATERIAL	ALLOY 20	TYPE 416 HARD	TYPE 440 HARD	17-4PH	ENC(1)	Cr PLATE	Al BRONZE
304 Stainless Steel	P	F	F	F	F	F	F
316 Stainless Steel	P	F	F	F	F	F	F
Bronze	S	F	F	F	F	F	F
Inconel®	F	F	F	F	F	F	S
Monel®	F	F	F	F	F	F	S
Hastelloy® C	F	F	F	F	F	S	S
Nickel	P	F	F	F	F	F	S
Alloy 20	P	F	F	F	F	F	S
Type 416 Hard	F	F	F	F	S	S	S
Type 440 Hard	F	S	F	S	S	S	S
17-4PH	F	F	S	P	S	S	S
ENC(1)	F	S	S	S	P	S	S
Cr Plate	S	S	S	S	S	P	S
Al Bronze	S	S	S	S	S	S	P

1. Electroless Nickel Coating
F - Fair
S - Satisfactory
P - Poor

Equivalent Lengths of Pipe Fittings and Valves

TYPE OF FITTING OR VALVE	LENGTHS IN FEET OF STANDARD PIPE																	
	Nominal Pipe Size in Inches																	
	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	6	8	10	12	14 O.D.	16 O.D.	18 O.D.	20 O.D.	24 O.D.	30 O.D.
Standard tee with entry or discharge through side	3.4	4.5	5.5	7.5	9.0	12	14	17	22	33	43	55	65	78	85	105	115	135	170
Standard elbow or run(1) of tee reduced 1/2(2)	1.7	2.2	2.7	3.7	4.3	5.5	6.5	8	12	16	20	26	31	36	42	47	52	64	80
Medium sweep elbow or run(1) of tee reduced 1/4(2)	1.3	1.8	2.3	3.0	3.7	4.6	5.4	6.8	9.0	14	18	22	26	30	35	40	43	55	67
Long sweep elbow or run(1) of standard tee or butterfly valve	1	1.3	1.7	2.3	2.7	3.5	4.2	5.3	7	11	14	17	20	23	26	31	34	41	52
45° elbow	0.8	1.0	1.2	1.6	2.0	2.5	3.0	3.7	5.0	7.5	10	12	15	17	20	22	24	30	37
Close return bend	3.7	5.1	6.2	8.5	10	13	15	19	24	37	49	62	75	86	100	110	125	150	185
Globe valve, wide-open	0.6	22	27	40	43	45	65	82	120	170	240	290	340	400	440	500	550	680	850
Angle valve, wide-open	8.2	11	14	18	21	28	33	42	56	85	112	145	165	190	220	250	280	340	420
Swing check valve, wide-open	4.0	5.2	6.6	9.0	11	14	16	19	26	39	52	66	78	92	106	120	130	145	160
Gate valve, wide-open, or slight bushing reduction	0.4	0.5	0.6	0.8	0.9	1.2	1.3	1.7	2.3	3.5	4.5	5.7	6.7	8.0	9.0	11	12	14	17

1. A fluid is said to flow through the run of a tee when the flow is straight through the tee with no change of direction.
2. A tee is said to be reduced 1/4 if the internal area of the smaller connecting pipe is 25% less than the internal area of the larger connecting pipe.

Conversions, Equivalents, and Physical Data

Pipe Data: Carbon and Allow Steel—Stainless Steel											
NOMINAL PIPE SIZE (INCHES)	OUTSIDE DIAMETER (INCHES)	IDENTIFICATION			WALL THICKNESS (t) (INCHES)	INSIDE DIAMETER (d) (INCHES)	AREA OF METAL (SQUARE INCHES)	TRANSVERSE INTERNAL AREA		WEIGHT PIPE (POUNDS PER FOOT)	WEIGHT WATER (POUNDS PER FOOT OF PIPE)
		Steel		Stainless Steel Schedule No.				(a) (Square Inches)	(A) (Square Feet)		
		Iron Pipe Size	Schedule No.								
1/8	0.405	- - - -	- - - -	10S	0.049	0.307	0.0548	0.0740	0.00051	0.19	0.032
		STD	40	40S	0.068	0.269	0.0720	0.0568	0.00040	0.24	0.025
		XS	80	80S	0.095	0.215	0.0925	0.0365	0.00025	0.31	0.016
1/4	0.540	- - - -	- - - -	10S	0.065	0.410	0.0970	0.1320	0.00091	0.33	0.057
		STD	40	40S	0.088	0.364	0.1250	0.1041	0.00072	0.42	0.045
		XS	80	80S	0.119	0.302	0.1574	0.0716	0.00050	0.54	0.031
3/8	0.675	- - - -	- - - -	10S	0.065	0.545	0.1246	0.2333	0.00162	0.42	0.101
		STD	40	40S	0.091	0.493	0.1670	0.1910	0.00133	0.57	0.083
		XS	80	80S	0.126	0.423	0.2173	0.1405	0.00098	0.74	0.061
1/2	0.840	- - - -	- - - -	5S	0.065	0.710	0.1583	0.3959	0.00275	0.54	0.172
		- - - -	- - - -	10S	0.083	0.674	0.1974	0.3568	0.00248	0.67	0.155
		STD	40	40S	0.109	0.622	0.2503	0.3040	0.00211	0.85	0.132
		XS	80	80S	0.147	0.546	0.3200	0.2340	0.00163	1.09	0.102
		- - - -	160	- - - -	0.187	0.466	0.3836	0.1706	0.00118	1.31	0.074
		XXS	- - - -	- - - -	0.294	0.252	0.5043	0.050	0.00035	1.71	0.022
3/4	1.050	- - - -	- - - -	5S	0.065	0.920	0.2011	0.6648	0.00462	0.69	0.288
		- - - -	- - - -	10S	0.083	0.884	0.2521	0.6138	0.00426	0.86	0.266
		STD	40	40S	0.113	0.824	0.3326	0.5330	0.00371	1.13	0.231
		XS	80	80S	0.154	0.742	0.4335	0.4330	0.00300	1.47	0.188
		- - - -	160	- - - -	0.219	0.612	0.5698	0.2961	0.00206	1.94	0.128
		XXS	- - - -	- - - -	0.308	0.434	0.7180	0.148	0.00103	2.44	0.064
1	1.315	- - - -	- - - -	5S	0.065	1.185	0.2553	1.1029	0.00766	0.87	0.478
		- - - -	- - - -	10S	0.109	1.097	0.4130	0.9452	0.00656	1.40	0.409
		STD	40	40S	0.133	1.049	0.4939	0.8640	0.00600	1.68	0.375
		XS	80	80S	0.065	0.957	0.6388	0.7190	0.00499	2.17	0.312
		- - - -	160	- - - -	0.250	0.815	0.8365	0.5217	0.00362	2.84	0.230
		XXS	- - - -	- - - -	0.358	0.599	1.0760	0.282	0.00196	3.66	0.122
1-1/4	1.660	- - - -	- - - -	5S	0.065	1.530	0.3257	1.839	0.01277	1.11	0.797
		- - - -	- - - -	10S	0.109	1.442	0.4717	1.633	0.01134	1.81	0.708
		STD	40	40S	0.140	1.380	0.6685	1.495	0.01040	2.27	0.649
		XS	80	80S	0.191	1.278	0.8815	1.283	0.00891	3.00	0.555
		- - - -	160	- - - -	0.250	1.160	1.1070	1.057	0.00734	3.76	0.458
		XXS	- - - -	- - - -	0.382	0.896	1.534	0.630	0.00438	5.21	0.273
1-1/2	1.900	- - - -	- - - -	5S	0.065	1.770	0.3747	2.461	0.01709	1.28	1.066
		- - - -	- - - -	10S	0.109	1.682	0.6133	2.222	0.01543	2.09	0.963
		STD	40	40S	0.145	1.610	0.7995	2.036	0.01414	2.72	0.882
		XS	80	80S	0.200	1.500	1.068	1.767	0.01225	3.63	0.765
		- - - -	160	- - - -	0.281	1.338	1.429	1.406	0.00976	4.86	0.608
		XXS	- - - -	- - - -	0.400	1.100	1.885	0.950	0.00660	6.41	0.42
2	2.375	- - - -	- - - -	5S	0.065	2.245	0.4717	3.958	0.02749	1.61	1.72
		- - - -	- - - -	10S	0.109	2.157	0.7760	3.654	0.02538	2.64	1.58
		STD	40	40S	0.154	2.067	1.075	3.355	0.02330	3.65	1.45
		XS	80	80S	0.218	1.939	1.477	2.953	0.02050	5.02	1.28
		- - - -	160	- - - -	0.344	1.687	2.190	2.241	0.01556	7.46	0.97
		XXS	- - - -	- - - -	0.436	1.503	2.656	1.774	0.01232	9.03	0.77

