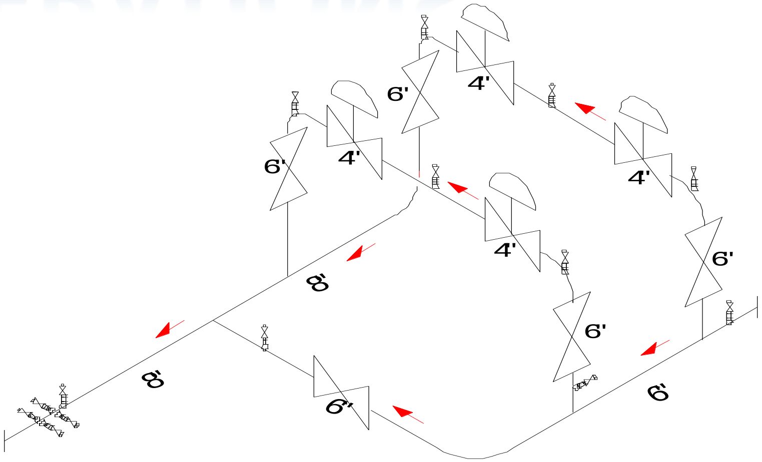
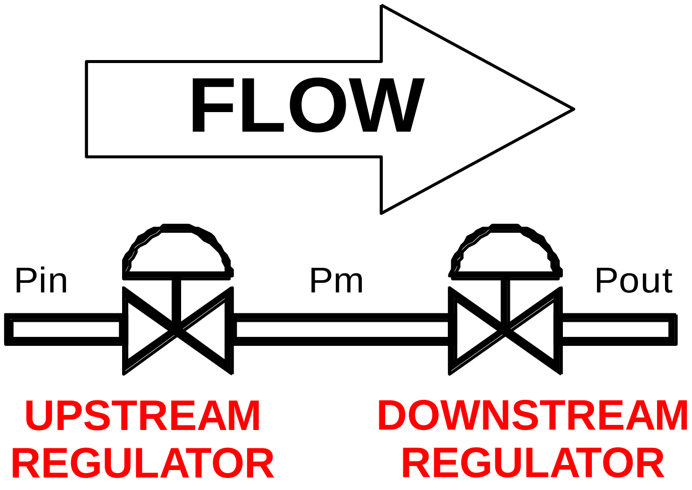
MONITOR REGULATOR SIZING AND OTHER CONSIDERATIONS



OGA 2015 Regulator Fundamentals Seminar

Monitor Regulator Sizing Theory



Maximum flow occurs through the regulator when:

1. The flow through the upstream regulator equals the flow through the downstream regulator
2. At the given pressure conditions and
3. Both regulators are wide open

Definitions

1) Flow Coefficients:

C_v .... Water (GPM) through valve@ 1 PSI DROP.

C_g .... Air specific gravity of 1.0

C_1 .... Efficiency coefficient (range 15 – 40) = C_g/C_v

X_T .... The pressure drop required to produce critical or maximum flow through the valve (Fisher Control Valves)

K .... Natural gas coefficient (0.6 specific gravity)

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k .... Ratio of specific heats = (cp/cv)

NOTE: Flow coefficients are stated in SCFH by the manufacturers

Definitions

2) Pressures:

P_{inlet} .... Inlet Pressure (PSIA)
P_m .... Intermediate Pressure (PSIA)
P_{outlet} .... Outlet Pressure(PSIA)

3) Flow Types:

a) Non-Critical (sub sonic) Flow
   Gas velocity not yet at the speed of sound
b) Critical (sonic) Flow
   Gas velocity at the speed of sound
c) Speed of sound in natural gas ≈ 1377 ft/sec
   for .6 Sg gas at standard temperature & pressure

Flow Equations

1) Non-Critical flow (Sub Sonic)

a) $$Q = K \times \sqrt{\left(P_{Inlet} - P_{Outlet}\right) \times P_{Outlet}}$$

Universal Gas Sizing Equation

b) $$Q = \sqrt{\frac{1}{S_g}} \times C_g \times P_{Inlet} \times \sin\left[\left(\frac{3417}{C_1}\right) \times \sqrt{\frac{P_{Inlet} - P_{Outlet}}{P_{Inlet}}}\right] deg$$

Flow Equations

2) Critical flow (Sonic)

a) $$Q = K \times \frac{P_{Inlet}}{2}$$

Universal Gas Sizing Equation

b) $$Q = \sqrt{\frac{1}{S_g}} \times C_g \times P_{Inlet}$$

$$Q = 1.291 \times C_g \times P_{Inlet}$$

The Rule of Forbidden Signals:

"The effect of pressure changes produced by a body moving at a speed faster than the speed of sound cannot reach points ahead of the body."

