2013 Western Gas Measurement Short Course
Reno, NV

INTRODUCTION TO REGULATOR AND RELIEF SIZING

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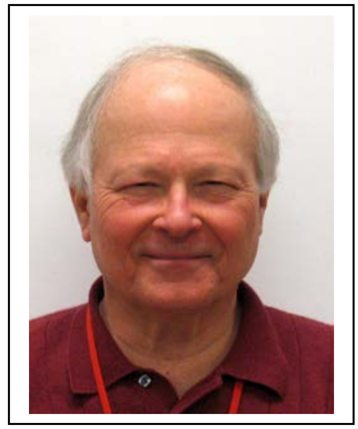


Introduction

The initial selection of a regulator to serve an application can be critical to the proper operation of the station afterward. This paper will cover some of the design considerations for sizing and selecting a regulator for pressure reduction applications and for sizing a relief valve for pressure protection. Sections to be covered include:

A. Basic terms
B. Pressure Protection Methods
C. DOT requirements (Part 192)
D. Regulator Sizing and Selection
E. Relief Valve Sizing

A. Basic terms

To begin, here are some basic terms that need to be understood. See Figure 1.

1. Gas Supply. Anything upstream (Inlet side) of the pressure regulator, ultimately to the gas well.

2. Gas Load. Anything downstream (Outlet side) of the pressure regulator, ultimately to the gas burner. With regard to gas measurement and regulation, the load may be a gas distribution system or even a pipeline – anything that needs or uses gas as a fuel.

3. Regulator Set-point. The pressure that a regulator is adjusted to deliver downstream to the gas load.

4. Control Line. Also called a sensing line, impulse line, equalizing line, or static line; this brings the downstream pressure back to the sensing element of the regulator.

5. Inlet Pressure. The pressure of the gas entering the regulator from the gas supply.

6. Outlet Pressure. The pressure of the gas leaving the regulator towards the gas load.

7. Differential Pressure. The difference in gas pressure from the inlet side to the outlet side of the regulator. Also called the pressure drop across the regulator. In general, the higher the differential pressure, the greater the amount of gas that will flow through the regulator.

8. Upstream and Downstream. Piping on the inlet side of the regulator is upstream

(gas supply) while piping of the outlet side is called downstream (gas load).

9. Regulator Vent. The part of the regulator that allows it inhale or exhale air as part of the normal working of the regulator.

10. Regulator Pressure Ratings. Regulators have two different pressure ratings – one for the inlet and another for the outlet.

11. Maximum Allowable Operating Pressure (MAOP). The maximum operating pressure at which a pipeline or any of its components can operate.

12. Critical Flow. The gas volume flowing through a regulator when the gas reaches the speed of sound.

13. Sub-Critical Flow. Gas flow through the regulator when the gas is flowing at less than the speed of sound.

Figure 1 shows some of these terms.

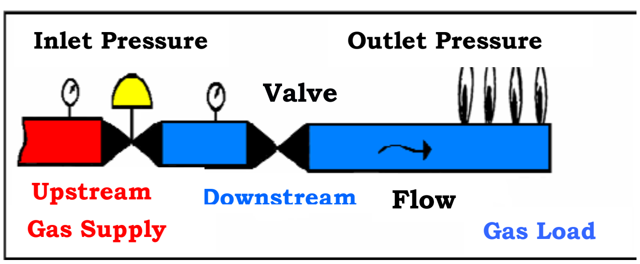


Figure 1. Basic Terms

C. Pressure Protection Methods

During the design of a gas regulator station, care must be taken to consider all possible problems that might develop and include solutions to those emergencies. In general, safety devices or methods that will protect against over and/or under-pressure conditions will include the following:

1. Multiple (Series) regulation

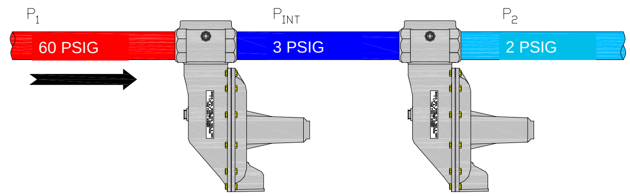


Figure 2. Series Regulation

The first regulator is set at an outlet pressure feeding the second regulator that is within the MAOP plus an allowable overpressure of the station's downstream system. Should the second regulator fail, the downstream pressure would still be within the downstream MAOP plus the allowable overpressure. Should the first regulator fail, the station's downstream pressure will still be at the set point of the second regulator. See Figure 2.

