

CHAPTER II

REGULATOR AND RELIEF DEVICES

This chapter contains a simplified description of the pipeline safety requirements. The complete text can be found in 49 CFR Part 192.

BASIC CONCEPT

In understanding the equipment used to regulate the pressure of natural gas, it is helpful to be familiar with some fundamental physical units and concepts. Four are particularly important. Taken in pairs they are:

PRESSURE and FORCE

FLOW and THROTTLING PRESSURE

In the natural gas business the commonly used pressure units are:

pounds per square inchpsi

ounces per square inch.....osi

inches water column... in. w.c

For convenience, the three units are usually referred to as pounds, ounces, and inches.

It is important to remember that "pounds," "ounces," and "inches" are the short form of expressing pressure units. There really is no such thing as a pound of pressure or an ounce of pressure. They are incomplete terms. Pressure is defined as force per unit area. Pounds and ounces express only the "force" portion of that definition. The fourth unit of "area" is missing. Thus, the complete terminology should be "pounds per square inch" and "ounces per square inch."

When gas is under pressure, it exerts a given force against each unit of exposed area. For example, gas at a pressure of 10 psi pushes with a force of 10 pounds against each square inch of surface exposed to the gas. Gas at a pressure of 5 ounces (remember... ounces per square inch) pushes with a force of 5 ounces against each square inch of surface exposed to the gas.

Such units as pounds or ounces per square foot, per square yard, or other unit area are quite correct. However, for the gas business the unit area used is the square inch. And, to repeat, the complete expressions are pounds per square inch (psi), and ounces per square inch (osi).

Returning to psi, there are some other terms to note as follows:

pounds per square inch absolute....psia

pounds per square inch gauge.....psig

The relationship between the two is simple:

$$\text{psia} = \text{psig} + \text{atmospheric pressure}$$

Absolute pressure (psia) uses a perfect vacuum as the zero point. A perfect vacuum is 0 psia.

Gauge pressure (psig) uses the actual atmospheric pressure as the zero point. In Miami, sea level atmospheric pressure is 14.7 psia. Thus, 0 psig is 14.7 psia in Miami. In Denver (5,280 feet elevation), atmospheric pressure is 12.1 psia. And 0 psig for Denver is 12.1 psia.

Inches of water column (in. w.c.) are often used to express the pressure at which gas is delivered to residential customers. Pressure measurement in inches is usually done with an instrument called a manometer (see FIGURE II-1). The important relationships to remember are these:

$$\text{For inches of water column:} \quad 1 \text{ psig} = 2.71 \text{ in. w.c. (at sea level)}$$

Note the physical limitations to pressure measurement with the manometer. The highest pressure that could be measured with a "U" type manometer 5-feet high would be only a little over 2 psig (56 in. w.c.). However, note also that it offers a very precise way of measuring low pressures.

When expressing pressure in inches, it is necessary to identify the liquid. To put it another way, there really is no such thing as an inch of pressure. Instead, it is inches of a particular liquid, in the gas business generally water or mercury. Thus, the correct expression is inches water column (in. w.c. or in. H₂O). Figure II-1 illustrates how to read a manometer.

PRESSURE AND FORCE

Force is simply a push or a pull. It is measured in pounds.

Note that pounds of pressure is incomplete (it should be pounds per square inch) whereas pounds of force is complete. Thus, it would be "x" pounds of pushing force or pulling force.

FIGURE II-2 shows the relationship between pressure and force. Note that pressure is used to create a total force. Also, note how much force (200 pounds) can be created with only a small amount of pressure (2 psig.) It is all a matter of diaphragm area or piston area. A diaphragm, of course, is simply a low friction, tightly sealed, short stroke piston (just the thing for use in regulators).

In FIGURE II-2, the effective area of the piston or diaphragm is 100 square inches (100 in.²). Applying 2 psig pressure to the 100 in.² area gives an upward pulling force of 200 pounds (100 in.² x 2 lbs/in.² = 200 pounds).

Note that the pressure above both the diaphragm and the piston is atmospheric (0 psig). The differential pressure across the diaphragm and across the piston is 2 psi (2 psig - 0 psig = 2 psi).

Note also that the effective diameter of the diaphragm and the piston is only about 11 inches. An 11 inch diaphragm is not very large. This is quite a common size for regulators, particularly on commercial and industrial applications. But an 11 inch diaphragm has a large area (100 in.²). It does not take much pressure (2 psig, for example) to develop a large total force (200 pounds).

FLOW AND THROTTLING

To throttle the flow of a fluid is to allow only a certain amount to flow and to hold back the remainder. A faucet provides a good example. How much water is wanted determines how far the faucet is opened. The faucet (a valve) is a throttling device. Depending on how far it is opened, it allows only a certain amount of water to flow and holds the rest back. It restricts flow to a certain amount.

