SECTION 13C - GAS APPLIANCE REGULATORS

GAS APPLIANCE REGULATORS

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HISTORY

Every manufactured product has an interesting, romantic story connected with its development, and the gas pressure regulator is no exception.

Gas was first used commercially for lighting purposes shortly after 1800. One of the early problems faced by gas producers was the need for adequate metering devices. About 1820, a Mr. John Malam of London accidentally developed a pressure regulator in the course of his efforts to improve on the design of existing meters.

Early regulators employed a globe type valve construction very similar to conventional types in wide use today. The valve stem on these regulators was attached to an inverted metal cup whose skirt floated in a well of mercury. Small weights placed on top of the floating cup served as the valve loading. Gradually, leather diaphragms were substituted for the mercury seal, and now synthetic materials have replaced the leather diaphragm.

As gas became more widely used for lighting public buildings and homes, utility companies began leasing regulators to their customers. About 1870, an enterprising American brought several British regulators home with him. Between 1875 and 1880, a firm was incorporated leasing regulators to householders at rates of fifty cents per month and up.

Gradually, gas became more widely used in home and industry, and with increased distribution, the need for pressure regulation assumed greater importance. However, it was not until 1934 that American Standards were established for gas pressure regulators.

DEFINITIONS

A GAS PRESSURE REGULATOR is a device or mechanism, either adjustable or non-adjustable, for controlling and maintaining a uniform outlet gas pressure under variable flow rates and inlet pressures.

The function of a regulator is the same, whether it is designed for operation on a transmission pipeline where pressure is in excess of 1,000 psi, or in a residence on a gas appliance where pressure is in inches of water column.

ADJUSTMENT OUTLET PRESSURE OR SETTING. The outlet pressure to which the regulator is adjusted.

ADJUSTMENT MEANS. A means for loading the diaphragm and thus regulating the outlet pressure.

BODY. The principal structure of the regulator, which contains and supports the actuating mechanism.

DIAPHRAGM. A flexible member upon which gas pressure acts to either open or close the valve.

DIAPHRAGM PLATE. A rigid disc in contact with the diaphragm, which transmits the force of the adjustment weights or spring to the diaphragm.

VALVE. The part of a gas pressure regulator which is actuated by the mechanism to control the outlet pressure.

VALVE SEAT. The stationary portion of an assembly, which in conjunction with the valve controls the outlet pressure.

VENT LIMITING MEANS. A means which limits the flow of air or gas from the atmospheric diaphragm chamber to the atmosphere. This may be either a limiting orifice or a limiting device. A limiting device permits rapid response of the regulator during the opening cycle.

PRESSURE DROP CAPACITY. The equivalent flow rate for a loss in pressure equal to 0.3 inch water column with the regulator valve in a normally wide open position.

RANGE OF REGULATION. The high and low limits of flow between which is found acceptable regulating characteristics. For regulators designed to control pilot flow, the minimum regulation capacity is 0.12 cubic foot per hour of 1,000 Btu per cubic foot, 0.64 specific gravity gas.

TYPES OF GAS PRESSURE REGULATORS

Gas pressure regulators commonly are classified by their usage, for example:

HIGH PRESSURE REGULATOR: Often called "let down valves", and used in a pressure range in excess of 1,000 psi down to 50 psi. Transmission lines from the gas well to the city distribution system would be a typical application for this regulator.

INTERMEDIATE PRESSURE REGULATOR: Referred to as "pounds-to-pounds" regulator used in a pressure range of 1 to 50 psi. Regulators of this type are applied within the city distribution system.

SERVICE REGULATOR: "Pounds-to-ounces or inches" regulator, reduces pounds from the street main to ounces or inches for residential house piping.

APPLIANCE REGULATOR: "Ounces-to-inches" or "inches-to-inches" regulator. Gas pressure in residential house piping may be as high as 8 oz. or 14 inches, but generally is 4 oz. or 7 inches. This pressure is further reduced on the average to 2 oz. or 3.5 inches at the gas appliance regulator.

This chapter will be confined to the low pressure appliance regulator.

OPERATION

High-pressure and high-capacity regulators are complicated devices, whereas, the low pressure appliance regulator is relatively simple. Basically, any regulator consists of three essential parts: (1) a diaphragm, (2) an opposite-acting force, and (3) a variable restriction.

The DIAPHRAGM is a flexible member upon which gas pressure acts to either open or close the regulator valve (variable restriction).