2. Monitoring

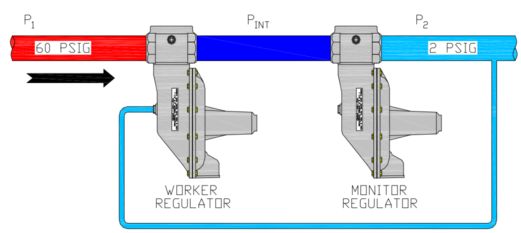


Figure 3. Monitoring station

A monitoring station normally has two separate regulators installed in series with an active pressure control regulator (worker) and a monitor regulator (monitor) that is normally not in action until there is a problem and the downstream pressure starts to build. The worker can be either the first regulator or the second. The monitor regulator is a redundant device used only during emergency. See Figure 3.

3. Over-ride (Working Monitor) Regulation

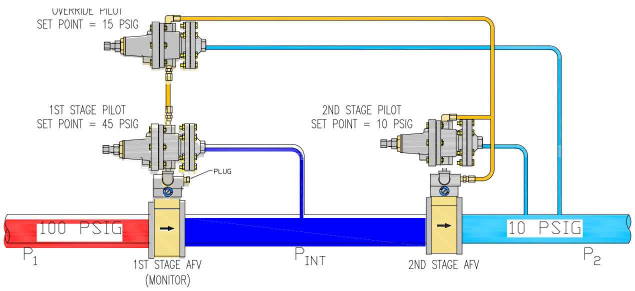


Figure 4. Over-ride/Working Monitor

A combination of a two-stage pressure reduction and an over-ride monitor system. The second regulator will normally control the downstream pressure form the station. The first regulator will reduce the pressure from the inlet down to some intermediate pressure between the two regulators. There is a second pilot on the first regulator that is sensing the station's outlet pressure. Should that pressure start to climb higher than this pilot's set pressure, the first regulator will start to throttle back and control the downstream pressure coming out of the station. See Figure 4.

4. High and/or low pressure shutoffs

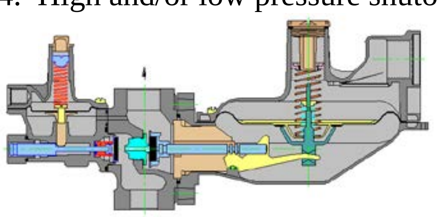


Figure 5. High/Low Pressure Shutoffs

Shutoff devices can either be internal to the regulator or external stand-alone devices. In either case, they sense and monitor the downstream pressure and shut the gas flow off should the pressure go to some unacceptable level – either a high pressure or low pressure condition. See Figure 5.

5. Relief Valves

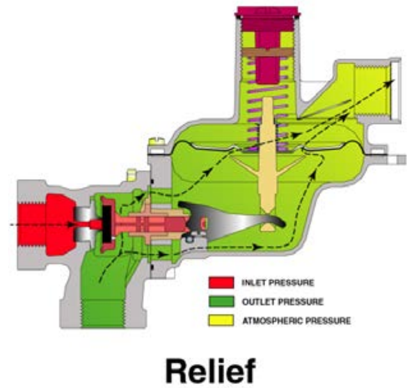


Figure 6a. Internal Relief

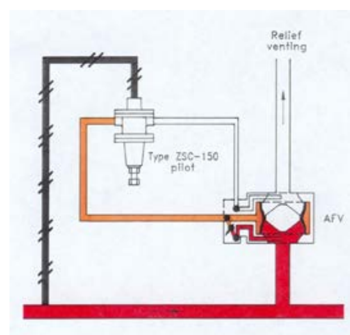


Figure 6b. External Relief

Relief valves are used to release any excess gas pressure downstream of the regulator so as to prevent the outlet pressure from exceeding the desirable limits. They can be either internal to the regulator (See Figure 6a) or a separate external device. (See Figure 6b). External relief valves can be either spring-operated or pilot-loaded similar to a pressure reducing type of regulator. But in a relief valve application, the inlet pressure is the pressure that is being controlled not the outlet.