Throttling is a basic function in a regulator. The part that throttles is a valve. It allows only a certain amount of gas to flow. The valve part of a regulator is a type of variable restrictor.

Not all valves can be used for throttling (i.e., used as a variable restrictor). Some (like many gate valves) are designed to be either wide open or fully closed. If used in an intermediate position (one-third open, half open, three-fourths open, etc.), they become unstable. They may chatter, rattle, hammer, etc. They are unsatisfactory.

For a regulator, the valve must be mechanically stable from wide open to as small a flow as possible. In addition, it must change the flow smoothly as it is opened or closed.

The most widely used valve for regulators is the single-port, unbalanced, globe valve. It is economical in construction yet provides good throttling. In addition, it has a smooth stroke, little friction, and good shut-off (lock-up) characteristics.

FIGURE II-1 U TUBE MANOMETER

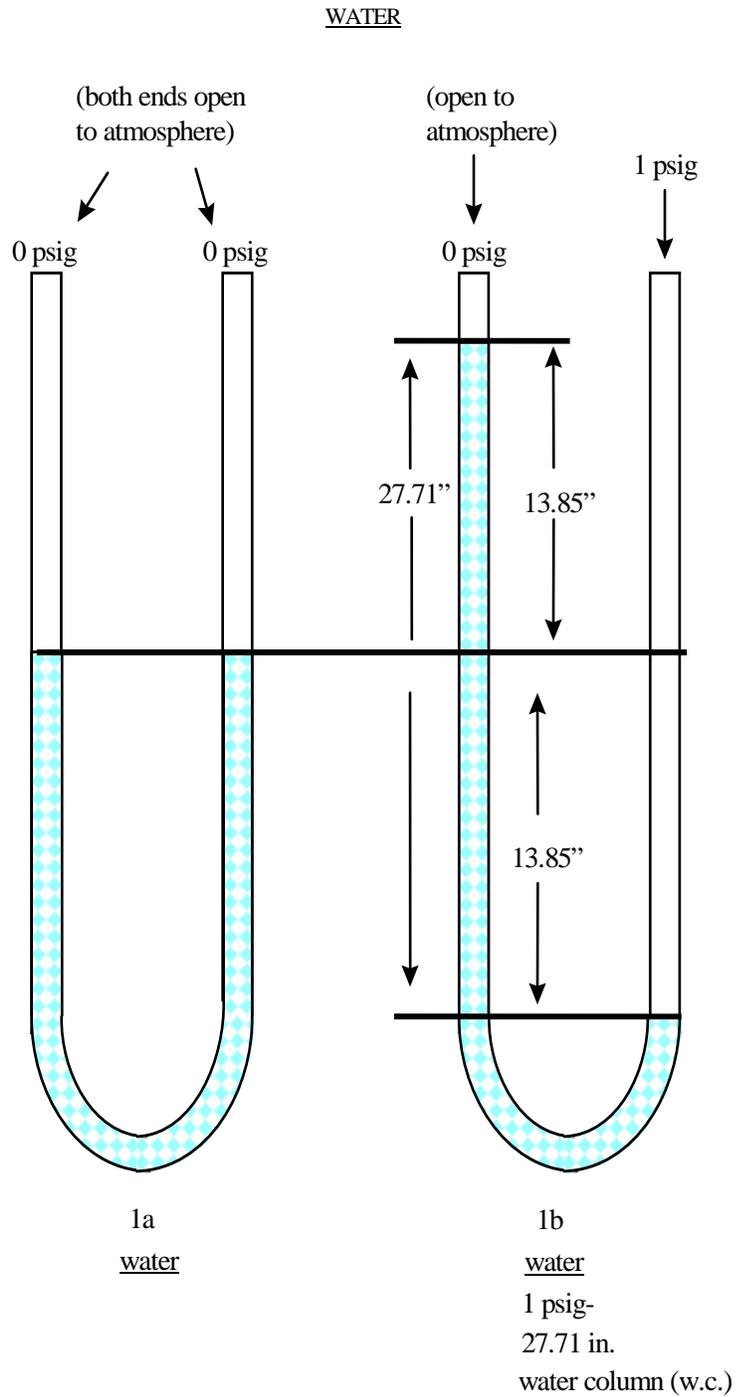


FIGURE II-2

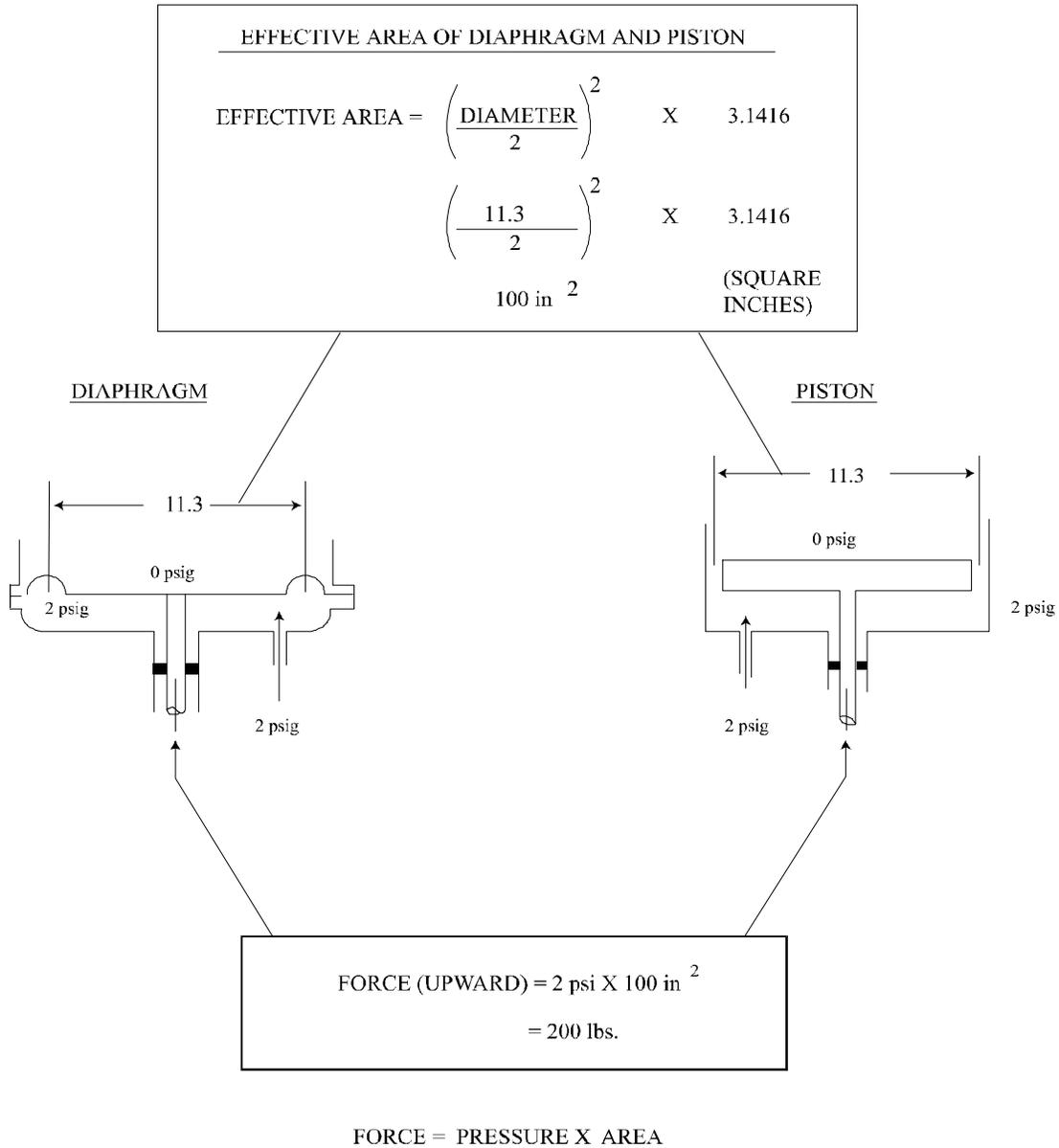


FIGURE II-3

TYPICAL SINGLE PORT SPRING REGULATORS

Figure II-3A: Control Line

STANDARD SPRING REGULATOR
(WITH CONTROL LINE)

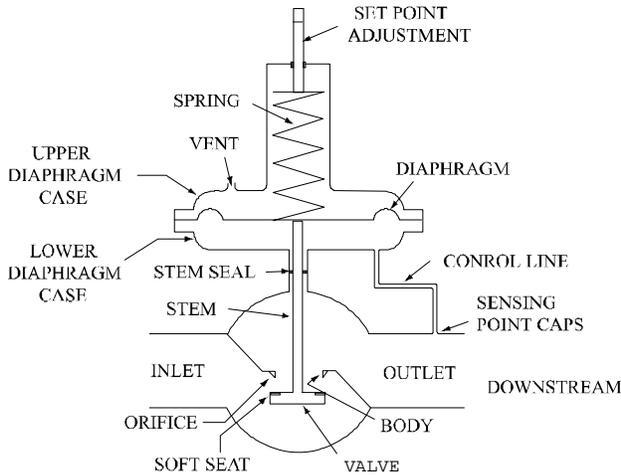


Figure II-3B: Internal Control

STANDARD SPRING REGULATOR
(WITH INTERNAL CONTROL)

