Introduction to Gas Regulators

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INTRODUCTION

Spring operated gas regulators are force balanced mechanical devices that operate everything from your gas grill at home to large distribution & transmission systems. Regulators are often referred to as control valves, governors, or pressure reducers. System designers use regulators for several reasons; first and foremost safety, economics, and a way to deliver an acceptable working pressure to downstream gas appliances. With gas fired equipment and distribution systems becoming more sophisticated due to higher efficiency and lower emissions requirements, understanding gas system requirements and selecting an appropriate regulator is becoming more important.

An ideal distribution system would deliver gas directly from the wellhead through mains and service lines to the consumer without any regulation. Unfortunately, ideal conditions don't exist. We need regulators to ensure a safe and reliable pressure is consistently delivered to downstream equipment while being subject to dynamic and ever-changing flow conditions in distribution systems.

Generally speaking there are three categories of pressure systems in a gas distribution system. A "low pressure system" is designated as a system that operates at 2 PSIG or less; normally in inches water column (" W.C). "Medium & Intermediate Pressure" systems refer to gas distribution systems that operate above 2 PSIG and less than 60 PSIG. And finally "High Pressure" refers to systems that operate above 60 PSIG. These terms vary slightly from utility to utility.

Pressure Units

There are two main units of pressure that we deal with; gage pressure and absolute pressure. Gauge pressure is usually expressed as either psi or psig, although psig is the more appropriate and relevant to everyday life. Absolute pressures are expressed in psia.

$$P_{abs} = P_{atm} + P_g$$

It's important to know the difference in pressures first because Boyle's Law applies to gases in absolute pressure (Pabs) units. Secondly, it's very important because the maximum flow through an opening such as a valve or an orifice is calculated using pressures. The pressures used in flow calculations must be in absolute pressure. Failure to use absolute pressures can result in incorrect calculations. Consider relief valves are sized using Pabs to determine their flow capacities. Using a pressure other than P(abs) could potentially result in an undersized relief valve that is not able to protect the downstream pressure system from over pressurization.

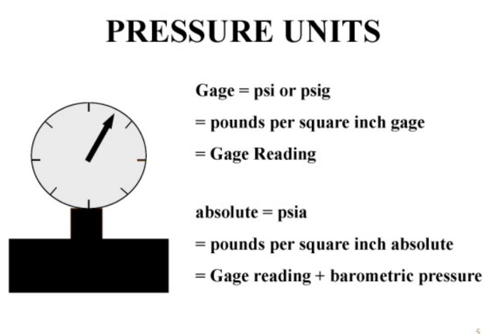

Figure 1

In the example below, assuming atmospheric pressure in Atlanta, GA is 14.5 and in Denver, CO is 11.3. In Atlanta, GA, the absolute pressure would calculate as shown in figure 2. In higher elevations such as Denver, atmospheric pressure is less. Gas molecules are further apart from each other. Therefor absolute pressure for Denver would be less than that in Atlanta, GA

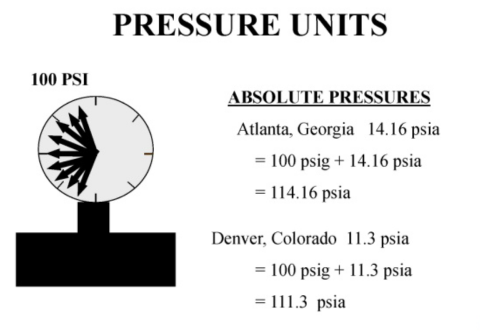

Figure 2

FUNCTIONS OF A GAS REGULATOR

The primary function of a gas regulator is to take gas from a high pressure system and reduce the gas pressure to an acceptable lower working pressure required of downstream equipment while maintaining a desired outlet pressure within an expected degree of accuracy.

Typical installations are similar to Figure 3 below where the regulator is installed upstream of a valve and gauge.

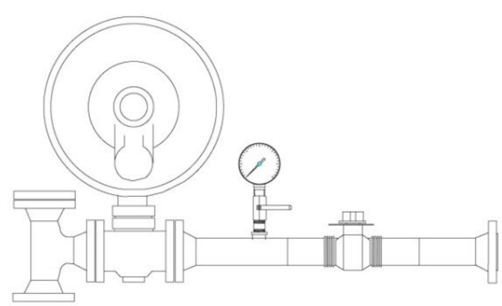

FIGURE 3

Types of Spring Acting Regulators

There are basically 2 types of spring acting regulators; direct acting and lever operated regulators:

1). Direct Acting:

The first example is a direct acting regulator where the stem, diaphragm, and valve are directly connected as depicted below in figure 4.

