Sizing Problem

A food industry need a new **control valve** for a process stream at the following conditions:

fluid: sunflower oil
density: $\rho_f = 0.032$ lb/in^3
downstream pressure P_2: atmospheric
vapor pressure: $P_v = 0.1$ psi
$F_F = 0.956$
nominal size of piping: DN = 60 mm

However, the process stream undergoes to variability in the following variables:

mass flow rate: $\dot{m} = 8 \div 10$ lb/s
upstream pressure: $P_1 = 37 \div 44$ psi

a. With respect to the above range of variations, calculate the **flow coefficient C_v** for the valve working conditions that appear to be the most demanding

A steel-made, flange mounted globe valve Combraco 57 is available. It may adopt either a **linear** or **equalpercentage** or **parabolic** intrinsic characteristic. The *rangeability* is r = 20. The valve manufacturer data are:

DN mm	**K_{vn} m^3 (H_2O) /h bar^{½}**
8	3.0
15	9.2
20	12.1
40	17.0
60	29.3
80	34.6

The conversion for **K_v** to the **flow coefficient C_v** is as follows:

$$\mathbf{C_v = 1.16\, K_v} \; [=] \; \text{gpm (USA) psi}^{-1/2}$$

b. What is the **valve nominal size**?
c. **Size the valve** and choose that one with the most appropriate DN and intrinsic characteristic
d. Check **cavitation** according to the IEC norm

The valve chosen above is to install in a plant circuit that has an overall pressure drop $\Delta P_0 = 3$ atm = constant.

e. What is the **installed characteristic**?
f. Choose an optimal value for the **valve authority V**, which should be congruent with the previous choice of the intrinsic characteristic
g. Draw a quantitative diagram that displays the flow rate ratio $\frac{\dot{V}(h)}{\dot{V}_n}$ just for the above chosen **valve authority**
h. For the same value of the **valve authority V**, calculate the nominal pressure drop across the valve ΔP_n?
i. Correspondingly, how much is the new value of the nominal flow rate $\dot{V}_n$?

The pink painted variables are DATA   The blu painted text is COMMENT

PROBLEM DATA

fluid: *sunflower oil* (olio di girasole)

$\rho_f := 0.89 \cdot \frac{kg}{L}$ density   ☞ $\rho_f = 0.032 \cdot \frac{lb}{in^3}$

$G_f := \frac{\rho_f}{1000 \cdot \left(\frac{kg}{m^3}\right)}$ specific density   ☞ $G_f = 0.89$

$P_2 := 1. \cdot atm$ ☞ $P_2 = 14.696 \cdot psi$ downstream pressure

$P_v := 0.1 \cdot psi$ ☞ $P_v = 6.805 \times 10^{-3} \cdot atm$

$F_F := 0.956$ DN = 60 mm

OTHER VALVE DATA

$F_L := 0.9$ ISA S.75.01 norm, Annex D: Globe Valve

$K_c := 0.8 F_L^2$ $K_c = 0.648$

$r := 20$ rangeability

$$DN := \begin{pmatrix} 8 \\ 15 \\ 20 \\ 40 \\ 60 \\ 80 \end{pmatrix} mm \qquad K_{vn} := \begin{pmatrix} 3 \\ 9.2 \\ 12.1 \\ 17 \\ 29.3 \\ 34.6 \end{pmatrix} \frac{m^3}{hr \cdot bar^{\frac{1}{2}}}$$

NEW DEFINITIONS

$bar \equiv 10^5 \, Pa$ global definition of a new unit (pressure) in MathCad

$$conversion\_factor := 1.16 \cdot \frac{gal\,min^{-1} \cdot psi^{-0.5}}{m^3 \cdot hr^{-1} \cdot bar^{-0.5}}$$

$C_{vn} := conversion\_factor \cdot K_{vn}$

$$C_{vn} = \begin{pmatrix} 3.48 \\ 10.672 \\ 14.036 \\ 19.72 \\ 33.988 \\ 40.136 \end{pmatrix} \cdot gal\,min^{-1} \cdot psi^{-0.5}$$

DESIGN CALCULATIONS

1) C_v CALCULATION

1st case (lowest pressure and largest flow rate)

$P_1 := 37 \cdot psi$ ☞ $P_1 = 2.518 \cdot atm$ upstream absolute pressure

$m\_punto := 10 \cdot lb \cdot s^{-1}$ ☞ $m\_punto = 4.536 \cdot \frac{kg}{s}$ mass flow rate

$V\_punto := \frac{m\_punto}{\rho_f}$ ☞ $V\_punto = 5.097 \times 10^{-3} \frac{m^3}{s}$ $V\_punto = 80.782 \cdot \frac{gal}{min}$ volume flow rate

$C_{v1} := \frac{V\_punto}{\sqrt{\frac{P_1 - P_2}{G_f}}}$ ☞ $C_{v1} = 16.137 \cdot gal\,min^{-1} \cdot psi^{-0.5}$ Valve Flow Coefficient

2nd case (largest pressure and largest flow rate)