Identification, wall thickness and weights are extracted from ASME B36.10 and B39.19.
The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe, respectively.
Transverse internal area values listed in "square feet" also represent volume in cubic feet per foot of pipe length.

- continued -

Conversions, Equivalents, and Physical Data

Pipe Data: Carbon and Allow Steel—Stainless Steel (continued)											
NOMINAL PIPE SIZE (INCHES)	OUTSIDE DIAMETER (INCHES)	IDENTIFICATION			WALL THICKNESS (t) (INCHES)	INSIDE DIAMETER (d) (INCHES)	AREA OF METAL (SQUARE INCHES)	TRANSVERSE INTERNAL AREA		WEIGHT PIPE (POUNDS PER FOOT)	WEIGHT WATER (POUNDS PER FOOT OF PIPE)
		Steel		Stainless Steel Schedule No.				(a) (Square Inches)	(A) (Square Feet)		
		Iron Pipe Size	Schedule No.								
2-1/2	2.875	- - - -	- - - -	5S	0.083	2.709	0.7280	5.764	0.04002	2.48	2.50
		- - - -	- - - -	10S	0.120	2.635	1.039	5.453	0.03787	3.53	2.36
		STD	40	40S	0.203	2.469	1.704	4.788	0.03322	5.79	2.07
		XS	80	80S	0.279	2.323	2.254	4.238	0.02942	7.66	1.87
		- - - -	160	- - - -	0.375	2.125	2.945	3.546	0.02463	10.01	1.54
		XXS	- - - -	- - - -	0.552	1.771	4.028	2.464	0.01710	13.69	1.07
3	3.500	- - - -	- - - -	5S	0.083	3.334	0.8910	8.730	0.06063	3.03	3.78
		- - - -	- - - -	10S	0.120	3.260	1.274	8.347	0.05796	4.33	3.62
		STD	40	40S	0.216	3.068	2.228	7.393	0.05130	7.58	3.20
		XS	80	80S	0.300	2.900	3.016	6.605	0.04587	10.25	2.86
		- - - -	160	- - - -	0.438	2.624	4.205	5.408	0.03755	14.32	2.35
		XXS	- - - -	- - - -	0.600	2.300	5.466	4.155	0.02885	18.58	1.80
3-1/2	4.000	- - - -	- - - -	5S	0.083	3.834	1.021	11.545	0.08017	3.48	5.00
		- - - -	- - - -	10S	0.120	3.760	1.463	11.104	0.07711	4.97	4.81
		STD	40	40S	0.226	3.548	2.680	9.886	0.06870	9.11	4.29
		XS	80	80S	0.318	3.364	3.678	8.888	0.06170	12.50	3.84
4	4.500	- - - -	- - - -	5S	0.083	4.334	1.152	14.75	0.10245	3.92	6.39
		- - - -	- - - -	10S	0.120	4.260	1.651	14.25	0.09898	5.61	6.18
		STD	40	40S	0.237	4.026	3.174	12.73	0.08840	10.79	5.50
		XS	80	80S	0.337	3.826	4.407	11.50	0.07986	14.98	4.98
		- - - -	120	- - - -	0.438	3.624	5.595	10.31	0.0716	19.00	4.47
		- - - -	160	- - - -	0.531	3.438	6.621	9.28	0.0645	22.51	4.02
		XXS	- - - -	- - - -	0.674	3.152	8.101	7.80	0.0542	27.54	3.38
5	5.563	- - - -	- - - -	5S	0.109	5.345	1.868	22.44	0.1558	6.36	9.72
		- - - -	- - - -	10S	0.134	5.295	2.285	22.02	0.1529	7.77	9.54
		STD	40	40S	0.258	5.047	4.300	20.01	0.1390	14.62	8.67
		XS	80	80S	0.375	4.813	6.112	18.19	0.1263	20.78	7.88
		- - - -	120	- - - -	0.500	4.563	7.953	16.35	0.1136	27.04	7.09
		- - - -	160	- - - -	0.625	4.313	9.696	14.61	0.1015	32.96	6.33
		XXS	- - - -	- - - -	0.750	4.063	11.340	12.97	0.0901	38.55	5.61
6	6.625	- - - -	- - - -	5S	0.109	6.407	2.231	32.24	0.2239	7.60	13.97
		- - - -	- - - -	10S	0.134	6.357	2.733	31.74	0.2204	9.29	13.75
		STD	40	40S	0.280	6.065	5.581	28.89	0.2006	18.97	12.51
		XS	80	80S	0.432	5.761	8.405	26.07	0.1810	28.57	11.29
		- - - -	120	- - - -	0.562	5.501	10.70	23.77	0.1650	36.39	10.30
		- - - -	160	- - - -	0.719	5.187	13.32	21.15	0.1469	45.35	9.16
		XXS	- - - -	- - - -	0.864	4.897	15.64	18.84	0.1308	53.16	8.16
9	8.625	- - - -	- - - -	5S	0.109	8.407	2.916	55.51	0.3855	9.93	24.06
		- - - -	- - - -	10S	0.148	8.329	3.941	54.48	0.3784	13.40	23.61
		- - - -	20	- - - -	0.250	8.125	6.57	51.85	0.3601	22.36	22.47
		- - - -	30	- - - -	0.277	8.071	7.26	51.16	0.3553	24.70	22.17
		STD	40	40S	0.322	7.981	8.40	50.03	0.3474	28.55	21.70
		- - - -	60	- - - -	0.406	7.813	10.48	47.94	0.3329	35.64	20.77
		XS	80	80S	0.500	7.625	12.76	45.66	0.3171	43.39	19.78
		- - - -	100	- - - -	0.594	7.437	14.96	43.46	0.3018	50.95	18.83
		- - - -	120	- - - -	0.719	7.187	17.84	40.59	0.2819	60.71	17.59
		- - - -	140	- - - -	0.812	7.001	19.93	38.50	0.2673	67.76	16.68
		XXS	- - - -	- - - -	0.875	6.875	21.30	37.12	0.2578	72.42	16.10
		- - - -	160	- - - -	0.906	6.813	21.97	36.46	0.2532	74.69	15.80
10	10.750	- - - -	- - - -	5S	0.134	10.482	4.36	86.29	0.5992	15.19	37.39
		- - - -	- - - -	10S	0.165	10.420	5.49	85.28	0.5922	18.65	36.95
		- - - -	20	- - - -	0.250	10.250	8.24	82.52	0.5731	28.04	35.76
		- - - -	30	- - - -	0.307	10.136	10.07	80.69	0.5603	34.24	34.96
		STD	40	40S	0.365	10.020	11.90	78.86	0.5475	40.48	34.20
		XS	60	80S	0.500	9.750	16.10	74.66	0.5185	54.74	32.35
		- - - -	80	- - - -	0.594	9.562	18.92	71.84	0.4989	64.43	31.13
		- - - -	100	- - - -	0.719	9.312	22.63	68.13	0.4732	77.03	29.53
		- - - -	120	- - - -	0.844	9.062	26.24	64.53	0.4481	89.29	27.96
		XXS	140	- - - -	1.000	8.750	30.63	60.13	0.4176	104.13	26.06
		- - - -	160	- - - -	1.125	8.500	34.02	56.75	0.3941	115.64	24.59

Identification, wall thickness and weights are extracted from ASME B36.10 and B39.19.
The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe, respectively.
Transverse internal area values listed in “square feet” also represent volume in cubic feet per foot of pipe length.