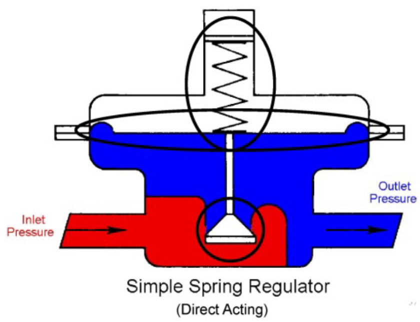

Figure 4

2). Lever Operated:

The second is a lever operated regulator where we use a lever as a mechanical advantage to improve the overall performance of the regulator; refer to figure 5 below.

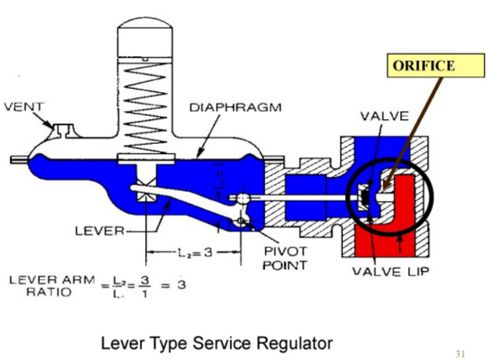

Figure 5

WHAT INFORMATION DO YOU NEED TO SIZE A REGULATOR?

1. **Understanding of Application**
2. **Turndown requirement of the system**
3. **Maximum capacity in BTU or SCFH**
4. **Maximum inlet pressure**
5. **Normal inlet pressure**
6. **Minimum inlet pressure**
7. **Downstream delivery pressure**
8. **Downstream piping diameter – limit downstream velocities to minimize turbulence**

Application

This is where we choose what kind of regulator we need. Equipment such as a fast acting, on-off boiler, we would choose a direct acting regulator.

On the other hand, if it is a large commercial building and we're serving a number of roof top heating units, a faster acting regulator is not required. In this case we would likely choose a lever type acting regulator.

TURNDOWN RATIO (TDR)?

Turndown is the ratio of the maximum rated capacity as compared to the minimum rated capacity a regulator can control and maintain a desired delivery or set pressure.

If turndown is 20:1 and the maximum capacity of a selected regulator is 10,000 SCFH; the minimum capacity at which you would want to size for is 10,000/20= 500 SCFH.

If the low end flow rate required of a regulator is too low (i.e. below the calculated TDR of the regualor), the valve is trying to operate too close to the orifice. Its very difficult for a regulator to maintain such a slightly open position. Just as the regulator opens and satisfies downstream, it has to close immediately thereafter to be able to maintain and not over-shoot downstream the desired downstream set pressure. This is when regulators can begin to "chatter" and become unstable.

Typical Turndown Ratios:

- A direct acting regulator has a typical turndown of 25:1.
- A typical service regulator, with a 3:1 lever ratio, has a turndown of 50 to 1 or more.

Other Sizing Considerations

There are a number of other considerations when sizing a regulator for an application. For example, the speed of response of a direct acting regulator is the fastest since the valve stem is connected directly to the diaphragm. Lever operating regulators are slightly less because of the typical 3:1 lever ratio. Pressure loaded or pilot operated regulators, although the most accurate, are the slowest acting regulators due to their pilot system. Other considerations:

- **Speed of Response**
- **Accuracy**
- **Inlet Pressure Variations**
- **Internal vs. External Control**
- **Internal Relief Valve (IRV)**
- **Body Size**
- **Fluid - LPG, air, H2, Natural Gas**

Maximum Inlet Pressures

The maximum inlet pressure of a regulator is generally dependent upon the size of the orifice, as per the catalog example below.

Maximum Inlet Pressures–Standard IRV Models and High-Pressure Models							
Orifice	5/8″	1/2″	3/8″	5/16″	1/4″	3/16″	1/8″
Pressure	10 psi	20 psi	40 psi	40 psi	60 psi	125 psi	125 psi

The orifice size selected is based on the inlet pressure and the downstream load. Refer to image below. Imagine gas is entering the orifice of a regulator. Gas strikes the valve pad, effecting an area the size of the orifice. The resultant force is a function of the *inlet pressure* x *area*. The area of a smaller orifice results in a force relatively smaller than that of a larger orifice. Therefore, smaller orifices can generally be subjected to higher inlet pressures as in figure 6, unlike the larger orifice in figure 7.

