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CSE PE Exam Review: Final Control Elements

EN00W5 Version 1.4

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Seminar Logistics

- Seminar materials
  - Downloadable presentation
  - Question and Answer session (audio and email)
  - Survey
  - Earn 1 Professional Development Hour (PDH)
- Seminar length
  - 60 minute presentation
  - Three 10-minute question and answer sessions

Audio Instructions

- As a participant, you are in a “listen-only” mode.
- You may ask questions via the internet, using your keyboard, at any time during the presentation. However, the presenter may decide to wait to answer your question until the next Q&A Session.
- If you have audio difficulties, press *0.

Audio Instructions for Q&A Sessions

- Questions may be asked via your telephone line.
- Press the *1 key on your telephone key-pad.
- If there are no other callers on the line, the operator will announce your name and affiliation to the audience and then ask for your question.
- If other participants are asking questions, you will be placed into a queue until you are first in line.
- While in the queue, you will be in a listen-only mode until the operator indicates that your phone has been activated. The operator will announce your name and affiliation and then ask for your question.

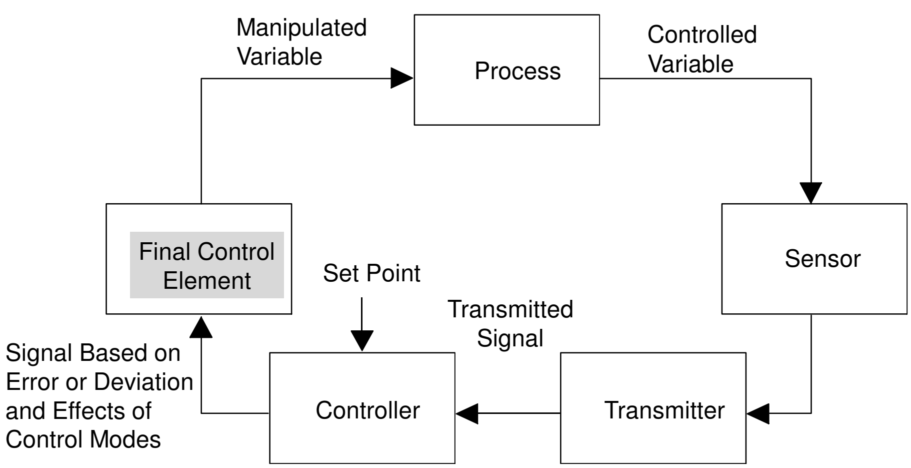
Introduction of Presenter

- **Gerald Wilbanks, P.E.** Vice President of Documentation and Engineering Services in Birmingham, Alabama has over 40 years of experience in engineering, management, consulting, and design in heavy industry. He is a registered professional engineer in 4 states, a member of NSPE, ASQ, and an International Former President (1995) of ISA. Gerald is a graduate of Mississippi State University with a Bachelors Degree in Electrical Engineering and was recognized as the Engineer of the Year in 1991 by the Engineering Council of Birmingham. He is a Distinguished Engineering Fellow of Mississippi State University and is a Life Fellow member of ISA. He has served as an instructor in many courses, seminars, and other educational sessions for ISA and in his own business.

Key Benefits of Seminar

- Identify areas of focus for more effective studying to assist with passing the PE examination
- Discuss process control valves
- Identify control valve sizing and application
- Determine dynamic system functions of a control valve
- Final Control Elements (Domain III) represents 16 questions or 20% of the CSE PE exam