The OPPOSITE-ACTING force may be a deadweight, spring or gas pressure acting on the diaphragm in the direction opposite the force exerted by the pressure to be controlled.

The VARIABLE RESTRICTION may be a poppet valve, conical valve, double seated valve, slide valve, piston or butterfly valve. It is directly connected to the diaphragm and is positioned in the gas stream by the pressure-responsive movements of the diaphragm. The basic principle of construction and operation of a gas pressure regulator will be readily understood from Figure 1 showing a cross sectional view of a typical appliance regulator and the three essential parts.

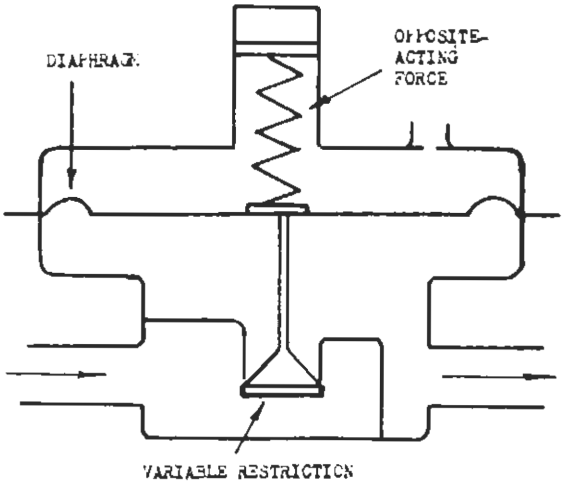

Figure 1 - Elementary Regulator Single-Valve, Spring-Loaded

Now let us look at the operation of a regulator as it goes through a cycle and see how it functions.

Figure 2 represents a simplified manifold consisting of a manual valve, regulator, orifice and burner. With the manual valve closed, there is no pressure in the manifold. The spring (OPPOSITE-ACTING FORCE), has forced the diaphragm down and the regulator valve (VARIABLE RESTRICTION), wide open.

In Figure 3, the manual valve is wide open. Gas pressure builds up against the orifice and the manifold. The regulator diaphragm being flexible, the gas pressure on the outlet side of the regulator valve pushes upon the diaphragm, moving the diaphragm upward, opposing the spring force. The upward movement of the diaphragm pulls the valve up toward the valve seat, partially closing the regulator valve. The regulator valve now is restricting the gas flow from the inlet side to the outlet side, and a point is reached where the force of the gas pressure pushing up against the diaphragm is equal to the downward force of the spring. Equilibrium being reached, the diaphragm and valve remain in a fixed position, producing a constant set outlet pressure.

Should the inlet pressure increase, the flow across the partially open regulator valve increases (flow varies with a change in pressure differential across an orifice or restriction), tending to increase the outlet pressure. However, the increased outlet