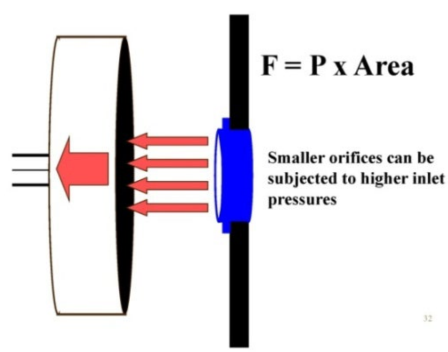

Figure 6

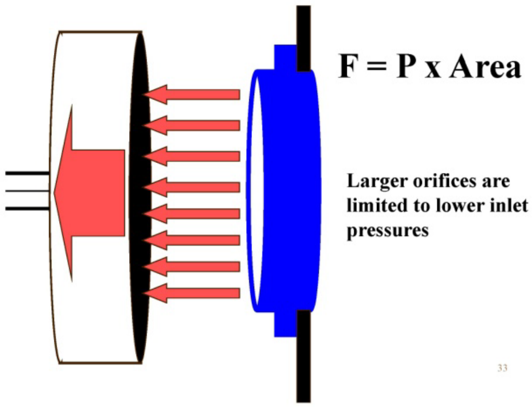

Figure 7

Full Open & Failed Capacity

A regulator's flowing capacity is based upon its desired or expected level of performance. Flowing capacity is not necessarily the most gas a regulator can flow. On the other hand we need to know and understand a regulator's full open failure flow capacity inorder to properly size external relief valves. The full open flow through an orifice or valve can be calculated using simple flow equations such as below in Fig. 8.

$$\frac{P_{in}}{P_{out}} \geq 1.894 \ ?$$

ABSOLUTE PRESSURES

Yes $Q = P_{in}K / 2$

No $Q = K\sqrt{P_{out}(P_{in} - P_{out})}$

Figure 8

To determine the equation to use when calculating full open capacity, it is necessary to evaluate the ratio of the absolute inlet and absolute outlet pressure. In this equation, if the ratio is greater than or equal to 1.894, the following flow equation is used:

$$Q = P_{in}K / 2$$

If the ratio is less than 1.894, the following equation is used:

$$Q = K\sqrt{P_{out}(P_{in} - P_{out})}$$

K is the constant associated with the orifice size or opening in the regulator (Reference Fig. 9 below).

ORIFICE	5/8"	1/2"	3/8"	5/16"	1/4"	3/16"	1/8"
K	820	520	292	206	132	74	33

Figure 9

Sizing:

Most regulator applications are sized using capacity tables found in regulator bulletins; Reference Fig. 10 below.

Inlet	Orifice					
Psig	1/8"	3/16"	1/4"	5/16"	3/8"	1/2"
1	–	110	200	220	–	–
2	–	210	240	300	–	–
5	220	290	330	390	–	–
10	290	350	420	480	–	–
15	350	410	470	550	–	–
20	410	490	500	560	–	–
25	430	500	550	580	–	–
30	470	520	580	590	–	–
40	500	570	600	600	–	–
50	550	600	600	–	–	–
60	570	600	600	–	–	–
80	600	600	–	–	–	–
100	600	600	–	–	–	–

Body Size Outlet: 3/8"

Figure 10

When choosing an orifice, you never want to select an orifice that matches and provides an identical flow rate to that of your desired flow rate.

As a general *rule of thumb* for maximum performance, you should choose an orifice that will satisfy your required flow at about 60-80% of the orifice's capacity. There are instances based on turndown and operating conditions when the orifice will need to be sized larger. Please consult the individual manufacturer for their recommendations for these types of applications.

Example - If we had an inlet pressure of 5 psig and need to satisfy a flow rate of Q = 200 SCFH, we would choose a desired orifice in order to flow:

$$\textbf{80\% SCFH} = \frac{200\ SCFH}{.8\ (80\%)} = \textbf{250 SCFH}$$

If we were to look at 5 PSIG for an inlet pressure on the left hand column of Fig. 10, we would look for a capacity equal to or slightly greater than our required 250 SCFH calculated above. In this particular case we would chose the 3/16" orifice resulting in a capacity of 290 SCFH for this scenario.

Please keep in mind that most regulator manufacturers today are providing sizing programs to size and select their regulators. These sizing programs are very accurate and take into consideration most all characteristics of their regulators. It is highly recommended to use these programs when available and get comfortable with them because they minimize the risk of making mistakes when selecting and sizing regulators.