Conversions, Equivalents, and Physical Data

American Pipe Flange Dimensions

ASME CLASS FLANGE DIAMETER - INCHES, PER ASME B16.1, B16.5, AND B16.24

Nominal Pipe Size	125 (Cast Iron) or 150 (Steel)[1]	250 (Cast Iron) or 300 (Steel)[2]	600	900	1500	2500
1	4.25	4.88	4.88	5.88	5.88	6.25
1-1/4	4.62	5.25	5.25	6.25	6.25	7.25
1-1/2	5.00	6.12	6.12	7.00	7.00	8.00
2	6.00	6.50	6.50	8.50	8.50	9.25
2-1/2	7.00	7.50	7.50	9.62	9.62	10.50
3	7.50	8.25	8.25	9.50	10.50	12.00
4	9.00	10.00	10.75	11.50	12.25	14.00
5	10.00	11.00	13.00	13.75	14.75	16.50
6	11.00	12.50	14.00	15.00	15.50	19.00
8	13.50	15.00	16.50	18.50	19.00	21.75
10	16.00	17.50	20.00	21.50	23.00	26.50
12	19.00	20.50	22.00	24.00	26.50	30.00
14	21.00	23.00	23.75	25.25	29.50	----
16	23.50	25.50	27.00	27.75	32.50	----
18	25.00	28.00	29.25	31.00	36.00	----
20	27.50	30.50	32.00	33.75	38.75	----
24	32.00	36.00	37.00	41.00	46.00	----
30	38.75	43.00	----	----	----	----
36	46.00	50.00	----	----	----	----
42	53.00	57.00	----	----	----	----
48	59.50	65.00	----	----	----	----

1. Sizes 1 through 12-inch also apply to ASME Class 150 bronze flanges.
2. Sizes 1 through 8-inch also apply to ASME Class 300 bronze flanges.

American Pipe Flange Dimensions

ASME CLASS, NUMBER OF STUD BOLTS AND HOLE DIAMETER IN INCHES, PER ASME B16.1, B16.5, AND B16.24

Nominal Pipe Size	125 (Cast Iron) or 150 (Steel)[1]		250 (Cast Iron) or 300 (Steel)[2]		600		900		1500		2500	
	No.	Ø	No.	Ø	No.	Ø	No.	Ø	No.	Ø	No.	Ø
1	4	0.50	4	0.62	4	0.62	4	0.88	4	0.88	4	0.88
1-1/4	4	0.50	4	0.62	4	0.62	4	0.88	4	0.88	4	1.00
1-1/2	4	0.50	4	0.75	4	0.75	4	1.00	4	1.00	4	1.12
2	4	0.62	8	0.62	8	0.62	8	0.88	8	0.88	8	1.00
2-1/2	4	0.62	8	0.75	8	0.75	8	1.00	8	1.00	8	1.12
3	4	0.62	8	0.75	8	0.75	8	0.88	8	1.12	8	1.25
4	8	0.62	8	0.75	8	0.75	8	0.12	8	1.25	8	1.50
5	8	0.75	8	0.75	8	1.00	8	1.25	8	1.50	8	1.75
6	8	0.75	12	0.75	12	1.00	12	1.12	12	1.38	8	2.00
8	8	0.75	12	0.88	12	1.12	12	1.38	12	1.62	12	2.00
10	12	0.88	16	1.00	16	1.25	16	1.38	12	1.88	12	2.50
12	12	0.88	16	1.12	20	1.25	20	1.38	16	2.00	12	2.75
14	12	1.00	20	1.12	20	1.38	20	1.50	16	2.25	----	----
16	16	1.00	20	1.25	20	1.50	20	1.62	16	2.50	----	----
18	16	1.12	24	1.25	20	1.62	20	1.88	16	2.75	----	----
20	20	1.12	24	1.25	24	1.62	20	2.00	16	3.00	----	----
24	20	1.25	24	1.50	24	1.88	20	2.50	16	3.50	----	----
30	28	1.25	28	1.75	----	----	----	----	----	----	----	----
36	32	1.50	32	2.00	----	----	----	----	----	----	----	----
42	36	1.50	36	2.00	----	----	----	----	----	----	----	----
48	44	1.50	40	2.00	----	----	----	----	----	----	----	----

1. Sizes 1 through 12-inch also apply to ASME Class 150 bronze flanges.
2. Sizes 1 through 8-inch also apply to ASME Class 300 bronze flanges.

EN 1092-1 Cast Steel Flange Standard-PN 16 (Nominal Pressure 16 bar)

NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm		
		Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter
10	6	90	16	60	4	M12	14
15	6	95	16	65	4	M12	14
20	6,5	105	18	75	4	M12	14
25	7	115	18	85	4	M12	14
32	7	140	18	100	4	M16	18
40	7,5	150	18	110	4	M16	18
50	8	165	20	125	4	M16	18
65	8	185	18	145	4	M16	18
80	8,5	200	20	160	8	M16	18
100	9,5	220	20	180	8	M16	18
125	10	250	22	210	8	M16	18
150	11	285	22	240	8	M20	23
175	12	315	24	270	8	M20	23
200	12	340	24	295	12	M20	23
250	14	405	26	355	12	M24	27
300	15	460	28	410	12	M24	27
350	16	520	30	470	16	M24	27
400	18	580	32	525	16	M27	30
500	21	715	36	650	20	M30	33
600	23	840	40	770	20	M33	36
700	24	910	42	840	24	M33	36
800	26	1025	42	950	24	M36	39
900	27	1125	44	1050	28	M36	39
1000	29	1255	46	1170	28	M39	42
1200	32	1485	52	1390	32	M45	48
1400	34	1685	58	1590	36	M45	48
1600	36	1930	64	1820	40	M52	56
1800	39	2130	68	2020	44	M52	56
2000	41	2345	70	2230	48	M56	62
2200	43	2555	74	2440	52	M56	62

EN 1092-1 Cast Steel Flange Standard-PN 25 (Nominal Pressure 25 bar)

NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm		
		Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter
10	6	90	16	60	4	M12	14
15	6	95	16	65	4	M12	14
20	6,5	105	18	75	4	M12	14
25	7	115	18	85	4	M12	14
32	7	140	18	100	4	M16	18
40	7,5	150	18	110	4	M16	18
50	8	165	20	125	4	M16	18
65	8,5	185	22	145	8	M16	18
80	9	200	24	160	8	M16	18
100	10	235	24	190	8	M20	23
125	11	270	26	220	8	M24	27
150	12	300	28	250	8	M24	27
175	12	330	28	280	12	M24	27
200	12	360	30	310	12	M24	27
250	14	425	32	370	12	M27	30
300	15	485	34	430	16	M27	30
350	16	555	38	490	16	M30	33
400	18	620	40	550	16	M33	36
500	21	730	44	660	20	M33	36
600	23	845	46	770	20	M36	39
700	24	960	50	875	24	M39	42
800	26	1085	54	990	24	M45	48
900	27	1185	58	1090	28	M45	48
1000	29	1320	62	1210	28	M52	56
1200	32	1530	70	1420	32	M52	56
1400	34	1755	76	1640	36	M56	62
1600	37	1975	84	1860	40	M56	62
1800	40	2195	90	2070	44	M64	70
2000	43	2425	96	2300	48	M64	70

