Minor Losses in Pipes and Ducts

Real Internal Flows – Lesson 4

Ansys

Intro

- In the preceding lessons we have examined flows through simple straight pipes. We found that the pressure loss is related to the flowrate, pipe diameter, fluid properties and flow state (laminar or turbulent). We also developed a simplified analysis where the flow could be considered effectively 1D with the flow loss computed from empirically derived correlations.

- What about geometries that are not straight pipes or channels? These flows will generally be complex and thus require more rigorous methods for analysis.

- However, for many common fluid system components, it is possible to represent the losses empirically so as to incorporate them into a more comprehensive fluids system analysis. Flow losses represented this way are called Minor Losses. We will examine this type of flow loss representation in this lesson.

  - It should be noted that the term "minor" loss should not imply that the pressure drops from minor loss components will necessarily be small!

Typical Minor Loss Components

- Components which are considered under the umbrella of “minor losses” can be grouped into several categories as follows:

  - Pipe Features: Entrance and exit geometries, cross-sectional area changes
  - Restrictions: Flow nozzles, orifice plates, screens and grids, louvers
  - Fluid System Components: Pipe elbows, tees and branches, valves and similar plumbing components

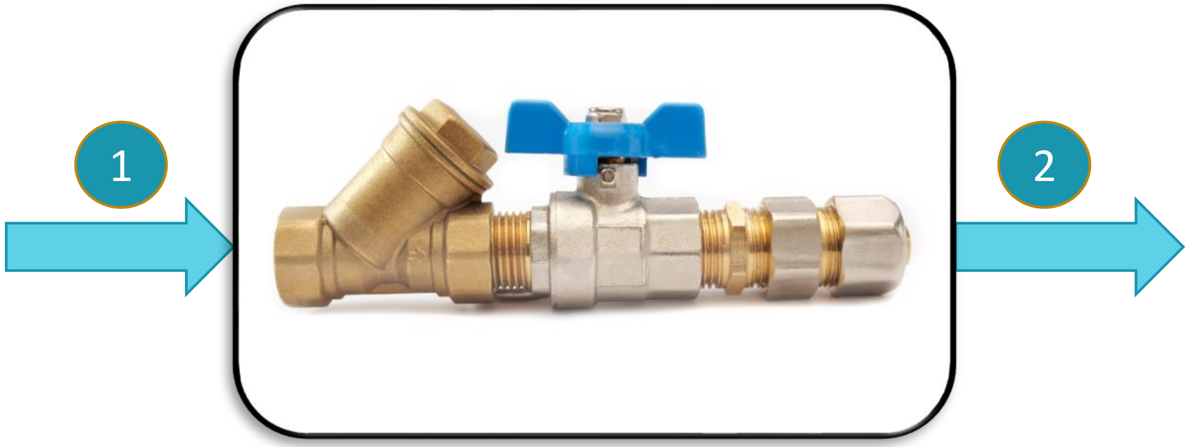
Pipe with “minor losses” components

1D Component Model

- The flow through a bend, restriction or other component is multidimensional and complex. However, we can characterize the pressure drop through the component in the same way as a pipe flow.

