TESCOM TECHNICAL TRAINING

PRESSURE REGULATORS EXPLAINED

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CONTENTS:

Pressure Reducing Regulator / Valve (PRV)

The function of a pressure reducing regulator is to precisely reduce a high upstream pressure of a gas or liquid (from a cylinder, compressor, pump, etc) to a lower, stable pressure for the user's application. Furthermore, the regulator will attempt to maintain and control the outlet pressure within limits as other conditions vary but the regulator will not control flow, only the delivery pressure. A regulator is also not to be used as a shut-off device as there is always a small amount of leakage across the seat. A shut-off valve must be used downstream of the regulator if isolation is required.

Back Pressure Regulator / Valve (BPR)

The function of a back pressure regulator is to limit and precisely control the upstream pressure of a gas or liquid (from a tank, pump, etc) and is much more accurate than a relief valve. Most direct spring operated safety relief valves have a high reseating pressure which is inconsistent and unreliable. This the primary difference between a safety relief valve and a back pressure regulator. A safety relief valve is designed to protect downstream personnel and equipment should over-pressurization take place. As such, when it's set pressure is overcome, it will blow wide open immediately and exhaust all of the pressure. It needs to be able to handle the full flow of the system in order to rapidly exhaust to protect downstream apparatus. A back pressure regulator is not a safety device it is designed for precision upstream pressure control. When the regulator set-point is overcome, it will "crack" open (not blow wide open) and try to exhaust just the excess pressure above the set-point. When it cracks open, it uses its sensing element (relief valve's do not have sensing elements) to try and reseat very close to its set pressure. Most Tescom back pressure regulators have "crack to reseat" pressures less than ± 2% of the set-point (relief valves are typically ± 10%).

Section A: General Function of a Regulator

How Pressure Regulation Works:

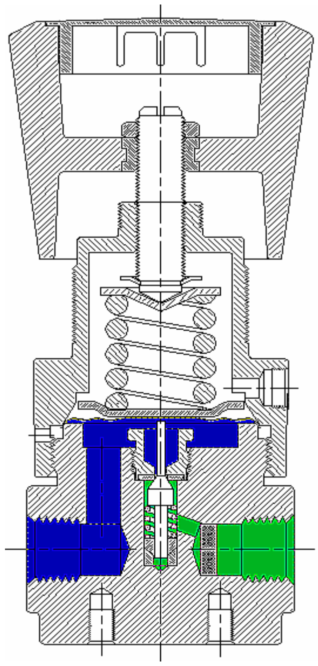
High pressure media enters the regulator through the inlet port into the high pressure chamber (**P1**). When turning the hand-knob clockwise, this compresses the load (range) spring and exerts a downward force on the diaphragm ▼. This in turn pushes the main valve stem downwards opening the seat and allowing the high pressure gas (**P1**) into the low pressure chamber (**P2**) which in turn exerts an opposing force on the diaphragm ▲.

The outlet pressure (**P2**) remains constant when equilibrium is reached between the two opposing forces. This is the valve set-point.

As the inlet pressure (**P1**) decreases, we would see an increase in the outlet pressure (**P2**) as there is less gas pressure (**P1**) exerted on the valve stem. This is termed as the 'decaying inlet characteristic' in which differently designed regulators possess different values:

BB-1 series has a 7 psig rise per 100 psig decaying inlet
44-2200 series has a 1.5 psig rise per 100 psig decaying inlet
44-1300 series has a 0.1 psig rise per 100 psig decaying inlet

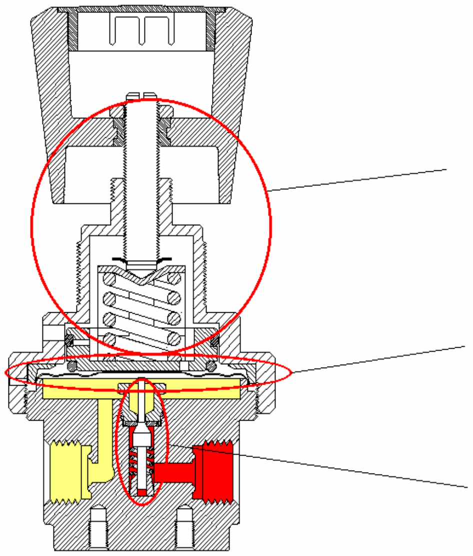
To overcome the effect of the decaying characteristic we can use two single stage regulators in series or utilise a 2 stage regulator (e.g. 44-3400).



Regulators supplied by Tescom offer high ratings on design and burst pressures:

- Design pressure: 150% of operating pressure (still work as designed)
- Burst pressure: 400% of operating pressure (pressure which body may withstand)

The 3 basic elements involved in the mechanics of a pressure regulator



A. Load Mechanism:

a load spring applies a downward force when it is compressed as the handle is turned clockwise

B. Sensing Element:

the diaphragm sees the load force from the top (spring) and will move downwards

C. Control Element:

the stem is pushed downwards by the diaphragm and opens the seat

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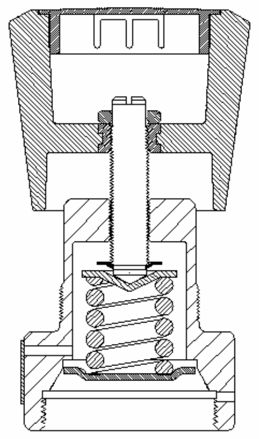
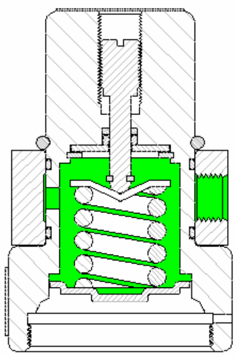
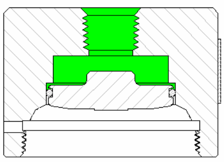
A.1. - LOADING MECHANISMS:



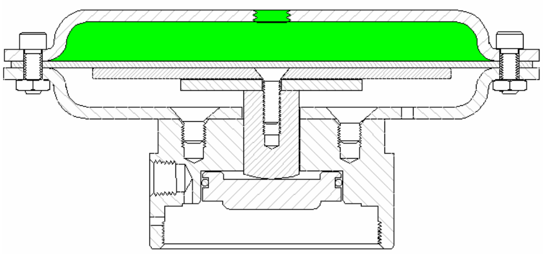
Spring Loaded



Combination Dome & Spring

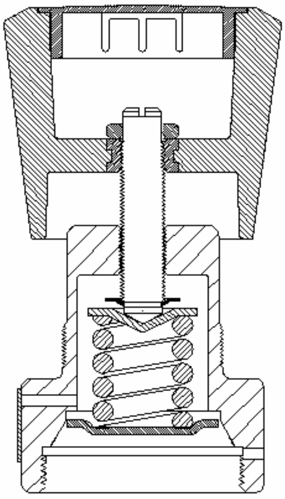


Dome Loaded



Air Actuated

A.1.1 - SPRING LOADING:



Advantages

- simplicity; there is little to go wrong
- economical because of many different suppliers
- springs can be wound in various thicknesses
- most common loading mechanism

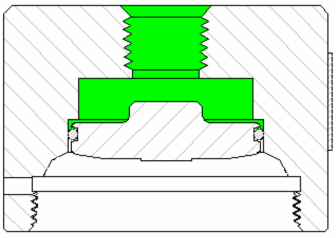
Disadvantages

- spring forces vary with compression
- the load is not constant
  (major contributor of droop)
- sensitive to the effects of shock, vibration

A.1.2 - DOME LOADING:

Advantages

- ratio 1:1 (dome pressure = outlet pressure)
- enables remote pressure control in combination with a small pilot regulator to control
- ideal for high flow applications (no big spring)
- low pressure drop under dynamic conditions (which minimises droop)
- can be combined with the electronic PID controller ER3000



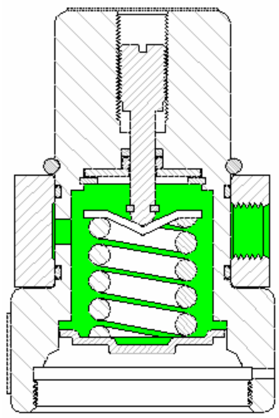
Disadvantages

- pilot regulator with self-venting needed
- increased cost
- two regulators require more space for the installation

A.1.3 – COMBINATION DOME + SPRING LOADING:

Advantages

- Outlet pressure = Dome pressure + bias pressure
- provides gas pressure accurately for tracking applications (agitator seals)
- low pressure drop under dynamic conditions (minimized droop)
- can be combined with the electronic PID controller ER3000



Disadvantages

- increased cost: it is more expensive than either a spring or dome loaded regulator

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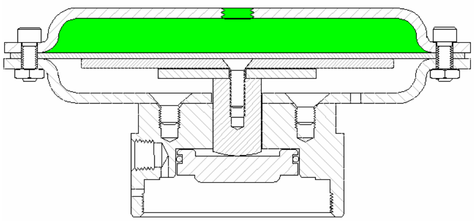
A.1.4 - AIR LOADING:

Advantages

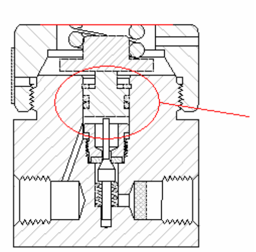
- provides a ratio between actuator pressure and media pressure e.g. 1:75
- enables remote pressure control in combination with pilot regulators
- low pressure drop under dynamic conditions (minimized droop)
- can be combined with the electronic PID controller ER3000



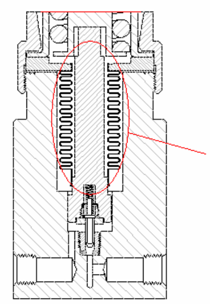
Disadvantages

- pilot regulator with self-venting needed = increased cost
- two regulators require more space for the installation

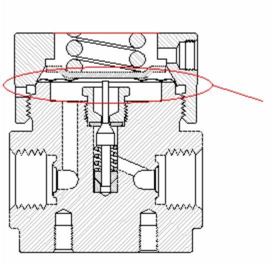
A.2. - SENSING ELEMENTS:



Piston sensed



Bellows sensed

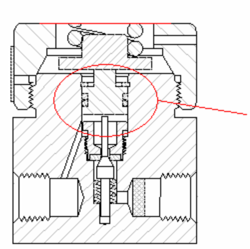


Diaphragm sensed

A.2.1 - PISTON SENSED:

Advantages/Features

- designed for high pressures (up to 1400 bar)
- consist of sensor and o-rings
- regulators available with different sensor sizes use sensor back-ups
- for high pressures the o-rings are supported by back-up rings



sensor

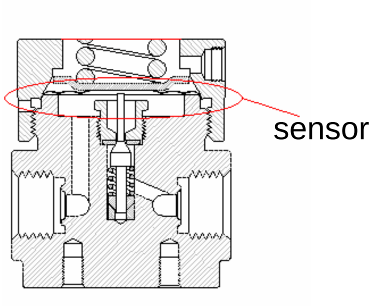
Disadvantages

- most o-rings need lubrication
- less sensitive than diaphragm because of friction

A.2.2 - DIAPHRAGM SENSED:

Advantages/Features

- sensitivity, simplicity
- metal diaphragms have two concentric convolutions to extend cycle life
- typical materials are 316 SST, elgiloy and rubber
- metal diaphragm provides a true metal seal
- eliminates outgassing problems associated with soft seals.



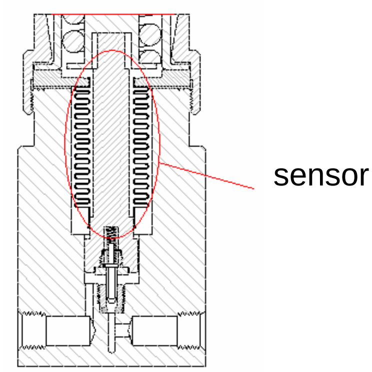
Disadvantages

- diaphragms rupture at high pressure differentials
- outlet pressure limited to 35 bar

A.2.3 - BELLOWS SENSED:

Advantages/Features

- the accordion style flexing points provide the capability for longer travel of the main valve
- most sensitive of the 3 sensing elements
- metal bellows can provide true metal seal



Disadvantages

- most expensive; SST bellows are rarely used as the sensing element in regulators
- the long travel of the bellows results in larger regulator bodies