(von Kármán, Jour. Aero. Sci., Vol. 14, No. 7 (1947)) This rule can be applied to pneumatic flow restrictors where the body is not moving, but flow velocity relative to the body can reach, or exceed, the speed of sound. Whenever the downstream pressure is low enough to produce Mach 1 at the restrictor throat, any effect of changes in the downstream pressure cannot reach points upstream of the throat. Thus, flow rate will be independent of downstream pressure. This situation applies to a single orifice restrictor flowing gas when the overall pressure ratio exceeds 1.814

Determination of Non-Critical / Critical Flow

The critical pressure conditions depend on the ratio of the specific heats Factor as stated below

The value of the *specific heats ratio Factor " k"* is equal to *k* = 1.27 for natural gas

$$\frac{P_{In}}{P_{out}} = \left(\frac{k+1}{2}\right)^{\left(\frac{k}{k-1}\right)} = 1.814$$

Non-Critical / Critical Regulator Equations

1) Non-Critical (sub sonic) Flow

$$\frac{P_{Inlet}}{P_{Outlet}} \leq 1.814 \qquad Q = K \times \sqrt{(P_{Inlet} - P_{Outlet}) \times P_{Outlet}}$$

$$Q = \sqrt{\frac{1}{S_g}} \times C_g \times P_{Inlet} \times \sin\left[\left(\frac{3417}{C_1}\right) \times \sqrt{\frac{P_{Inlet} - P_{Outlet}}{P_{Inlet}}}\right] deg$$

2) Critical (sonic) Flow

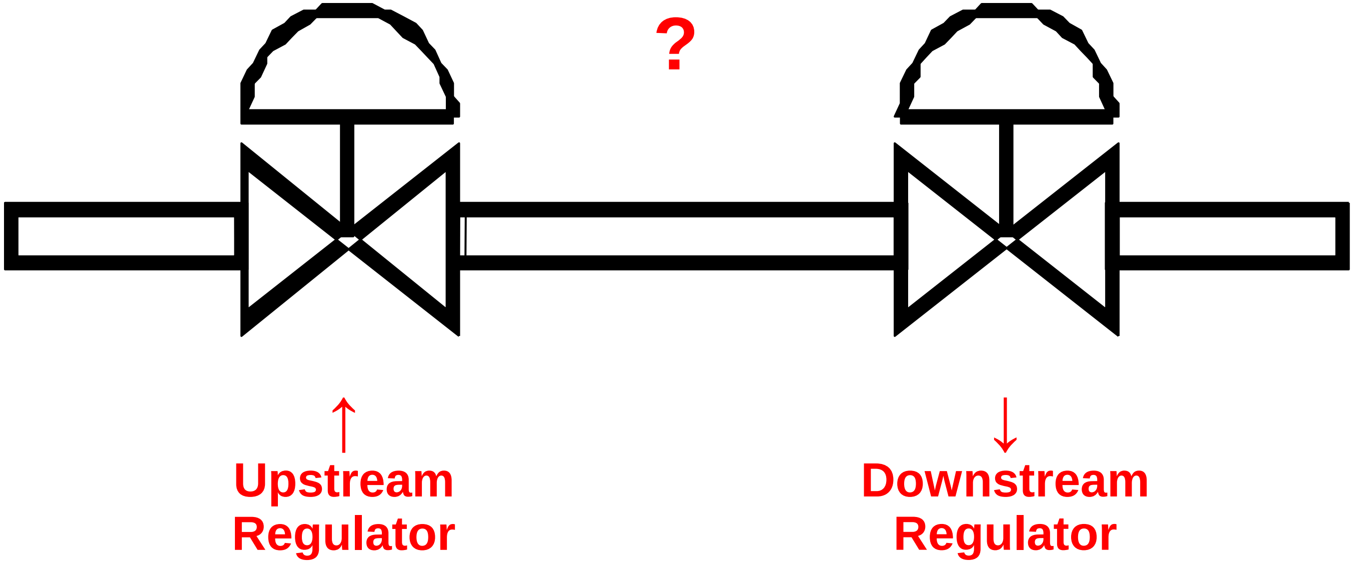
$$\frac{P_{Inlet}}{P_{Outlet}} \geq 1.814 \qquad Q = K \times \frac{P_{Inlet}}{2}$$

$$Q = 1.291 \times C_g \times P_{Inlet}$$

Manufacturers Capacity Tables

- An alternate method is the manufacturers capacity tables.
  - Tables provide capacity at various pressures
  - Recommended pressure & spring limitations
- Also these tables should be reviewed when sizing by equations for:
  - Pressure limitations
  - Spring limitations and
  - Available orifice sizes