$P_1 := 44 \cdot psi$ ☞ $P_1 = 2.994 \cdot atm$ upstream absolute pressure

$m\_punto := 10 \cdot lb \cdot s^{-1}$ ☞ $m\_punto = 4.536 \cdot \frac{kg}{s}$ mass flow rate

$V\_punto := \frac{m\_punto}{\rho_f}$ ☞ $V\_punto = 5.097 \times 10^{-3} \frac{m^3}{s}$ $V\_punto = 80.782 \cdot \frac{gal}{min}$ volume flow rate

$C_{v2} := \frac{V\_punto}{\sqrt{\frac{P_1 - P_2}{G_f}}}$ ☞ $C_{v2} = 14.078 \cdot gal\,min^{-1} \cdot psi^{-0.5}$ Valve Flow Coefficient

3rd case (lowest pressure and lowest flow rate)

$P_1 := 37 \cdot psi$ ☞ $P_1 = 2.518 \cdot atm$ upstream absolute pressure

$m\_punto := 8 \cdot lb \cdot s^{-1}$ ☞ $m\_punto = 3.629 \cdot \frac{kg}{s}$ mass flow rate

$V\_punto := \frac{m\_punto}{\rho_f}$ ☞ $V\_punto = 4.077 \times 10^{-3} \frac{m^3}{s}$ $V\_punto = 64.625 \cdot \frac{gal}{min}$ volume flow rate

$C_{v3} := \frac{V\_punto}{\sqrt{\frac{P_1 - P_2}{G_f}}}$ ☞ $C_{v3} = 12.909 \cdot gal\,min^{-1} \cdot psi^{-0.5}$ Valve Flow Coefficient

4th case (largest pressure and lowest flow rate)

upstream absolute pressure

$P_1 := 44 \cdot psi$ ☞ $P_1 = 2.994 \cdot atm$

mass flow rate

$m\_punto := 8 \cdot lb \cdot s^{-1}$ ☞ $m\_punto = 3.629 \cdot \frac{kg}{s}$

$V\_punto := \frac{m\_punto}{\rho_f}$ ☞ $V\_punto = 4.077 \times 10^{-3} \frac{m^3}{s}$ $V\_punto = 64.625 \cdot \frac{gal}{min}$ volume flow rate

$C_{v4} := \frac{V\_punto}{\sqrt{\frac{P_1 - P_2}{G_f}}}$ ☞ $C_{v4} = 11.263 \cdot gal\, min^{-1} \cdot psi^{-0.5}$ Valve Flow Coefficient

Therefore, sizing will be carried out in the most "challenging" case from the options above, that is:

$C_v := C_{v1}$ ☞ $C_v = 16.137 \cdot gal\, min^{-1} \cdot psi^{-0.5}$

2) VALVE SIZING

Equal Percentage Valve

$\phi(h) := r^{h-1}$

For DN = 40 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.407$ $C_{vn_4} = 19.72 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_4} \cdot \phi_{0.7} = 8.028 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} < C_v$; This choice doesn't fulfill the 70% criterion !

For DN = 60 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.407$ $C_{vn_5} = 33.988 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_5} \cdot \phi_{0.7} = 13.836 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} < C_v$; This choice doesn't fulfill the 70% criterion !

Linear Valve

$$\phi(h) := h + \frac{1 - h}{r}$$

For DN = 40 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.715$ $C_{vn_4} = 19.72 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_4} \cdot \phi_{0.7} = 14.1 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} < C_v$; This choice doesn't fulfill the 70% criterion !

For DN = 60 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.715$ $C_{vn_5} = 33.988 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_5} \cdot \phi_{0.7} = 24.301 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} > C_v$; **OK!**

PARABOLIC VALVE

$$\phi(h) := h^2 + \frac{1 - h^2}{r}$$

For DN = 40 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.515$ $C_{vn_4} = 19.72 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_4} \cdot \phi_{0.7} = 10.166 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} < C_v$; This choice doesn't fulfill the 70% criterion !

For DN = 60 mm

$\phi_{0.7} := \phi(0.7)$ $\phi_{0.7} = 0.515$ $C_{vn_5} = 33.988 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$ $C_{vn_5} \cdot \phi_{0.7} = 17.521 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$

it's $C_v^* = \phi(0.7) C_{vn} > C_v$; **OK!**

This choice is even better than the linear characteristic!

4) CHECK FOR NO CAVITATION (IEC norm) **--->** $(\Delta P - \Delta P_{max}) < 0$

$\Delta P := P_1 - P_2$ $\Delta P = 29.304 \cdot psi$

$\Delta P_{max} := F_L^{\,2} (P_1 - F_F \cdot P_v)$ $\Delta P_{max} = 35.563 \cdot psi$

$\Delta P - \Delta P_{max} = -6.259 \cdot psi$

6) INSTALLED CHARACTERISTIC

VALVE AUTHORITY

Since the valve chosen above has a parabolic charateristic, it must be: $0.25 < V < 0.4$

