Homework #1 : Flow Balance in a Pipe Network

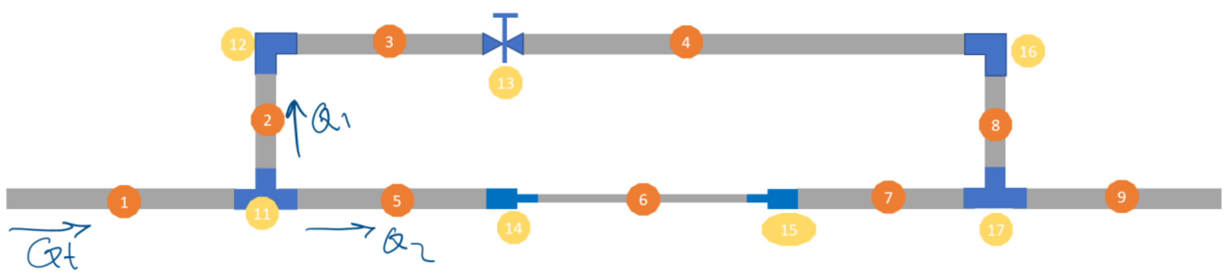
Consider a flow network as shown below, where coolant is flowing through pipe (1), and is then split into two parallel branches, namely Q1 and Q2. From mass continuity we know Qt = Q1 + Q2.

Flow in branch 2 (Q2) is passing through a heat exchanger, where for simplicity is depicted by a long and narrow tube, pipe (6).

Due to the high pressure drop of flow through this heat exchanger, a valve (13) is placed on branch (1) to balance the flow between the two branches and ensure that the heat exchanger will receive its required flowrate.

The dimensions of the pipes are given in the table below.

For pressure drop in sections (12), (13), (14), (15), (16) use the provided correlations in Appendix A. For pressure drop in the straight pipe sections, use appropriate formulas provided in Appendix B. For transition and turbulent regimes, use the Haaland formula. Assume new stainless-steel pipe, where roughness is given in Appendix B.



Pipe section	L [m]	D [m]
2	0.2	0.02
3	0.3	0.02
4	1	0.02
8	0.2	0.02
5	0.2	0.02
6	2	0.01
7	1	0.02

Homework #1 : Flow Balance in a Pipe Network

Develop a parametric pressure drop calculation between the two branches, and discuss the following three scenarios on the flow balance between the two branches.

You should submit a report that at least includes:

1- Formulas used for pressure drop calculations
2- Algorithm and methodology used to balance the flow between the two branches
3- A plot depicting Q1/Q2 ratio versus the parameters explained in the three scenarios below.
4- A plot depicting Q1 and Q2 and Qt versus the parameters explained in the three scenarios below.
5- A physical explanation of the trend in Q1/Q2 split as a function of the parameters involved for each one of the three scenarios.

You can use any software from Excel, Matlab, or Python. The source code/file should be attached to the solution as well.

Scenario 1

Discuss the trend of Q1, Q2, and Q1/Q2 ratio for Qt values between 1 lpm to 10 lpm, assuming

- Coolant has physical properties of
  - Density = 1000 Kg/m3
  - Viscosity = 0.001 Pa.s
- The valve position is fixed corresponding to a minor loss coefficient of 5

Scenario 2

Discuss the trend of Q1, Q2, and Q1/Q2 ratio for different positions of the valve corresponding to minor loss coefficient values of 0 to 10, assuming

- Coolant has physical properties of
  - Density = 1000 Kg/m3
  - Viscosity = 0.001 Pa.s
- Total Flowrate is fixed at 5 lpm

Scenario 3

Discuss the trend of Q1, Q2, and Q1/Q2 ratio for different values of coolant viscosity from 0.001 Pa.s to 0.01 Pa.s, assuming

- Coolant density is constant at 1000 Kg/m3
- Total Flowrate is fixed at 5 lpm
- The valve position is fixed corresponding to a minor loss coefficient of 5