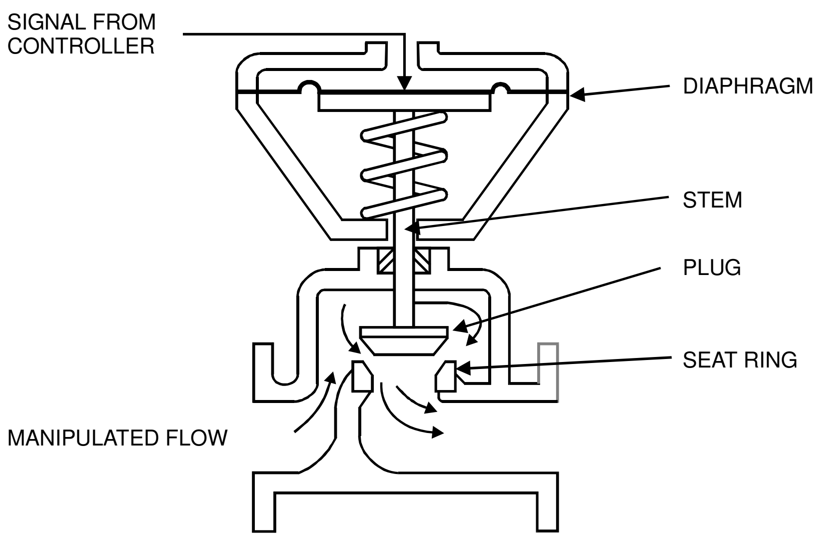
Typical Control Loop



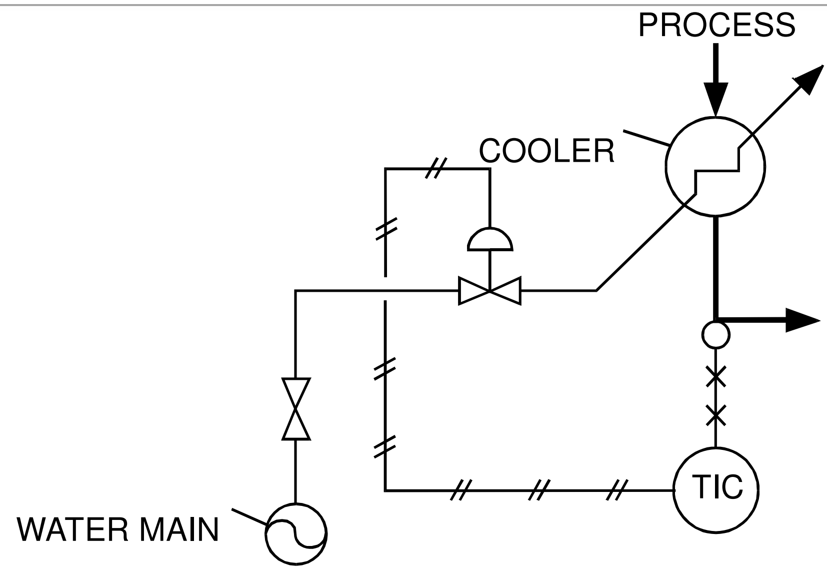
Section 1: Control Valve Types and Characteristics

- Definition and Description
- Terminology
- Applications
- Types of control valves
- Characteristics of body types
- Components

Schematic of a Typical Control Valve



Valve in Control Loop



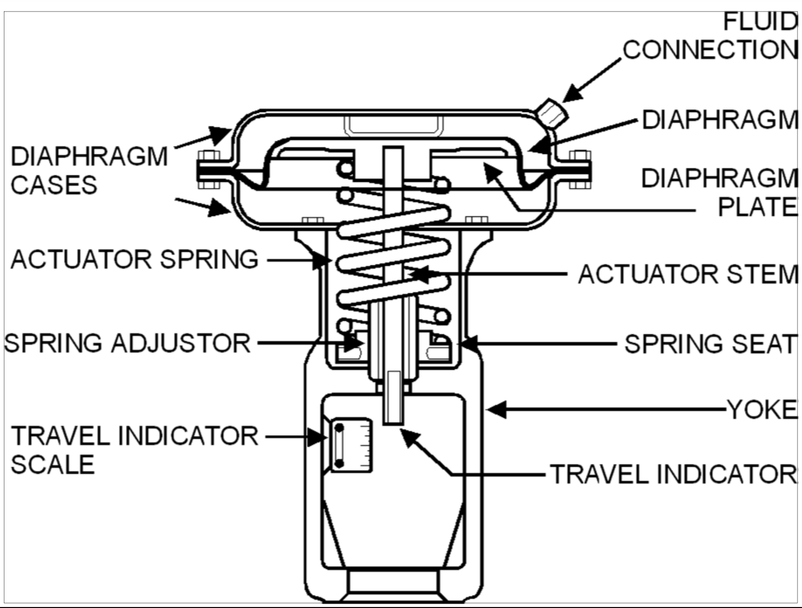
Control Valve Types

- Globe
- Gate
- Diaphragm
- Pinch
- Angle body
- Ball
- Butterfly
- Plug

Actuators

- Spring diaphragm
- Piston
- Electrohydraulic
- Electromechanical
- Forces
- Applications