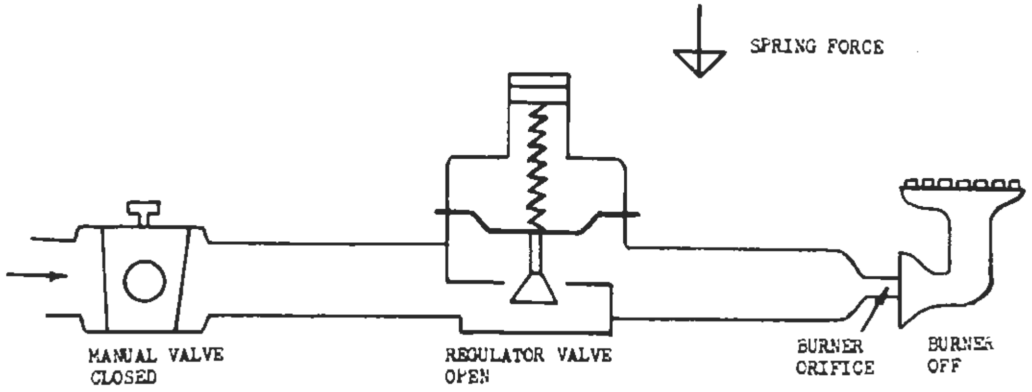

Figure 2 - Simplified Manifold, Manual Valve Closed

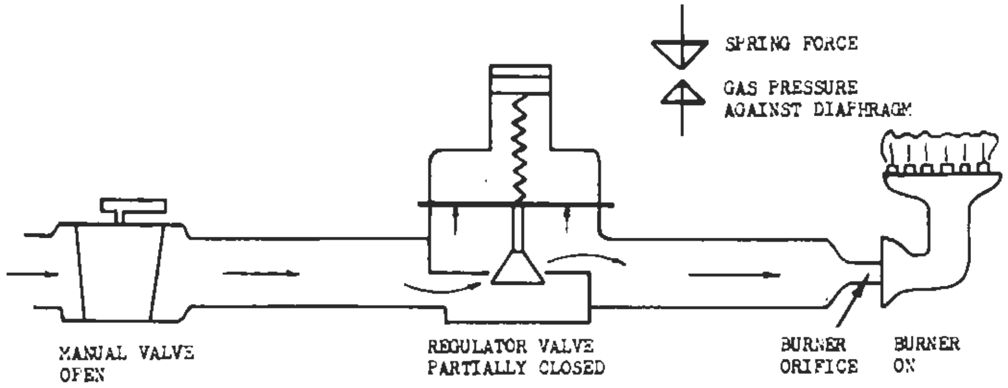

Figure 3 - Simplified Manifold, Manual Valve Open

pressure exerts a greater upward push against the diaphgram, moving the diaphragm and valve upward toward the valve seat, further restricting the regulator valve. A point is reached where the force of the gas pressure pushing up against the diaphragm is equal to the downward force of the spring. Equilibrium again is restored, the diaphragm and valve come to a fixed position, producing the original constant set outlet pressure.

Conversely, a decrease in inlet pressure results in a decreased flow across the partially open regulator valve, tending to decrease the outlet pressure. The decreased outlet pressure exerts less of an upward push against the diaphragm, the spring force moves the diaphragm down and valve away from the valve seat, opening the regulator valve. A point is reached where the downward force of the spring is equal to the force of gas pressure pushing up against the diaphragm. Again equilibrium is restored, the diaphragm and valve coming to a fixed position, producing the original constant set outlet pressure.

Let us insert an automatic gas valve, such as a solenoid valve, in the manifold between the pressure regulator and burner, and see what happens to the operation of the regulator. Under normal operating conditions, we have the same operation as shown in Figure 3.

When the solenoid valve closes, as shown in Figure 4, there is no flow across the regulator valve, downstream outlet pressure increases, exerting a greater upward push against the diaphragm, moving the diaphragm and valve upward toward the valve seat. Since outlet pressure cannot be bled off, the gas pressure upward overcomes the downward force of the spring, closing the regulator valve. This condition is commonly called "lock up". When the solenoid valve opens, outlet pressure is bled off, the spring force moves the diaphragm down and the valve away from the seat, opening the regulator valve. A point is reached where equilibrium is restored as previously discussed, and again produces a constant set outlet pressure.

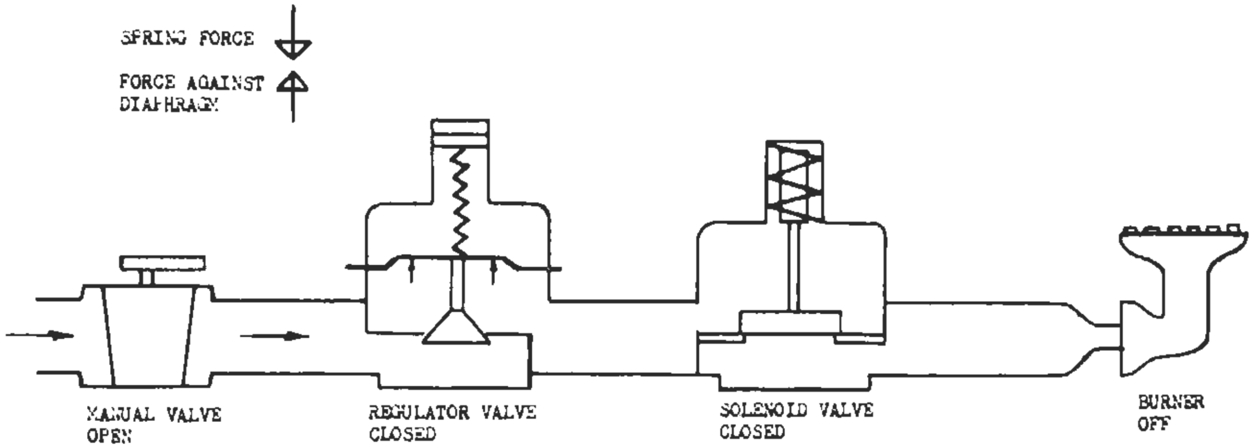

Figure 4 - Simplified Manifold, Manual Valve Open, Solenoid Valve Closed

The principle of regulator operation may thus be stated:

> The outlet pressure exerts a force on a flexible member (diaphragm) which varies the flow across the regulator valve (variable restriction). The diaphragm movement is opposed by a force (opposite-acting) tending to fully open the regulator valve. The outlet pressure is automatically maintained at the point where the downward spring force is balanced by the upward force of the gas pressure against the diaphragm.