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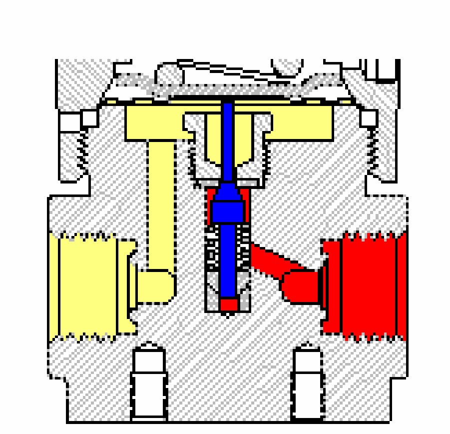
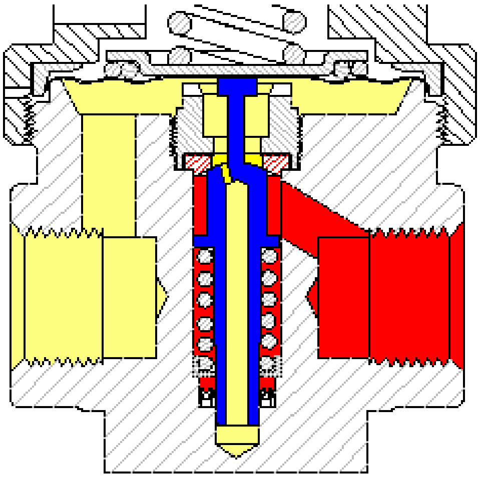
A.3. - CONTROL ELEMENTS:

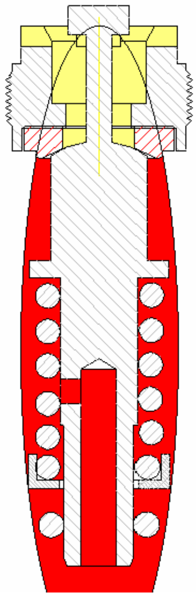


Unbalanced
Main Valve



Balanced
Main Valve

A.3.1 - UNBALANCED MAIN VALVE:



Advantages/Features

- inexpensive and simple, easy to manufacture
- inlet pressure acts to close the valve against the seat

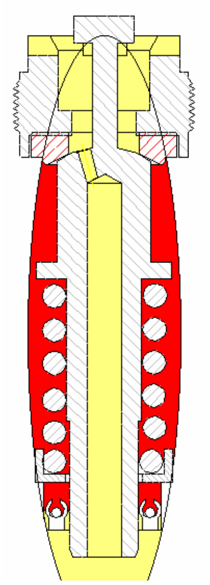
Disadvantages

- unbalanced main valves show decaying inlet characteristic - decreasing inlet pressure/increasing outlet pressure
- limited to small orifice sizes or low inlet pressures
- high seat forces at high inlet pressures require harder seat material

A.3.2 - BALANCED MAIN VALVE:

Advantages/Features

- the seal on the stem eliminates the closing force of the inlet pressure on the main valve
- the hole through the main valve from the P2 cavity balances the forces caused by the outlet pressure
- reduced seat load allows larger seat orifice at high pressures
- reduced decaying inlet characteristic



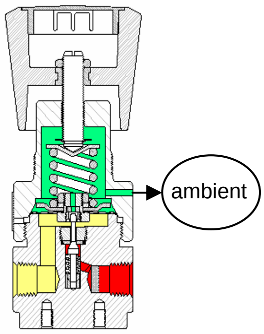
Disadvantages

- more expensive to manufacture
- large seats make low flows difficult

Section B: Regulator Features

B.1 - VENTING OPTIONS:

- Self-Venting feature enables complete relieving of the downstream pressure in dead-ended systems when the hand-knob is turned in the decrease direction (anti-clockwise). The regulator incorporates a 2nd valve to vent the downstream pressure through the bonnet in the standard venting model.

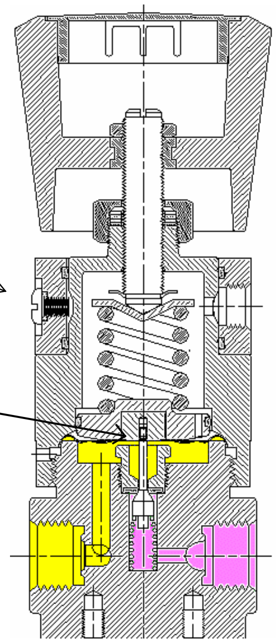


- Captured-Venting feature offers a separate vent port to pipe away the expelled downstream gas or fluid to a safe discharge point. and is suitable for toxic or corrosive media.
- Non-Venting feature is available where venting is not desirable

B.2 - CORROSIVE MEDIA OPTIONS:

44-2800 & 64-2800 Series

Features from both a safety and economical point of view:



- Position-able Captured Bonnet:

  Should the media reach the bonnet chamber, it will be piped away to a safe area via the bonnet port, which may be positioned 360 degrees around the regulator body.

- Tied Diaphragm:

  This design ensures positive shut-off as the valve stem is mechanically connected to the diaphragm, controlling the valve position in both directions. The benefit of the tied diaphragm design is that if the regulator begins to creep, the increasing outlet pressure causes the diaphragm to flex upward away from the orifice pulling the valve stem tighter and tighter into the seat. The more outlet pressure drift or creep, the more sealing force is created. The sealing force will try to compress the contamination into the seat. Another name for the tied diaphragm design is a positive seal regulator.

B.3 - RESONANCE IN REGULATORS:

Harmonic Resonance - sometimes occurs in metal diaphragm sensed pressure reducing regulators when the combination of a high inlet pressure, low outlet pressure, and lighter gas exists and is also known to occur with traditional atmospheric gases. The regulator's thin metal diaphragm is torqued into place between the body and bonnet, acting much like the cone of a speaker. The bonnet cavity acts like a speaker case, together they amplify the sound of the gas travelling through the orifice past the main valve. The sound of **Harmonic Resonance** is often characterized as a hissing sound, often mistaken for gas leaking through the bonnet port of the regulator. A quick verification of **Harmonic Resonance** is to cover the bonnet port of the subject regulator with a finger. The sound should go away. Bubble checking the bonnet port will verify the existence of Harmonic Resonance or a leaking diaphragm; a constant stream of bubbles indicates diaphragm leakage. Lack of bubbles verifies the Harmonic Resonance condition. Harmonic Resonance is not a destructive condition.

Resonance - occurs primarily in hydraulic regulators, especially with aqueous-based liquids that don't provide much lubrication to the internal regulator parts. Resonance occurs when the regulator internals are rubbing against one another, and the main valve is unable to stabilize. The sound of Resonance is characterized as a loud chatter combined with vibration. The outlet pressure fluctuates, sometimes wildly. You can feel Resonance when you touch the regulator. **This is a destructive condition that must be remedied or the regulator will fail!**

B.4 - HEATED REGULATORS:

Certain speciality gases used in the semiconductor industry such as Hydrogen Chloride (HCl), Nitrous Oxide (N_2O) or Carbon Dioxide (CO_2) have a high Joule-Thomson coefficient. This results in a significant cooling effect when these gases expand in the gas distribution system on their way to the respective process. Especially the use of HCl rises the risk that remaining residual moisture is condensating forming hydrochloric acid, causing corrosion to the whole gas supply system but especially to the pressure regulator where the cooling effect is highest. Commonly used heat tracing cables have low heat transfer and only heat fraction reaches the inside of the regulator body.