Diaphragm Actuator - Air to Close



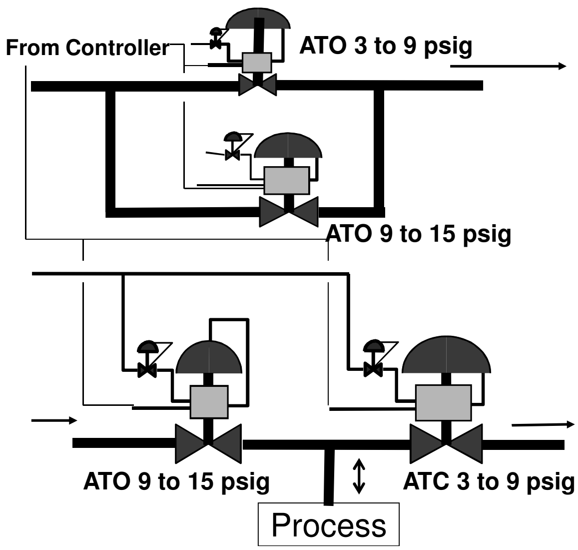
Electrohydraulic Actuators - A and D

- Advantages
  - High output capability
  - High actuator stiffness
  - Excellent throttling ability
  - Fast stroking speed
- Disadvantages
  - High cost
  - Complexity and maintenance difficulty
  - Large size and weight
  - Fail-safe action only with accessories

Electromechanical Actuators - A and D

- Advantages
  - Compact
  - Very high stiffness
  - High output capability
  - No need for air
- Disadvantages
  - High cost
  - Fail-safe usually dependent on battery
  - Limited duty cycle
  - Slow stroking speed

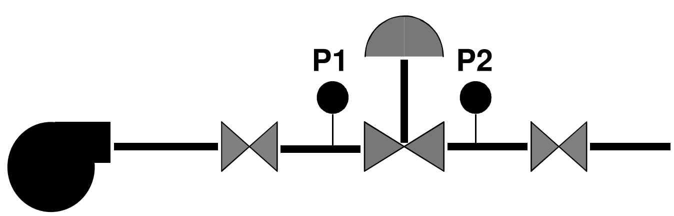
Split Range With Positioners



Split Range Valves can be used when both precise low and high flowrates must be controlled

Split Range Valves can be used for pressure control when an inert gas is fed into the vessel and also vented

Control Valve Test Flow Loop

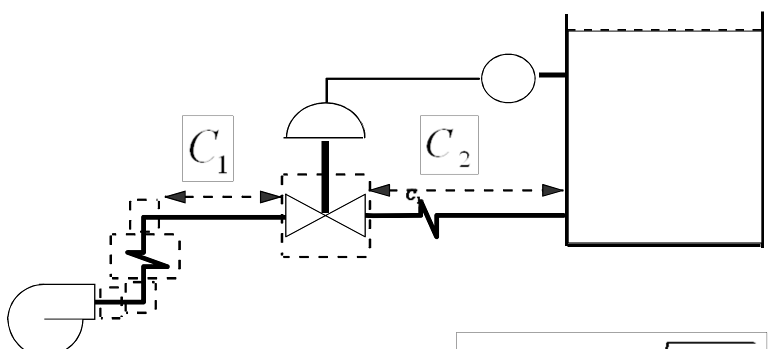


Cv Equation for Liquid Flow

$$C_V = Q\sqrt{\frac{G_f}{\Delta P}}$$

- Q = Flow (gpm)
- G_f = Specific gravity
- ΔP = Inlet pressure - outlet pressure
- $\Delta P = P_1 - P_2$