For simplicity, V can be chosen as:

$$V := \frac{0.25 + 0.4}{2} \qquad V = 0.325$$

PARABOLIC VALVE with DN = 60 mm

$$\phi(h) := h^2 + \frac{1 - h^2}{r}$$

$$C_{vn} := C_{vn_5} \qquad C_{vn} = 33.988 \cdot gal \cdot min^{-1} \cdot psi^{-0.5}$$

DATA PREPARATION TO PLOT THE INSTALLED CHARATERISTIC

NOTES on MathCad usage

$$h := 0, 0.1 .. 1$$

This is Mathcad's **range variable operator**.
NB: Notice that when you type the semicolon character [;], it displays on the screen as two dots (▪..▪) surrounded by placeholders.
Notice that **,0.1** represents the **increment** of the **range variable**.

h =	$\phi(h)$ =
0	0.05
0.1	0.06
0.2	0.088
0.3	0.136
0.4	0.202
0.5	0.288
0.6	0.392
0.7	0.516
0.8	0.658
0.9	0.82
1	1

These are the values chosen for the independent variable (**h**) and the values calculated for its function **φ(h)**.

Range variables in Mathcad are always displayed in a table.

Let us define the flow ratio for the INSTALLED CHARATERISTIC:

ratio = V_punto(h)/V_punto$_n$

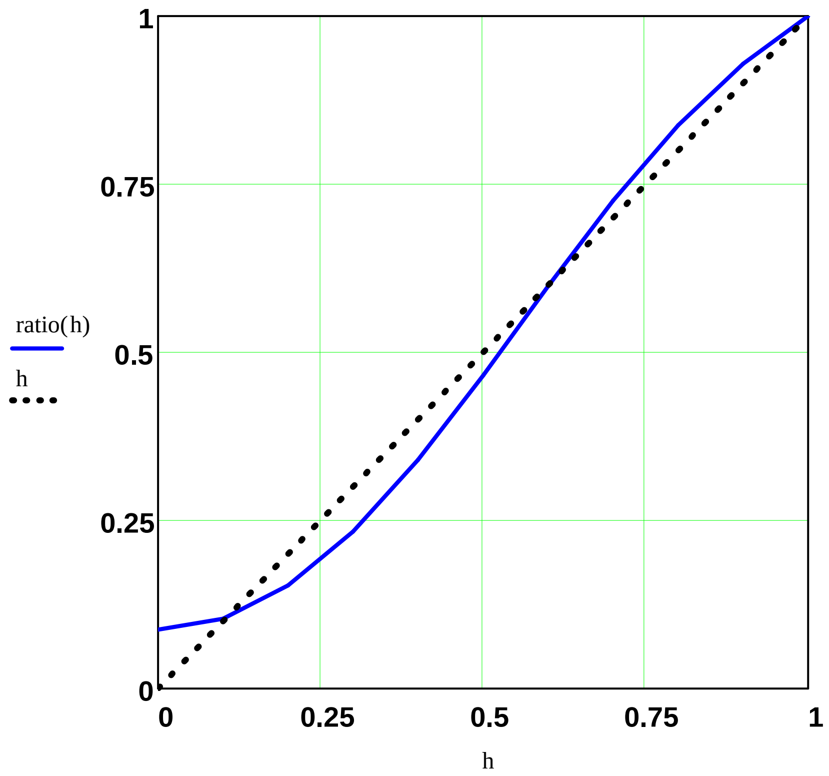
$$ratio(h) := \frac{1}{\sqrt{1 - V + \frac{V}{\phi(h)^2}}}$$

This instruction defines **ratio(h)** as a new function of the independent variable **h**.

h =	ratio(h) =
0	0.087
0.1	0.104
0.2	0.153
0.3	0.233
0.4	0.34
0.5	0.466
0.6	0.599
0.7	0.726
0.8	0.838
0.9	0.929
1	1

These are the values chosen for the independent variable (**h**) and the values calculated for its function **ratio(h)**.

Range variables in Mathcad are always displayed in a table.



This is the diagram (non-dimensional) of **ratio(h).**

NB:
Notice that they are obtained in Mathcad by simply typing the function and the independent variable on the axes, respectively.

8) NOMINAL PRESSURE DROP ACROSS THE VALVE

$\Delta P_0 := \mathbf{3} \cdot atm$

overall pressure drop in the circuit

$\Delta P_n := V \cdot \Delta P_0$ ☞ $\Delta P_n = \mathbf{14.329} \cdot psi$ $\Delta P_n = \mathbf{0.975} \cdot atm$

$\Delta P_u := \Delta P_0 - \Delta P_n$ ☞ $\Delta P_u = \mathbf{29.759} \cdot psi$ $\Delta P_u = \mathbf{2.025} \cdot atm$

9) NOMINAL FLOW RATE

$V\_punto_n := C_{vn} \sqrt{\frac{\Delta P_n}{G_f}}$ ☞ $V\_punto_n = \mathbf{136.374} \cdot gal \cdot min^{-1}$

$m\_punto_n := V\_punto_n \cdot \rho_f$ ☞ $m\_punto_n = \mathbf{7.657} \frac{kg}{s}$ $m\_punto_n = \mathbf{16.882} \cdot \frac{lb}{s}$