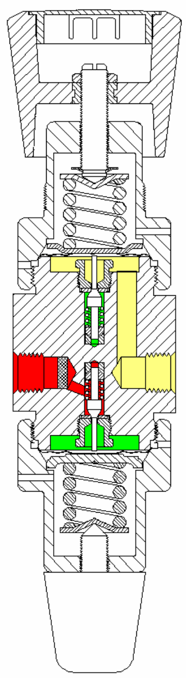
To fight the Joule-Thomson effect, Tescom has developed the 44-3200 and 64-3200 series of ultra high purity gas regulators which come with an integrated heater element. This element transfers almost 100% of the heat into the regulator body and avoids by this not only condensation and internal corrosion, it also prevents reliquifying of gas after pressure reduction mainly observed with liquified gases.

The electronically controlled 100 W heating element guarantees a constant regulator temperature, even in high flow applications or with frequent flow variations. The water-tight connection to the electrical installation allows outdoor use. Other features of the positive seal pressure reducing regulators are a flow capacity of up to Cv=1,2, a tied diaphragm design and the Hastelloy C22 trim option including the seat retainer, valve stem and diaphragm.

B.5 – DUAL STAGE REGULATORS:

Advantages

- combination of two pressure regulators in-line
- P1 (red) is reduced to the preset inter-stage pressure (green)
- the inter-stage pressure is reduced to the adjustable outlet pressure P2 (yellow)
- reduces decaying inlet characteristic
- decaying inlet effect on the inter-stage is equal to an unbalanced single stage regulator
- the final outlet pressure P2 is stable



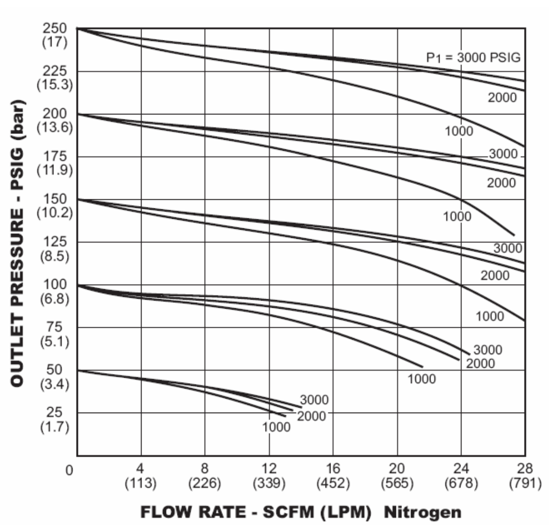
Disadvantages

- more expensive to manufacture
- dual stage regulators require more space

SECTION C: FREQUENTLY ASKED QUESTIONS (FAQ)

C.1 - What is a flow chart?

Flow charts are the graphic representation of test results which show the change in outlet pressure (P2) with a varying flow rate. All curves are based on using air or water as a media at ambient conditions. Inlet pressures (P1) are shown on the right end of each curve.



To use these charts, select the curve to fit the following:

a) Regulator model

b) Inlet pressure range (P1)

c) Outlet pressure range (P2)

d) Determine the zero flow P2 pressure permitted by your system.

e) Locate this pressure on the P2 (vertical) axis.

f) If no curve is plotted for that exact pressure, extrapolate a new curve between the two closest existing curves and follow from the zero flow point to the intersection of the new curve and the vertical coordinate of the desired flow.

g) Read horizontally to locate the corresponding P2 pressure.

C.2 - What is the flow capacity (Cv) rating?

The maximum flow capability of a regulator or valve established at a specific set of conditions. The standard coefficient is the term **Cv** which by definition is the flow of one GPM of water at one PSI drop. The term **Cv** for gaseous service is dependent on the ratio of inlet to outlet pressure and must be determined by the use of appropriate formulae.

Definitions:

Cv: Flow coefficient for regulators and valves that expresses flow capabilities of a unit at full open condition. For gases Kv = Cv / 1.17SL: Specific gravity of liquids relative to water, both at standard temperature of 15℃. (Specific gravity of water = 1.0 @ 15℃).Sg: Specific gravity of a gas relative to air ; equals the ratio of the molecular weight of the gas to that of air. (Specific gravity of air = 1.0 @ 15 ℃).

P1: Inlet pressure expressed in barg

P2: Outlet pressure expressed in barg

ΔP: Differential pressure (P1 - P2).

QL: Liquid flow in liters per minute (l/min).

Qg: Gas flow in liters per minute (l/min).

(At standard conditions of 15℃ and 1.01 bar).

1. Liquid Cv formula

$$Cv = \frac{(Q_L/3.78) \times \sqrt{S_L}}{\sqrt{\Delta P \times 14{,}5}}$$

2. Gas Cv formulas

a) When P_1 is greater than or equal to $2 \times P_2$

$$Cv = \frac{(2 \times Q_g) / 28.3}{(P_1 \times 14.5) + 14.7} \times \sqrt{S_g}$$

b) When P_1 is less than $2 \times P_2$

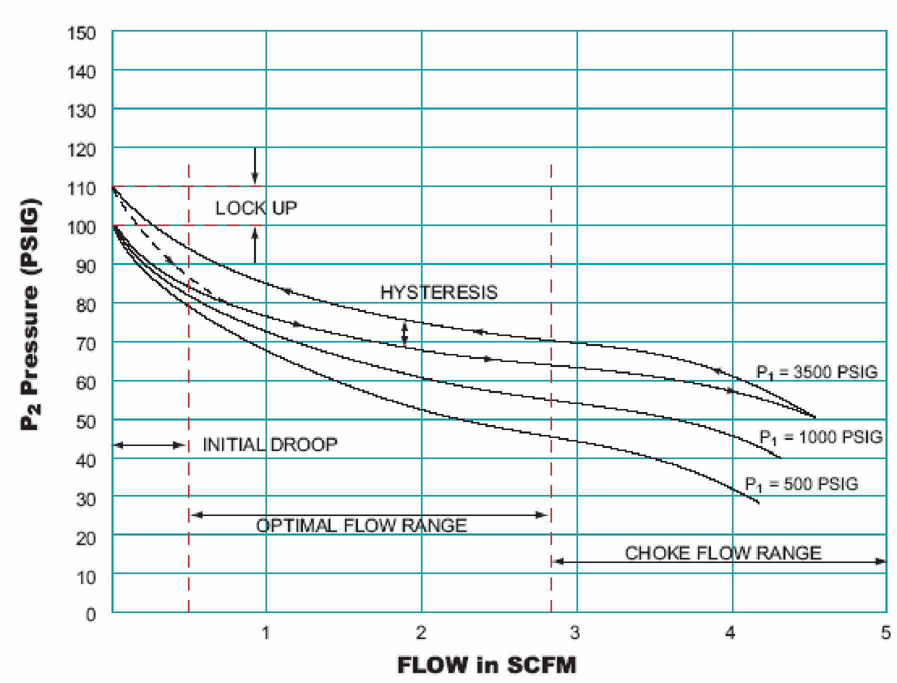
$$Cv = \frac{Q_g}{28.3} \times \sqrt{\frac{S_g}{\Delta P \times 14.5\,[(P_2 \times 14.5) + 14.7]}}$$