Determination of Intermediate Pressure P_m



Determination of Intermediate Pressure P_m

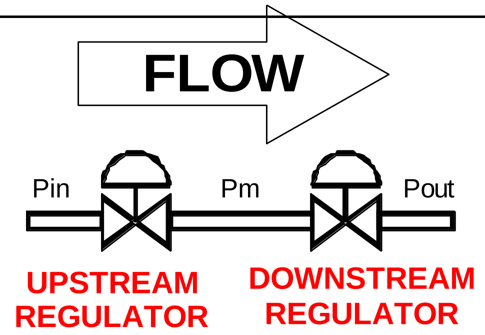
1) Non-critical flow where regulator flow coefficients $K_m = K_c$

$$P_m = \frac{\left(P_{Inlet} - P_{Outlet}\right) + \sqrt{\left(P_{Inlet} - P_{Outlet}\right)^2 + \left(4 \times P_{Outlet}{}^2\right)}}{2}$$

2) Critical flow where regulator flow coefficients $K_m = K_c$

$$P_m = \frac{4}{5} \times P_{Inlet} \quad \text{or} \quad P_m = 0.8 \times P_{Inlet}$$

Capacity Calculation Process

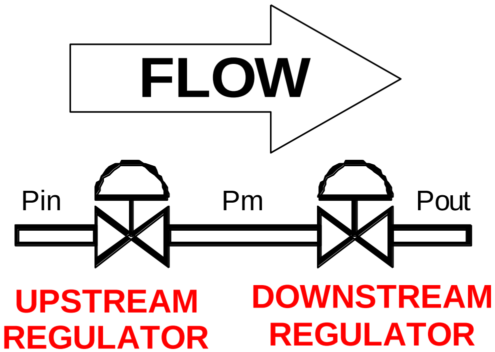


- STEP BY STEP PROCESS
- DETERMINE:
  1) SONIC / NON-SONIC ACROSS REGULATOR SETTING. (Inlet/Outlet)
  2) INTERMEDIATE PRESSURE Pm.
  3) SONIC / NON-SONIC ACROSS UPSTREAM REGULATOR. (Inlet/Intermediate)
  4) FLOW RATE ACROSS UPSTREAM REGULATOR. (Inlet/Intermediate)
  5) SONIC / NON-SONIC ACROSS DOWNSTREAM REGULATOR. (Intermediate/Outlet)
  6) FLOW RATE ACROSS DOWNSTREAM REGULATOR. (Intermediate/Outlet)

Sample Calculation

Pin = 50 Psig   Pout =25 Psig

Add 15 Psia to the inlet and outlet pressure to make them absolute pressures



Question: Is Pin/Pout greater or less than 1.814?

$$\frac{P_{Inlet}}{P_{Outlet}} = ?$$

$$\frac{P_{in}}{P_{out}} = \frac{65}{40} = 1.625 \quad \text{Less than } 1.814$$

Determine the intermediate pressure

$$P_m = \frac{\left(P_{Inlet} - P_{Outlet}\right) + \sqrt{\left(P_{Inlet} - P_{Outlet}\right)^2 + \left(4 \times P_{Outlet}^{\,2}\right)}}{2}$$

$$P_m = \frac{(65 - 40) + \sqrt{(65 - 40)^2 + \left(4 \times 40^2\right)}}{2}$$

$$P_m = 54.4076 \quad \text{PSIA}$$

Sample Calculation

Determine the capacity of the ***upstream regulator***

Do we have
Sonic flow ?

$$\frac{P_{in}}{Pm} = \frac{65}{54.4} = 1.19$$

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

$$Q = 1 \times \sqrt{(65 - 54.4076) \times 54.4076}$$

$$Q = 24.0 \quad \text{Mscfh}$$

Determine the capacity of the ***downstream regulator***

Do we have
Sonic flow ?

$$\frac{P_m}{Pout} = \frac{54.4}{40} = 1.36$$

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

$$Q = 1 \times \sqrt{(54.4076 - 40) \times 40}$$

$$Q = 24.0 \quad \text{Mscfh}$$

Sample Calculation

If you have a design flow rate of 100 MSCFH:
What size flow coefficient do you need?

Good regulation is between 80% to 90% of maximum calculated capacity of regulation. Therefore, divide the required flow rate by 0.8 and divide by the calculated flow rate.