C. DOT Requirements Part 192

The following subparts in Part 192 cover some of the federal requirements regarding pressure protection

Subpart D – Design of Pipeline Components

Subpart D Paragraph 192.195 - Protection against accidental overpressuring. This requires all distribution systems being supplied by a high pressure source that has an MAOP greater than the MAOP of the downstream system to be protected by some method from being overpressured should there be a failure.

Subpart D Paragraph 192.197 – Control of the pressure of gas delivered from high-pressure distribution systems. Sets the requirements for service regulation, pressure protection, and delivery to the customer.

Subpart D Paragraph 192.199 - Requirements for design of pressure relief and limiting devices. Lists the requirements for relief valve installations, such as supports, protection from weather conditions, testing, and single incident damage.

Subpart D Paragraph 192.201 - Required capacity of pressure relieving and limiting stations. Lists the operational requirements for relief valves and what the allowances for increased pressures above the MAOP are when operating under abnormal operating conditions.

Subpart H – Customer Meters, Service Regulators, and Service Lines.

Subpart H Paragraph 192.353 Customer meters and regulators: Location. Lists requirements for protecting meter sets from damage, location outside a building, and sources of ignition.

Subpart H Paragraph 192.355 Customer meters and regulators: Protection from damage. Lists the requirements for the regulation installation to protect from outside forces, rain, and venting of gas safely.

Subpart H Paragraph 192.357 Customer meters and regulators: Installation. Requirements for reducing stress on the meter and regulator.

Subpart M – Maintenance

Subpart M Paragraph 192.739 Pressure limiting and regulating stations: Inspection and testing. Requirements for testing to insure good mechanical condition and operation.

Subpart M Paragraph 192.741 Pressure limiting and regulating stations: Telemetering or recording gauges. Requirements for telemetering or recording gauges at district regulator stations.

Subpart M Part 192.743 Pressure limiting and regulating stations: Capacity of relief valves. Requirements for reevaluating the capacity of relief valve installations.

D. Regulator Sizing and Selection

To start sizing any regulator the following information must be known:

Inlet Pressure Range – maximum and minimum pressures. The regulator must be able to physically handle the maximum inlet and outlet pressures while the orifice must be sized such that the regulator can allow the desired flow downstream at the lowest inlet pressure.

Outlet Pressure Range – maximum and minimum. These are needed to select the proper spring for the desired outlet pressure range.

Load requirement – Should be in Standard Cubic Feet per Hour (SCFH) as this is how the capacity tables for each regulator are listed. Consider future load requirements, changes in load characteristics, gas composition, gas quality, and other elements of the current and foreseeable load requirements. Add a "Factor of Safety".

Specific Gravity of the Gas – Regulators in many cases can handle a variety of gases, but the listed capacity tables may be for air or for natural gas. So match the capacity table being used with the gas for which the station is being designed. Published capacities can be modified by the specific gravity factor for the gas being used.

Pressure Protection Requirements – What type of pressure protection device(s) are to be used? Overpressure, underpressure, shutoff, or some type of combination of these types of pressure protection may be available. If so, what will be the relief or shutoff setting?

Assembly position – How will the regulator be field installed? Will flow be horizontal or vertical? Make sure the vent is positioned to prevent water, insects, or dirt from being able to get inside the regulator.

Location of the installation – Check federal, state, and local regulations and plumbing codes regarding their requirements placed on the installation based on where it is to be located. The regulator must be protected from extreme heat, away from ignition sources, and protected from physical damage.

Other considerations –

- Screw or flanged connections
- Pipe size
- Access for inspection and maintenance
- Pressure taps
- Seat disc material
- Straight or angle body
- Gas velocity

Regulator Sizing Example

Inlet pressure range:

- Maximum MAOP: 60 psig
- Minimum pressure: 40 psig

Outlet pressure:

- 7" W. C. delivery pressure

Load:

Residential customer with a connected load of 300 SCFH. To insure proper operation of the regulator under future unknown conditions, multiply the load by a "factor of safety" such as 1.25. This would make the total load equal 300 SCFH x 1.25 = 375 SCFH. This "factor of safety" will take into account future load changes, a possible lower than expected inlet pressure under very unusual operating conditions and other unknown circumstances.

