UNIVERSITÁ DEGLI STUDI DI SALERNO
FACOLTÀ DI INGEGNERIA

Dipartimento di Ingegneria Industriale

Bachelor Degree in Chemical Engineering

Course:
Instrumentation and Control of Chemical Processes

CONTROL VALVE SIZING

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Rev. 3.5 – May 15, 2012

THE CONTROL VALVE SIZING PROBLEM

Calculations or choices to do:

- Capacity (based on the concept of C_V introduced in the 40's)
- DN
- Inherent characteristic
- Valve type (globe, butterfly, modulating ball, etc.)
- Construction material (depending upon temperature, pressure, corrosive and erosive properties of the fluid)
- Body shape, cap and plug
- Type and size of the actuator, servo-positioning device
- Safety items (e.g., action type in case of failure), reliability, maintenance

CONTROL VALVE SIZING
Design case

KNOWN DATA:
- NPS (NOMINAL PIPE SIZE) OF THE PIPING
- FLUID (LIQUID IN OUR CASE)
- INLET TEMPERATURE T_1
- $\Delta P = (P_1 - P_2)$
- FLOW
  - ➢ mass flow rate, volume flow rate
  - ➢ design at nominal / max / min flow rate
- MANUFACTURER TABLE

1. **TO BE CHOSEN:**
   - VALVE TYPE (GLOBE / BALL / BUTTERFLY)
   - TYPE OF INHERENT CHARACTERISTIC
   - CONSTRUCTION MATERIAL
2. **TO BE DETERMINED:**
   - NPS
   - C_{vn}
3. **TO BE CHECKED:**
   - CAVITATION (calculation of $\mathbf{\Delta P_c}$ or $\mathbf{\Delta P_{MAX}}$)

Taking suitable data from the "MANUFACTURER TABLE"

MANUFACTURER TABLE
An example for an angle globe valve

FLOW CHARACTERISTIC	VALVE SIZE		MAXIMUM TRAVEL	PORT DIA.	DESIGNS ED AND ET (FLOW DOWN)					DESIGN ES (FLOW UP)				
					Valve Opening, Percent of Total Travel									
					10	30	70	100	100	10	30	70	100	100
	DIN	Inches	mm	mm	C_v				F_L	C_v				F_L
Equal Percentage	DN 25	1, 1-1/4	19	33.3	.783	2.20	7.83	17.2	.88	.783	1.86	9.54	17.4	.95
	DN 40	1-1/2	19	47.6	1.52	3.87	17.4	35.8	.84	1.54	3.57	17.2	33.4	.94
	DN 50	2	29	58.7	1.66	4.66	25.4	59.7	.85	1.74	4.72	25.0	56.2	.92
	DN 65	2-1/2	38	73.0	3.43	10.8	49.2	99.4	.84	4.05	10.6	45.5	82.7	.93
	DN 80	3	38	87.3	4.32	10.9	66.0	136	.82	4.05	10.0	59.0	121	.89
	DN 100	4	51	111.1	5.85	18.3	125	224	.82	6.56	17.3	103	203	.91
	DN 150	6	51	177.8	12.9	43.3	239	394	.85	13.2	41.1	223	357	.86
	DN 200	8	76	203.2	27.0	105	605	818	.96	25.9	97.8	618	808	.85
					X_T				---	X_T				---
	DN 25	1, 1-1/4	19	33.3	.766	.587	.743	.667	---	.754	.763	.630	.721	---
	DN 40	1-1/2	19	47.6	.780	.716	.690	.679	---	.674	.694	.698	.793	---
	DN 50	2	29	58.7	.827	.774	.702	.687	---	.863	.849	.792	.848	---
	DN 65	2-1/2	38	73.0	.778	.678	.661	.660	---	.747	.745	.783	.878	---
	DN 80	3	38	87.3	.774	.682	.663	.675	---	.768	.761	.754	.757	---
	DN 100	4	51	111.1	.731	.643	.672	.716	---	.722	.739	.718	.822	---
	DN 150	6	51	177.8	.688	.682	.736	.778	---	.723	.767	.808	.816	---
	DN 200	8	76	203.2	.644	.636	.725	.807	---	.825	.681	.735	.827	

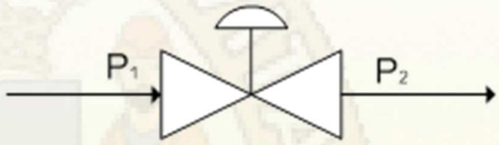
C_{vn} C_{vn}

When F_L is not present in MANUFACTURER TABLE:

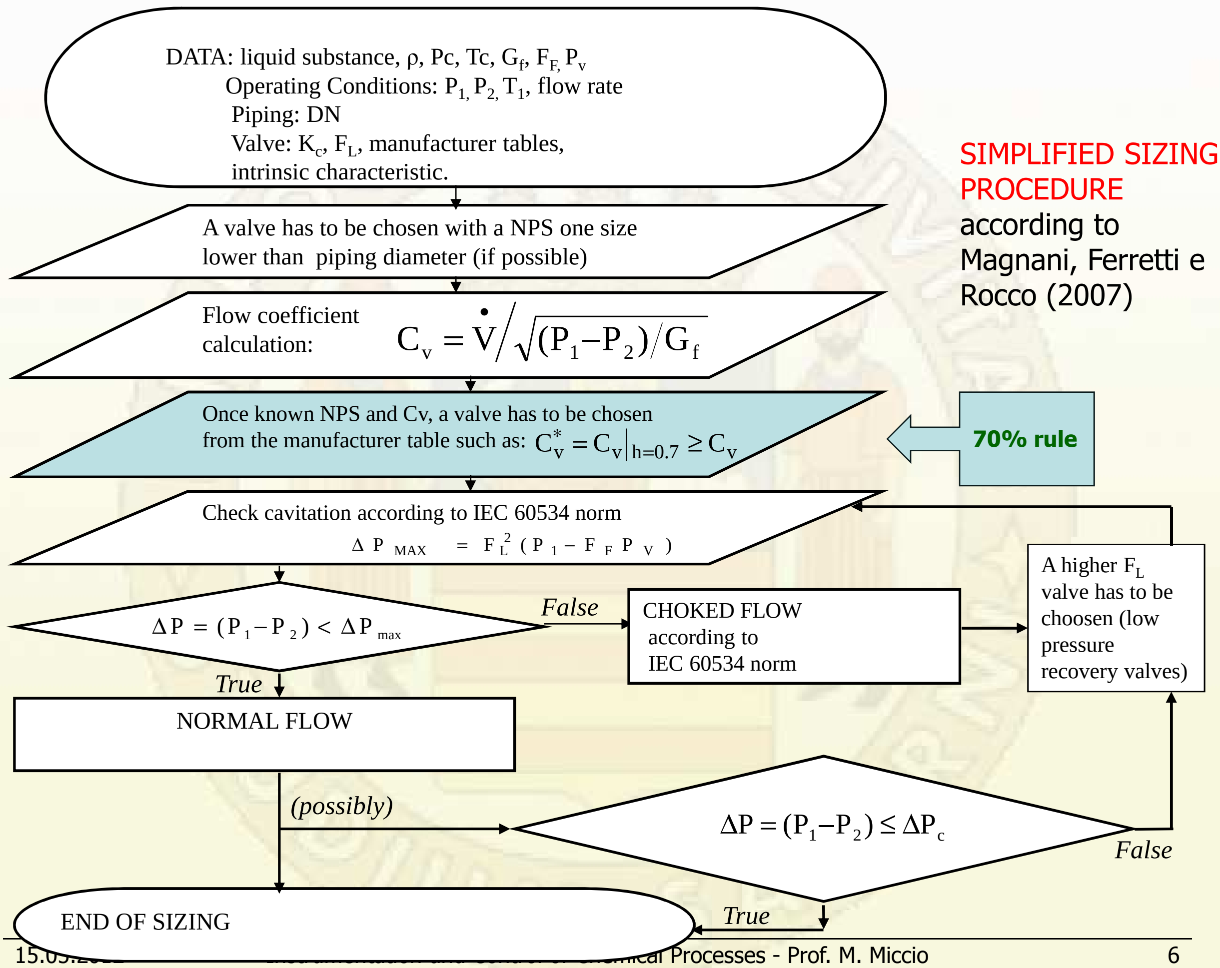
☞ AnnexD_ISA_7501-1985

VALVE SIZING PROBLEM
2 different design cases

1. the valve is a stand-alone unit



2. the valve is inserted in an equipment process scheme



SIMPLIFIED SIZING PROCEDURE according to Magnani, Ferretti e Rocco (2007)

CONTROL VALVE SIZING
Design case

Rotary Valves

The simplified procedure presented in the flow chart is valid for globe valves.