Example:

$$\mathbf{K} = \frac{\left(\frac{100}{0.8}\ \mathbf{MSCFH}\right)}{\mathbf{24.0\ MSCFH}} = \mathbf{5.2}$$

Determination of Intermediate Pressure P_m UTI

3) Non-Critical flow where Regulator flow coefficients $K_m \neq K_c$

$$P_m = \frac{\left[\left[\left(\frac{K_m}{K_c}\right)^2 \times P_{Inlet}\right] - P_{Outlet}\right] + \sqrt{\left[\left[\left(\frac{K_m}{K_c}\right)^2 \times P_{Inlet}\right] - P_{Outlet}\right]^2 + \left(4 \times P_{Outlet}{}^2\right)}}{2 \times \left(\frac{K_m}{K_c}\right)^2}$$

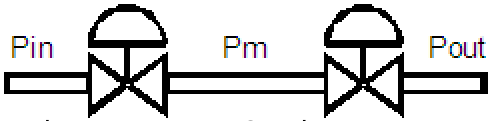
4) Critical flow where Regulator flow coefficients $K_m \neq K_c$

$$P_m = \frac{4 \times \left(\frac{K_m}{K_c}\right)^2 \times P_{Inlet}}{1 + 4 \times \left(\frac{K_m}{K_c}\right)^2}$$

Determination of Intermediate Pressure P_m

Pin = 100 Psig   Pout =35 Psig,   (K_m =2) ≠ (K_c = 1)
Add 15 Psia to the inlet and outlet pressure to make them absolute pressures

Question: Is Pin/Pout greater or less than 1.814?



$$\frac{P_{Inlet}}{P_{Outlet}} = ?\ \frac{P_{in}}{P_{out}} = \frac{115}{50} = 2.3 \Rightarrow \quad > 1.814$$

Determine the intermediate pressure

Critical flow where Regulator flow coefficients $K_m \neq K_c$

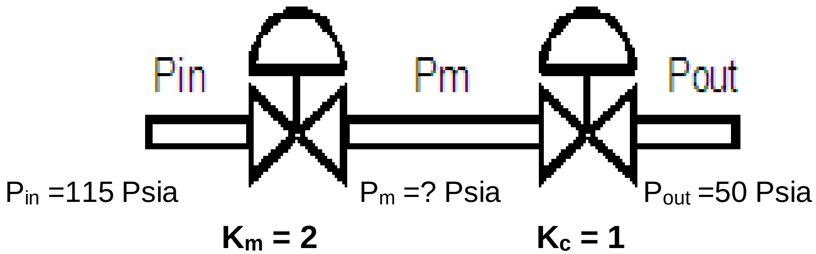
$$P_m = \frac{4 \times \left(\frac{K_m}{K_c}\right)^2 \times P_{Inlet}}{1 + 4 \times \left(\frac{K_m}{K_c}\right)^2}$$

Intermediate Pressure P_m

Sample Calculation

Determine the intermediate pressure

Critical flow where Regulator flow coefficients $K_m \neq K_c$



$$P_m = \frac{4 \times \left(\frac{K_m}{K_c}\right)^2 \times P_{Inlet}}{1 + 4 \times \left(\frac{K_m}{K_C}\right)^2}$$

$$P_m = \frac{4 \times \left(\frac{2}{1}\right)^2 \times 115}{1 + 4 \times \left(\frac{2}{1}\right)^2} = 108.2\ \text{Psia}$$

Intermediate Pressure P_m

Sample Calculation

Determine the capacity of the ***upstream regulator*** **$K_m = 2$**

$$\frac{P_{in}}{Pm} = \frac{115}{108.2} = 1.06 \Rightarrow \quad < 1.814$$

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

$$Q = 2 \times \sqrt{(115 - 108.2) \times 108.2}$$

$$(K_m = 2) \neq (K_c = 1)$$

$$Q = 54.2 \quad \text{Mscfh}$$

Determine the capacity of the ***downstream regulator*** **$K_c = 1$**

$$\frac{P_{in}}{Pm} = \frac{108.2}{50} = 2.2 \Rightarrow \quad > 1.814$$

$$Q = K \times \frac{P_m}{2}$$

$$Q = 1 \times \frac{108.2}{2}$$

$$Q = 54.1 \quad \text{Mscfh}$$

Conversion Equation

for C_g & C_1 Values to K Values

Note: C_g values are in SCFH

$$K = \log\left(\frac{3417}{C_1}\right) \times C_g \times 1.291$$

Conversion Equation for C_v & X_T Values to C_g Values

$$C_g = 40 \times C_v \times \sqrt{X_T}$$

$$C_1 = \frac{C_g}{C_v}$$

Sizing of Regulator Risers

Use gas velocity for sizing the diameter of the inlet & outlet risers on regulator settings