Performance Characteristics

A. IDEAL PERFORMANCE

An ideal regulator would provide a constant outlet pressure at any inlet pressure and all flow conditions from zero up to the maximum capacity of the valve. The performance of a regulator is best shown by plotting the outlet pressure versus the rate of flow. In Figure 15, flow is plotted along the horizontal axis and the outlet pressure is plotted on the vertical axis.

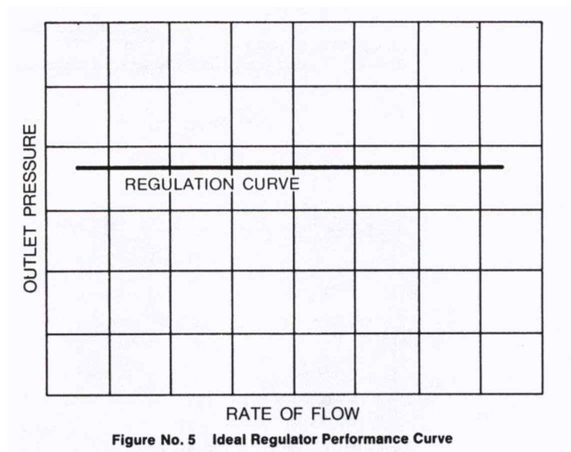

Figure 15

Note the "ideal" outlet pressure is a horizontal line. This indicates that at any flow condition, the same outlet pressure is obtained from the regulator. This would be true for any pressure setting or desired delivery pressure. The ideal condition and actual performance of a regulator may differ greatly, depending on the design of the regulator and the type of control system employed.

ACTUAL PERFORMANCE

In reality, there is no perfect regulator. Actual regulator performance is affected by the following effects:

1. **Diaphragm Effects**

In the regulator described previously in Figure15, a weight is used to load the diaphragm. For a given position of the valve, the forces in the **upward direction (F_u) must equal the forces in the downward (F_d) direction**. If we ignore any change of force on the valve and impingement effects from the flow on the diaphragm, the remaining forces are the weight acting downward and the gas pressure on the diaphragm area acting upward.

The force upward, (F_u) in pounds, is equal to the diaphragm area, (A_d) in square inches, times the pressure, (p) in pounds per square inch or (F_u) = Ad x p. Since the force downward (Fa) is constant, and F_d = F_{du} the outlet pressure should remain constant if the area of the diaphragm remains constant.

Unfortunately, flat diaphragms and many molded diaphragms do not display a constant area characteristic when in operation. Generally speaking, a diaphragm increases in area as it travels downward.

Figure 16 shows the typical changes that occur in the "effective diameter*' of the diaphragm with its position.

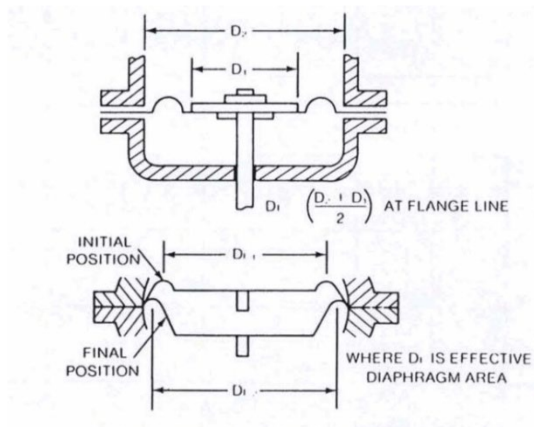

Figure No. 6 Diaphragm Effective Area

Figure 16

The actual change is dependent upon the area of the diaphragm, physical size, and the clearance between the diaphragm pans and the clamping flange.

Now that you can see this typical change in area, it is easy to see that the force equation for the upward force opposing the weight will cause a variation in the diaphragm area (A). Therefore to maintain a constant diaphragm force there needs to be a varying pressure. At the highest position of travel, or where the valve is nearly closed, the diaphragm area is small, therefore the pressure would be greater as compared to the lowest position. If we were to reference numerical values, assume the weight to be ten pounds and the initial diaphragm area, (at position De, in Figure 16 above to be 10 square inches; the pressure required for a balance of forces is:

F_u = F_d

F_d = 10 pounds

Ad = 10 in.^{2}

FU=A_d x P

p= 1.0psi

For the final position of the diaphragm, (position D_{e2} 6) assuming that the diaphragm area is 12 square inches. Thus, the pressure would equal :

(F_u) = Ad x p

10= 12xp

P= $\frac{10}{12}$ = 0.833 PSI

This diaphragm effect is shown in Figure 17, illustrating the effect of the diaphragm area change in the performance of the basic regulator.