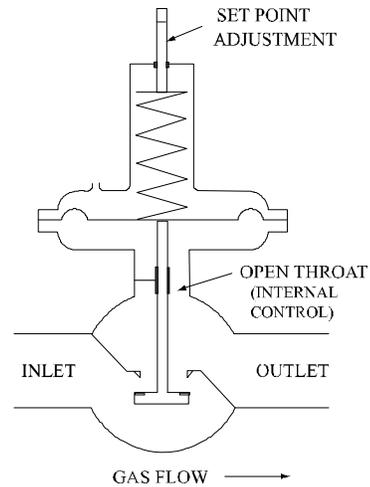
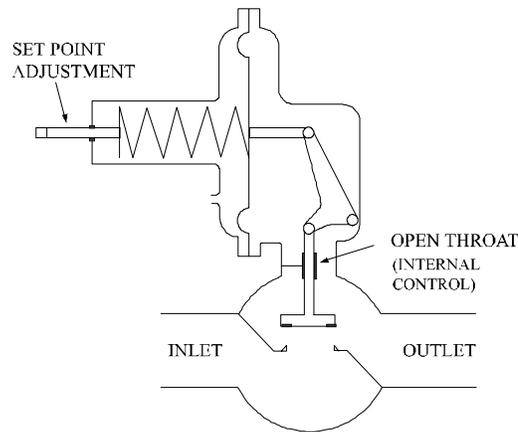


Figure II-3C



SERVICE REGULATOR
(WITH INTERNAL CONTROL)

GAS FLOW →

FIGURE II-3 shows a simple section of a standard spring regulator. The various parts are labeled. For most master meter operators this will be the only type of regulator in the system. Service regulators are this type of regulator. Referring to FIGURE II-3, the following is a simple explanation of how it works.

1. Spring compression works to open the valve.

The rule is: The PRIMARY VALVE OPENING FORCE in a spring regulator comes from the spring (usually, spring compression).

2. The diaphragm works to close the valve.

The rule is: The PRIMARY VALVE CLOSING FORCE in a spring regulator comes from other pressure acting against the effective area of the diaphragm.

3. An increase in outlet pressure creates valve closing action. Conversely, a decrease creates opening action.
4. Set point (the outlet pressure a regulator is adjusted to deliver) is determined by spring compression. Turning the set point adjustment clockwise increases spring compression which increases set point, and vice versa.

Pilot type regulators are used at city gate stations or for large industrial customers. These regulators are more complicated than spring regulators. These types of regulators will not be discussed in this manual. A consultant should be used to select the correct type and size regulator for most applications except for house regulators.

BASIC NAMES AND TERMS

Referring to FIGURE II-3, the inlet is the opening through which gas enters a regulator. The pressure of the entering gas is usually called the inlet pressure, although it could also be called the upstream or supply pressure.

The outlet is the opening by which gas leaves a regulator. The pressure of the exiting gas is usually called outlet pressure, although it could also be called downstream pressure.

In general, the more the inlet pressure exceeds the outlet pressure, the greater the amount of gas that can flow through the regulator, (to put it another way, the greater the capacity of the regulator). The difference between inlet and outlet pressures is sometimes called the differential across the regulator.

Piping on the inlet side is upstream and piping on the outlet side is downstream. As stated previously, a regulator takes higher pressure gas from the supply and reduces it to the pressure required by the load. To do this, something is needed on the regulator to adjust it for the specific pressure required. This adjustment is called the set point adjustment and on most of today's regulators it is a screw-type device of some kind, usually a simple adjustment screw. Set point is the pressure a regulator is adjusted to deliver. It is the pressure required by the load and, in general, is the same as the outlet pressure.

Note the control line referred to in FIGURE II-3A. It is also called a sensing line, impulse line, equalizing line or static line. The control line and the sensing point are vital parts of a regulator installation. They must be carefully planned and correctly installed if the regulator is to operate satisfactorily and safely.

Many regulators, particularly smaller ones, do not have the external control line shown in FIGURE II-3A. Instead, it is internal as represented by FIGURE II-3B. Called internal control, it is inside some form of open throat construction or venturi tube. However, whether located internally or externally, every regulator has a control line or the equivalent.

Control lines must be adequately protected against breakage. If they are broken, the regulator opens wide and this could result in the full upstream line pressure (that is high) being dumped into the low-pressure system. This can lead to a catastrophic situation.

The next item is the vent. While often appearing insignificant, the vent is important to a regulator. Regulators breathe. As the internals move in the work of controlling pressure, a regulator will inhale or exhale through the vent. Therefore, the vent must be adequately protected from obstructions such as dirt, insects, ice, etc. If an obstructed vent prevents a regulator from breathing, the diaphragm will not work properly.

In the event that the regulator fails to open, the higher pressure gas dissipates thru the vent.

Also, water can get inside a regulator through an improperly positioned and unprotected vent. Water inside a regulator can cause problems. Therefore, vents must be positioned and protected to keep the water out. This is particularly important on outdoor installations.