D in Inches, Q in Mcfh, P in Psia

40 MPH $D = 3.61 \times \sqrt{\frac{Q}{P}}$ $\frac{58.7ft}{sec}$

60 MPH $D = 2.95 \times \sqrt{\frac{Q}{P}}$ $\frac{88ft}{sec}$

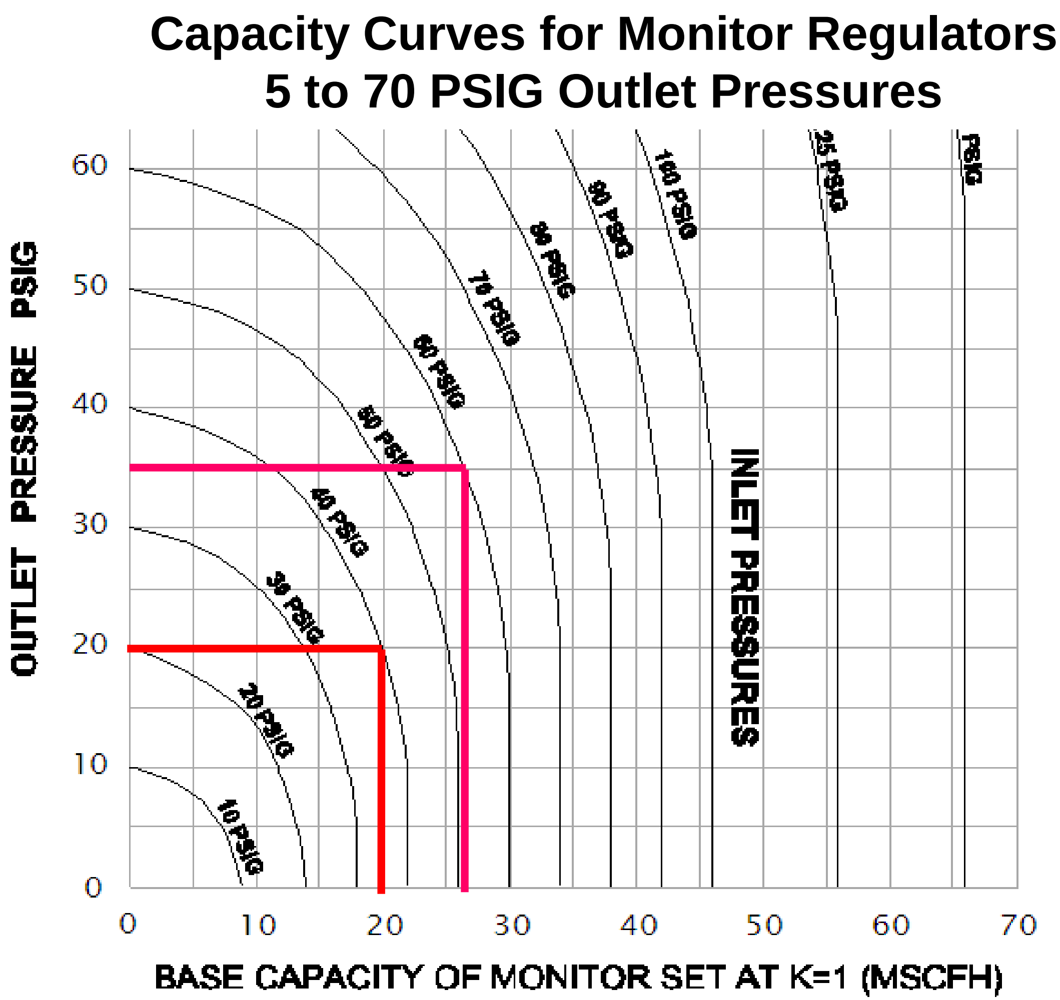
54.5 MPH $D = 3.00 \times \sqrt{\frac{Q}{P}}$ $\frac{80ft}{sec}$

80 feet per second is defined by API 12K as the erosion velocity

$$V_{el} = \frac{511.5 \times Q_{flow} Mcfh}{(14.73\ Psia + P_{flow} Psig) \times D^2} = MPH$$

$$V_{el} = \frac{MCF}{Hr} \times \frac{1000ft^3}{MCF} \times \frac{14.73Psia}{14.73\ Psia + P_{flow}Psig} \times \frac{1\,Mile}{5280\ ft} \times \frac{4}{\pi \times D^2 inch^2} \times \frac{144\ inch^2}{ft^2}$$

Regulator Flow Curves



Regulator Flow Curves

Instructions for calculating maximum capacity of a monitor set of regulators with identical orifice.