P in bar, $\Delta P = (P_1 - P_2)$, Q in l/min. Calculations with Cv require always a cross-check with flow diagrams.
Please consider always that normally a regulator operates not at its max. Cv. So calculated Cv should be increased by minimum 30% when selecting a regulator.

C.3 - What is droop?

This is the outlet pressure (P2) change (offset) from the set (static) pressure which occurs as the flow rate increases. We've all heard the term droop used when referring to regulator performance, but most of us never fully understand the meaning of this term. In a pressure reducing regulator, the outlet pressure drops (or droops) as the flow increases. As the flow decreases, the P2 pressure goes up, or recovers to just above the original set point. Droop is the result of loading force changes in the regulator, and is caused primarily by the load spring.

How does it work? - To better understand droop, let's evaluate the performance of a regulator for a typical application. A customer needs a regulator for nitrogen service, set at 100 PSIG. The gas source is a cylinder, pressurized to 2600 PSIG (P1 pressure.) Most nitrogen cylinders are packaged at 2200 – 2600 PSIG when full. If the cylinder sits outside on a gas pad in the heat of the sun, you can assume that the initial cylinder pressure will be on the high side of this range. Small lecture bottles are packaged at lower pressures, but will still exhibit pressure decay as the process consumes the gas. The subject regulator needs to deliver 2 SCFM. If you refer to the flow (or droop) curve for the subject regulator you will note that at zero flow, the regulator set point (P2) is established as 100 PSIG.



We will use the flow curve labeled for P1=3500 PSIG to evaluate our subject regulator's performance, since our inlet pressure is 2600 PSIG. To determine the droop at 2 SCFM, follow the 3500 PSIG flow curve until it intersects the vertical line marked 2 SC FM. At this point, draw a horizontal line to the left until it intersects the vertical line marked with P2 pressures, and read the pressure value on the vertical (P2) scale. In our example, we find that the outlet pressure has drooped to approximately 68 PSIG. We just learned that at a flow rate of 2 SC FM, the outlet pressure of our regulator would drop from 100 PSIG to 68 PSIG; the droop is 32 PSIG. Moving further along the droop curve to 3 SC FM, we see that the P2 pressure is now 65 PSIG. At approximately 2.8 SC FM, the droop curve starts to drop off significantly. This is the point at which the main valve of the regulator is wide-open, and no longer regulating pressure. We call this area of the flow curve the choke flow range. The regulator is no longer working; it's really nothing more than a fixed orifice in a piece of pipe. We generally don't consider the choke flow range as part of the regulator's working flow range, so try to avoid specifying a regulator with a flow requirement that falls into the choke flow range of the regulator you're evaluating for an application. If we start to reduce the flow from 3 SC FM towards zero flow, we note that the P2 pressure climbs toward the original 100 PSIG set point. Something interesting occurs, however. The P2 pressure at 2 SC FM is approximately 75 PSIG, not the 68 PSIG we observed when the flow was increasing. This phenomenon is known as the hysteresis of the regulator, and is usually consistent in flow excursions. Other than recognizing it for what it is, hysteresis is usually not an issue in evaluating the performance of a regulator. T o get a full picture of how the regulator will perform in our application, we should take into account the fact that the inlet pressure will decrease as we consume gas from the cylinder. In fact, most people try to get as much gas from the cylinder as possible, usually allowing cylinder pressure to drop to 200 PSIG before they change out the cylinder. Therefore, we should perform a droop evaluation at P1 = 500 PSIG to see if the regulator will still meet our customer's expectations. Using the flow curve labeled P1 = 500 PSIG, we see that the droop at 2 SC FM is now approximately 52 PSIG, or nearly half of the original 100 PSIG setpoint. Clearly, the droop gets worse as the inlet pressure falls. If our customer had specified an outlet pressure of 100 PSIG, +/- 40 PSIG, we might have considered the subject regulator as suitable for the application if we only considered its performance when the cylinder is full. But, by conducting an evaluation with a low inlet pressure, we see that the regulator would not meet the customer's expectations under this condition. Therefore, we would not have specified this regulator for our customer's application, thereby eliminating that dreaded phone call from an unhappy customer! Evaluating droop for gases other than air or nitrogen You can use the flow curves to evaluate applications for gases other than air or nitrogen. Using compensation factors found in Tescom's document, 'Flow Formulas For Computing Gas and Liquid Flow Through Regulators and Valves', you multiply the flow values by the appropriate multiplier to get a new flow scale for the gas involved. For example, to convert nitrogen flow to hydrogen flow, the multiplier is 3.79; 1 SC FM of nitrogen equals 3.79 SC FM of hydrogen, 2 SC FM of nitrogen equals 7.58 SC FM of hydrogen, and so on. The shape of the flow curves remains the same, only the flow scale changes. Dealing with Droop There are several ways to deal with droop. To minimize droop, choose a regulator with a better droop curve, such as one that has a lowdroop bonnet construction. Since droop is caused mostly by the load spring, then a better spring should provide better droop performance. The taller low-droop bonnet houses a longer load spring (see photo page 1), which provides better droop performance. Low droop bonnets are available for most of the high purity regulators we offer. Another approach is to eliminate the load spring altogether, by using a dome or air-loaded construction. Dome and air-loaded regulators generally have much flatter flow curves, often cutting the droop of a given regulator by half. For the ultimate in droop control, a closed-loop control scheme that uses Tescom's ER3000 in conjunction with a properly sized dome or air-loaded regulator will eliminate droop all together. Accumulation Pressure So far we've only discussed droop, which applies only to pressure reducing regulators. Back pressure regulators exhibit a similar trait, though it's not called droop. Since back pressure regulators control the upstream pressure (P1), rather than the downstream pressure, we notice that as the flow increases, the set-point goes up. The increase in set-point as flow increases is called accumulation, and is also caused primarily by the load spring. To minimize accumulation, choose a pressure regulator with a low-droop bonnet, or a dome or air-loaded regulator.