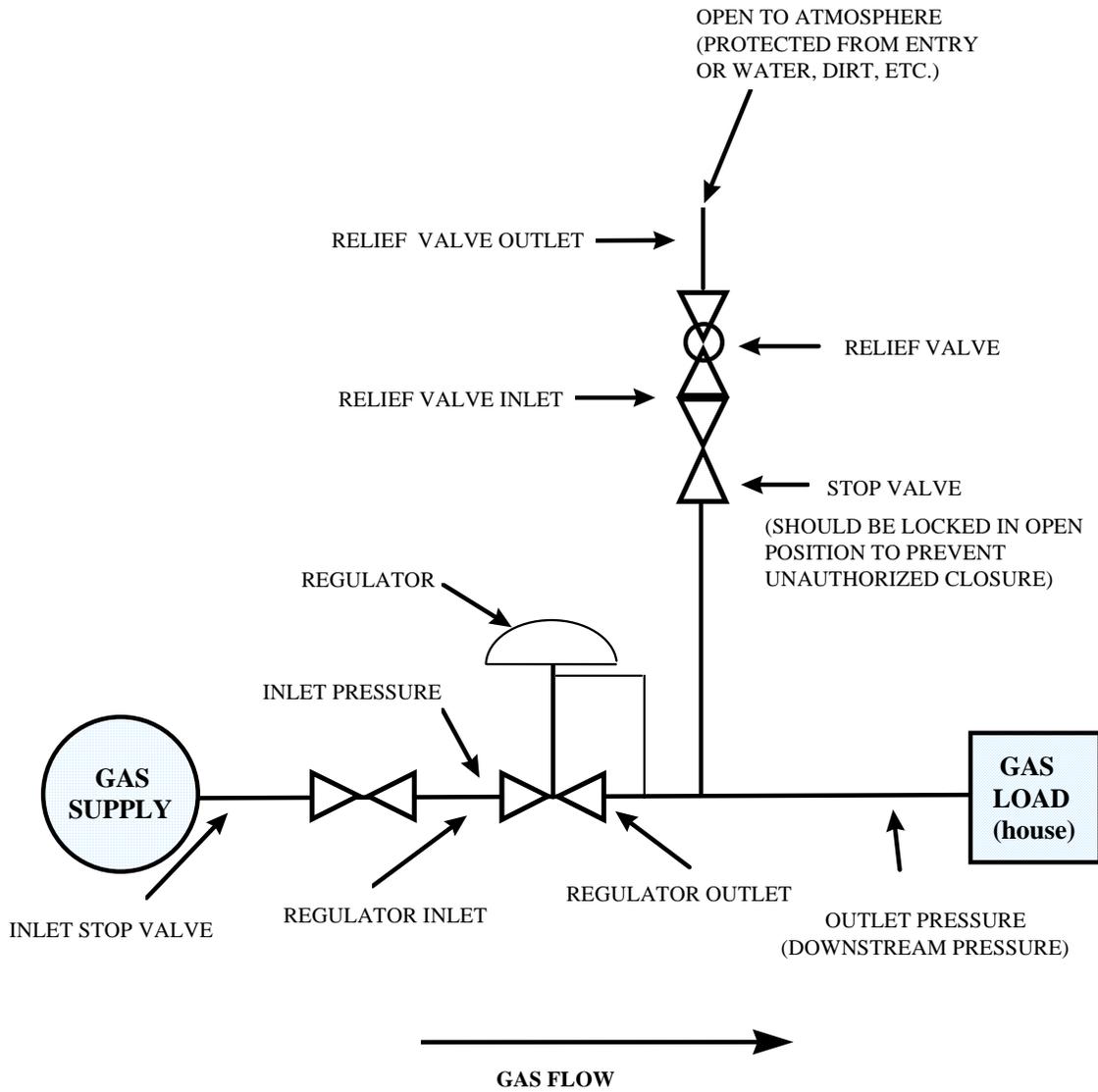
The last item is the stop valve (FIGURE II-4). A simple installation (such as at a house) usually has only one. A more complex installation such as a regulator station would have several stop valves (inlet stop valve, outlet stop valve, control line valve, bypass valve, and perhaps others).

The most important of all is the inlet stop valve. The inlet stop valve should be used with extra care, particularly when being opened. Do not open it until everything is correct and safe. Then open it slowly. Allow the inlet gas to enter slowly, and the pressure to build up slowly.

Stop valves make it possible to put a regulator into service or take it out of service. They make it possible to isolate a regulator for testing and servicing. Correct opening and closing sequences should be adequately understood (these are often specified in gas company standards and procedures). Understanding usage in case of an emergency is also important.

In most cases operators of small natural gas systems need to rely on a consultant for major repair work on regulator stations. The operations and maintenance plan must name the person who is responsible for determining when a regulator needs to be serviced. The operations and maintenance plan should also list those consultant(s) capable of working on regulator stations.