In fact the rotary valves are not **characterized by the travel "h", but by the opening angle θ.**

For rotary valves, the simplified sizing procedure is referred to an **angle θ***, which corresponds the 70% max opening angle (90°):

Strictly ➡ $\theta^* = (70/100) \cdot 90° = 63°$

In practice ➡ $\theta^* = 65°$ or $70°$

Remarks

- A rotary valve usually has one and only one inherent characteristic.
- Butterfly valves have often an inherent characteristic with an inflection point (such as V-port).
- Modulating ball valves have often an equal percentage inherent characteristic.

CONTROL VALVE SIZING
Design case

The MANUFACTURER TABLE: several cases are possible

a) For each NPS, the MANUFACTURER TABLE reports C_{vn} as well as C_v values for different values of h (θ)

☞ Inherent characteristic already known "for points"

b) The MANUFACTURER TABLE only shows the value of C_{vn} for each NPS, furthermore the manufacturer gives a diagram of ϕ or C_v as a function of h (θ).

☞ For the inherent characteristic use the manufacturer's diagram

c) The MANUFACTURER TABLE only shows the C_{vn} value for each NPS

☞ Use formulas for the inherent characteristic

INTERACTIVE EXERCISES on the WEB

Initial exercises and **reference examples/problems** are interactively available on the WEB.

NOTE:
They work by means of **Mathcad® Calculation Server** without the Mathcad® software installed on your own PC.

http://asp.diin.unisa.it

http://asp.diin.unisa.it/MCS/miccio/WEB_diagramma_PHI_EN.xmcd

CONTROL VALVE SIZING PROBLEM

Verify case

KNOWN DATA:

- VALVE TYPE
- NPS (NOMINAL PIPE SIZE) OF THE VALVE
- NOMINAL FLOW COEFFICIENT C_{vn}
- INHERENT CHARACTERISTIC
- FLUID (LIQUID IN OUR CASE)
- TEMPERATURE T_1
- $\Delta P = (P_1 - P_2)$

1. TO BE DETERMINED:

- NOMINAL FLOW RATE (h = 1 OR $\theta = 90^\circ$)
- FLOW RATE at a given value of h OR θ

2. TO BE CHECKED:

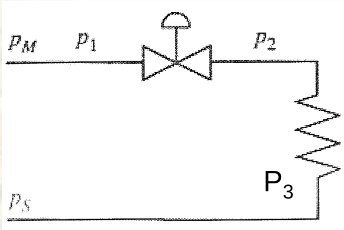
CAVITATION (calcolo di $\mathbf{\Delta P_c}$ or $\mathbf{\Delta P_{MAX}}$)

INSTALLED CHARACTERISTIC

DEFINITIONS:

INSTALLED CHARACTERISTIC:

It is the relationship between the flow rate and the (linear or rotary) valve opening when the valve is inserted in the circuit and influenced by process condition.



PRESSURE DROP across the valve: ΔP_v

NOMINAL (or RATED) PRESSURE DROP: $\Delta P_n = \Delta P_v \big|_{h=1}$

VALVE AUTHORITY:

It is the ratio between the nominal pressure drop (ΔP_n) across the valve and the total pressure drop of the circuit (ΔP_0).

$$V = \frac{\Delta P_n}{\Delta P_0}$$

The installed characteristic will be an implicit function:

$$w(h) = N_1 C_v(h) \sqrt{G_f \cdot \Delta P_v(w(h))} \;\; [=] \; kg/s$$

INSTALLED CHARACTERISTIC

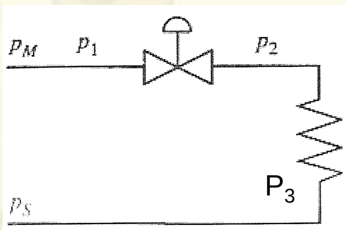
The circuit is formed by a control valve and an user in which all the pressure drop is concentrated.
A pump supplies the pressure $P_M - P_S$, assumed constant.
We can evaluate the role of the pressure drop across the valve comparing it with the total pressure drop of the circuit:

I. it should be high in order to improve the control of the flowrate;
II. on the other hand. It should be low in order to reduce costs of pump energy.

The aim is to find a good technical compromise solution between these two opposing evidences.