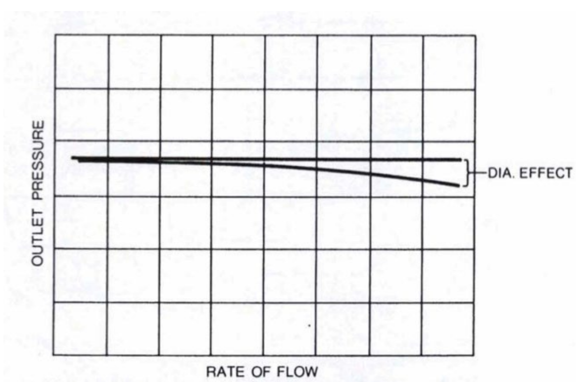

Figure 17

Some diaphragm designs provide constant area over their stroke but of notable design is one which changes its area in the opposite direction. This type will be discussed later. Note however, that if the diaphragm area were constant, the output of the regulator would be constant with the forces that have been considered.

Large diaphragms of the flat design display less percentage change of area than the smaller diaphragms. Large diaphragm areas can be used only for lower pressures due to the strength of the diaphragm materials. As working pressures increase, diaphragm sizes decrease.

Keep in mind on high pressure services, the change in area of a regualor's diaphragm can exceed 10 percent over its operating range, Also, it should be noted that as the diaphragm size decreases, the travel of the valve also decreases, thereby limiting their applications.

A method of minimizing diaphragm effect is using a lever between the diaphragm assembly and the valve assembly. This is why lever operated regulators are so popular

2. Spring Effects

The basic regulator design in Figure 13 uses a weight to balance the pressure on the diaphragm. In Figure18, the

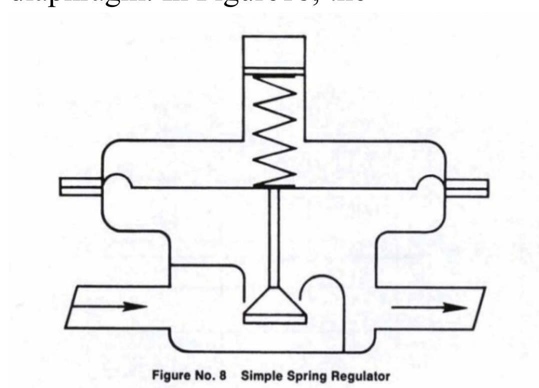

Figure 18

same basic design is modified to use a spring to balance the diaphragm. A spring is used because it can provide variations in applied force with a simple adjustment. When a spring is used the force exerted by the spring varies, depending on its compression or the amount it is squeezed. Figure 19 shows three identical springs under different loading conditions. Note that each spring has decreased in length in relation to the weight applied. When a spring is installed in a regulator, one end is fixed while the other end rests on the diaphragm and moves with the flexible element or diaphragm.

The spring constant (K) is the force produced per inch of compression; thus, in the illustration below

$$K = \frac{5\ pounds}{1\ inch}$$

or a spring constant of five pounds per inch. If the diaphragm in the regulator in Figure 18 has an initial diaphragm area of 10 sq in., and the spring in Figure19 is compressed 2 in. initially to obtain a force of 10 pounds, we would observe an outlet pressure of 1 psig. Now assume the diaphragm travel to be 0.20 inches

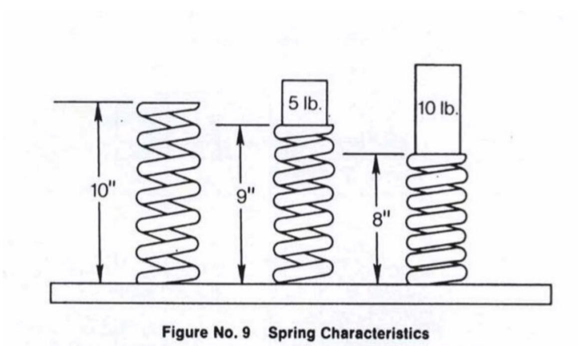

Figure 19

for full valve opening. The spring would exert less force by the value of 0.20 inches times five pounds per inch or one pound. The diaphragm area changes from ten inches to twelve inches for its final position, and we can recalculate the pressure for these conditions as follows: Again, force upward is equal to the diaphragm area, times the gas pressure. The force downward is produced by the spring, neglecting weight of parts, and is equal to the spring constant K times the total compression of the spring.

F_d= K x compression = 5 x (2-0.2) = 9 Ibs.