Conversions, Equivalents, and Physical Data

EN 1092-1 Cast Steel Flange Standard–PN 40 (Nominal Pressure 40 Bar)

NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm		
		Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter
10	6	90	16	60	4	M12	14
15	6	95	16	65	4	M12	14
20	6,5	105	18	75	4	M12	14
25	7	115	18	85	4	M12	14
32	7	140	18	100	4	M16	18
40	7,5	150	18	110	4	M16	18
50	8	165	20	125	4	M16	18
65	8,5	185	22	145	8	M16	18
80	9	200	24	160	8	M16	18
100	10	235	24	190	8	M20	23
125	11	270	26	220	8	M24	27
150	12	300	28	250	8	M24	27
175	13	350	32	295	12	M27	30
200	14	375	34	320	12	M27	30
250	16	450	38	385	12	M30	33
300	17	515	42	450	16	M30	33
350	19	580	46	510	16	M33	36
400	21	660	50	585	16	M36	39
450	21	685	50	610	20	M36	39
500	21	755	52	670	20	M39	42
600	24	890	60	795	20	M45	48
700	27	995	64	900	24	M45	48
800	30	1140	72	1030	24	M52	56
900	33	1250	76	1140	28	M52	56
1000	36	1360	80	1250	28	M52	56
1200	42	1575	88	1460	32	M56	62
1400	47	1795	98	1680	36	M56	62
1600	54	2025	108	1900	40	M64	70

EN 1092-1 Cast Steel Flange Standard–PN 63 (Nominal Pressure 63 Bar)

NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm		
		Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter
10	10	100	20	70	4	M12	14
15	10	105	20	75	4	M12	14
25	10	140	24	100	4	M16	18
32	12	155	24	110	4	M20	23
40	10	170	28	125	4	M20	22
50	10	180	26	135	4	M20	22
65	10	205	26	160	8	M20	22
80	11	215	28	170	8	M20	22
100	12	250	30	200	8	M24	26
125	13	295	34	240	8	M27	30
150	14	345	36	280	8	M30	33
175	15	375	40	310	12	M30	33
200	16	415	42	345	12	M33	36
250	19	470	46	400	12	M33	36
300	21	530	52	460	16	M33	36
350	23	600	56	525	16	M36	39
400	26	670	60	585	16	M39	42
500	31	800	68	705	20	M45	48
600	35	930	76	820	20	M52	56
700	40	1045	84	935	24	M52	56
800	45	1165	92	1050	24	M56	62
900	50	1285	98	1170	28	M56	62
1000	55	1415	108	1290	28	M64	70
1200	64	1665	126	1530	32	M72X6	78

EN 1092-1 Cast Steel Flange Standard—PN 100 (Nominal Pressure 100 Bar)

NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm			NOMINAL BORE, mm	PIPE THICKNESS, mm	FLANGE, mm			BOLTING, mm		
		Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter			Outside Diameter	Thickness	Bolt Circle Diameter	Number of Bolts	Thread	Bolt Hole Diameter
10	10	100	20	70	4	M12	14	150	18	355	44	290	12	M30	33
15	10	105	20	75	4	M12	14	175	20	385	48	320	12	M30	33
25	10	140	24	100	4	M16	18	200	21	430	52	360	12	M33	36
32	12	155	24	110	4	M20	23	250	25	505	60	430	12	M36	39
40	10	170	28	125	4	M20	22	300	29	585	68	500	16	M39	42
50	10	195	30	145	4	M24	26	350	32	655	74	560	16	M45	48
65	11	220	34	170	8	M24	26	400	36	715	78	620	16	M45	48
80	12	230	36	180	8	M24	26	500	44	870	94	760	20	M52	56
100	14	265	40	210	8	M27	30	600	51	990	104	875	20	M56	62
125	16	315	40	250	8	M30	33	700	59	1145	120	1020	24	M64	70

EN 1092-1 Pressure/Temperature Ratings for Cast Steel Flanges

PN	MATERIAL GROUP	MAXIMUM ALLOWABLE PRESSURE, PSIG (bar)[1]							
		14 to 212°F (-10 to 100°C)	302°F (150°C)	392°F (200°C)	482°F (250°C)	572°F (300°C)	662°F (350°C)	707°F (375°C)	752°F (400°C)
16	1C1	232 (16,0)	226 (15,6)	219 (15,1)	209 (14,4)	194 (13,4)	186 (12,8)	180 (12,4)	157 (10,8)
	1C2	218 (15,0)	218 (15,0)	218 (15,0)	225 (15,5)	216 (14,9)	206 (14,2)	199 (13,7)	157 (10,8)
25	1C1	363 (25,0)	354 (24,4)	344 (23,7)	326 (22,5)	303 (20,9)	290 (20,0)	281 (19,4)	245 (16,9)
	1C2	363 (25,0)	363 (25,0)	363 (25,0)	363 (25,0)	338 (23,3)	322 (22,2)	310 (21,4)	245 (16,9)
40	1C1	580 (40,0)	567 (39,1)	550 (37,9)	522 (36,0)	486 (33,5)	463 (31,9)	451 (31,1)	392 (27,0)
	1C2	580 (40,0)	580 (40,0)	580 (40,0)	580 (40,0)	540 (37,2)	516 (35,6)	496 (34,2)	392 (27,0)
63	1C1	914 (63,0)	892 (61,5)	864 (59,6)	824 (56,8)	764 (52,7)	730 (50,3)	711 (49,0)	616 (42,5)
	1C2	914 (63,0)	914 (63,0)	914 (63,0)	914 (63,0)	851 (58,7)	812 (56,0)	780 (53,8)	616 (42,5)
100	1C1	1450 (100)	1417 (97,7)	1374 (94,7)	1307 (90,1)	1252 (86,3)	1157 (79,8)	1128 (77,8)	979 (67,5)
	1C2	1450 (100)	1450 (100)	1450 (100)	1450 (100)	1350 (93,1)	1289 (88,9)	1239 (85,4)	979 (67,5)

1. These ratings apply only for flange types 05, 11, 12, 13, and 21 having nominal sizes up and including DN 600.

Conversions, Equivalents, and Physical Data

Drill Sizes for Pipe Taps

NOMINAL PIPE SIZE, (INCHES)	TAP DRILL SIZE, (INCHES)	NOMINAL PIPE SIZE, (INCHES)	TAP DRILL SIZE, (INCHES)
1/8	11/32	1-1/2	1-23/32
1/4	7/16	2	2-3/16
3/8	19/32	2-1/2	2-9/16
1/2	23/32	3	3-3/16
3/4	15/16	4	4-3/16
1	1-5/32	5	5-5/16
1-1/4	1-1/2	6	6-5/16