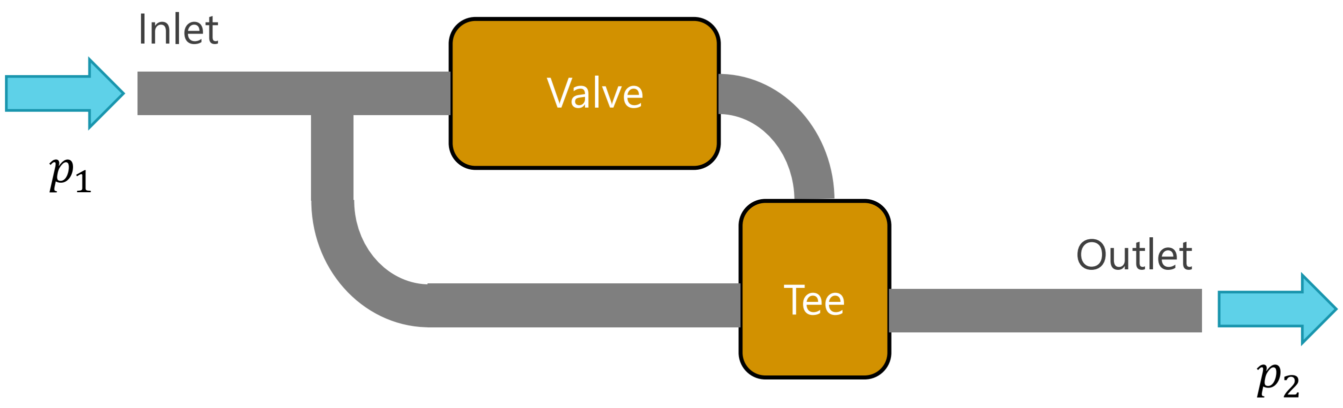
- To do this, we define suitable inlet and outlet stations for the component and then measure the pressure drop between these stations. Like a pipe flow, this pressure drop can be correlated to a Reynolds number based on a suitable geometric dimension (usually an upstream hydraulic diameter).

- In this way, the component can be treated like a “black box” in a 1D system model as depicted below. All we need is the empirical data for modeling the component.

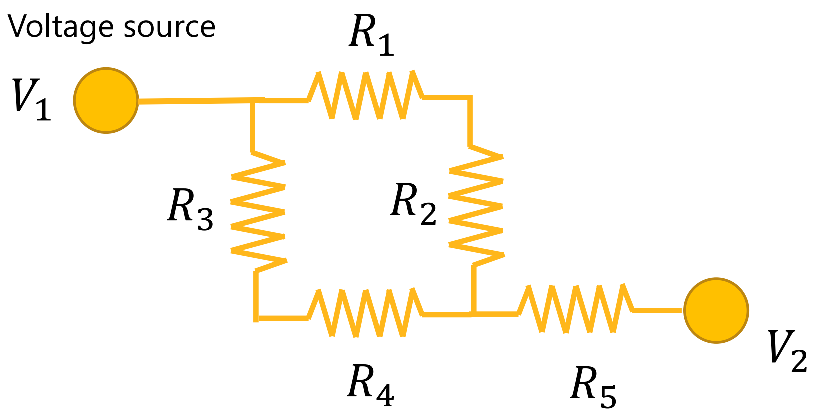


1D Fluid System Model

- The 1D component model allows us to develop systems of connected components. The goal is to determine the flow through each component and the pressures at all inlet, outlet and intermediate stations. This is essence of the 1D fluid system model.
- Note that the components can be connected in series or parallel using straight pipes or elbows. This model is, in fact, very similar to an electrical resistance network, where the pipes are electrical wires, flow losses are represented by resistors, and pressure and fluid flowrate are represented by voltage and electrical current flow, respectively.



1D fluid system model



Equivalent electrical resistance network

The Minor Loss Model

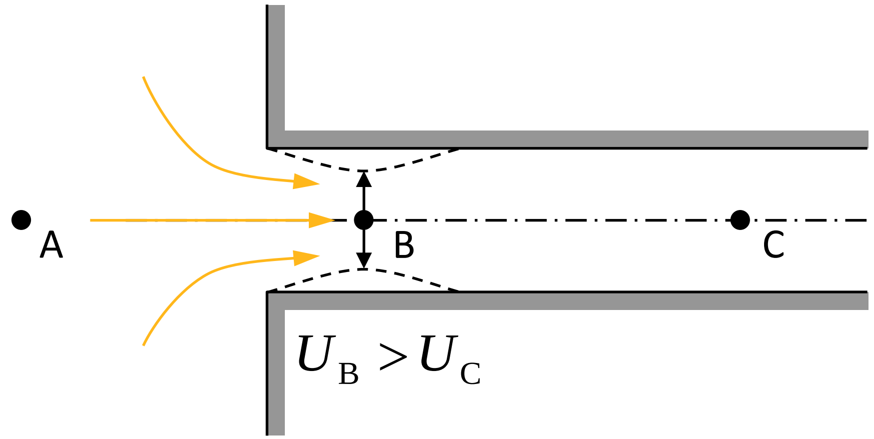
- For a given minor loss component, we can model the loss using a generalized "*K* Factor" equation, which is similar to the 1D pipe flow loss model:

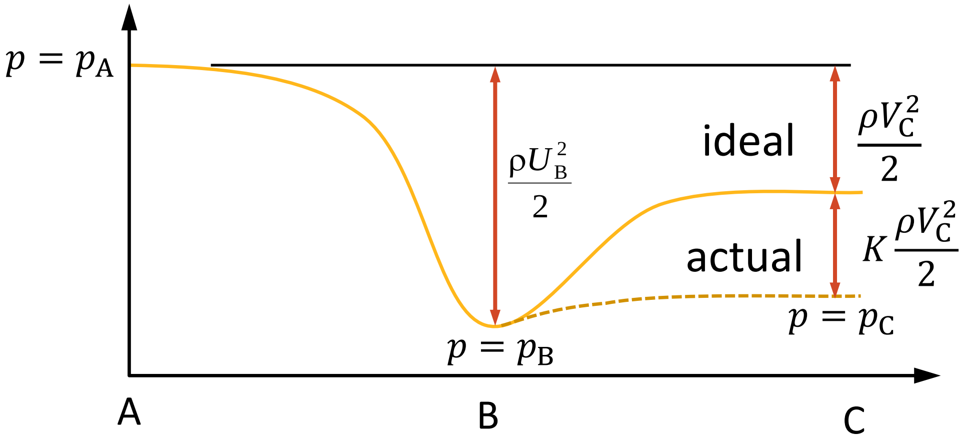
$$\Delta p = K_L \frac{\rho V^2}{2} \quad \text{or} \quad h_L = K_L \frac{V^2}{2g} \qquad K_L = K_L(\text{geometry}, Re)$$

loss coefficient or *K* Factor

Note that for this model to be valid, the flow should be dominated by inertial effects.

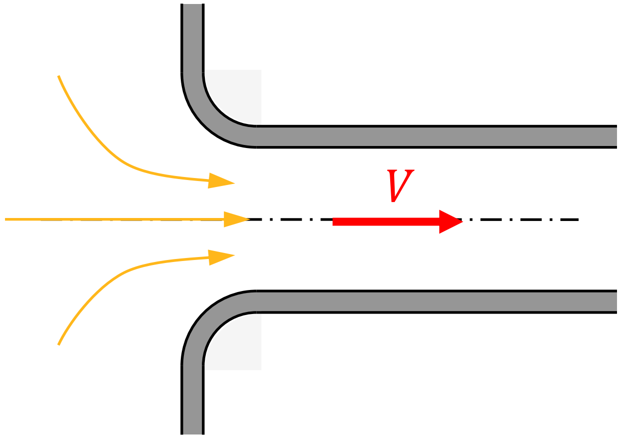
- An example of this loss model is shown below for a pipe entrance. Notice how the complex flow is reduced to a 1D model of the pressure drop between points A and C in the diagram.





Minor Losses – Empirical Data

- We will now examine the K factors associated with a range of different minor losses.
- The losses we will examine are:
  - Sudden contractions and expansions
  - Pipe bends and elbows
  - Other miscellaneous pipe components