PERFORMANCE

The performance of a regulator, how well it serves to maintain a constant set outlet pressure under conditions of variable flow rates and inlet pressures, can be visualized by plotting the outlet pressure against the flow rate. Theoretically, a perfect regulator would give a constant pressure at all flow rates from zero to maximum, or a straight line curve as shown in Figure 5.

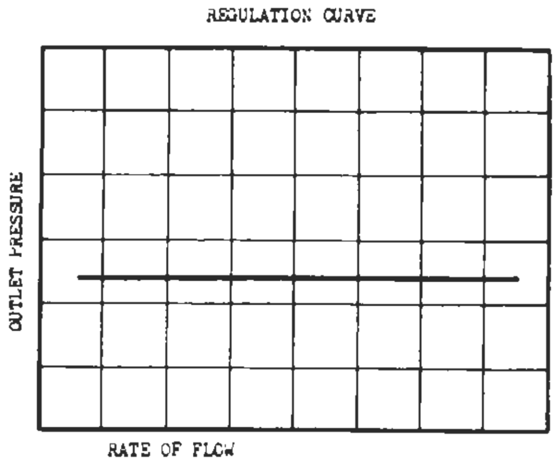

Figure 5 - Theoretically Perfect Pressure Regulation

There are several factors, however, which keep the elementary regulator from producing a truly constant outlet pressure, or straight line performance curve. We can illustrate the first effect by holding a spring in our hand. As the hand is closed, we compress the spring and will note a force. The more we compress the spring the greater the force, but as the hand is opened, the spring length is increased and the force of the spring is decreased. The effect in a regulator is similar.

As the rate of flow increases, the valve opens wider to keep the pressure loss constant across the regulator valve. Referring to Figure 1, the spring length will increase as the valve opens wider. As the spring lengthens, it exerts a decreasing downward force. Since the spring force is decreasing as the flow rate increases, the upward force of the gas pressure compresses the spring, resulting in decreased outlet pressure. The straight line performance curve in Figure 5 will drop to a value shown in Figure 7, and is known as the SPRING EFFECT. The amount of this decrease depends upon the flexibility of the spring and the diaphragm area.

The second factor is the variation in the effective diaphragm area at various positions. As the diaphragm moves down to open the regulator valve, the area becomes greater as shown in Figure 6. As the diaphragm area increases, less pressure is required below the diaphragm to counterbalance the force of

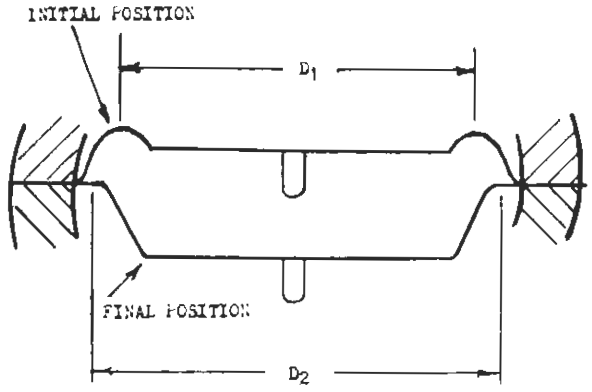

Figure 6 - Diaphragm Area

the spring. This is known as the DIAPHRAGM EFFECT, further decreasing the outlet pressure, and dropping the performance curve as shown in Figure 7.

A third factor affecting the performance curve, is the turbulence of the gas and frictional loss as the gas passes between the regulator valve and the outlet of the regulator, resulting in static pressure changes (gas exerts pressure equally in all directions by reason of being compressed in the regulator) due to the frictional loss or velocity pressure change (gas exerts pressure by reason of flow through the regulator). Should flow through the regulator valve impinge directly on the diaphragm, the impact pressure exerted tends to close the valve. This is known as the BODY EFFECT, decreasing the outlet pressure still further and dropping the performance curve as shown in Figure 7.

