PIPELINE SYSTEMS

Henryk Kudela

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1 Pipes in Series and in Parallel

In many pipe systems there is more than one pipe involved. The governing mechanisms for the flow in multiple pipe systems are the same as for the single pipe systems discussed in earlier lectures (n5,n6). However, because of the numerous unknowns involved, additional complexities may arise in solving for the flow in multiple pipe systems. Some of these complexities are discussed in this section.

The simplest multiple pipe systems can be classified into series or parallel flows, as are shown in Fig. 8.35. The nomenclature is similar to that used in electrical circuits. Indeed, an analogy between fluid and electrical circuits is often made as follows. In a simple electrical circuit, there is a balance between the voltage e, current i, and resistance R as given by Ohms law:$e = iR$. In a fluid circuit there is a balance between the pressure drop Δp the flowrate q_V, and the flow resistance R as given in terms of the friction factor and minor loss coefficients f and K_L. For a simple flow $\Delta h = \Delta p/\rho g = f(l/D)(v^2/2g$ it follows that $\Delta h = R^* q_V^2$,where R^* a measure of the resistance to the flow, is proportional to f.

The main differences between the solution methods used to solve electrical circuit problems and those for fluid circuit problems lie in the fact that Ohms law is a linear equation (doubling the voltage doubles the current), while the fluid equations are generally nonlinear (doubling the pressure drop does not double the flowrate unless the flow is laminar).

When the pipes are connected **in seris**, the the flow rate through the entire system remains constant regardless of the diameters of the individual pipes in the system. This is a natural consequence of the conservation of mass principle for steady incompressible flow. The total head loss in the system, including the sum of the head losses in individual pipe in the system, including the mirror losses.

$$\Delta h = R_1^* q_v^2 + R_2^* q_v^2 + \cdots R_n q_v^2 = (R_1^* + R_2^* + \cdots R_n^*)q_v^2 = R_{res}^* q_v^2 \tag{1}$$

where $R^*_{res} = R^*_1 + R^*_2 + \cdots + R^*_n$ means resultant hydraulic resistance.

For a pipe that branches out into two (or more) parallel pipes and then rejoins at a junction downstream, the total flow rate is the sum of the flow rates in the individual pipes. The pressure drop (or head loss) in each individual pipe connected in parallel must be the same since $\Delta p = p_A - p_B$. The governing equations for parallel pipes are

$$q = q_{v_1} + q_{v_2} + q_{v_3} \tag{2}$$

and

$$\Delta h_1 = R^*_1 q_{v_1} = R^*_2 q_{v_2} = R^*_3 q_{v_3} \tag{3}$$

Using (3) the Eq. 2) can be rewrite

$$\sqrt{\frac{\Delta h}{R}^*}_{res} = \sqrt{\frac{\Delta h}{R}^*}_1 + \sqrt{\frac{\Delta h}{R}^*}_2 + \sqrt{\frac{\Delta h}{R}^*}_3 \tag{4}$$

The resultant hydraulic resistance for parallel connection is expressed as

$$\boxed{\frac{1}{\sqrt{R^*_{res}}} = \frac{1}{\sqrt{R^*_1}} + \frac{1}{\sqrt{R^*_2}} + \frac{1}{\sqrt{R^*_3}}} \tag{5}$$
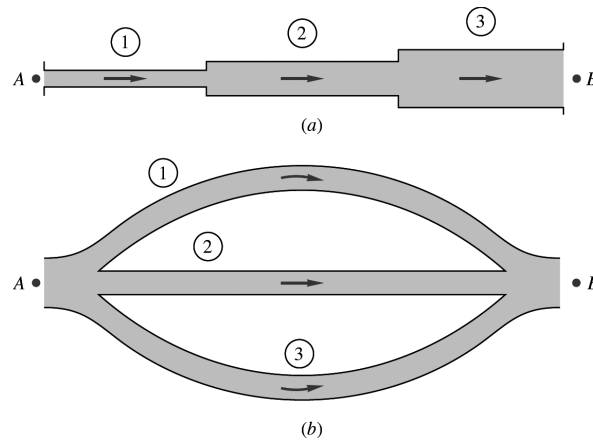

Figure 1: (a) Series systems – the flow rate through the entire system remains constant, the total head loss in this case is equal to the sum of the head losses in individual pipes, (b) parallel pipe system – head loss is the same in each pipe, and the total flow rate is the sum of the flow rates in individual pipes.