Standard Twist Drill Sizes

DESIGNATION	DIAMETER (IN.)	AREA (SQ. IN.)	DESIGNATION	DIAMETER (IN.)	AREA (SQ. IN.)	DESIGNATION	DIAMETER (IN.)	AREA (SQ. IN.)
1/2	0.5000	0.1963	3	0.213	0.03563	3/32	0.0938	0.00690
31/64	0.4844	0.1843	4	0.209	0.03431	42	0.0935	0.00687
15/32	0.4688	0.1726	5	0.2055	0.03317	43	0.0890	0.00622
29/64	0.4531	0.1613	6	0.204	0.03269	44	0.0860	0.00581
7/16	0.4375	0.1503	13/64	0.2031	0.03241	45	0.0820	0.00528
27/64	0.4219	0.1398	7	0.201	0.03173	46	0.0810	0.00515
Z	0.413	0.1340	8	0.199	0.03110	47	0.0785	0.00484
13/32	0.4063	0.1296	9	0.196	0.03017	5/64	0.0781	0.00479
Y	0.404	0.1282	10	0.1935	0.02940	48	0.0760	0.00454
Z	0.397	0.1238	11	0.191	0.02865	49	0.0730	0.00419
25/64	0.3906	0.1198	12	0.189	0.02806	50	0.0700	0.00385
W	0.386	0.1170	3/16	0.1875	0.02861	51	0.0670	0.00353
V	0.377	0.1116	13	0.185	0.02688	52	0.0635	0.00317
3/8	0.375	0.1104	14	0.182	0.02602	1/16	0.0625	0.00307
U	0.368	0.1064	15	0.1800	0.02554	53	0.0595	0.00278
23/64	0.3594	0.1014	16	0.1770	0.02461	54	0.0550	0.00238
T	0.358	0.1006	17	0.1730	0.02351	55	0.0520	0.00212
S	0.348	0.09511	11/64	0.1719	0.02320	3/64	0.0473	0.00173
11/32	0.3438	0.09281	18	0.1695	0.02256	56	0.0465	0.001698
R	0.339	0.09026	19	0.1660	0.02164	57	0.0430	0.001452
Q	0.332	0.08657	20	0.1610	0.02036	58	0.0420	0.001385
21/64	0.3281	0.08456	21	0.1590	0.01986	59	0.0410	0.001320
P	0.323	0.08194	22	0.1570	0.01936	60	0.0400	0.001257
O	0.316	0.07843	5/32	0.1563	0.01917	61	0.039	0.001195
5/16	0.3125	0.07670	23	0.1540	0.01863	62	0.038	0.001134
N	0.302	0.07163	24	0.1520	0.01815	63	0.037	0.001075
19/64	0.2969	0.06922	25	0.1495	0.01755	64	0.036	0.001018
M	0.295	0.06835	26	0.1470	0.01697	65	0.035	0.000962
L	0.29	0.06605	27	0.1440	0.01629	66	0.033	0.000855
9/32	0.2813	0.06213	9/64	0.1406	0.01553	67	0.032	0.000804
K	0.281	0.06202	28	0.1405	0.01549	1/32	0.0313	0.000765
J	0.277	0.06026	29	0.1360	0.01453	68	0.031	0.000755
I	0.272	0.05811	30	0.1285	0.01296	69	0.0292	0.000670
H	0.266	0.05557	1/8	0.1250	0.01227	70	0.028	0.000616
17/64	0.2656	0.05542	31	0.1200	0.01131	71	0.026	0.000531
G	0.261	0.05350	32	0.1160	0.01057	72	0.025	0.000491
F	0.257	0.05187	33	0.1130	0.01003	73	0.024	0.000452
E 1/4	0.2500	0.04909	34	0.1110	0.00968	74	0.0225	0.000398
D	0.246	0.04753	35	0.1100	0.00950	75	0.021	0.000346
C	0.242	0.04600	7/64	0.1094	0.00940	76	0.020	0.000314
B	0.238	0.04449	36	0.1065	0.00891	77	0.018	0.000254
15/64	0.2344	0.04314	37	0.1040	0.00849	78	0.016	0.000201
A	0.234	0.04301	38	0.1015	0.00809	1/64	0.0156	0.000191
1	0.228	0.04083	39	0.0995	0.00778	79	0.0145	0.000165
2	0.221	0.03836	40	0.0980	0.00754	80	0.0135	0.000143
7/32	0.2188	0.03758	41	0.0960	0.00724	- - - -	- - - -	- - - -

Note: Designations are in fractions of an inch, in standard twist drill letters, or in standard twist drill numbers, the latter being the same as steel wire gauge numbers.

A

Absolute Pressure (abs press) - Gauge pressure plus barometric pressure. Absolute pressure can be zero only in a perfect vacuum.

Absolute Viscosity (abs visc) - The product of fluid kinematic viscosity times its density. Absolute viscosity is a measure of fluid tendency to resist flow, without regard to its density. Sometimes the term dynamic viscosity is used in place of absolute viscosity. Refer to Viscosity, Absolute.

Accuracy - A measure of how close a regulator can keep downstream pressure (P_2) to the setpoint. Regulator accuracy is expressed as percent droop or proportional band or offset in percent of setpoint or in units of pressure.

ACFH - Actual Cubic Feet per Hour. The actual volume of fluid measured by the meter. This is not SCFH (standard cubic feet per hour).

Active/Working Regulator - A regulator that is in service performing a control function.

Adjusting Screw - A screw used to change the compression setting of a loading spring.

AGA - The American Gas Association or Australian Gas Association.

Airsets - See Filter/Supply Regulators.

ALPGA - Australian Liquefied Petroleum Gas Association, Ltd.

ANSI - American National Standards Institute.

API - American Petroleum Institute.

Appliance (Equipment) - Any device that uses gas as a fuel or raw material to produce light, heat, power, refrigeration, or air conditioning.

ASME - American Society of Mechanical Engineers.

Aspirator - Any device using fluid velocity effect to produce a low-pressure zone. Used in regulator control and combustion systems.

Atmospheric Pressure - The pressure exerted by the atmosphere at a given location and time. Sea level pressure is approximately 14.7 pounds per square inch absolute (1.0 bar absolute).

Automatic Control System - A control system that operates without human intervention.

Automatic Cutoff - A device used on some regulators to close the main valve in the event of pressure deviation outside of a preset range. Must be reopened manually.

B

Backpressure Regulator - This is a device that controls and responds to changes in its upstream/inlet pressure. Functions the same as a relief valve in that it opens on increasing upstream pressure.

Barometer - An instrument for measuring atmospheric pressure, usually in inches, centimeters, or millimeters of mercury column.

Barometric Pressure - The atmospheric pressure at a specific place according to the current reading of a barometer.

Bellows - A flexible, thin-walled cylinder made up of corrugations one next to the other that can expand or contract under changing pressures.

Bimetallic Thermal System - A device working on the difference in coefficient of expansion between two metals to produce the power to position a valve plug in response to temperature change.

Bleed - Removal of fluid from a higher pressure area to a lower pressure area in a regulator pilot system.

Bode Diagram - A plot of log amplitude ratio and phase values on a log frequency base for a transfer function. (It is a common form of graphically presenting frequency response data.)

Body - Pressure retaining shell enclosing the restricting element.

Boiler - A closed vessel in which a liquid is heated or vaporized.

Bonnet - The regulator component that connects the valve body to the actuator.

Boost - The increase in control pressure above setpoint as flow is increased from low flow to maximum flow. Some regulators exhibit droop instead of boost.

British Thermal Unit (BTU) - The quantity of heat required to raise one pound of water from 59° to 60°F.

Build-up - In a relief valve, the pressure increase above setpoint required to produce a given flow rate.

BSPT - British Standard Pipe Thread.

C

C_1 - A term used in a sizing equation. It is defined as the ratio of the gas sizing coefficient and the liquid sizing coefficient and provides a numerical indicator of the valve's recovery capabilities.

Cage - A hollow, cylindrical trim element that is a guide to align the movement of a valve plug with a seat ring and/or retains the seat ring in the valve body. The walls of the cage contain openings that usually determine the flow characteristic of the control valve.

Capacity, Flow - The amount of a specified fluid that will flow through a valve, specific length and configuration of tubing, a manifold, fitting, or other component at a specified pressure drop in a fixed period of time. (SCFH, gpm, Nm^3/h, Lpm, bph).

Capacity, Rated - The rate of flow through the regulator specified by the manufacturer for a given inlet pressure, outlet pressure, offset, and size.

Capacity, Wide-Open - If a wide-open failure occurs, this is the amount a regulator will flow.

Cavitation - A phenomenon whereby liquid flowing through a valve under reduced pressure will form gaseous bubbles that will collapse upon pressure recovery, producing potential trim damage. This is a concern when high-pressure drops exist across the valve.

Centipoise - A unit for measurement of absolute viscosity. One centipoise is equal to one hundredth of a poise, the metric (cgs) unit of absolute viscosity. The absolute viscosity of water at 20°C is approximately one centipoise.