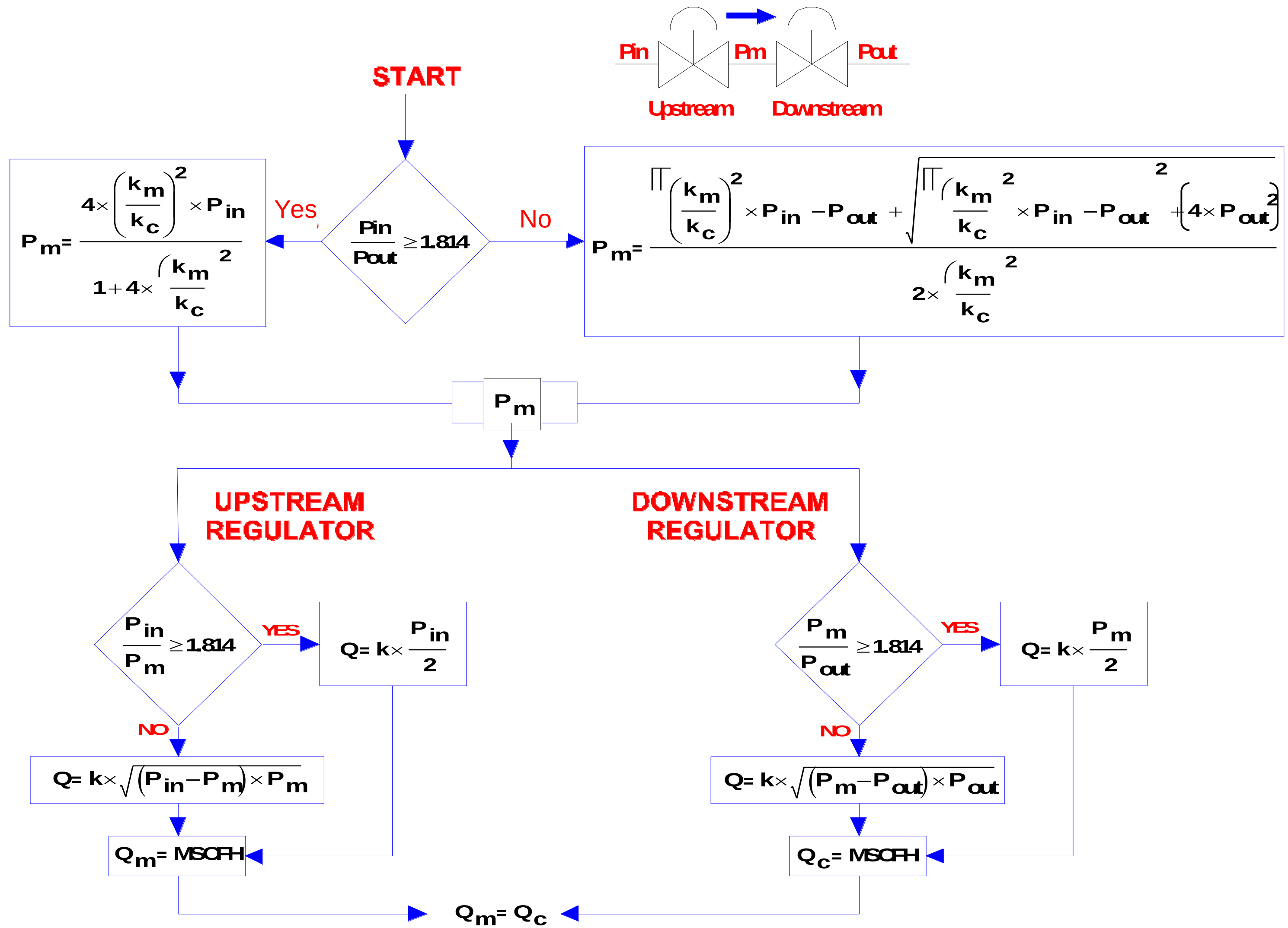
1. Locate inlet pressure curve on chart from previous slide
2. Locate maximum outlet pressure along Y axis
3. From the outlet pressure, follow the line across the chart left to right, until it intersects the inlet pressure curve
4. Draw a vertical line down and read the base capacity along the X axis
5. To obtain the capacity of a set of regulators, with a K value greater than or less than the base capacity K value of 1, multiply the base capacity by the K value of the regulators
6. EXAMPLE: Calculate the maximum capacity of a monitored set of 2” Sensus 441-57S regulators equipped with a 1 ½” double seated inner valves. K value equals 4.27. The inlet pressure is 60 psig and the outlet pressure is 35 psig