Non-Linear System



$$C_V = Q\sqrt{\frac{G_f}{\Delta P}}$$

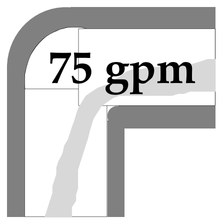
Pressure Drop

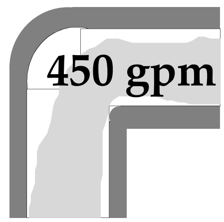
$$C_V = Q\sqrt{\frac{G_f}{\Delta P}}$$

$$\Delta P = \frac{Q^2 G_f}{{C_V}^2}$$

$$C_V = 240$$
$$G_f = 1$$

$$\Delta P = 0.0000173Q^2$$





$$Q^2 = 5{,}625$$
$$\Delta P = 0.1 psi$$

$$Q^2 = 202{,}500$$
$$\Delta P = 3.5 psi$$

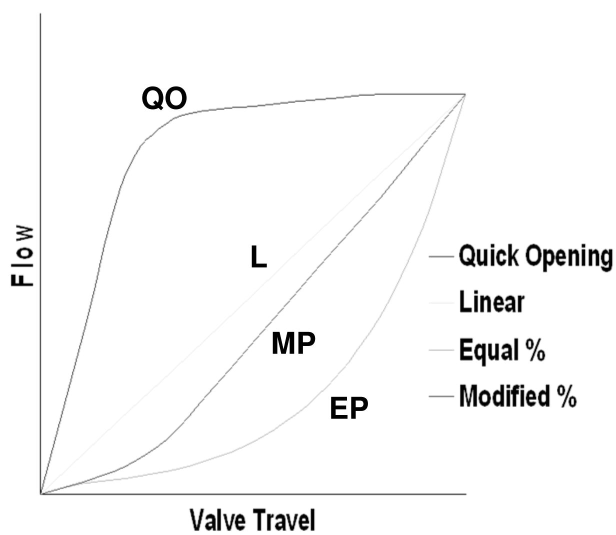
Characteristics

- Quick Opening
  - Rapid increase in flow capacity when valve begins to open
  - Rate of change decreases as travel increases
- Linear
  - Flow rate proportional to amount of travel
  - Change in flow rate is constant with valve travel

Characteristics (cont'd)

- Equal Percentage
  - Change in flow rate is always proportional to the flow rate just before the change in valve position is made
  - Rate of change in flow increases with increased travel
  - At low % opening, low changes in flow rate
  - At high % opening, high changes in flow rate
- Modified Percentage (modified parabolic)
  - Throttling action at low % opening
  - Almost linear after approximately first 20% of opening

Inherent Flow Characteristics



Equal Percentage

- A flow characteristic in which equal increments in the valve opening cause a constant percentage increase in Cv

% Open	20%	30%	40%	50%	60%
Cv	5.0	7.5	11.25	16.88	25.32
Cv Change	2.5	3.75	5.625	8.44	

$$Cv = Cv\max * R^{(M/100)-1}$$

R = Valve Rangeability

M = Valve % Open

Linear

- Responds to input signal in a uniform fashion over the operating range with unchanging dynamics
- A flow characteristic in which equal increments in valve opening cause equal increment changes in Cv

% Open	20%	30%	40%	50%	60%
Cv	10.0	15.0	20.0	25.0	30.0
Cv Change	5.0	5.0	5.0	5.0	

$$Cv = Cv\max \times M \div 100$$

M = Valve % Open

Process Gain

The relationship of the input signal change and the resulting process change is the process gain

$$\frac{\%\ \text{Process Change}}{\%\ \text{Signal Change}}$$

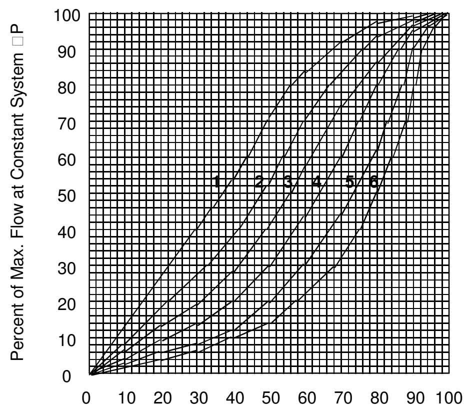
Rangeability and Turndown

- Rangeability
  - Max. controllable flow/min. controllable flow

  or
  - Required Cv Max./required Cv min.