Centistoke - A unit for measurement of kinematic viscosity. One centistoke is equal to one hundredth of a stoke, the metric (cgs) unit of kinematic viscosity. The kinematic viscosity in centistokes times the density equals the absolute viscosity in centipoises.

CFH - Cubic Feet per Hour (ft^3/h). Volumetric measurement of gas flow per hour, generally at line conditions.

C_g (Flow Coefficient) - A term used in gas and steam valve sizing equations. The value of C_g is proportional to flow rate and is used to predict flow based on physical size or flow area.

CGA - Canadian Gas Association.

Coal/Coke Oven Gas - A gas with a high sulfur content that is produced from baking coal. It may also contain tar that can cause sticking in moving parts of a regulator. Regulators with brass or copper parts should not be used with this gas. Often this gas requires the use of fluoroelastomers.

Compressibility Effect - The change in density of gas or air under conditions of compression.

Compression (Spring) - The action on a spring which decreases its length relative to the force to which it is subjected.

Condensate - The liquid resulting when a vapor is cooled and/or when its pressure is increased.

Control Line - The external piping which connects the regulator actuator or pilot to the point on the main line where control is required.

Control Valve - A mechanically, electrically, or hydraulically operated valve, using an external power source to effect its operation, that modifies the fluid flow characteristics in a process. It consists of a valve connected to an actuator mechanism that is capable of changing the position of the flow controlling element or closure member in the valve in response to a signal from the controlling device.

Controller - A device that operates automatically to regulate a controlled variable.

Critical Flow - The rate at which a fluid flows through an orifice when the stream velocity at the orifice is equal to the velocity of sound in the fluid. Under such conditions, the rate of flow may be increased by an increase in upstream pressure, but it will not be affected by a decrease in downstream pressure. Critical flow occurs when P_2 is approximately 1/2 of P_1 absolute.

Critical Velocity - The velocity at critical flow. Also called sonic velocity.

CSA - Canadian Standards Association.

C_s (Flow Coefficient) - Steam valve sizing coefficient. At pressures below 1000 psig, a constant relationship exists between the gas sizing coefficient (C_g) and the steam coefficient (C_s). This relationship is expressed: $C_s = C_g \div 20$.

C_v (Flow Coefficient) - Liquid sizing coefficient. It is numerically equal to the number of U.S. Gallons of water at 60°F that will flow through the valve in one minute when the pressure differential across the valve is one pound per square inch.

D

Dead Band - The range through which an input can be varied without initiating observable response.

Delta P (DP) (ΔP) (Pressure Drop) - The difference between the inlet and outlet pressures.

Demand - The rate at which fluid is delivered to or required by a system, part of a system, or a piece of equipment, usually expressed in terms of volume per unit of time.

Density - The weight of a unit volume of a substance. Also called specific weight.

Diaphragm - A flexible membrane used in a regulator or relief valve to sense changes in downstream pressure and respond to them, thus moving the restricting element or closure member to which it is attached.

Diaphragm Actuated Regulator - A regulator utilizing a diaphragm and actuator to position the valve plug.

Diaphragm Case - A housing used for supporting a diaphragm and establishing one or two pressure chambers.

Diaphragm Effect - The change in effective area of the diaphragm as the regulator strokes from low to high flow.

Diaphragm Plate - A plate used to transmit force in conjunction with a diaphragm and fluid pressure on a spring to the actuator stem or pusher post.

Differential Pressure - The difference in pressure between two points in a system.

Differential Pressure Regulator - A device that maintains a constant differential pressure between a reference pressure and the pressure of the controlled fluid.

Digester Gas - A gas produced by sewage treatment plants. This gas is used to power burners and engines. Because of its high methane content, stainless steel construction might be required.

Disk - A movable part that is positioned in the flow path to modify the rate of flow through the valve. It is often made of an elastomer material to improve shutoff capability.

Downstream - Any site beyond a reference point (often a valve or regulator) in the direction of fluid flow.

Drift - A change in setpoint over an extended period of time.

Droop - The amount a regulator deviates below its setpoint as flow increases. Some regulators exhibit boost instead of droop.

DVGW - Deutscher Verein des Gas - und Wasserfaches e.v. (German approval agency).

Dynamic Unbalance - The force exerted on a valve plug when fluid is flowing through the valve.

E

Effective Area - In a diaphragm actuator, the part of the diaphragm area that generates operating force. The effective area is less than the total area. (The effective area of a diaphragm might change as it is stroked, usually being a maximum at the start and a minimum at the end of the travel range. Molded diaphragms have less change in effective area than flat-sheet diaphragms.)

End Connection - The style of joint used to make a pressure tight connection between the valve body and the pipeline.

Entropy - A thermodynamic quantity that measures the fraction of the total energy of a system that is not available for doing work.

Enthalpy - Total heat content, expressed in BTU per pound, above an arbitrary set of conditions chosen as the base or zero point.

External Pressure Registration - A regulator with a control line. The actuator pressure is isolated from the body outlet pressure within the regulator.

External Static Line - The same as control line.

F

Face-to-Face Dimension - The dimension from the face of the inlet opening to the face of the outlet opening of the regulator.

Fail-Closed - In the event of a regulator failure, a condition wherein the valve port remains closed. All regulators can fail open or closed.

Fail-Open - In the event of a regulator failure, a condition wherein the valve port remains open. All regulators can fail open or closed.

Filter/Supply Regulators - Pressure reducing regulators used in air service to simultaneously filter and reduce pressure. Used to supply process control instruments pneumatic power. Also called airsets.

First-Stage Regulator - A regulator used to reduce inlet pressure to a set value being fed to another regulator in series.

Fixed Factor Measurement - The measurement of gas at a controlled elevated pressure without the use of an automatic correcting device to correct the volume for variation from base or contract pressure. This is accomplished by placing an accurate regulator upstream of the meter. Also known as PFM (Pressure Factor Measurement).

Fixed Restriction - A small diameter hole in the pilot or piloting system that determines gain.

Flange - End connections of regulator valve bodies used for bolting onto another fitting or pipe element.

Flange Facing - The finish on the end connection of valves.

Flashing - A condition when liquid changes to the vapor state caused by pressure reduction inside a valve.

Flow Capacity - The rated flow through a regulator under stated inlet, outlet, and droop pressures.

Flow Characteristic - Relationship between flow through the valve and percent rated travel.

Flow Coefficient - See C_v, C_s, C_g, C_1.

Flow Rate - The amount (mass, weight, or volume) of fluid flowing through a valve body per unit of time.

Fluid - Materials in a liquid, gas, or vapor state, as opposed to a solid.

Fuel Gas - A commonly distributed gas used for fuel, such as natural gas, propane, landfill gas, etc.

Full Capacity Relief - A relief valve that has the capability of maintaining downstream pressure to within certain limits in the event of some type of failure, by venting the excess gas to the atmosphere.

G

Gage Pressure - (Psig or bar g) The difference between atmospheric pressure and the pressure being measured. Also written gauge pressure.

Gas - That state of matter which expands to fill the entire container which holds it. Gas is one of the forms of matter (solid, liquid, and gas).

Gas Utilization Equipment - Any device which utilizes gas as a fuel or raw material, or both.

Gauge Pressure - Pressure reading as shown on a gauge (psig or bar g). The difference between atmospheric pressure and the pressure the gauge is measuring. Also written gage pressure.

Gauge, Pressure - An instrument that measures the pressure of a fluid.

Governor - An attachment to a machine for automatic control or limitation of speed. Also, an archaic term used for a low-pressure, direct-operated, pressure reducing gas regulator.

H

Hard Facing - A material harder than the surface to which it is applied. Used to resist galling or fluid erosion.

Header - A piping configuration where a number of pipes are combined at one location.