FIGURE II-4



OVERPRESSURE PROTECTION

There are three basic methods of providing overpressure protection:

- Pressure Relief
- Monitoring
- Automatic Shutoff

Pressure relief is simply a dumping of excess gas safely into the atmosphere. The excess gas is that which would cause pressure to exceed the safety limit. The relief valve is the most widely used piece of equipment in this category. However, liquid seals and rupture discs may also be used.

There are two basic kinds of relief valves – self-operated and relay-operated. The spring-type relief valve is the most widely used. The pilot-operated type is also frequently used, and it offers more precise operation. The pilot operated type is more frequently used as pressures become higher and capacities greater. Monitoring involves a standby regulator. The standby prevents pressure from exceeding the safety limit.

The most widely used form of monitoring is standby monitoring. It is also called passive monitoring. It consists of two regulators in series, one of which is operating to control pressure while the other is a standby. The standby unit is normally further open than necessary, usually wide open. It takes that position because it is adjusted to a higher set point than the operating regulator. If an operating regulator failure causes outlet pressure to rise, the monitor takes over and holds pressure at its set point.

Two other forms of monitoring are sometimes used. One simply consists of two-stage regulation which, when designed for the purpose, can provide monitoring protection. The other is called override monitoring or working monitoring. With it, the upstream regulator must be pilot operated and have an extra pilot. During normal operation, the set provides two-stage regulation. In an overpressure emergency it protects in the same way as standby monitoring.

Automatic shutoff involves a valve that normally remains in the wide open position and allows the gas to flow freely. It is located in series with the regulator, either upstream or downstream, depending on whether it uses a control line or internal control.

If a regulator failure results in a rising outlet pressure, the shutoff closes automatically when pressure reaches its set point. It protects by shutting off the gas and remains closed until manually opened and reset.

In general, there are three things to consider in choosing overpressure protection systems:

1. Continuity of service – does the user, or the load, need to be continuously supplied with gas?
2. Containment – is gas released into the atmosphere or does it remain contained within the gas system?
3. Alerting – is there provision for notification or warning that an emergency has occurred and that the overpressure protection equipment has gone into operation?

The following is a comparison of the three basic overpressure protection methods (based on the foregoing three considerations).

Pressure Relief

- **Continuity of Service.** In general, pressure relief valves do not interrupt gas service. They protect, while allowing gas to flow at a safe pressure. Customers continue to receive gas.
- **Containment.** Relief valves do not contain the gas. They protect by dumping the excess gas into the atmosphere.
- **Alerting.** Relief valves are usually good in this respect. They are noisy, particularly at full or near full blow. In addition, because the gas is odorized, the smell usually attracts attention. Another indication of overpressure is the rise in outlet pressure above normal, but this is probably the least effective notification.

Monitoring

- **Continuity of Service.** Monitoring does not interrupt service. Like the relief valve, the monitor protects while allowing gas to continue flowing.
- **Containment.** Monitoring contains the gas. It prevents the gas from blowing into the atmosphere and keeps it inside the piping.
- **Alerting.** This is probably the main disadvantage of monitoring. Generally speaking, the only warning or notification is the rise in outlet pressure to monitor set point.

Automatic Shutoff

- **Continuity of Service.** Automatic shutoff stops the flow of gas. It protects because it interrupts gas service by shutting off the gas.
- **Containment.** Automatic shutoff contains the gas. Like monitoring, it does not allow gas to blow into the atmosphere. It contains the gas within the piping.
- **Alerting.** In general, shutting the gas off results in good notification. Usually it is quickly noticed. However, there could be situations where it is not detected immediately and the lack of gas has undesirable or even serious results.

The next sections cover the three basic methods of overpressure protection in more detail.

PRESSURE RELIEF

FIGURE II-4 is a diagram of a typical relief valve installation. The purpose of the relief valve is to prevent outlet pressure from rising to an unsafe level when there is a regulator failure.

In general, regulator failure would result in either too much or too little pressure downstream. The failure would leave the regulator in what could be called a "failed-open" condition (regulator too far open, even fully open – too much gas flow) or a "failed-closed" condition (regulator too far closed, even fully closed – not enough gas flow). A relief valve is only useful in a "failed-open" regulator condition – too much gas flow, resulting in downstream pressure above normal. Relief valves do nothing for a "failed-closed" regulator condition – too little gas.

A relief valve protects by discharging the excess gas into the atmosphere. As long as a regulator operates correctly and downstream pressure is normal, a relief valve remains closed. If the regulator fails and allows too much gas to flow (a "failed-open" condition for the regulator), downstream pressure will increase. The relief valve will remain closed until pressure reaches its set point. At that point it will begin opening and will continue to do so as the pressure continues to rise. It will open far enough to discharge all of the excess gas into the atmosphere. When it reaches that point, there will be no further rise in the downstream pressure and, if the relief valve and its installation are correctly sized, the pressure downstream will not be high enough to be unsafe.