- Turndown
  - Max. flow/min. controllable flow

Equal Percentage Valves



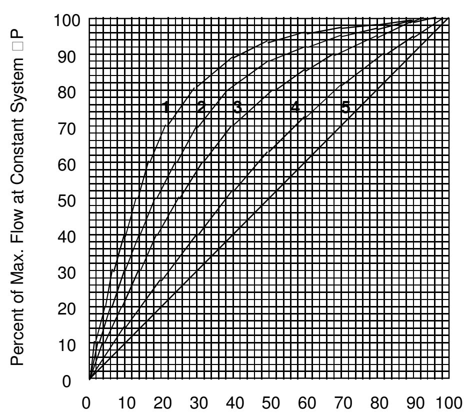
Percentage of total system pressure drop across valve at maximum flow conditions with valve wide open

1: 2%
2: 5%
3: 10%
4: 20%
5: 50%
6: 100% (Valve only)

Controlled Flow: % Max C_V

1:	14-100%	approx. 7:1
2:	10-100%	approx. 10:1
3:	7-100%	approx. 15:1
4:	4-100%	approx. 25:1
5:	2-100%	approx. 50:1

Linear Valves



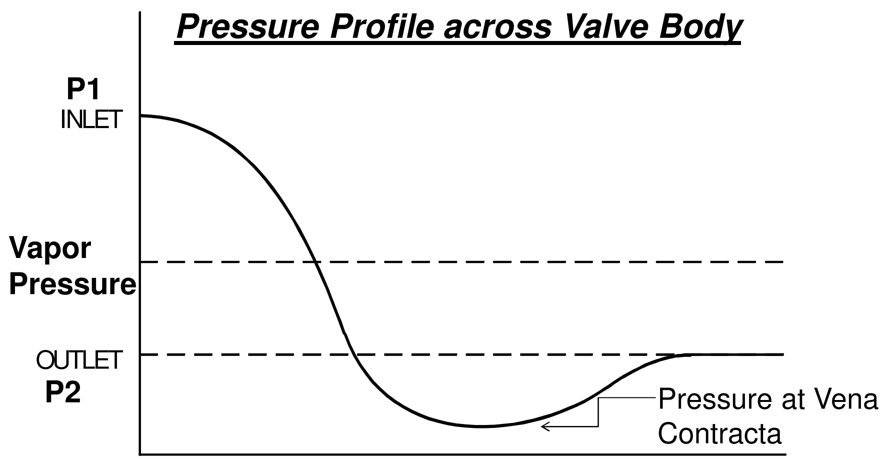
Percentage of total system pressure drop across valve at maximum flow conditions with valve wide open

1: 5%
2: 10%
3: 20%
4: 50%
5: 100% (Valve only)

Controlled Flow: % Max C_V

1:	40-100%	approx. 2.5:1
2:	30-100%	approx. 3.3:1
3:	22-100%	approx. 4.6:1
4:	14-100%	approx. 7.0:1
5:	10-100%	approx. 10:1

Flashing



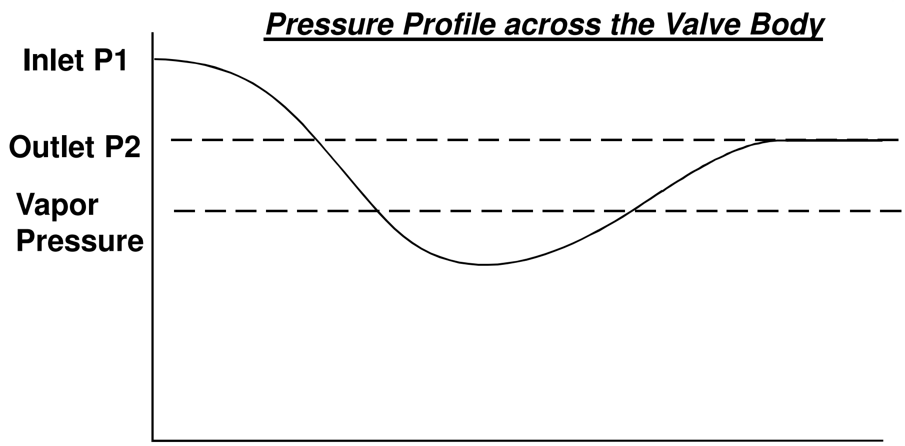
Flashing

- Flashing occurs when valve outlet pressure is below the liquid vapor pressure
- The outlet stream is part liquid and part vapor
- Can cause sizing and mechanical problems
- Avoiding the problem:
  - Minimizing downstream piping by locating the valve orifice so that it discharges directly into the receiving vessel

Cavitation Defined

- A two-stage phenomenon of liquid flow involving the formation of vapor bubbles and their subsequent collapse
- The implosion of the vapor bubbles results in noise and can cause extreme damage to the valve
- Under severe cavitating conditions, extremely hard control valve components have failed in a matter of hours