Force up = Force down

Force up= A_d x p

9 Ibs. = 12 in.^{2} x p

$$P = \frac{9}{12} = 0.75 \text{ psi}$$

In the second example for a weight-loaded regulator, the pressure was calculated to be 0.833 psi. In this example the pressure is 0.75 psi revealing that an additional pressure change occurred due to the change in forces. This is illustrated in Figure 20. An ideal spring is one which is infinitely long since there would be no change in force for small changes in compression. However a regulator case would be so large that a compromise is made in the design to provide for a flexible spring of reasonable size. The curve below in figure 20 shows the additional effect a spring has on the performance of a regulator.

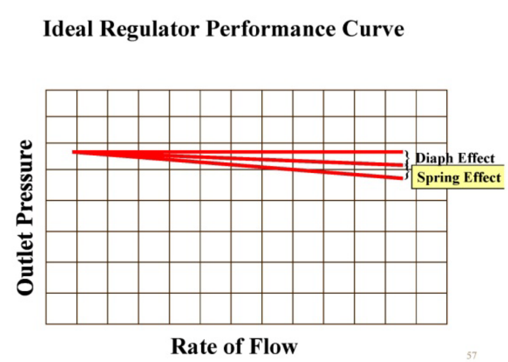

Figure 20

When choosing a spring for a regulator try to never use a spring at the very beginning or end of its range. Always choose a spring that is in the middle of the pressure range you need.

3. Body Effect

A third factor governing a regulator's performance can be termed the body effect or amount of turbulence between the diaphragm and the point of measurement on the downstream pipe where the pressure is normally measured. Figure 21 show the additional affect of the body.

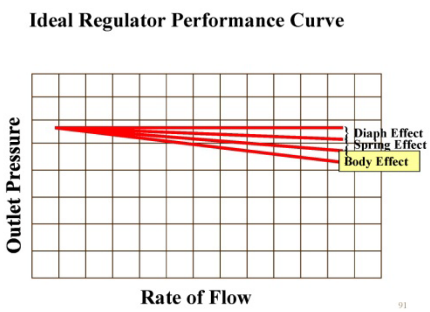

Figure 21

4. Inlet Pressure Effect

Inlet pressure effects the following:

- **The effect of inlet pressure acting on the underside of a valve**
- **The impingement of the valve discharge on the diaphragm**
- **Pressure loss due to turbulent flow through body**
- **Pressure loss due to friction when decreasing velocity**

When gas enters the body of a regulator, inlet pressure acts on the bottom side of the valve. This pressure results in an upwards force of magnitude (pressure x area of the valve). Likewise, outlet pressure acts on the top of the valve(s) creating a downward force. However, since the outlet pressure is less than inlet pressure, the resulting force is upward, acting against the opening of the valve.

One way of eliminating inlet pressure effect is to utilize a balanced double ported valve or balanced valve design. With a double valve, inlet pressure acts on the bottom side of one valve while it acts on the opposite of the second valve, practically cancelling the pressure effect out with respect to one another. Therefore, the effect of inlet pressure on the valve is removed.

The second inlet pressure effect to realize is the impingement of the valve discharge on the diaphragm as depicted in figure 22.

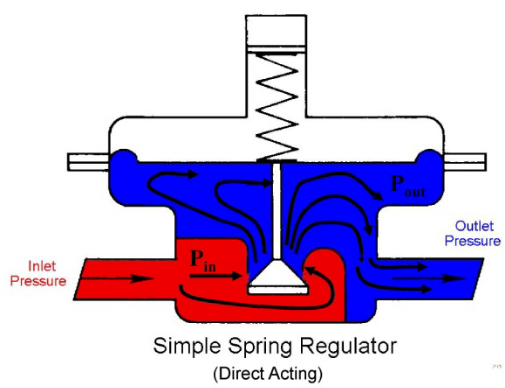

Figure 22

5. Boost

The opposite of droop is called boost. Boost is a method of counteracting droop by creating a false pressure under the diaphragm. Most service type regulators in the industry incorporate some type of boost to counteract droop.

A regulator with velocity boosting, is designed so the control pressure is no longer applied to the diaphragm. Instead a pitot tube is inserted in the outlet of the regulator in an area of lower pressure within the body.