Monitor Regulator Sizing Charts

1. Monitor Regulator Flow Curves
   a. Simple ease to determine monitor set capacities
   b. No calculations required

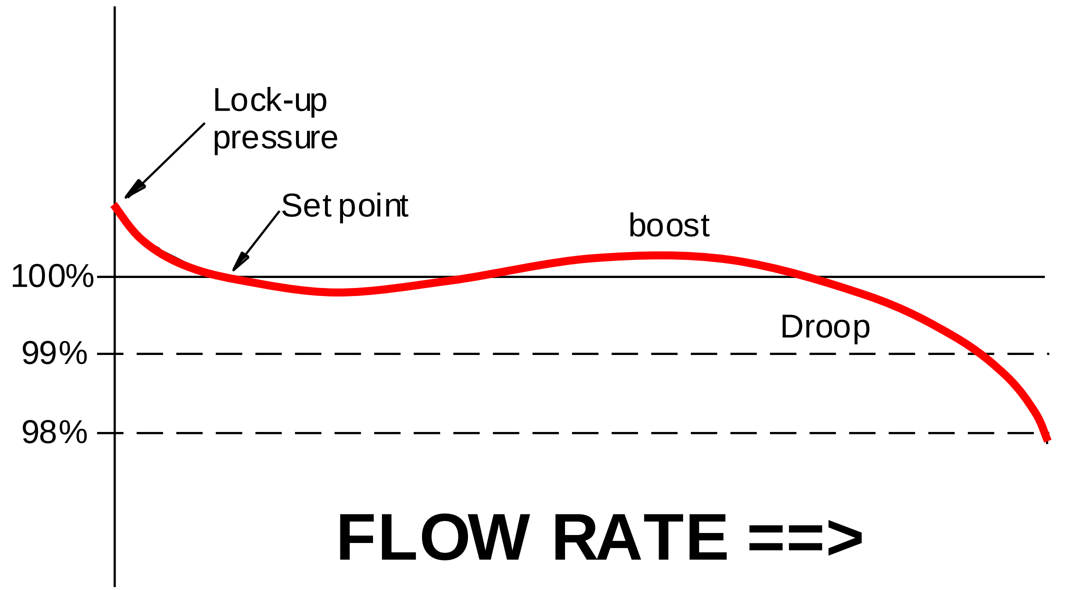
2. Monitor Regulator Flow Chart
   a. Ease to follow step by step
   b. Can be used for programming