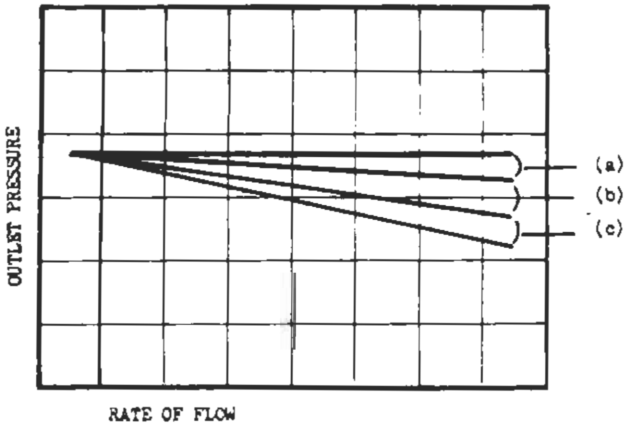

Figure 7 - Cumulative Effect of Spring (a), Diaphragm (b), and Body (c) upon Performance Curve.

The cumulative effect of the 3 factors which prevent a straight line performance curve are shown in Figure 7. We can now see that the elementary regulator would not satisfactorily maintain a constant set outlet pressure at all rates of flow.

Regulator manufacturers have developed design features which overcome one or all of these effects. Spring effect is overcome by using longer more flexible springs and larger diaphragm cases (that part of the regulator which houses the diaphragm). The larger diaphragm case also reduces the diaphragm effect. This may also be stated as: increasing the diaphragm to port (regulator valve opening) area. While friction loss cannot be overcome, friction loss in pressure can be eliminated by placing a control line or sensing hole to the diaphragm case in the downstream or outlet passage of the regulator. This will also eliminate gas impingement directly on the diaphragm. Body effect can be overcome by adopting the principles observed in pressures passing through a venturi, and knowing that static and velocity pressures are inversely proportional.

Total pressure in a regulator or pipeline is the sum of static pressure and velocity pressure. If velocity pressure is increased due to area reduction, as when passing through a venturi, static pressure is decreased. Figure 8 shows the relationship of a pressure graph to a venturi.

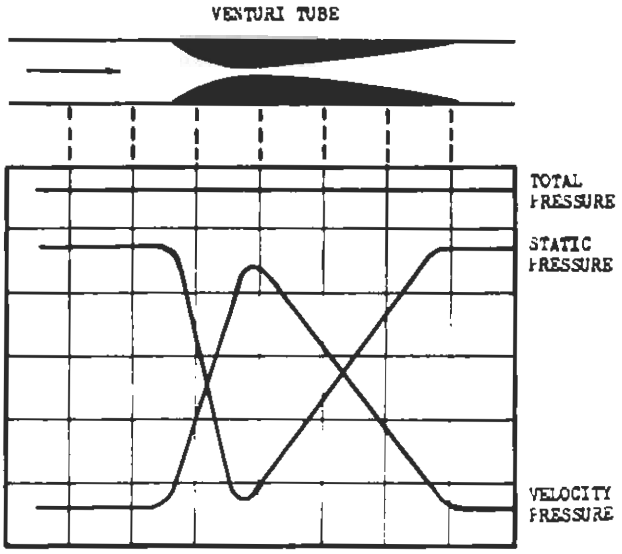

Figure 8 - Effect of Venturi Upon Static and Velocity Pressures

The amount of drop in static pressure depends upon the volume of gas passing through. Thus, correctly placing a restriction in the outlet passage, velocity pressure is increased, static pressure is decreased, overcoming the body effect.

If we now compare the elementary regulator in Figure 1 with that of the more highly developed regulator in Figure 9, we can see the features that overcome the factors that affect the straight line performance curve.

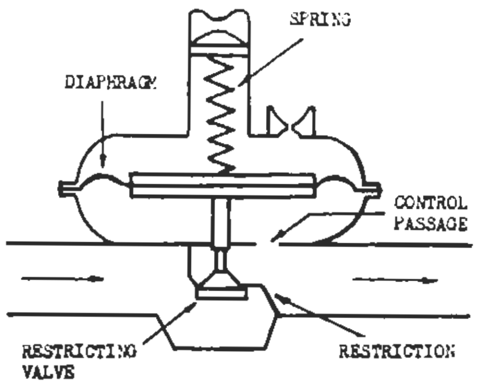

Figure 9 - Sketch of Design Features to Overcome Factors Affecting Performance.

DESIGN VARIATION OF GAS PRESSURE REGULATORS

The single valve regulator in Figure 9 is commonly referred to as a "poppet type". This design lends itself to excellent regulator performance over the normal residential pressures up to 1/2 psi or 1 psi inlet pressure, as specified by the manufacturer.