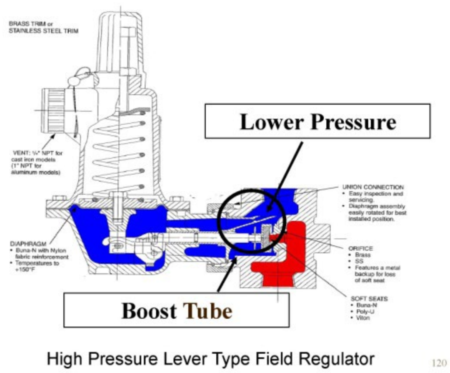

Figure 23

In this high pressure regulator shown in Fig 23, the boost tube is shown projecting into the outlet pressure side of the body of the high pressure field regulator. The tip of the boost tube is located strategically at a location of lower pressure. The lower pressure is a result of the venturi effect of the gas as it passes downstream around the tube. This lower pressure is communicated back to the underside of the diaphragm which reacts to the lower pressure by opening the valve further. Again, the downstream pressure boosts upward and the regulators capacity increases. Note that in a regulator with a boost tube like this, a model that requires an internal relief valve, cannot use the boost tube. The small opening in the boost tube would not allow for the adequate relieving of the downstream gas through the IRV.

Additional methods of boosting include body rings which alter the flow of gas through the body to again, create a false, lower sense pressure. The design of a valve pad can also help to create boost too.

6. Positive Lockup Zero Flow

Lockup is the term used to describe a regulator that closes off completely so as not to allow any gas to pass downstream. With all of the new electronic gas utilizing equipment used today, it is more important than ever that regulators achieve a positive lockup. This is because today there are less and less equipment with standing pilots that can be used to burn a small amount of gas that would seep by a nicked orifice or damaged valve seat in a regulator. When operating properly, a regulator will close off and “lockup” when the downstream requires no gas.

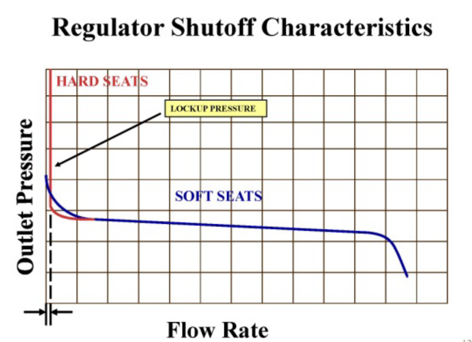

Figure 24

In order to obtain complete shut-off, soft seat valves are required. The actual regulation curve of the soft seat will be determined by the physical condition of the soft material. If the material is irregular, the curve will bow as shown. However, if the material is very flat, the curve bows less. As the material hardness increases, the curve approaches the hard seat curve with lock-up increasing as hardness increases. It should be remembered, however, that the flatness or the contour of the soft material has a great influence on the final lock-up pressure. A hard seat valve has a relatively smooth, true surface, and requires more force to close.

The harder the material, the higher the lockup pressure. There are a variety of valve seat materials available today. Buna-Nitrile is a common rubber like material, resistant to oils and other petrochemicals. Viton compared to Buna-Nitrile is more resistant to harsh gas and susceptible to higher temperatures. Polyurethane is a plastic polymer that is much harder in comparison. It comes in different hardness depending upon the color of polyurethane chosen; And then there is Nylon which is one of the hardest seat materials available. Although they are all hard seats in a sense, these seat materials are all considered "soft seats" since they can achieve 100% lockup.

Common Lockup Problems

So why won't a regulator lockup? The most common reasons are:

- Dirt/Obstruction
- Mechanical Bind
- Damaged Seat Material
- Over-pressurized orifice
- Damaged Orifice Edge
- Bent/Damaged
- Leak by Orifice Threads

7. Droop

When viewing a regulator performance chart of flow rate versus outlet pressure, as the regulator flow increases, it eventually reaches a point in which the outlet pressure drops off or "droops." Regulator manufacturers determine the capacity of the regulator based upon a certain amount of droop. So, 100% capacity is quantified by say a 2" w.c. droop. This does not mean that the regulator will not provide additional capacity. However, the outlet pressure will continue to droop or drop further below desired set point with more flow. Usually, a regulator will be sized based at a maximum of 75 - 80% of its capacity in order to stay within an acceptable operating pressure range. Refer to Fig 25.

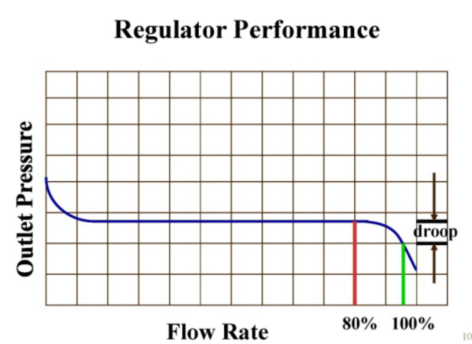

Figure 25

8. Internal Relief Valve (IRV)

An internal relief valve is an opening in the center of the diaphragm that is held closed by a smaller IRV spring. It was originally sized to relieve sudden excursions in outlet pressure when the regulator shuts off. In some cases when the inlet pressure and orifice are correctly sized the IRV can be used as a full capacity relief valve.