Installation

- 1" pipe size in an meter set assembly
- Flow will be up through the regulator
- 0.6 specific gravity natural gas

One manufacturer's capacity table for a 0.6 specific gravity gas with a 1" outlet regulator set at 7" W.C. outlet pressure is shown in Table 1.

Inlet PSIG (bar)	1/8" x 3/16" Orifice	3/16" Orifice	1/4" Orifice
1 (0.07)	—	175 (5.0)	250 (7.1)
2 (0.14)	—	250 (7.1)	350 (9.9)
3 (0.21)	—	300 (8.5)	450 (12.7)
5 (0.34)	250 (7.1)	450 (12.7)	650 (18.4)
10 (0.70)	350 (9.9)	700 (19.8)	1000 (28.3)
15 (1.00)	425 (12.0)	900 (25.5)	1400 (39.6)
20 (1.40)	500 (14.2)	1100 (31.2)	1700 (48.1)
30 (2.10)	600 (17.0)	1400 (39.6)	2300 (65.1)
40 (2.80)	750 (21.2)	1700 (48.1)	2500 (70.8)
60 (4.10)	1000 (28.3)	2400 (68.0)	2500 (70.8)

Table 1. Regulator Capacity Table

Based on the minimum inlet pressure of 40 psig, drop down the inlet pressure column until 40 psig is selected. Go right across the capacity columns until reaching a capacity that is greater than that needed, which in this example it would be 375 SCFH.

Inlet PSIG (bar)	1/8" x 3/16" Orifice
40 (2.80)	750 (21.2)

Table 2. Regulator Capacity Table

The first orifice (1/8" x 3/16") would provide 750 SCFH which is twice of what is needed. Select that size orifice for this application.

Next determine the spring range for the regulator. The manufacturer lists the following spring ranges that are available for this regulator.

Pressure Spring - Steel, zinc plated and yellow chromate. Color coded for identification.

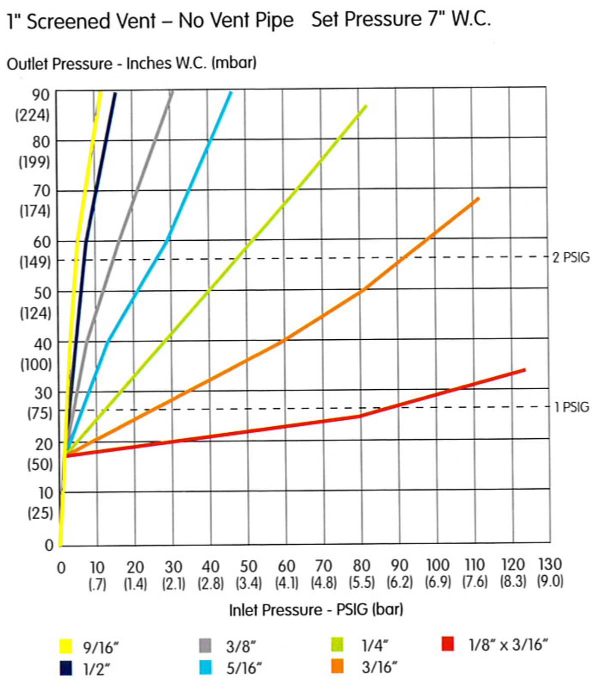
Outlet Pressure	Color Code	Part Number
3.5" to 6" W.C.	Blue	70017P043
3.5" to 7.5" W.C.	Tan	70017P089
5.5" to 8.5" W.C.	Yellow	70017P044
6" to 12" W.C.	Brown	70017P137
6" to 15" W.C.	Purple	70017P042
12" to 28" W.C.	White	70017P060
24" to 48" W.C.	Red	70017P082
42" W.C. to 2 PSIG	Red - Red	70017P049

Table 3. Spring Ranges

Select the 5.5" to 8.5" W.C. spring range as the desired outlet pressure is 7" W.C. meaning the regulator will be operating about mid-range of the spring.