Cavitation



Avoiding Cavitation

- Use anti-cavitation valves
- Select high FL type trim
- Relocate valve to a point of higher static pressure
- Place an additional restrictor downstream
- Size valve properly
- Place valves in series
- (Note: Selecting a hardened trim will only prolong the service)

Relative Noise Levels

• Threshold of hearing	0 dBA
• Electric clock	20 dBA
• Cocktail party	65 dBA
• Vacuum cleaner (10’)	70 dBA
• Power mower (3’)	95 dBA
• Threshold of PAIN	125 dBA
• Rock band	130 dBA

Review of Key Points

- Valve body style determines proper applications
- Valve actuator is selected based on application and utilities available
- Each valve style has different flow characteristics
- Pressure and temperature considerations will determine flashing or cavitation of the fluid
- Each valve style has specific flow capacity ratings for specific sizes
- Control valves are the primary final control element

Live Question and Answer Session

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Section 2: Control Valve Sizing

- Definitions and Terms
- Equation Development
- Valve Flow Coefficient
- Sizing and Selection
- Valve Types and Applications

Control Valve Sizing

- For liquid service
- For gas and steam service
- Bench set
- Manual vs. computer

Cv - Valve Flow Coefficient

- The number of U.S. gallons of water at 60^0F which will pass through a given restriction, per minute, with a pressure drop of one psi
- The following equation is used for volumetric flowrate

$$C_V = \frac{Q}{F_P}\sqrt{\frac{G_f}{P_1 - P_2}}$$

Where:

Q = Flow thru valve in gpm

P_1 = Inlet pressure in psia

P_2 = Discharge pressure in psia

G_f = Flowing specific gravity

F_p = Piping reduction factor (dimensionless)

Critical Flow on Liquids

When Pvc is lower than Pv (Vapor Pressure) the fluid will flash and possibly choke the valve. Flashing and/or cavitation occurs

Critical flow occurs when:

$$\Delta P \geq F_L^2 (P_1 - F_F P_V)$$

F_L *is provided by manufacturer for the particular valve at the desired opening*

$$F_L = \sqrt{\frac{P_1 - P_2}{P_1 - P_{VC}}}$$

$$F_F = 0.96 - 0.28\sqrt{Pv/Pc}$$

Pc, critical pressure is available from tables

The following equation is used for critical flow:

$$C_V = \frac{Q}{F_L}\sqrt{\frac{G_f}{P_1 - F_F P_V}}$$

Gas Cv Equations

Gas Volumetric Flow Rate can be determined from following equation:

$$C_v = \frac{Q}{1360 F_P P_1 Y}\sqrt{\frac{G_g T_1 Z}{x}}$$

$$Y = 1 - \frac{P_1 - P_2}{3 F_k X_T P_1}$$

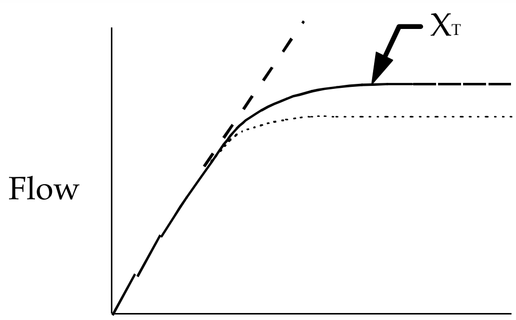
$$X_T = 0.85 F_L^{\,2}$$

$$F_k = \frac{k}{1.4}$$

- Q = Flow in scfh
- G_g = Specific gravity at 60^0F, 14.7 psia
- Z = Gas compressibility factor
- x = Valve pressure drop ratio (P1 - P2)/P1
- x_T = Limit of x in critical flow provided by mfg.
- F_K = Ratio of specific heats of gas and air
- T_1 = Temperature in ^{0}R

When $x \geq x_T$, x_T is used in place of x

Fully Choked Flow



$$\sqrt{\frac{P_1 - P_2}{P_1}}$$

$$X = \sqrt{\frac{P_1 - P_2}{P_1}}$$

$$\text{Sub-critical flow if} \quad 0.5F_L^2 > X$$

X = Pressure drop ratio factor
X_T = Point of fully choked flow

Valve Sizing for Steam

- Valves in steam service can be sized by entering the steam physical properties into the gas equation
- For saturated, dry steam, the following simplified equation can be used and will provide better than 5% accuracy

$$W = C_V P_1 \left(3 - \frac{x}{x_T}\right)\sqrt{x}$$

For choked flow where $x \geq x_T$

The following equation may be used

$$W = 2 C_V P_1 \sqrt{x_T}$$

- Superheat compensation can be obtained from the equation

Cv (superheated) = (1 + 0.0007 TSH) Cv (saturated)

TSH = Degrees of superheat in ^{0}F

Steam Valve Sizing Equation

Plant Equation:

Where: W is in pounds per hour.