Hunting - A condition in which a regulator's outlet pressure slowly fluctuates on either side of a setpoint.

Hysteresis - A deviation from setpoint caused by friction and parts clearance.

I

Impulse Line - See control line.

Inch of Water - A unit of pressure measurement. The pressure required to support a column of water one inch high. Typically reported as inches w.c. (water column); 27.68-inches of water is equal to one pound per square inch (psi).

Inlet Pressure - The pressure at the inlet opening of a valve (P_1).

Inlet Pressure Sensitivity - The increase or decrease in the outlet pressure caused by changes in the inlet pressure which results in differing degrees of force being applied to the seat disk and diaphragm.

Internal Relief Valve - A small, spring-loaded pressure relief valve contained within the regulator at the center of the diaphragm to prevent outlet pressure from exceeding a predetermined pressure.

Isolation Valve - Refer to Valve, Isolation.

I/O - Input/Output -- Electrical inputs and electrical outputs.

J - K - L

K_m - Value recovery coefficient - used in liquid sizing equations to determine ΔP allowable for cavitation.

Kinematic Viscosity (kin visc) - The relative tendency of fluids to resist flow. The value of the kinematic viscosity includes the effect of the density of the fluid. The kinematic viscosity is equal to the absolute viscosity divided by the density. Refer to Viscosity, Kinematic.

LCD - Liquid crystal display; readout panel which displays alphanumeric sequences in digital format.

Landfill Gas - A gas produced by decaying organic matter in a garbage landfill. This gas is used to power burners and engines. This gas has a high methane content and may contain other gases; therefore, stainless steel construction is usually required.

Liquid Expansion Thermal System - A closed system containing liquid whose expansion and contraction in response to temperature changes provides the power to position a valve member.

Liquefied Petroleum Gas (LPG) - Butane, propane, or a mixture of the two, obtained from oil or gas wells, or as a by-product from the refining of gasoline. It is sold in metal bottles under pressure as a liquid; hence, sometimes called bottled gas.

Loading Element - In a regulator, the means for placing a measured amount of force against the regulator's diaphragm. The loading element is commonly a spring.

Loading Pressure - The pressure employed to position a pneumatic actuator. (This is the pressure that actually works on the actuator diaphragm or piston to change the position of the valve plug.)

Lockup Pressure - Increase over setpoint when the regulator is at no-flow condition.

M

Maximum Allowable Operating Pressure (MAOP) - The maximum pressure that the system may be operated at as determined by its components, taking into account function and a factor of safety based on yield of parts or fracture.

Maximum Operating Pressure - The maximum pressure existing in a piping system during normal operation.

Measuring Element - A diaphragm that senses (measures) changes in downstream pressure and causes the regulator restricting element to move toward the open or closed position.

Meters Cubed per Hour (Normal or Standard) - Refer to Nm^3/h or Sm^3/h.

Minimum Controllable Flow - The lowest flow at which a steady regulated condition of the controlled variable can be maintained.

Modbus - Protocol used for communications between electronic devices developed by Gould Modicon.

N - O

NACE - National Association of Corrosion Engineers

Natural Gas - A hydrocarbon gas consisting mainly of methane.

Needle Valve - Refer to Valve, Needle.

Nm^3/h - meters cubed per hour (normal); measurement of volume rate of a gas at atmospheric pressure and 0°C. Also refer to Sm^3/h.

NPT - National Pipe Thread, a standard for tapered thread used on pipes and pipe fittings.

Offset - The deviation from setpoint for a given flow. Negative offset is equivalent to droop.

Operating Pressure - The actual pressure at which a device operates under normal conditions. This pressure may be positive or negative with respect to atmospheric pressure.

Orifice - A fixed opening, normally the inside diameter of a seat ring, through which fluid passes. The term can also refer to the inlet or outlet of a regulator or pilot valve. Also called a port.

Outlet Pressure (Reduced Pressure) - The pressure leaving the outlet opening of a valve (P_2).

Over-Pressure Cut-Off Device - A mechanical device incorporated in a gas pipework system to shutoff the supply of gas when the pressure at the sensing point rises to a predetermined value.

P

P_1 - Inlet or upstream pressure.

P_2 - Outlet or downstream pressure.

PFM (Pressure Factor Measurement) - The measurement of gas at a controlled elevated pressure without the use of an automatic correcting device to correct the volume for variation from base or contract pressure. This is accomplished by placing an accurate regulator upstream of the meter. Also known as Fixed Factor Measurement

PID - Proportional/Intergral/Derivative device. Usually used as a controller.

Pilot (Amplifier) - A relatively small controlling regulator that operates the main regulator. They are used to increase accuracy.

Piston Actuated Regulator - A regulator utilizing a piston rather than a diaphragm actuator.

Pitot Tube - A hollow tube that connects the area beneath the regulator diaphragm with the vena contracta area of gas flow. The pitot tube causes the diaphragm to sense a pressure lower than that which exists downstream of the regulator, and thus allows the regulator to open more for any given change in downstream pressure. The result is increased regulator accuracy.

P_L - Loading pressure. Pressure of fluid on the main diaphragm that is controlled by a pilot regulator.

Plug - Piece that throttles against an orifice to increase and decrease flow.

Poise - A metric unit for measuring absolute viscosity. One poise equals one dynesecond per square centimeter, or one gram per centimeter second.

Port - A fixed opening, normally the inside diameter of a seat ring, through which fluid passes. The term can also refer to the inlet or outlet of a regulator or pilot valve. Also called an orifice.

Powder Paint Coating - A paint process that uses dry powder with no solvents for surface finish. Dry powder can be reused, thereby reducing waste and pollutants. The powder coating over a clean surface provides better corrosion resistance than liquid coat.

Pressure - Force per unit area.

Pressure Buildup - In a relief valve, the pressure increase above setpoint required to produce a given flow rate.

Pressure Differential - The difference in pressure between two points in a system.

Pressure Drop - The difference between the inlet and outlet pressures.

Pressure Reducing Regulator - A valve that satisfies downstream demand while maintaining a constant reduced pressure. As the pressure decreases, the valve opens to increase flow.

Pressure Relief Valve - A valve that opens and closes to ensure that pressure does not rise above a predetermined value.

Propane - An easily liquefiable hydrocarbon gas. Propane is one of the components of raw natural gas, and it is also derived from petroleum refining processes. Its chemical formula is C_3H_8.

Proportional Band (Amount of Deviation) - The amount a regulator deviates from setpoint as the flow increases from minimum to maximum. Also referred to as droop or offset.

psia - pounds per square inch, absolute - The pressure above a perfect vacuum, calculated from the sum of the pressure gauge reading and the (local or ambient) atmospheric pressure (approximately 14.7).

psid - Pounds per square inch, differential.

psig - Pounds per square inch, gauge. The pressure above atmospheric pressure. Near sea level the atmospheric pressure is approximately 14.7 pounds per square inch.

Q - R

Range - The region between the limits within which a quantity is measured, received, or transmitted, expressed by stating the lower and upper range values (Example: 3 to 15 psi; -40° to 212°F (-40° to 100°C)).

Rangeability - The ratio of maximum rated capacity to the minimum controllable flow within the specified accuracy band.

Rate of Flow - The volume of material passing a given point in a system per unit of time.

Rated Working Pressure - The maximum allowable pressure specified by the manufacturer.

Reduced Pressure - The pressure leaving the outlet opening of a valve (P_2). More commonly called outlet pressure.

Regulator, Direct-Operated - See Pressure Reducing Regulator.

Regulator, Pilot-Operated - Two regulators connected so that one increases the effect of downstream pressure changes on the other. This arrangement is used to provide increased accuracy and flow capacity compared to direct-operated regulators.

Relief Valve - See Pressure Relief Valve.

Relief Valve, Pilot-Operated - Two relief valves connected so that one increases the effect of inlet pressure changes on the other. This arrangement is used to provide increased capacity and reduced buildup compared to other relief valve types.