HYPOTHESES:

- $\Delta P_0 = P_M - P_S$ = constant
- Negligible pressure drop along the pipe:
  a) $P_M = P_1$
  b) $P_S = P_3$
- User pressure drop as a square function of the velocity and therefore, for incompressible fluid, is a square function of the mass flowrate : $\Delta P_u = P_2(w(h)) - P_3 = \gamma w^2(h)$
- No accumulation in the circuit



$\Delta P_v = P_1 - P_2$

$\Delta P_0 = \Delta P_u + \Delta P_v$

INSTALLED CHARACTERISTIC

With these hypotheses, the installed characteristic equation can be evaluated assuming **V** as parameter.

It is important to evidence the trend of the installed characteristic when changing **V** for a valve having linear or equal percentage inherent characteristic.

travel	nominal travel
h	1
$\phi(h)$	1
$C_v(h)=\phi(h)\ C_{vn}$	C_{vn}
$w(h) = N_1 C_{vn} \phi(h) \sqrt{G_f \Delta P(w(h))}$	$w_n = N_1 C_{vn} \sqrt{G_f \Delta P_n}$
$P_2(w(h)) = P_3 + \gamma w^2(h)$	$P_2 = P_3 + \gamma w_n^2$
$\Delta P_v(w(h)) = P_1 - P_2(w(h)) = P_M - P_S - \gamma w^2(h) = \Delta P_0 - \gamma w^2(h)$	$\Delta P_n = \Delta P_0 - \gamma w_n^2$

INSTALLED CHARACTERISTIC

For: $\Delta P_v = \Delta P_0 - \Delta P_u$ where $\Delta P_u = P_2 - P_3$ and $\Delta P_0 = P_1 - P_3$

$$\Delta P_n = \Delta P_0 - \gamma w_n^2$$

$$\gamma = \frac{\Delta P_0 - \Delta P_n}{w_n^2}$$

$$\Delta P_v[w(h)] = P_1 - P_2[w(h)] = P_1 - P_3 - \gamma[w(h)]^2 = \Delta P_0 - \gamma[w(h)]^2$$

Replacing in previous equation, we have:

$$w(h) = N_1 C_{vn} \phi(h) \sqrt{G_f \left[\Delta P_0 - \left(\frac{\Delta P_0 - \Delta P_n}{w_n^2} \right) w_n^2 \right]}$$

$$w^2(h) = N_1^2 C_{vn}^2 [\phi(h)]^2 G_f \cdot \left[\Delta P_0 - \left(\frac{\Delta P_0 - \Delta P_n}{w_n^2} \right) w^2(h) \right]$$

$$w^2(h) = \frac{N_1 C^2_{vn} [\phi(h)]^2 G_f \Delta P_0}{1 + N_1^2 C^2_{vn} [\phi(h)]^2 G_f \cdot \left(\frac{\Delta P_0 - \Delta P_n}{w_n^2} \right)}$$

see ch.5 in Magnani, Ferretti e Rocco (2007)

INSTALLED CHARACTERISTIC

Multiplying and dividing numerator and denominator for $\frac{\Delta P_n}{\Delta P_n}$ we obtain:

$$w(h)=\sqrt{\frac{N_1^{\,2}C^2_{vn}[\phi(h)]^2 G_f \Delta P_0 \cdot \frac{\Delta P_n}{\Delta P_n}}{\frac{w^2_{\,n}+N_1^{\,2}C^2_{vn}[\phi(h)]^2 G_f \Delta P_0 - N^2_{\,1}C^2_{vn}[\phi(h)]^2 G_f \Delta P_n}{w^2_{\,n}} \cdot \frac{\Delta P_n}{\Delta P_n}}}$$

$$w_n = N_1 C_{vn}\sqrt{G_f \Delta P_n} \quad \rightarrow \quad w^2_{\,n} = N^2_1 C^2_{vn} G_f \Delta P_n$$ replacing:

$$w(h)=w_n \cdot \sqrt{\frac{w^2_{\,n}[\phi(h)]^2 \cdot \frac{\Delta P_0}{\Delta P_n}}{w_n^{\,2}+w_n^{\,2}[\phi(h)]^2 \cdot \frac{\Delta P_0}{\Delta P_n} - w_n^{\,2}[\phi(h)]^2}}$$