C.4 - What is creep?

Any increase in the outlet pressure subsequent to lock-up, usually a long-term slow pressure increase. This indicates a regulator leak and calls for the immediate removal of the regulator for service. This may be caused when contaminants from upstream of the regulator are deposited on the valve seat or actually damage the seat during flow – this will obstruct the valve stem from sealing on the seat due to surface damage. Should this happen, positive shut-off cannot occur and the downstream pressure will gradually try to reach the same as the inlet pressure (dependent on media flow). A tied diaphragm regulator can be used to minimize creep where the design will try to compress the contamination into the seat to achieve positive shut-off and protect the diaphragm from rupturing as well as components in the system downstream of the regulator.

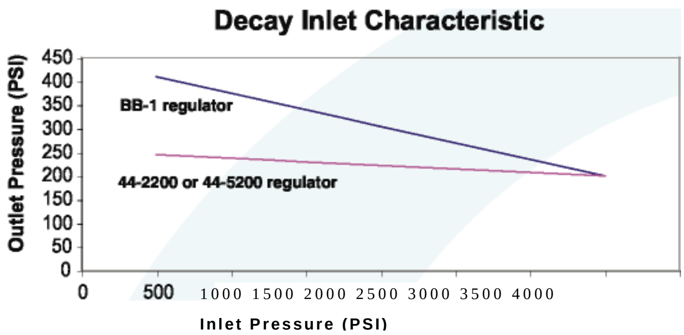
C.5 - What is the decaying inlet characteristic? *(Application story by Louis J. Arcuri)*

The effect on the set pressure of a regulator as a result of an inlet pressure change which is normally an increase in outlet pressure due to a decrease in inlet pressure. Some people work with pressure regulators all of their lives and never know what is really going on inside. Tescom spends a great deal of time teaching our distributors and customers about the key operating characteristics of pressure regulators. We're never surprised at how many engineers and technicians don't know what droop and decaying inlet are, since so little is published about these effects. Nevertheless, understanding them and using the flow curves to properly evaluate a regulator's performance for an application is the secret to a trouble-free installation.

Definition: The decaying inlet characteristic is the amount of change seen on the set point of a pressure reducing regulator as the inlet pressure varies. The decaying inlet characteristic has an inverse relationship between the inlet and outlet pressure of a single stage regulator; as the inlet pressure goes down, the outlet pressure goes up (see chart below).

Considerations:

We must consider decaying inlet when our pressure source is a compressed source, such as a cylinder or tube trailer. When our source gas comes from a compressor, or liquid source such as a dewar, the inlet pressure is fairly stable, and the effect of the decaying inlet characteristic on set point is negligible.



How It Works: - To see how decaying inlet works, let's consider a few Tescom regulators for the same application.

Parameters: Our application is a compressed gas that is packaged at 3500 PSIG. Our process requires a 200 PSIG set point.

Scenario A:

We'll look at the BB-1, which is rated for 3500 PSIG max inlet pressure, and has a 7 PSIG/100 PSIG decaying inlet characteristic. Assuming that we start with full inlet pressure of 3500 PSIG, and that the source pressure will decay to 500 PSIG before it is either changed out or recharged, the net change on the inlet of the regulator is 3000 PSIG. If the regulator is initially set for an outlet pressure of 200 PSIG with 3500 PSIG on inlet, then the outlet pressure will rise by 210 PSIG to 410 PSIG.

3000 PSIG change in inlet pressure ÷ 100 PSIG = Factor of 30

Factor of 30 x 7 PSIG decaying inlet characteristic = 210 PSIG increase

Scenario B:

The 44-2200 and 44-5200 have much lower decaying inlet characteristics (1.5 PSIG/100 PSIG). Using the same operating conditions in the previous example, we find that these regulators will see a pressure rise of 45 PSIG on the outlet, from 200 PSIG to 245 PSIG. Clearly, we get better outlet pressure stability with these regulators.

Scenario C:

To further reduce the decaying inlet effect, we should consider taking the pressure reduction in two steps, or stages. We typically use a two-stage regulator like the 44-3400 to do this. The 44-3400 is composed of two 44-2200 regulators built into the same body and internally connected in series with one another. The decaying inlet characteristic of the 44-2200 is 1.5 PSIG/100 PSIG. The first stage is preset at a nominal pressure of, say, 500 PSIG. The second stage is adjusted to our original 200 PSIG set point. When the source pressure decays from 3500 to 500 PSIG, the first stage sees a net decrease of 3000 PSIG on its inlet. The outlet pressure of the first stage will increase by 30 PSIG, to 530 PSIG. The second stage now sees a net increase of 30 PSIG on its inlet. The outlet of the second stage will go down by .45 PSIG (.3 x 1.5 decaying inlet characteristic = .45 PSIG). To anyone reading a typical pressure gauge on the downstream side of the two-stage regulator, the decaying inlet characteristic is transparent.

Controlling decaying inlet characteristic - Two-stage pressure regulators are frequently employed as cylinder regulators for packaged specialty gases. The flows are typically low, and the two stage reduction allows the operator to provide stable delivery pressures to the process. There are times when a single stage regulator is used on the cylinder, which feeds a header in a lab or process facility. Point of use regulators are installed along the header, permitting individual users to adjust their pressures accordingly. The use of a single stage source regulator, along with point-of-use regulators, provides the two-stage reduction necessary for controlling decaying inlet characteristic. For higher flow applications, Tescom offers regulators with balanced main valves, like the 44-1300. The 44-1300 is so highly balanced that its decaying inlet characteristic is a very low .1 PSIG/100 PSIG with a 0 – 300 PSIG control pressure. For a 3000 PSIG reduction on its inlet, the 44-1300 would yield a 3 PSIG increase on its outlet, nearly transparent to anyone working with this regulator. The 44-1300 is often used as a tube-trailer regulator because of its high flow, and extremely low decaying inlet characteristic. These qualities allow users to employ only one regulator to provide the required working pressure for their process.

Mistaken Identity - Many times, unknowing regulator users observe the decaying inlet characteristic and mistake it for a leaky regulator. In the non-flowing condition, the user observes that the set point has climbed above the original set point, and believes the regulator is creeping. One quick method to confirm that the regulator is not creeping is to observe the gauge reading for a short period of time. If the pressure has stabilized at a few pounds above the original set point, then this is probably decaying inlet. If the pressure is slowly climbing, and not stabilizing, then the regulator seat is contaminated, and the regulator must be removed for servicing. By confirming that the source pressure is a compressed source such as a cylinder, you can quickly correlate the drop in inlet pressure to the increase in set point.