Carefully seated poppet type regulators have the ability to maintain set outlet pressure from main burner load to main burner and pilot load, as defined by the A.G.A. Listing Requirements for Domestic Gas Appliance Pressure Regulators. Main burner and pilot load regulators are certified by A.G.A. as circle P regulators.

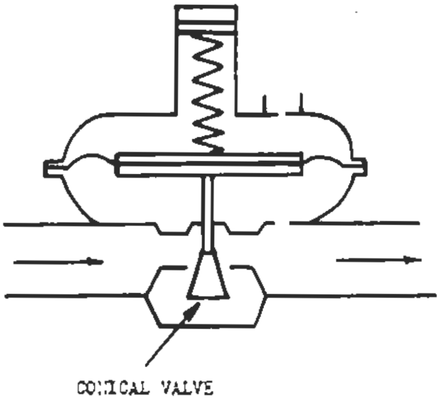

Figure 10 - Modification of Poppet Valve Regulator.

A modification of the poppet type regulator is shown in Figure 10. The valve is in the shape of a cone, and gas flows from the inlet, around the movable cone and out the outlet in a straight line. This design allows greater capacity than the poppet type of the same pipe size.

Conical type regulators lend themselves to excellent regulator performance up to 3 psi or 5 psi, as specified by the manufacturer. However, for good regulation, the inlet pressure should not exceed ten (10) times the set outlet pressure. These regulators generally are not used where downstream pressure must not be allowed to build-up under zero flow conditions.

Thus far, this chapter has dealt solely with the low pressure appliance regulator, its operation, performance, factors affecting its performance, design features that overcome factors, and drawings of several types of appliance regulators.

HIGH PRESSURE AND SERVICE REGULATORS

It may be desirous to know the difference between "appliance" regulators and "high-pressure" or "service" regulators. The difference in operating conditions makes it necessary to incorporate more complicated design features, and it follows that these regulators are more costly to manufacture. Some of the basic types will be briefly presented to facilitate an understanding of special types of gas pressure regulators which will not be discussed.

Inlet pressure changes affect the outlet pressure of a regulator. In the appliance

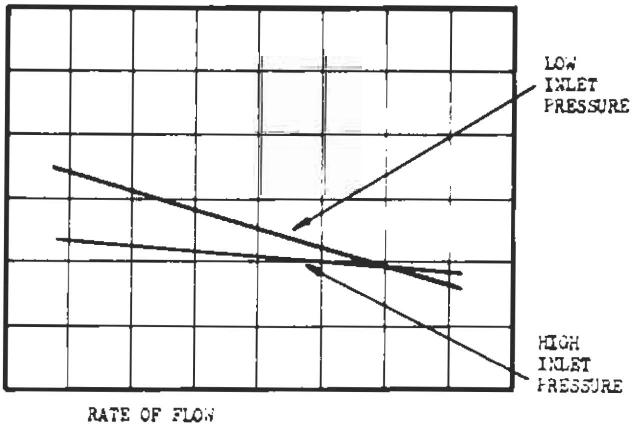

Figure 11 - Effect of High Inlet Pressure Upon Outlet Pressure

regulator, the inlet pressure acts upward on the regulator valve to create a force opposing the downward force of the spring. Increased inlet pressure tends, therefore, to decrease the downward force and decrease the outlet pressure as shown in Figure 11. On appliance regulators, the inlet pressure changes are relatively small so that a single valve regulator with a properly sized diaphragm will give satisfactory performance.

The spread in the performance curves can be minimized by use of large diaphragms or leverage between the valve and diaphragm. A simple service regulator is shown in Figure 12.

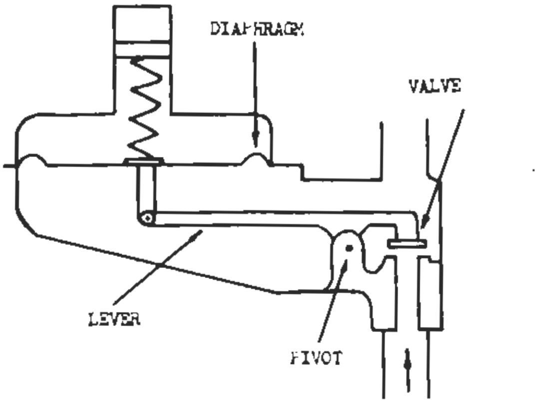

Figure 12 - Simplified Service Regulator. Utilizes Lever for More Positive Valve Action.