Keep in mind that the relief valve does not discharge all of the gas into the atmosphere. It only discharges the excess. There is still a normal flow for the load. Customers continue to receive gas.

Relief Valve Sizing

Sizing is vitally important. This applies not only to the relief valve itself, but also to the piping of the entire installation. A relief valve must be big enough to handle the maximum emergency. When properly installed and maintained, relief valves are very dependable. The question is not so much whether it will work, but rather whether it is large enough to provide full protection during a maximum emergency. When a relief valve is in full operation, it can discharge an enormous volume of gas into the atmosphere. For that reason they cannot be used everywhere. This must be carefully considered when a relief valve installation is being planned and engineered. The vital questions are these: What happens to the gas after it leaves the relief valve? Will it disperse harmlessly? Or, could it create another emergency? This matter is addressed in 49 CFR §192.199(e).

FIGURE II-4 shows a stop valve ahead of a relief valve. This stop valve is required to allow for system maintenance and testing. However, there can be serious consequences if it is closed during an emergency because this would cut the relief valve out of the pipeline system. Closure could be an innocent act or it could be malicious. Nonetheless, certain cautions are essential. Only authorized personnel may use the stop valve. Likewise, it must be adequately protected against unauthorized closure. Most important, it should be locked in an open position.

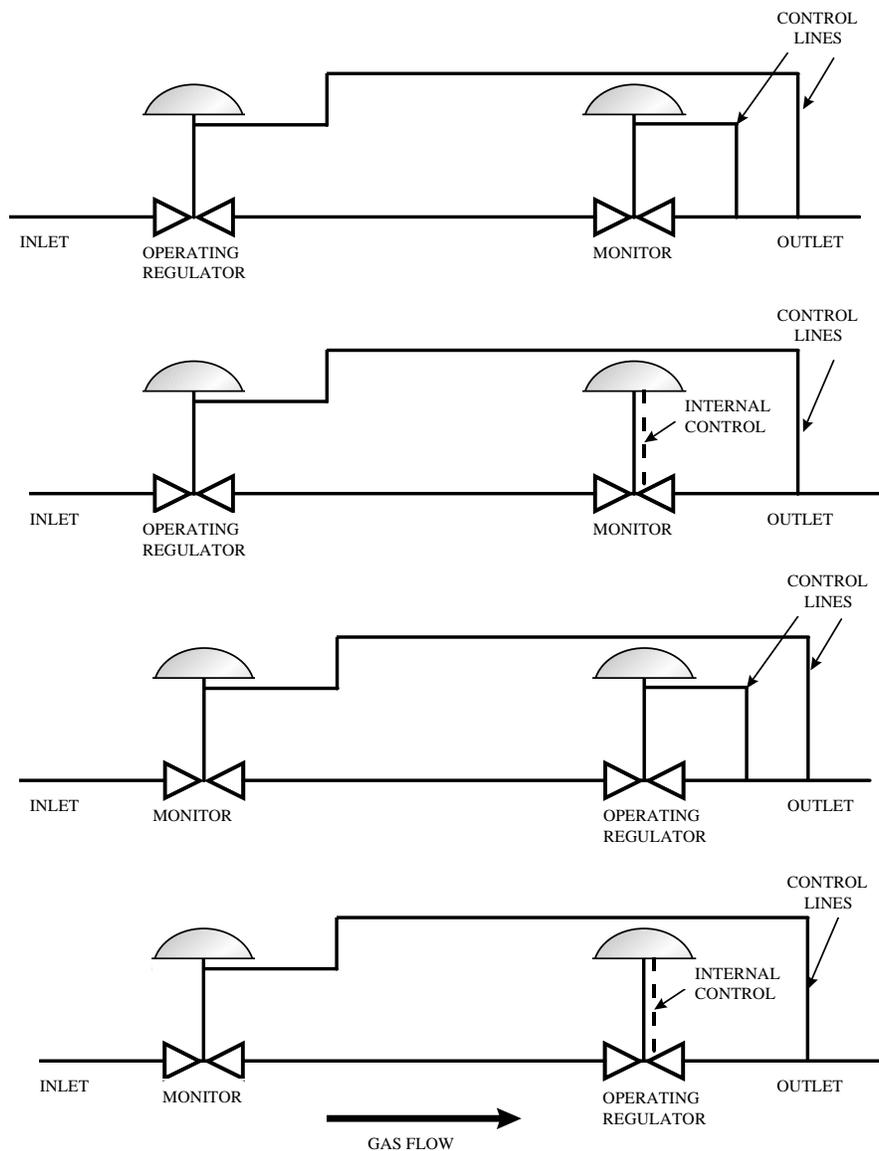
MONITORING

This section deals with the most widely used form of monitoring, standby or passive monitoring. FIGURE II-5 shows standby monitoring in four basic arrangements using regulators with control lines and with internal control. Note the following:

- Either the upstream or the downstream regulator can be the monitor.
- The downstream regulator can have either a control line or internal control.