Relief Valve, Pop Type - A spring-loaded poppet type relief valve.

Repeatability - The closeness of agreement of a regulated value when returned to the same steady-state conditions after upset(s).

Reseat Point - In a relief/backpressure valve which is opened by an increase in inlet pressure, the point where the valve closes.

Restricting Element - The element that restricts and controls fluid flow in a system. In a regulator this element is typically a disk and orifice combination, or plug and cage assembly.

RTD - Resistance Temperature Detector. A resistance device used to measure temperature.

RTU - Remote Terminal Unit or Remote Telemetry Unit.

S

SAE Number Viscosity - Refer to Viscosity, SAE Number.

Saybolt Furol - A scale used for measuring the viscosity of heavy oils. The instrument has a larger orifice and is used at a higher temperature than the Saybolt Universal instrument used for lighter oils.

Saybolt Universal - A scale used for measuring the viscosity of oil, expressed in seconds required for a specified amount of oil to flow through an orifice; hence, the larger the number of seconds, Saybolt Universal (SSU), the more viscous the oil.

SCFH - Standard cubic feet per hour. Volumetric gas measurement of flow per hour at standard or at base conditions.

Seat - The portion of the seat ring or valve body which a closure member contacts for shutoff.

Seat Leakage - Flow of fluid past a seat or seal when in the closed position.

Seat Ring - A separate piece inserted in a valve body to form a valve body port. It generally provides a seating surface for a plug or disk.

Self-Contained Regulator - Pressure control device that is powered by the process media pressure and does not require outside energy.

Setpoint - The pressure at which the regulator or relief valve is set to control.

Set Pressure Range - The range of pressures, specified by the manufacturer, within which the device can be adjusted.

Sm^3/h - meters cubed per hour (standard); measurement of volume rate of a gas at atmospheric pressure and 60°F. Also refer to Nm^3/h.

Soft Seat - An elastomeric, plastic, or other readily deformable material used either in the valve plug or seat ring to provide tight shutoff with minimal force.

Sonic Velocity - The speed of sound for a particular gas at a given inlet pressure and temperature.

Sour Gas - Gaseous fuel that contains a relatively large proportion of sulfur or sulfur compounds. See the discussion on Sulfide Stress Cracking in the Technical Section.

Specific Gravity - The ratio of weight of a given volume of fluid to the weight of an equal volume of liquid/gas at stated temperature.

Speed of Response (Stroking Speed) - The amount of time it takes the valve plug or disk to travel from completely closed to completely open (0 to 100%).

Spring - Part used as the loading element in a regulator. Length is adjusted to establish setpoint.

Spring Adjustment Screw - A screw used to compress the spring to establish the regulator setpoint.

Spring Rate (K) - Spring rate is defined by the amount of force required to compress a spring a given distance. Spring rate is given in force/length (for example, lbf/in).

Stability - The ability to hold a steady controlled variable within the limits of stated accuracy of regulation.

Standard Atmosphere - The accepted normal atmospheric pressure at sea level, equal to 14.696 pounds per square inch.

Standard Barometer - The reading of a barometer for standard atmospheric pressure; equal to 29.92 inches of mercury column.

Standard Gravity - Standard accepted value for the force of gravity. It is equal to the force which will produce an acceleration of 32.17 feet per second per second.

Standard Pressure - The same as standard atmosphere; equal to a pressure of 14.696 pounds per square inch.

Static Line - See Control Line.

Static Pressure - The pressure in a fluid at rest.

Static Unbalance - The force exerted on a valve plug due to fluid pressure in the non-flowing condition.

Stoke - The cgs unit of kinematic viscosity. One stoke equals one centimeter squared per second.

Supercompressibility - Many gases are more compressible under high pressure at ordinary temperatures than indicated by Boyle's Law. These gases, measured at the high pressures, will occupy a greater volume when the pressure is reduced to near atmospheric pressure.

SUS (or SSU) Viscosity - Refer to Viscosity, SUS (or SSU).

T - U

Therm - 100,000 BTU.

Thermostat - A device that automatically maintains a predetermined temperature in an appliance or component.

Travel - The amount of linear movement of the valve closure member from the closed position to the rated full-open position.

Travel Indicator - An external, visible device used to indicate the travel of the valve plug.

Trim - The replaceable internal parts of a regulator, usually made up of a seat ring or orifice, valve plug or disk and disk holder, and stem; other replaceable internal parts may be considered trim.

Under-Pressure Cut-Off Device - A mechanical device incorporated in a gas pipe work system to shutoff the supply of gas when the pressure at the sensing point falls to a predetermined figure.

V - W

Vacuum Breaker - A valve used to limit an increase in vacuum. An increase in vacuum (decrease in absolute pressure) beyond a certain value registers on the diaphragm. The valve disk will open permitting atmospheric, positive pressure, or an upstream vacuum that has a higher absolute pressure than the downstream vacuum, to enter the system and restore to setpoint.

Vacuum Regulator - A device that maintains a vacuum at a setpoint. A decrease in this vacuum (increase in absolute pressure) beyond this value registers underneath the diaphragm and opens the valve. This permits the downstream vacuum of lower absolute pressure than the upstream vacuum to restore the upstream vacuum to its original pressure setting.

Valve - A device used for the control of fluid. It consists of a fluid retaining assembly, one or more parts between end openings, and a movable closure member which opens, restricts, or closes the port(s).

Valve Body - A pressure retaining housing for internal parts having inlet and outlet flow connections.

Valve Closure Member - The movable part which is positioned in the flow path to modify the rate of flow through the valve, often made of an elastomer material to improve shutoff.

Valve Linkage - A lever or levers connecting the diaphragm to the valve plug or valve plug stem.

Valve Plug - A movable part which provides a variable restriction in a port.

Valve, Needle - A small, adjustable valve in which the position of a pointed plug or needle relative to an orifice or tapered orifice permits or restricts fluid flow.

Valve, Isolation - Simple valves located in the piping system used to isolate individual equipment. They are designed to be operable by hand and installed to be readily accessible to the consumer.

VDC - Volts direct current.

Vena Contracta - The location where cross-sectional area of the flow stream is at its minimum size, where fluid velocity is at its highest level, and fluid pressure is at its lowest level. (The vena contracta normally occurs just downstream of the actual physical restriction in a regulator.)

Vent - An opening in the regulator spring case to allow atmospheric pressure access to the diaphragm, thus allowing free movement of the diaphragm during operation.

Viscosity - The tendency of a fluid to resist flow.

Viscosity, Absolute - The product of a fluid's kinematic viscosity times its density. Absolute viscosity is a measure of a fluid's tendency to resist flow, without regard to its density. Sometimes the term dynamic viscosity is used in place of absolute viscosity.

Viscosity, Kinematic - The relative tendency of fluids to resist flow. The value of the kinematic viscosity includes the effect of the density of the fluid. The kinematic viscosity is equal to the absolute viscosity divided by the density.

Viscosity, SAE Number - The Society of Automotive Engineers' arbitrary numbers for classifying fluids according to their viscosities. The numbers in no way indicate the viscosity index of fluids.

Viscosity, SUS (or SSU) - Saybolt Universal Seconds (SUS), which is the time in seconds for 60 milliliters of oil to flow through a standard orifice at a given temperature (ASTM Designation D88.56).

Volume Corrected - The volume metered times metering pressure plus atmospheric pressure/base pressure equals volume corrected.

Water Column - A unit of measurement. The pressure required to support a column of water one inch high. Typically reported as inches w.c. (water column); 27.68-inches of water is equal to one pound per square inch (psi).

Weight, Specific - The weight per unit volume of a substance. The same as density.

X - Y - Z

Yoke - A structure by which the diaphragm case or cylinder assembly is supported rigidly on the bonnet assembly.