Inlet pressure effect must be eliminated where control accuracy is required. Balanced valves and seal diaphragms will accomplish this. Balanced valves are actually a double-valve arranged so that the pressure pushes upward on one valve and downward on the other, thereby canceling the force. This is shown in Figure 13.

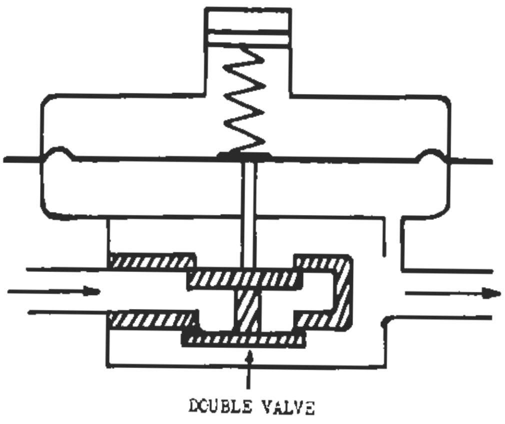

Figure 13 - Balanced Valve Regulator

Seal diaphragm regulators utilize a second diaphragm with the same effective area as the regulator valve. The upward force against the second diaphragm balances the downward force on the regulator valve. This is shown in Figure 14. Construction of a seal diaphragm regulator is simplified over that of a double valve regulator.

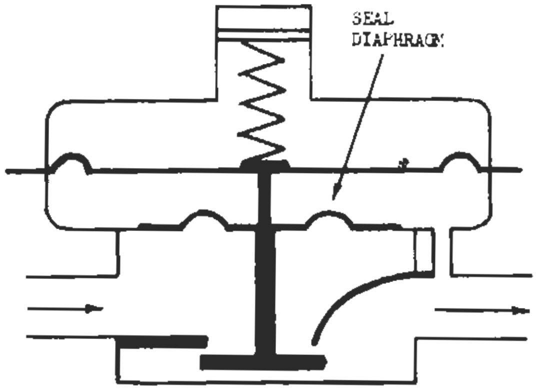

Figure 14 - Seal Diaphragm Regulator

PRESSURE DROP AND CAPACITY FORMULAS

This chapter has been devoted largely to the discussion of the operation and performance characteristics of the Gas Pressure Regulator. However, the words "pressure drop" and "capacity" will be frequently mentioned when sizing gas pressure regulators and controls for a specific gas appliance application.

"Pressure drop" is the loss of pressure caused by the flow of gas thru the pressure regulator, controls, and manifold.

"Capacity" is the flow of gas expressed in terms of Btu/hr at a given pressure drop.

All gas pressure regulators and controls certified by the American Gas Association Test Laboratories, are listed under appropriate classification in the A.G.A. Directory, at a capacity based upon 1.0", or in the case of pressure regulators, 0.3" water column pressure drop, using 1,000 Btu per cubic foot, 0.64 specific gravity Natural Gas.

The following information will be helpful in determining the proper sizing of gas pressure regulators and controls, by the use of formulas for calculating flow rates at various pressure drops, or pressure drops at various rates from the known A.G.A. Listings.

TO CALCULATE FLOW RATES AT VARIOUS PRESSURE DROPS:

Known: Regulator with A.G.A. capacity of 262,000 Btu/hr at 0.3" w.c. pressure drop.

Problem: Determine flow rate of the regulator at pressure drop of 0.4" w.c.

Formula:

$$Q_2 = Q_1 \times \sqrt{\frac{P_2}{P_1}}$$

Q_2 = Flow rate at selected pressure drop.

Q_1 = Known A.G.A. rating at 0.3" w.c. pressure drop.

P_2 = New selected pressure drop (this example, 0.4" w.c.).

P_1 = Known pressure drop (this example, 0.3" w.c.).

Solution: Substituting known valves for symbols in formula,

$$Q_2 = 262,000 \times \sqrt{\frac{0.4}{0.3}}$$

$$Q_2 = 262,000 \times 1.154$$

$$Q_2 = 302,350 \text{ Btu/hr}$$

TO CALCULATE PRESSURE DROPS AT VARIOUS FLOW RATES:

Known: Regulator with A.G.A. capacity of 262,000 Btu/hr at 0.3" w.c. pressure drop.

Problem: Determine pressure drop of the regulator at flow rate of 302,350 Btu/hr.

Formula:

$$P_2 = P_1 \times \left(\frac{Q_2}{Q_1}\right)^2$$

P_2 = Pressure drop at new selected flow rate.