Sizing a regulator - There are several reasons to consider the decaying inlet characteristic when evaluating a regulator. First and foremost, can the system handle the increase in outlet pressure? What if the outlet pressure decays to a point where a relief valve triggers or rupture disk ruptures for example? Secondly, can the process itself tolerate the pressure swing involved? In our BB-1 example mentioned earlier, could the process tolerate a 210 PSIG increase on the set point? Are gauges and other instrumentation downstream of the regulator sized to handle this increase in pressure? Our responsibility as applications specialists is to consider all possibilities when selecting a regulator for the customer's application and by taking into account the decaying inlet characteristic when you size a regulator, you can avoid any surprises that would otherwise result when the regulator is placed into service.

C.6 – Why is my regulator freezing? (Joule-Thompson Effect) *(Application story by Louis J. Arcuri)*

Have you ever seen a regulator that was encased in a ball of ice on a hot summer day?

It is strange to think that a regulator would be buried under a frozen mass of water when the ambient temperature is high and the rest of the piping is not frozen! Chances are that you're seeing the results of the Joule-Thompson Effect in action.

Just what is the Joule-Thompson (or J-T Effect) and why should it be important to you?

First described by the noted scientists James Joule and William Thompson in 1852, the J-T Effect, or J-T for short, is simply described as the cooling effect of a high pressure gas as it expands into a lower pressure area. We've all come to heavily depend on the practical benefits of the J-T Effect; think air conditioning, Yes, the J-T Effect is what gives us that splendid cool air in our home, car or office on a hot summer day. Refrigerant is compressed to high pressure which then flows through an orifice where it expands into the heat exchanger tubes of the air conditioner. A fan moves fresh air over the heat exchanger tubes which cool the air as it moves into the ducts and flows through your home, car or office. The gas warms as it absorbs the heat from the air and is re-circulated, compressed and expanded over and over again to maintain the cool temperatures we crave on those hot summer days. If you use a spray can of air freshener, deodorant or other product you will feel the can cool in your hands as you spray the product. You are feeling the effect of the gas expanding as you spray it, cooling the can.

The J-T Effect is responsible for that large ball of ice around the regulator we observed earlier. High pressure gas is fed to the regulator and expands as it flows past the main valve and through the seat into the P2 chamber then on to the process. The gas is flowing at supersonic speed as it expands out of the seat, cooling the body of the regulator as it flows. If the gas has a high enthalpy (stored energy) it will cool off a lot. If the gas has a low enthalpy then its cooling is minimal. The ice builds up on the regulator because the body of the regulator is cooler than the surrounding air; the cooling effect of the expanding gas is greater than the ability of the regulator to absorb heat from the surrounding air to offset the cooling. This allows the moisture in the air to condense on the body of the regulator in much the same way we see condensation form on the glass of a cold drink on a hot, humid summer day. If the regulator body is colder than 32°F, the condensation freezes on the regulato r body. Over time, the frozen condensate can grow into a substantial ball of ice, making the problem worse, as the ice prevents the regulator body from absorbing heat from the surrounding air. Certain specialty gases, such as Carbon Dioxide (CO2) and Hydrogen Choride (HCl) have a high enthalpy and are very susceptible to J-T. Ammonia is another gas with a high enthalpy and is often used in large, commercial and industrial refrigeration systems. The air conditioning system on the International Space Station employs ammonia as the refrigerant. Though the sight of an ice-covered regulator may be surprising, there is no real harm occurring to the regulator itself. Rather, there more likely may be a problem with the controllability of the downstream pressure and this is a problem to the customer. Controllability may be affected if the cooling of the gas is so great that the gas actually liquefies briefly in the regulator after it passes through the main valve. This liquid then vaporizes back to a gas as it moves through the warmer piping beyond the regulator. Vaporizing the liquid produces pressure surges that are uncontrollable resulting in unstable downstream pressures = not good.

There are several ways to deal with J-T and minimize or prevent the gas from liquefying. Often, we use a two-stage pressure reduction scheme to minimize the J-T Effect. By taking the pressure drop in two stages, the total cooling effect is split between the two regulators, each of which may be able to absorb enough heat from the atmosphere to prevent the gas from liquefying. For some gases, such as HCl, the enthalpy is so high that two stage-reduction alone will not prevent the liquefaction of the gas as its pressure drops. In this case, heat is applied to the piping before the first and second stage regulators, raising the gas temperature enough to prevent the gas from liquefying as it passes through the main valves of the regulators. For high flow HCl systems, heaters rated for several hundred watts may be required. Consider how hot a 100 watt light bulb gets, and you can better imagine the amount of heat required to prevent HCl from liquefying at high flows. For lower flow applications, simply separating the two regulators with a long length of tubing will usually allow the gas to recover enough temperature between stages to prevent liquefaction after the second stage reduction. Another approach is to use a vaporizing regulator such as the 44-4800, which employs heat exchanger tubes to warm the gas with integral electrical heaters or steam. The 44-4800 is an excellent choice for minimizing the J-T Effect in low flow applications. Sometimes, using regulators with larger bodies, such as the 44-3200 and 64-3200 series will help offset some of the J-T Effect as the larger mass of the body can absorb more heat from the surrounding atmosphere and requires more cooling from the gas to reach liquefaction temperatures.

Most gases exhibit a cooling effect when they expand; two notable exceptions are hydrogen and helium. These noble gases actually generate heat when they expand, though the heat generated is negligible. While it may seem the J-T Effect is undesirable, we have already seen a positive use for it in air conditioning. Another very important benefit of the J-T Effect is cryosurgery. Cryosurgery is used in removing warts and other unwanted skin conditions by flowing two gases at low flow, but under high pressure, through a surgical instrument that allows the gases to expand at the tip of the device. The expanding gases cool the skin and freeze it locally; the pressure of the gas then cuts through the skin to remove the offending condition. Cryosurgery is also used in a prostate cancer surgery procedure known as cryoablation. In this procedure, cryoprobes are inserted into the prostate gland. Argon and helium are circulated through the probes; the gases expand in the probes, producing the desired cooling effect. The cryoablation process freezes the tumor and kills the diseased tissue. Tescom makes a changeover panel, the NA-48, for cryosurgical gas applications.

J-T is one of those practical applications of physics that we see every day, but don't fully appreciate. Yet, without the beneficial effects J-T, our lives would be much less comfortable!