Monitor Regulator Capacity Calculation Flow Diagram

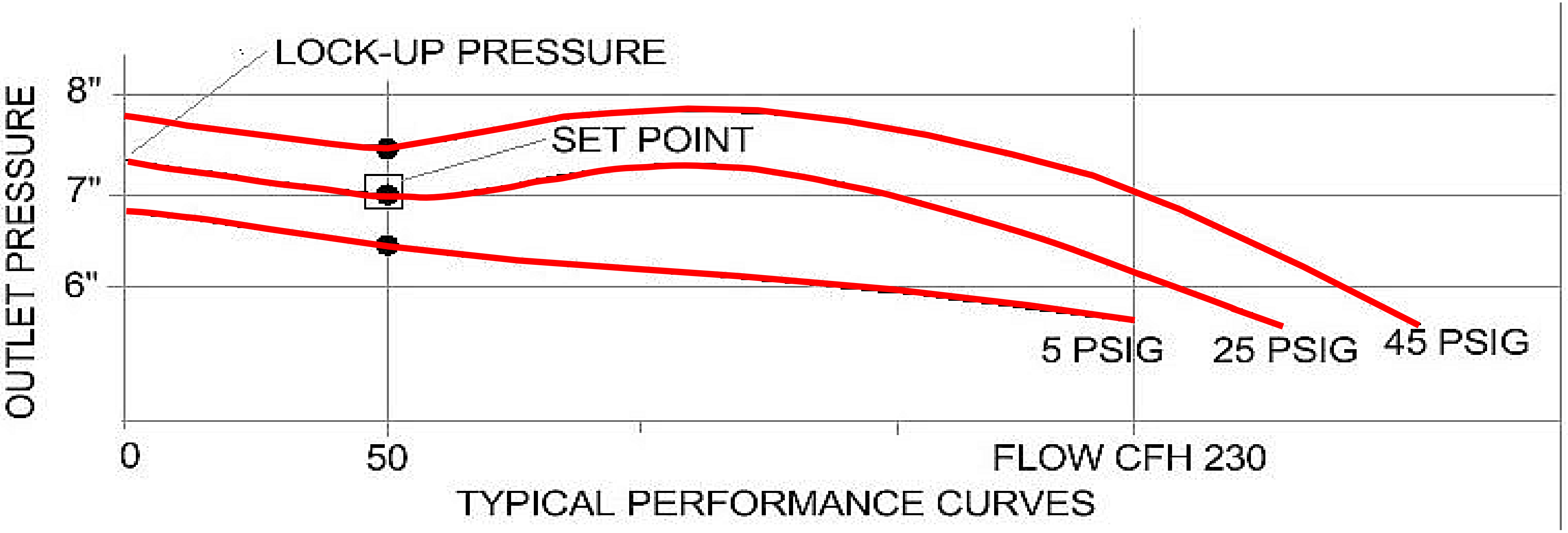


Regulator Outlet Droop

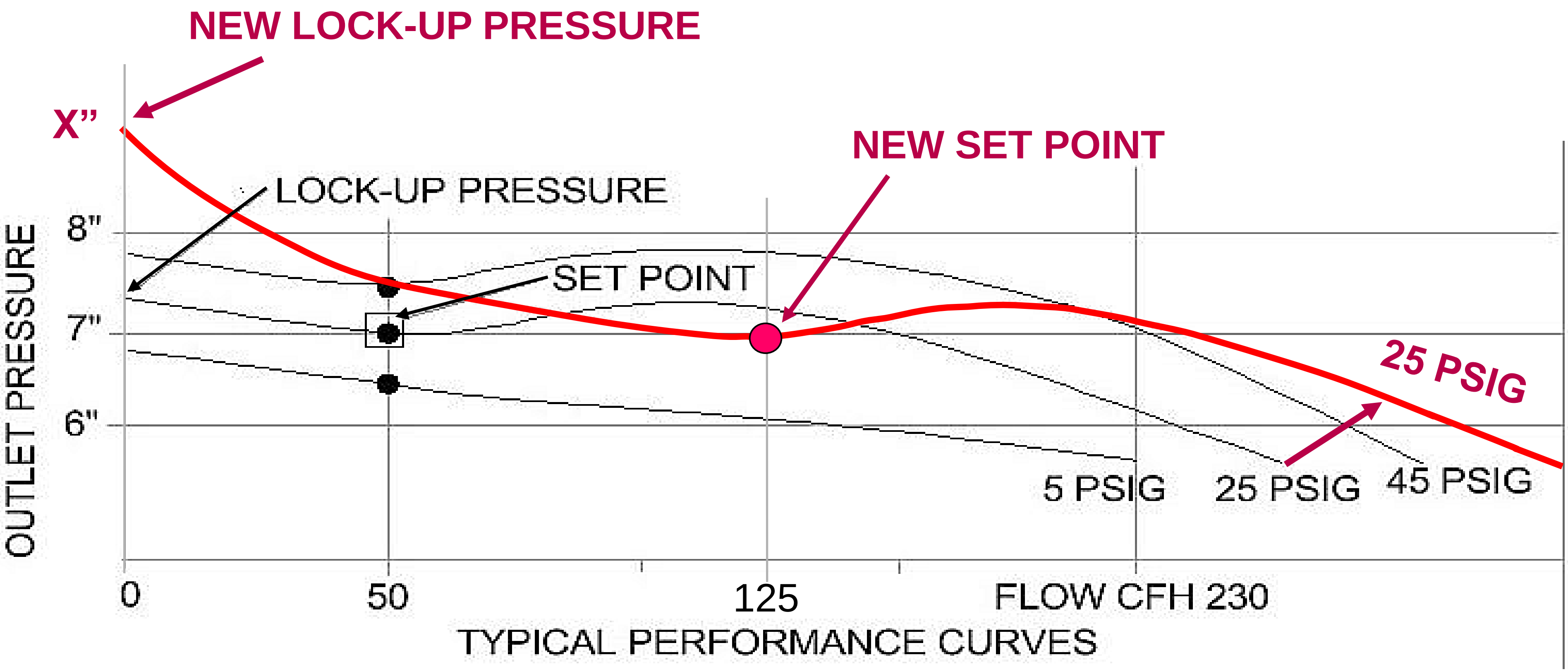
1. **What is Droop?** Droop is the decrease in outlet pressure from the set point. As flow increases from the set point to maximum capacity
2. **Spring and Diaphragm effect.** As the spring gets weaker (expanding) the diaphragm area gets larger. Therefore, a lower pressure under the diaphragm will balance the force of the spring at a greater valve opening



Regulator Performance Curves



Regulator Performance Curves



QUESTIONS?