•Sw = specific weight (pounds per cubic foot)

•P1 = psia

$$x = \frac{P_1 - P_2}{P_1}$$

$$Y = 1 - \frac{x}{3x_T}$$

$$x_T = .85 F_L{}^2$$

Steam Valve Sizing

When a certain condition exists, the following equation may be used:

$$C_V = \frac{W}{2.1\sqrt{(P_1 - P_2)(P_1 + P_2)}}$$

This is true when $\frac{P_1 - P_2}{P_1} \leq .1$

Sizing Equations: Sub-Critical Flow

Liquid

$$C_V = Q\sqrt{\frac{G_f}{P_1 - P_2}}$$

Gas/Vapor (Volume)

$$C_V = \frac{Q}{1360Y}\sqrt{\frac{G_g T_1 Z}{P_1(P_1 - P_2)}}$$

Gas/Vapor (Weight)

$$C_V = \frac{W}{63.3Y\sqrt{XP_1 sw}}$$

Superheated Steam

$$C_V = (1 + 0.0007T_{SH})C_{V_{Saturated\ Steam}}$$

Which Valve Do I Need?

- Performance (ability to control well)
- Installation and effects on environment
- Maintainability and long-term cost

Review of Key Points

- Control valves are rated by flow coefficients
- The flow capacity of a valve is based on the Cv, the pressure drop across the valve, fluid temperature, and fluid properties
- Control valves must be sized per application by hand or computer
- Specific valve styles are suited to unique fluid characteristics

Live Question and Answer Session

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Section 3: Pressure Relief Devices

- Relief Valve Definitions
- Terminology
- Physical Details
- Applications
- Sizing Practices
- Installation Considerations

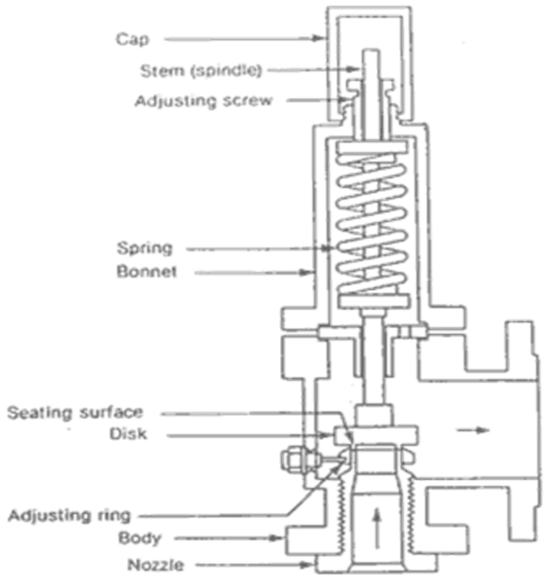
Relief Valve Definitions

- Relief Valve: Relieves upstream pressure in proportion to that pressure.
- Safety Valve: Relieves upstream pressure with rapid full opening or POP action.
- Safety Relief Valve: Either of the above, but to protect personnel and equipment by preventing excessive pressure buildup.

Relief Valve Terminology

- Operating Pressure – Normal vessel or system working pressure.
- MAWP – Maximum Allowable Working Pressure that is permissible for design.
- Set Pressure – Inlet pressure to which the valve is set to operate.
- Rated Capacity – Flow at given % over pressure permitted by code.
- Operating vs. Set Pressure Differential – Best if 10% or 25 psi Minimum.