The ability of an IRV to provide overpressure protection to a system is dependent upon a number of criteria.

- outlet set pressure.
- failure mode. Is the failure simply a small piece of plastic wedged between the valve and orifice.
- Venting. The level of protection depends on the size of the vent as well as any vent piping. The addition of vent piping reduces the amount of gas that can be relieved due to the associated buildup or line losses through the piping itself.
- Finally, the IRV spring itself determines at the pressure when the IRV will open. Some regulator manufacturers have a choice of two IRV springs. One opens at about 9” w.c. above set point. The other opens at approximately 20” w.c. above set point. If the IRV would open and exhaust gas to the outside of the gas system. As discussed previously, it is imperative that the vent opening is not blocked to restrict the passage of the gas.

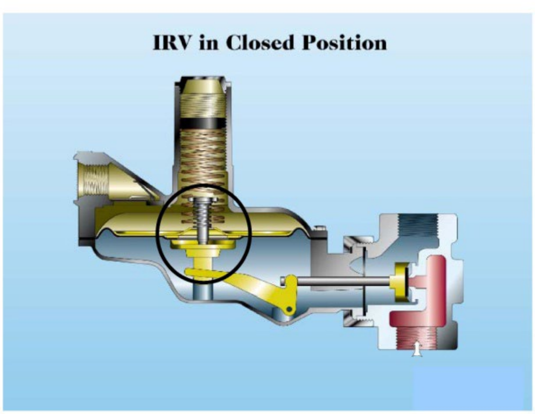

Figure 26

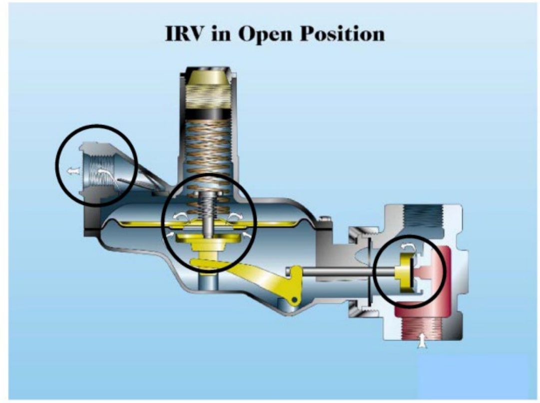

Figure 27

IRV performance is graphed for each orifice size by the manufacturer. The outlet pressure on the vertical column is the maximum pressure the downstream will build to. The horizontal x-axis is the maximum inlet pressure that the regulator will experience during a failure. The chart is read by first finding the maximum inlet pressure on the x-axis, then reading vertical to intersect with the orifice size. The maximum downstream pressure is then determined by simply reading horizontally to the y-axis. The lines can be expanded to get an approximate value for higher pressure builds. Please see the curve example in figure 28 below.

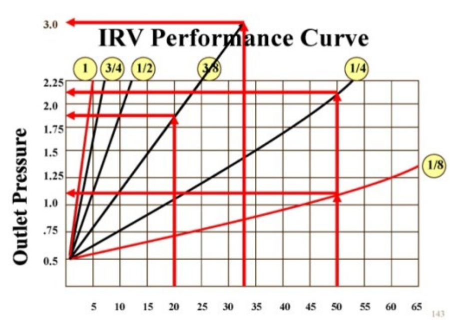

Figure 28

As you can see the internal relief valve can be full relief depending upon the orifice selected and the inlet pressure to the regulator.

CONCLUSION

It is very hard in a presentation like this to get into fine details of regulators. Though gas regulators of this type seem simple at first glance, there is a lot of time and effort spent on engineering & design to make sure they operate and perform properly and as close to ideal for all operating conditions. The fundamentals discussed in this presentation can seem somewhat complicated. However in a short amount of time you can become an expert if you consider the following items.

1. **Know/understand the application**
2. **Realize the turndown (TDR) requirement of the system**
3. **Required maximum capacity in BTU of SCFH**
4. **Understand the maximum, normal, and minimum operating inlet pressures**
5. **Select the smallest orifice available that can adequately serve your application**
6. **Chose the lightest spring for the optimal range. Avoid controlling at the top and bottom end of the rated spring range.**
7. **Finally, rely on you regulator vendor for technical questions, troubleshooting, and application assistance.**