INSTALLED CHARACTERISTIC

After using the AUTORITHY definition : $V = \frac{\Delta P_n}{\Delta P_0}$

$$\frac{w(h)}{w_n} = \sqrt{\frac{[\phi(h)]^2 \cdot \frac{1}{V}}{1+[\phi(h)]^2 \cdot \frac{1}{V} - [\phi(h)]^2}}$$

Dividing for [Φ(h)]² and multiplying for *V* in the square root, we have a non-dimensional final eq.:

$$\frac{w(h)}{w_n} = \frac{\dot{V}(h)}{\dot{V}_n} = \sqrt{\frac{1}{1-V+\frac{V}{[\phi(h)]^2}}}$$

The installed characteristic equation simplifies for the particular cases:

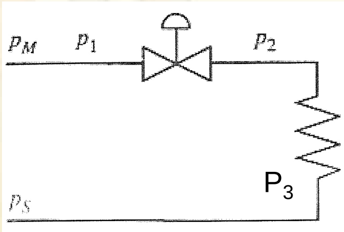
- ☞ V = 1
- ☞ ϕ(h) = 1

see ch.5 in Magnani, Ferretti e Rocco (2007)

VALVE SIZING PROBLEM
2 different design cases

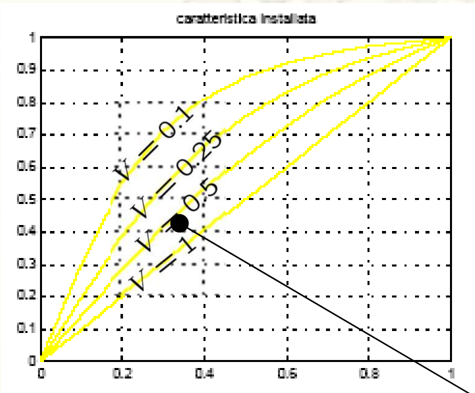
1. the valve is a stand-alone unit

2. the valve is inserted in an equipment process scheme

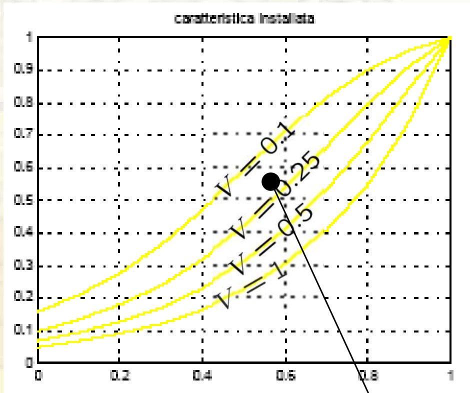


NOVEL SELECTION CRITERION OF THE CONTROL VALVE

- The selection of the **inherent characteristic** is based on the process requirements of the **installed characteristic**
- C_{vn} is always chosen after the C_v^* calculation based on the **70% rule**



Linear inherent characteristic



Equal percentage inherent characteristic

installed characteristic "closer" to linearity

Selection criterion of inherent characteristic

If *V* is known *a priori*, the selection is based on the value of *V*:

- if ***V* > 0.4**, the linear inherent characteristic is chosen
- if ***V* ≤ 0.25**, the equal percentage inherent characteristic is chosen
- if **0.25 < *V* ≤ 0.4**, the parabolic or equal percentage or "modified" linear inherent characteristic is chosen

If *V* is unknown, a parabolic or "modified " inherent characteristic is chosen

FLOW FACTOR K_v

It is not commonly used.
It defines the volume flow rate of water in m^3/h at 15℃ (5-40℃) which flows across the valve for a known closure member travel producing a pressure drop equal to 1 bar.

$$K_v = \dot{V}\sqrt{\frac{\Delta P(K_v)}{\Delta P}}\sqrt{\frac{\rho}{\rho_0}} \qquad [=]\ m^3(H_2O)/(h(bar)^{1/2})$$

where:

$\dot{V}$	=	volume flow rate
$\Delta P(K_v)$	=	reference pressure drop (usually 1 bar)
ΔP	=	actual pressure drop
ρ_0	=	density of water
ρ	=	actual density of the fluid

$C_v = 1.16\ K_v$

$K_v = 0.865 C_v$

CONTROL VALVE SIZING: other cases/problems

- LIQUID IN LAMINAR REGIME
- COMPRESSIBLE FLUIDS (GAS AND VAPORS)
- TWO-PHASE MIXTURES (LIQUID-GAS MIXTURES)
- PIPE SIZE REDUCTION
- NOISE EVALUATION