The upstream regulator must have a control line.

FIGURE II-5 STANDBY MONITORING



Standby monitoring is sometimes confused with two-stage or double-cut regulation. The big difference is in the control line for the upstream regulator. In standby monitoring, the control line for the upstream regulator goes all the way downstream. It does not connect between the regulators as in two-stage regulation. To repeat, the control line for the upstream regulator in standby monitoring goes on beyond the downstream regulator to a point somewhere in the outlet piping. That is the reason the upstream regulator in standby monitoring must have a control line, whereas in two-stage regulation the upstream, as well as the downstream, regulator can have either a control line or internal control.

Two-stage regulation can be used as a form of monitoring provided the following conditions are met:

- The system downstream of the second stage regulator (including the regulator) must have an MAOP equal to or greater than the outlet pressure of the first stage regulator.
- The second stage regulator must be rated for an inlet pressure as high as the maximum inlet pressure of the first stage regulator, and the diaphragm case of the first stage regulator must be able to safely withstand this maximum inlet pressure.

As shown in FIGURE II-5, the set point for the operating regulator is the normal outlet pressure, that is, the pressure normally required for the load.

The set point for the monitor is higher. Because it is higher, the monitor is further open than the operating regulator (usually the monitor is wide open) and allows the gas to flow normally.

If the operating regulator "fails-open" the outlet pressure will rise. It will rise until the pressure reaches the set point of the monitor. Then, the monitor will become the operating regulator and will hold outlet pressure at its set point.

The monitor set point, of course, must not exceed the MAOP of the downstream piping system. The difference between the set points of the monitor and the operating regulator is not critical. However, the two should not be so close as to cause the monitor to interfere with the operating regulator. Other than this, monitor set point is largely determined by the requirements of the installation and applicable practices and standards.

AUTOMATIC SHUTOFF

In an automatic shutoff installation, a special valve is used to shut off the gas completely if pressure reaches a preset level. During normal operation the valve remains fully open and allows gas to flow freely.

If a regulator failure ("fail-open") or another factor causes outlet pressure to rise, the automatic shutoff valve closes when pressure reaches its set point.

The normal outlet pressure is the regulator's set point. The set point of the automatic shutoff valve will, of course, be higher. How much higher must be decided when planning and

engineering the installation. It must not exceed the MAOP (the maximum safe limit) of the downstream piping.

Automatic shutoff valves close automatically, but must be manually reset. This has the advantage of preventing an emergency from passing unnoticed.

Shutting the gas off at times of emergency is imperative. However, in the natural gas business, continuity of service is also important. This is probably why automatic shutoff has found only limited use in the gas industry. Pressure relief and monitoring are preferred because they offer full protection while allowing a safe flow of gas to continue.

Automatic shutoff valves are available with control line or with internal control. Both are shown in FIGURE II-6.

Control Line

Because an automatic shutoff valve with a control line is located upstream of the regulator, the foregoing hazards from exposure to inlet pressure are eliminated. The entire regulator, as well as everything downstream, is isolated from exposure to inlet pressure.

Care should be used in installing the control line. It should be strong, and be protected and routed to minimize any possibility of breakage. If broken, the automatic shutoff valve becomes inoperative. If an emergency occurs, it will not close, as it should.

Some automatic shutoff valves are available with a temperature option. They close not only from excess pressure, but also excess temperature. If properly located, they can help in case of fire. Automatic shutoff is also available for closure in case of underpressuring (a "failed-closed" regulator failure).

Relief valves, monitors, and automatic shutoff valves are all effective, dependable devices for protection against the hazard of excess pressure. However, to be sure of this protection, they must be correctly engineered, installed, and maintained. They must be used in conformance with manufacturer's ratings and recommendations. Whenever any doubts or questions arise, it is always a good idea to ask the manufacturer.

Internal Control

This offers a simpler installation because there is no control line. However, due to its internal control, it must be located downstream of the regulator. Therefore, upon closure, everything upstream of the shutoff valve will be pressured to full inlet pressure.

This means that if the regulator has internal control, its main diaphragm will be exposed to full inlet pressure. This could result in severe damage, even to the extent of a burst regulator. The same applies to a regulator with a control line if the control line is connected (the sensing point) between the regulator and the automatic shutoff valve. If an automatic shutoff valve with

internal control is used, everything between it and the regulator, including the regulator itself, must be carefully checked for exposure to full maximum inlet pressure.

Moreover, if the piping for the regulator is larger than the inlet piping, an internal control type automatic shutoff valve will need to be a larger size than one with a control line.

FIGURE II-6 AUTOMATIC SHUTOFF VALVE INSTALLATIONS