Relief Valve Cutaway



Relief Valve Sizing

- Steam Application:

$$A_C = \frac{W}{51.5(K_d)(P_1)(K_{sh})(K_N)(K_b)}$$

- Where:
  - Ac = Area of valve nozzle (square inches)
  - W = Flow in lbs per hour
  - P1 = Rated flowing pressure (psia)
  - Ksh = Superheat correction
  - Kn = Napier Factor (only for >1580 psi)
  - Kb = Back Pressure Factor (normally 1)
  - Kd = Coefficient of orifice discharge

Sizing Example

- A 150 PSIG (nominal) Steam Header
- Inlet valve capacity = 50,000 PPH
- Wide open capacity = 100,000 PPH
- MAWP = 180 PSIG   Set Pressure = 165 PSIG
- Steam Temperature = 440 Deg. F

P1 = 1.1 (P) + 14.7 = 1.1 (165) + 14.7 = 196 PSIA

Ksh = .98   Kd = .855

Kb = 1.0   Kn = 1.0

Relief Valve Sizing Example

$$A_C = \frac{100{,}000}{51.5(.855)(196)(.98)}$$

- Ac = 11.82 square inches
- ASME has defined orifice sizes that are available from all manufacturers
- D is the smallest and T is the largest of the 17 sizes
- Orifice Q has an area of 12.85 square inches and will be the selected orifice in a 6”x8” valve
- The flange rating should match the flanges for the piping specs.

Installation Considerations

- Close couple to pipe or vessel
- Use same size inlet pipe as valve inlet
- Use Same size outlet pipe or larger when needed
- No isolation valves on inlet or outlet
- Allow for large reaction forces and thermal stresses in outlet piping
- Check noise level of vent stack exit
- Vent pipe must have rain hood and drain

Review of Key Points

- Relief valves are part of the overall safety system
- A primary concern is the determination of the capacity required for the safety valve
- Safety relief valves are installed to protect equipment from over pressure and the resulting damage

Live Question and Answer Session

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How Many People Are at Your Site?

- Poll Slide
- Click on the appropriate number indicating the number of people that are at your site.

Sample Exam Question - #1

- A control valve is to be sized for the following conditions:
  Liquid flow, 50 GPM, specific gravity = .81, inlet pressure of 240 psig, with a pressure drop of 10 psi. The required flow coefficient for the valve will most nearly be:

  A. 10.4
  B. 14.2
  C. 22
  D. 35.5

Sample Exam Question - #2

- A control valve is to be sized for the following conditions:
  Saturated steam at a maximum flow rate of 30,000 pounds per hour and an upstream pressure of 40 psia. P2 will be 30 psia according to the flow sheet and physical piping arrangement. The required flow coefficient for the valve will most nearly be:

  A. 260
  B. 540
  C. 760
  D. 198

Sample Exam Question - #3

- A relief valve is needed for a supply steam header in a plant. It is determined the maximum relief capacity needed is 100,000 pounds per hour with a set pressure of 165 psig for a maximum allowable working pressure of 180 psia. The steam temperature is 440 degrees F giving a superheat correction factor of .98. The calculated orifice area for the relief valve is most nearly equal to:

  A. 8.2 sq. in.
  B. 11.8 sq. in.
  C. 4.4 sq. in.
  D. 14.4 sq. in.

Sample Exam Question - #4

- In a gas flow control loop, the control valve has the following process conditions:

  Inlet Pressure (P1) = 65 psig

  Outlet Pressure (P2) = 15 psig

  Gas Temperature = 140 degrees F

  Gas Molecular Weight = 40

  If only the open flow area (X) of the valve increased, which of the following best describes how the mass flow (F) would change?

  A. F2 = F1 (X1/X2) ½
  B. F2 = F1 (X2/X1) ½
  C. F2 = F1 (X2/X1)
  D. F2 = F1 (X2/X1) 2

Related Courses from ISA

- Sizing, Selecting, and Applying Process Control Valves (EI30)

- All ISA courses are available any time as on-site training
- For more information: **www.isa.org/training** or **(919) 549-8411**

Other Related Resources from ISA

- *Control Valve Primer, 3rd Edition* (H. D. Baumann) from ISA Press
- *Control Systems Engineering Study Guide, 4th Edition* from ISA Press
- *Fisher Control Valve Handbook, 2nd Edition*
- ISA75.01.01-2002 – Flow Equations for Sizing Control Valves

Other Related Resources from ISA

- ISA Membership is just $100 per year, which includes free membership in two Technical Divisions (a $20 value) - one from each Department: Automation and Technology and Industries and Sciences.
  - For more information: **http://www.isa.org/membership/meminfo** or **(919) 549-8411**

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