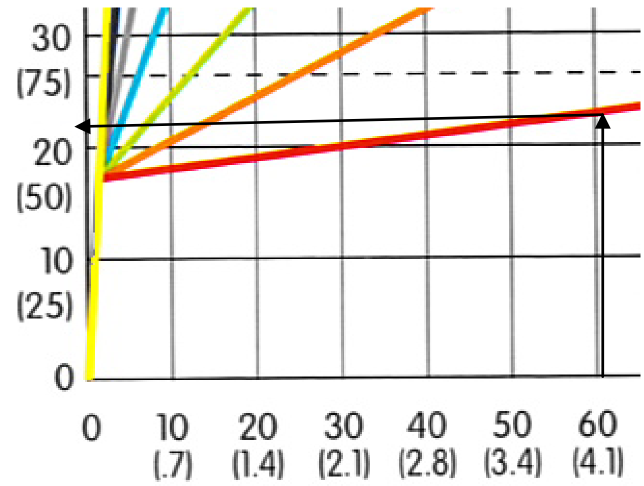
Next determine how what type of pressure protection is needed and what its set point or pressure limits should be.

In this case, overpressure protection is all that is necessary and this will be done with internal relief. The manufacturer has graphs showing what the downstream pressure will build up to should there be a total failure of the regulator. (See Graph 1). The issue is determining what that downstream pressure can build up to during a total failure. The difficulty is determining what the maximum inlet pressure the appliance regulator can handle during a failure. Let it be 2 psig in this example.



Graph 1. Internal Relief Characteristics

Go across the bottom grid until reaching the 60 psig pressure vertical line. Go up this line until reaching the line for the 1/8"x3/16" orifice. Follow this intersection to the left side of the graph to determine what the downstream pressure will build up to should the regulator totally fail. In this example, this outlet pressure will be about 22" W.C. which is well below the allowable 2 psig. With this regulator, the relief is preset to start relieving at 7"W.C. above set point so it will start at about 14" W.C. downstream pressure. (See Graph 2.)



Graph 2. Relief Performance

Next the Assembly Position must be determined. Since flow will be upward with the riser on the left side of the meter, the assembly position would be as shown in Figure 7.

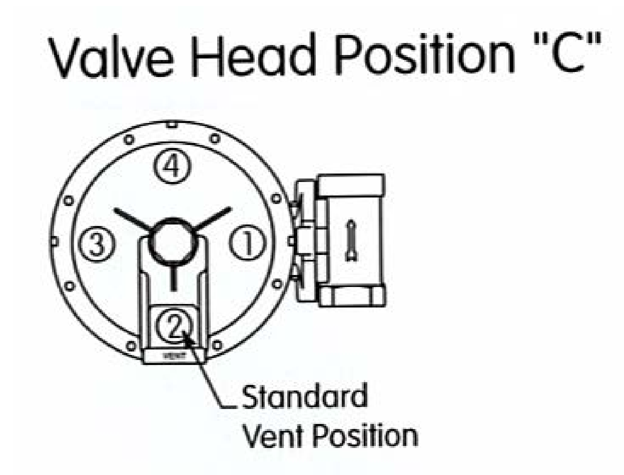


Figure 7. Assembly Position

The seat disk material would be selected as Buna N 70 Durometer which is the standard. It has an operating temperature range of -20^{0}F to 150^{0}F and is soft enough to insure lockup of the regulator under cold conditions.

The final meter set assembly should look like this:

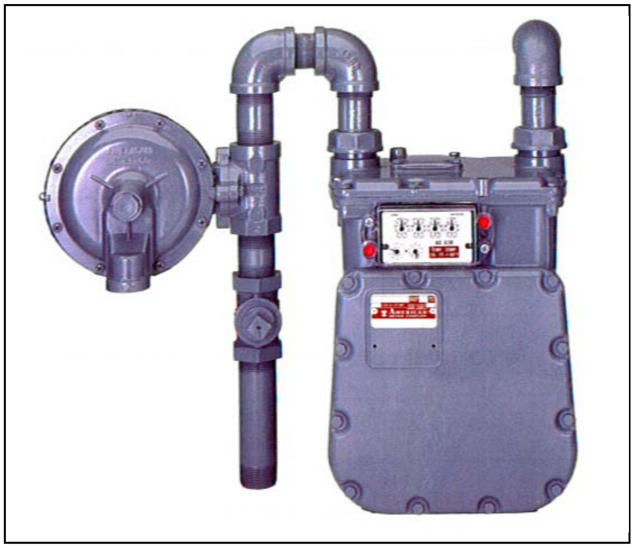


Figure 8. Final Assembly

The regulator vent is on the left side of the meter set in the riser, the vent is looking down, and gas flow is upward towards the meter.

E. Relief Valve Sizing

A typical external relief valve installation may look like this drawing:

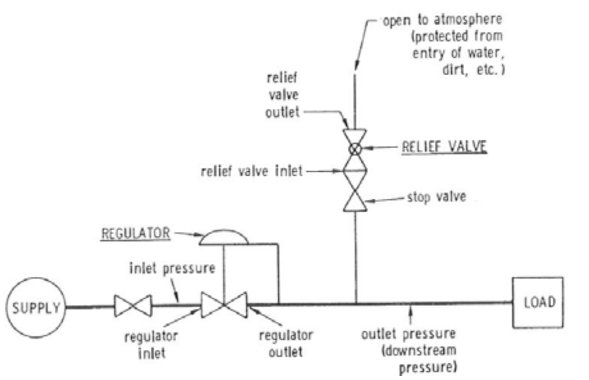


Figure 9. External Relief Valve

The relief valve will be used to protect the downstream system from becoming overpressurized should the regulator fail. The worst case scenario would be for a regulator failure with the supply being at its maximum pressure and with no downstream load to use or burn off the excess gas. The downstream pressure can not exceed its MAOP plus allowable overpressure.

The first step is to determine the fail-open flow through the pressure reduction regulator feeding the load. There are two situations that apply: critical flow or sub-critical flow. See Figure 10.

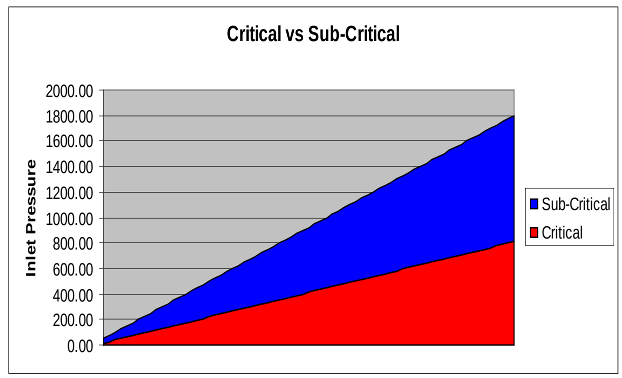


Figure 10. Critical vs. Sub-Critical Flow

The Boundary separates Critical Flow from Sub-Critical Flow through the regulator. If the pressure drop is greater than

0.5457 x Absolute Inlet Pressure,

then the failed open flow through the regulator is given by the Critical Flow Equation:

$$Q = (0.5\ C \times A_{bsolute\ Inlet})/\sqrt{G}$$

Where:

C = Orifice Constant

P = Absolute Inlet Pressure

G = Specific Gravity of gas

If the pressure drop is less than or equal to

0.5457 x Absolute Inlet Pressure

then the failed open flow through the regulator is given by the Sub-Critical Flow Equation:

$$Q = C \text{ x} \sqrt{Pxh} / \sqrt{G}$$

Where:

C = Orifice Constant
P = Absolute Outlet Pressure
G = Specific Gravity of gas
H = Differential Pressure
(Difference between Inlet and Outlet Pressures)

In the most conservative situation, a relief valve must be selected that will be able to blow all of this flow to atmosphere.