As it is ease to check in parallel connection resultant hydraulic resistance is always smaller then each individual resistance of the branch in the connection.

In computation of parallel –pipe systes,two types of problems occur:

1. with known elevation of the hydraulic grade line at A and B ($(p/\rho g + z)$ is given), the discharge q_v needs to be determined

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2. with q_v the distribution of the flow and the head loss need to be determined. Size of pipe, fluid properties, and roughnesses are assumed to be known

The first type problem is, in effect, the solution of simple pipe problems for discharge, since the head loss is the drop in hydraulic grade line. These discharges are added to determine the total discharge.// The second type problem is more complex, as neither the head loss nor the discharge for any one pipe is know. One can use the following procedure:

1. assume a discharge q'_{v_1} through pipe 1

2. solve for $\Delta h'_1$, using the assumed discharge

3. using $\Delta h'_1$, find q'_{v_2} and q'_{v_3}

4. with the tree discharges for a common head loss, now assume that the given q_v is split up among the pipes in the same proportion as $q'_{v_1}, q'_{v_2}, q'_{v_3}$. Thus,

$$q_{v_1} = \frac{q'_{v_1}}{\sum q'_{v_i}} q_v, \qquad q_{v_2} = \frac{q'_{v_2}}{\sum q'_{v_i}} q_v, q_{v_3} = \frac{q'_{v_3}}{\sum q'_{v_i}} q_v$$

5. check the correctness of the these discharges by computing Δh_1, Δh_2, and Δh_3 for the computed q_{v_1}, q_{v_2} and q_{v_3}

2 Three–reservoir problem

The branching system termed the ***three–reservoir problem*** in shown in the Fig. 2. Three reservoirs at known elevations are connected together with three pipes of known properties (lengths, diameters, and roughnesses). The problem is to determine the flowrates into or out of the reservoirs. If valve (1) were closed, the fluid would flow from reservoir B to C, and the flowrate could be easily calculated. Similar calculations could be carried out if valves (2) or (3) were closed with the others open. With all valves open, however, it is not necessarily obvious which direction the fluid flows. For the conditions indicated in Fig. 2, it is clear that fluid flows from reservoir A because the other two reservoir levels are lower. Whether the fluid flows into or out of reservoir B depends on the elevation of reservoirs B and C and the properties (length, diameter, roughness) of the three pipes. In general, the flow direction is not obvious, and the solution process must include the determination of this direction.

During this course I will be used the following books:

References

[1] F. M. White, 1999. *Fluid Mechanics*, McGraw-Hill.

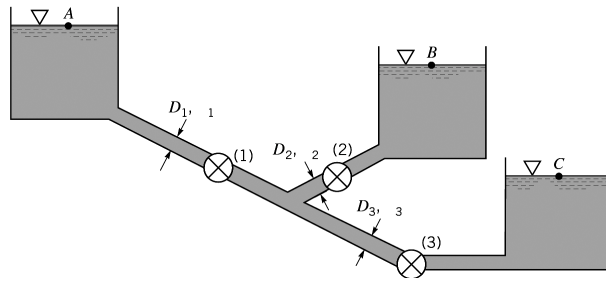[2] B. R. Munson, D.F Young and T. H. Okiisshi, 1998. *Fundamentals of Fluid Mechanics*, John Wiley and Sons, Inc. .

Figure 2: A three-reservoir system