COMMON REGULATOR TERMINOLOGY

accumulation pressure - The increase in the inlet pressure to a back pressure regulator required to obtain a specified flow rate.

accuracy - The variation in outlet pressure which occurs under steady state conditions within the control range of a regulator.

balanced valve - A main valve which has been designed to be pressure balanced, hence, the main valve spring provides the shut-off force. The three major benefits of the balanced valve design are: (1) a reduced seat load, (2) larger seat orifice capability (larger flows), and (3) reduced decaying inlet characteristics.

bellows - One of three styles of sensing elements. It is the most accurate of the three sensing elements. The sensitivity is due to its large sensing area and many flexing points.

bias - The pressure increment which is adjusted or preset into a regulator and is usually held constant during normal functioning.

burst pressure - A design test pressure which determines the ultimate structural strength of a regulator or valve. Permanent deformation and leakage are permitted, but parts must remain assembled (no sudden ruptures). Accepted industry standard per ANSI/ASTM B31.3 is 400% of design pressure.

captured venting - A feature incorporated in a self-venting pressure reducing regulator which provides an additional port to permit the piping away of the expelled fluids from the regulator's vent valve.

control element - One of the three basic elements of a pressure regulator. It acts to reduce a high inlet pressure to a lower working or outlet pressure. The control element sometimes called a main valve, valve stem, or poppet.

cracking pressure - A term used in back pressure control only and is the inlet pressure, to the regulator, at which flow starts.

creep - Any increase in the outlet pressure subsequent to lock-up, usually a long-term slow pressure increase. This indicates a regulator leak and calls for the immediate removal of the regulator for service.

Cv - See "Flow Capacity".

decaying inlet characteristic - The effect on the set pressure of a regulator as a result of an inlet pressure change; normally an increase in outlet pressure due to a decrease in inlet pressure.

diaphragm - One of several types of sensing elements. The diaphragm style is very sensitive in reacting to outlet pressure changes. Slightly less so when the diaphragm is metal. Common diaphragm materials are Buna-N, Viton, Ethylene Propylene, 316 Stainless Steel, and Elgiloy.

differential pressure regulator - A pressure control regulator which is designed to provide a controlled pressure which is the sum of a signal (reference) pressure and a bias pressure. The bias may be either positive or negative.

dome loading - One type of loading element. Gas or liquid is put into the dome of a dome regulator at a pressure equal to the outlet pressure desired. This dome pressure is normally provided by a second regulator called the pilot regulator.

droop - The outlet pressure change (offset) from the "set pressure" which occurs as flow rate increases.

flow capacity (Cv) - The maximum flow capability of a regulator or valve established at a specific set of conditions. The standard coefficient is the term Cv which by definition is the flow of one GPM of water at one PSI drop. The term Cv for gaseous service is dependent on the ratio of inlet to outlet pressure and must be determined by the use of appropriate formulae.

flow rate (Q) - The quantity of fluid being passed through a regulator or valve during a specified time period. Units of measure include: SCFM, SCFH, L/Mn, GPM, and GPH.

HPIC - High purity internal connection (internal female VCR)

inlet pressure (P1) - The pressure of the fluid media, gas, or liquid, to the supply connection of a regulator or valve. Typical units of measure are: PSIG, BAR, or PASCAL.

leakage - external - The loss of fluid from the external surfaces or joints of a regulator or valve. Example: From the body-bonnet-diaphragm joint.

leakage - internal - The loss of fluid through a regulator or valve, between pressure zones normally expected to be sealed. Example: Between the inlet pressure (P1) and the outlet pressure (P2) zones.

leakage - inboard - Leakage through an external joint or seal where the direction of flow is from the outside into the regulator or valve. The leakage rate is measured in atm cc/sec He(lium).

leakage - outboard - Leakage through an external joint or seal where the direction of flow is from the inside of the regulator or valve to the outside. The leakage rate is measured in atm cc/sec He(lium) and the pressure inside the regulator should be stated.

load element - One of the three basic elements of a pressure reducing regulator. It provides the means by which the operator can set the force that determines the outlet pressure of a regulator.

lock-up - The outlet pressure increase which occurs above the "set pressure" as the flow is decreased to zero.

minimum controllable flow - The lowest volume of fluid, gas, or liquid, a regulator can pass and still maintain steady state conditions.

minimum controllable pressure - The lowest pressure which a regulator can control and still maintain satisfactory performance.

outlet pressure (P2) - The pressure of the fluid media, gas, or liquid, from the discharge connection of a regulator or valve.

P1 - See "Inlet Pressure."

P2 - See "Outlet Pressure."

pilot regulator - A pressure reducing regulator which feed gas or hydraulic pressure into the dome of a dome loaded regulator. The pilot regulator should be a venting type regulator in order to permit pressure in the dome to be adjusted to a lower pressure.

piston - One type of sensing element. A very strong unit made of brass, 303, or 316 Stainless Steel and used in high pressure applications up to 15,000 PSIG.

proof pressure - A test pressure which is applied to all pressure zones of a pressure regulator or valve to verify structural integrity. No deformation or excessive leakage is permitted at this pressure. The regulator or valve must function normally after this test. The accepted industry standard is 1.5 times (150%) the rated working pressure.

psia (absolute pressure) - A measure of pressure in psi that is referenced to zero absolute pressure.

psig (gauge pressure) - A measure of pressure in psi that is referenced to ambient pressure.

RA finish - Roughness average. Tescom machines to a roughness average which does not exceed 10 RA.

repeatability - The ability of a regulator to return to the same set pressure subsequent to being subjected to various flow demands.

reseat pressure - The inlet pressure of a back pressure regulator at which flow stops.

self-venting - A feature incorporated in certain pressure reducing regulator which enables the unit to vent the outlet (downstream) pressure when the handknob is adjusted in the decrease direction (counterclockwise).

sensing element - One of the three basic elements of a pressure reducing regulator. It senses the changes in the outlet pressure permitting the regulator to react and attempt to return to the original "set pressure" by increasing or decreasing pressure.

sensitivity - The ability of a pressure regulator to respond to change in discharge conditions: pressure, flow, temperature, etc.

set pressure - The desired operational outlet pressure for a regulator, normally stated at NO FLOW conditions.

set-ability - The minimum pressure increment or fraction thereof, which can be achieved by an experienced operator, when setting a pressure regulator.

specific gravity (Sg) - Specific gravity of gases is the ratio of molecular weight of any gas to that of air.

specific gravity (SL) - Specific gravity of liquids is the ratio of specific weight of any liquid to that of water.

unbalanced main valve - The most common main valve design. Inlet pressure provides the majority of the shut-off force. The function of the main valve is to reduce the high inlet pressure to a lower outlet pressure.