Relief Valve Sizing Example:

Inlet MAOP = 30 psig
Atmosphere pressure = 14.4 psia
Outlet set pressure = 2 psig
Outlet MAOP = 2 psig
Outlet MAOP + allowable (1 psig)
= 3 psig in an emergency situation
¼" orifice in the regulator
Orifice Constant for the orifice = 110

0.5457 x $A_{\text{bsolute Inlet}}$ = 0.5457 x (30 + 14.4) = 0.5457 x 44.4 = 24.23 psia

Since the pressure drop across the regulator under emergency conditions would equal (30 - 3) = 27 psi which is greater than the 0.5457 x $A_{\text{bsolute Inlet}}$ = 24.23 psi, use the Critical Flow Equation for the flow through the regulator.

$$Q = (0.5 \text{ C x } A_{\text{bsolute Inlet}}) / \sqrt{G}$$

$$Q = (0.5 \text{ x } 110 \text{ x } 44.4) / \sqrt{0.6} = 3152 \text{ SCFH}$$

Here's a capacity table for a pop relief.

Capacity data

spring number	range psig	set pressure psig	maximum flowing pressure psig	capacity MCF/hr.
106-0	.5-1.0	1.0	2.0	3.5
106-A	1.5-5.0	4.5	6	8.0
106	1-25	25	50	28.0
106-1	26-35	35	60	32.5
106-2	36-50	50	75	39.0
106-3	51-60	60	80	41.0
106-4	61-75	75	100	48.0
106-5	76-100	100	125	60.4
106-6	101-175	175	200	92.8
106-9	176-200	200	225	103.6
106-10	201-300	300	325	146.9

Table 4. Relief Valve Capacity Table

For the spring number 106-A, the pressure range is 1.5 psig to 5.0 psig which would meet the requirements for this application where the relief is to be set for a little less than 3 psig to allow the relief to start to open at the lesser pressure at the set point and then become wide open at 3 psig.

This relief will blow around 8,000 SCFH under those conditions so it is more that adequate.

In this next example use the same regulator, but with a different outlet set pressure.

Inlet MAOP = 30 psig
Atmospheric pressure = 14.4 psia
Outlet set pressure = 10 psig
Outlet MAOP = 10 psig
Outlet MAOP + allowable (5 psig)
= 15 psig in an emergency situation
¼" orifice in the regulator
Orifice constant for the orifice = 110

Will this same pop relief valve work?

The pressure drop is this example would be 30 – 15 psi under emergency conditions = 15 psi. Since this is less than the boundary condition (24.23 psi) between Critical and Sub-Critical Flow conditions, use the Sub-Critical Flow Equation.

$Q = C \times \sqrt{Pxh} / \sqrt{G}$

$Q = 110 \times \sqrt{29.4x15} / \sqrt{0.6} =$

110 x 21/0.77 = 3000 SCFH

Using the same relief valve, but with a 106 spring range set at a little less than 15 psig will have a capacity of around 28,000 SCFH. In this case, consult with the manufacturer to get the exact flow with the relief set at 14 psig to insure plenty of capacity.

Conclusion

In summary, when sizing for either a pressure reduction regulator or relief valve there are several things to remember;

Capacity of regulator increases as the inlet pressure increases. Base capacity on the lowest pressure the regulator may see while in service.

Capacity increases as the differential pressure across the regulator increases.

Make sure that the regulator with the selected orifice can handle the full MAOP of the inlet pressure and function properly.

Compare the inlet and outlet MAOPs of the regulator to those of the systems to which it's being connected.

Increase the total connected load by some "safety factor" to insure the regulator will function correctly under very unusual or changing conditions such as an unexpected increase in the load or decrease in the inlet pressure.

Use the lightest spring range available that will provide the desired outlet pressure. Working mid-range of the spring range is a good choice.

Operating conditions make dictate some modifications to the installation. Unusual temperature conditions (extreme high or low temperatures will affect the seat disk material selection), gas condition (dirty gas may require filtration), load characteristics (rapid on-off flows), and other considerations will all enter into the decision as to which regulator to use.

When sizing for relief valves, first determine whether the failed regulator will go to Critical or Sub-Critical condition based on whether the differential will be more or less then the boundary at

0.5457 x Absolute Inlet Pressure

Make sure to use the absolute pressures when using either Critical or Sub-Critical Flow equations.

Conservative thought indicates that this flow must be blown to atmosphere through the relief valve. Select a relief valve that will discharge that flow at regulator failure plus some reserve capacity.