P_1 = Known pressure drop (this example, 0.3" w.c.).

Q_2 = New selected flow rate (this example, 302,350 Btu/hr.).

Q_1 = Known A.G.A. rating at 0.3" w.c. pressure drop (this example, 262,000 Btu/hr.).

Solution: Substituting known values for symbols in formula,

$$P_2 = 0.3'' \times \left(\frac{302,350}{262,000}\right)^2$$

$$P_2 = 0.3'' \times 1.33$$

$$P_2 = 0.4'' \text{ w.c.}$$

TO CALCULATE FLOW RATES IN DIFFERENT GASES OF VARIOUS SPECIFIC GRAVITIES:

Known: Regulator with A.G.A. capacity of 262,000 Btu/hr in 0.64 sp gr gas at 0.3" w.c. pressure drop.

Problem: Determine flow rate for 0.7 specific gravity gas.

Formula:

$$Q_2 = Q_1 \times \sqrt{\frac{S_1}{S_2}}$$

Q_2 = Flow rate in gas of new selected specific gravity.

Q_1 = Known flow rate (this example, 262,000 Btu/hr).

S_2 = New selected specific gravity (this example, 0.7 sp gr).

S_1 = Known specific gravity of A.G.A. standard gas (this example, 0.64 sp gr).

Solution: Substituting known values for symbols in formula,

$$Q_2 = Q_1 \times \sqrt{\frac{0.64}{0.70}}$$

$$Q_2 = 262,000 \times .956$$

$$Q_2 = 250,000 \text{ Btu/hr of 0.7 sp gr gas.}$$

TO CALCULATE PRESSURE DROP AT A GIVEN FLOW RATE IN DIFFERENT GASES OF VARIOUS SPECIFIC GRAVITIES:

Known: Regulator at 262,000 Btu/hr has a pressure drop of 0.3" w.c. in 0.64 sp gr gas.

Problem: At the same flow rate (262,000 Btu/hr) determine pressure drop using 0.7 sp gr gas.

Formula:

$$P_2 = P_1 \times \frac{S_2}{S_1}$$

P_2 = Pressure drop in gas of new selected specific gravity.

P_1 = Known pressure drop (this example, 0.3" w.c.).

S_2 = New selected specific gravity (this example, 0.7).

S_1 = Known specific gravity of A.G.A. standard gas (this example, 0.64 sp gr).

Solution:

$$P_2 = 0.3 \times \frac{0.7}{0.64}$$

$$P_2 = 0.3 \times 1.094$$

$$P_2 = 0.328$$

CONVERSION FACTORS

In terms of Btu/hr:

To convert from 1000 Btu, 0.64 sp gr gas to 800 Btu, 0.7 sp gr gas, multiply by .765.

To convert from 800 Btu, 0.7 sp gr gas to 1000 Btu, 0.64 sp gr gas, multiply by 1.31.

To convert from 1000 Btu, 0.64 sp gr gas to 500 Btu, 0.60 sp gr gas, multiply by .515.

To convert from 500 Btu, 0.60 sp gr gas to 1000 Btu, 0.64 sp gr gas, multiply by 1.94.

To convert from 1000 Btu, 0.64 sp gr gas to 2500 Btu. 1.53 sp gr gas, multiply by 1.61.

To convert from 2500 Btu, 1.53 sp gr gas to 1000 Btu, 0.64 sp gr gas, multiply by .621.

In terms of cubic feet per hour:

To convert from 0.64 sp gr gas to 1.0 sp gr air. multiply by .800.

To convert from 1.0 sp gr air to 0.64 sp gr gas, multiply by 1.25.

To convert from 1.53 sp gr gas to 0.64 sp gr gas, multiply by 1.55.

To convert from 0.64 sp gr gas to 1.53 sp gr gas, multiply by .645.

To convert from 1.53 sp gr gas to 1.0 sp gr air, multiply by 1.24.

To convert from 1.0 sp gr air to 1.53 sp gr gas, multiply by .807.

The above conversion factors can be used for simplified calculations when dealing with standard A.G.A. gases.

ACKNOWLEDGEMENTS

American Gas Association; Listing Requirements for Domestic Gas Appliance Pressure Regulators. Z21.18.

American Gas Journal; American Gas Fundamentals, Prepared by Howard J. Evans, Rockwell Manufacturing Company.

Columbia Gas System Service School; Teaching Manual on Gas Pressure Regulators.

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