Appendix A : Minor loss coefficients

Table 6.5 Resistance Coefficients $K = h_m/[V^2/(2g)]$ for Open Valves, Elbows, and Tees

	Nominal diameter, in								
	Screwed				Flanged				
	$\frac{1}{2}$	1	2	4	1	2	4	8	20
Valves (fully open):									
Globe	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	0.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Swing check	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Elbows:									
45° regular	0.39	0.32	0.30	0.29					
45° long radius					0.21	0.20	0.19	0.16	0.14
90° regular	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
90° long radius	1.0	0.72	0.41	0.23	0.40	0.30	0.19	0.15	0.10
180° regular	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20
180° long radius					0.40	0.30	0.21	0.15	0.10
Tees:									
Line flow	0.90	0.90	0.90	0.90	0.24	0.19	0.14	0.10	0.07
Branch flow	2.4	1.8	1.4	1.1	1.0	0.80	0.64	0.58	0.41

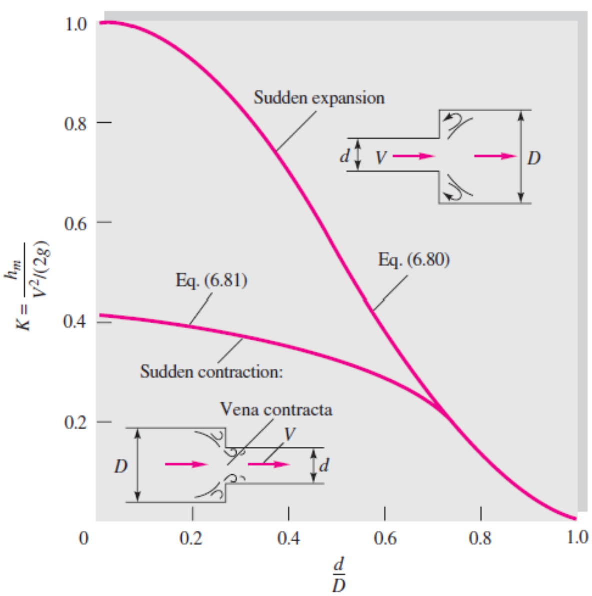


Fig. 6.22 Sudden expansion and contraction losses. Note that the loss is based on velocity head in the small pipe.

$$K_{SE} = \left(1 - \frac{d^2}{D^2}\right)^2 = \frac{h_m}{V^2/(2g)} \tag{6.80}$$

$$K_{SC} \approx 0.42\left(1 - \frac{d^2}{D^2}\right) \tag{6.81}$$

Appendix B

Correlations for friction factor in smooth pipes

$$h_f = f\,\frac{L}{d}\frac{V^2}{2g} \qquad \text{where } f = \text{fcn}\left(\text{Re}_d,\ \frac{\varepsilon}{d},\ \text{duct shape}\right)$$

The explicit formula given by Haaland as below :

$$\frac{1}{f^{1/2}} \approx -1.8\log\left[\frac{6.9}{\text{Re}_d} + \left(\frac{\varepsilon/d}{3.7}\right)^{1.1}\right]$$

Recommended roughness values for commercial ducts.

		ε		
Material	**Condition**	**ft**	**mm**	**Uncertainty, %**
Steel	Sheet metal, new	0.00016	0.05	±60
	Stainless, new	0.000007	0.002	±50
	Commercial, new	0.00015	0.046	±30
	Riveted	0.01	3.0	±70
	Rusted	0.007	2.0	±50
Iron	Cast, new	0.00085	0.26	±50
	Wrought, new	0.00015	0.046	±20
	Galvanized, new	0.0005	0.15	±40
	Asphalted cast	0.0004	0.12	±50
Brass	Drawn, new	0.000007	0.002	±50
Plastic	Drawn tubing	0.000005	0.0015	±60
Glass	—	Smooth	Smooth	
Concrete	Smoothed	0.00013	0.04	±60
	Rough	0.007	2.0	±50
Rubber	Smoothed	0.000033	0.01	±60
Wood	Stave	0.0016	0.5	±40