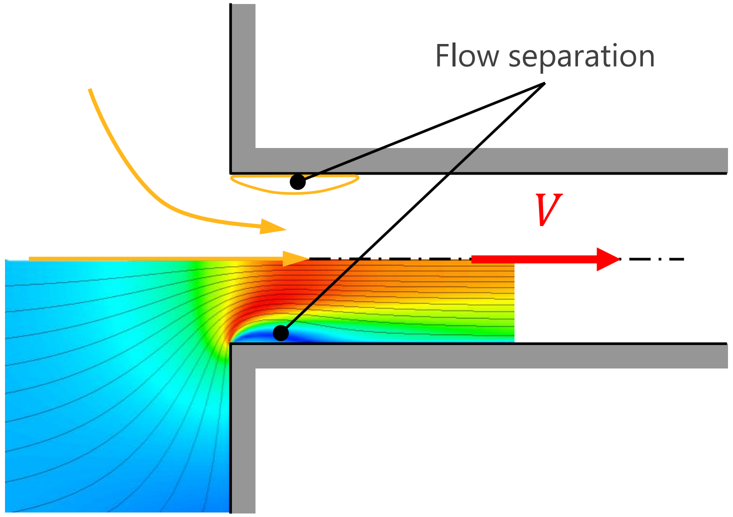


$$\Delta p = K\frac{\rho V^2}{2}$$

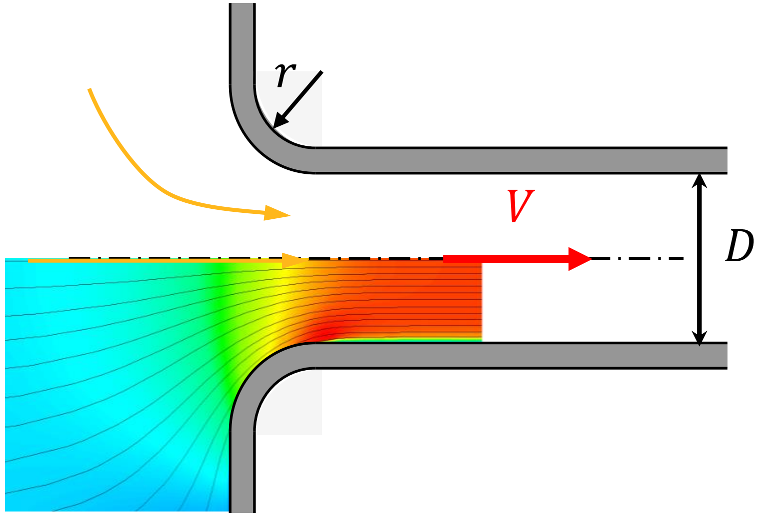
NOTE: It is important to observe the proper reference velocity when computing minor losses. Often, it will be an upstream velocity, but for geometries like contractions (above), it can be the downstream velocity. The reference velocity will be noted as we examine each component loss.

Entrance Losses

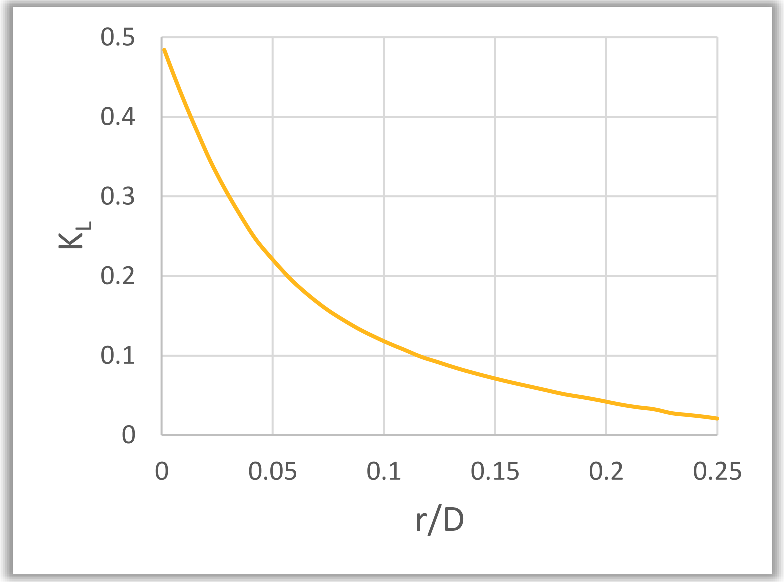
- Reservoirs are commonly connected to pipes to transport the fluid to its destination. As the flow moves from the reservoir to the pipe it can separate near the pipe entrance due to a sharp turn at the corner.
- This loss can be reduced significantly by rounding the entrance edges. The *K* factor becomes a function of the radius of curvature of the corner.



Sharp entrance schematics with overlaid numerical results

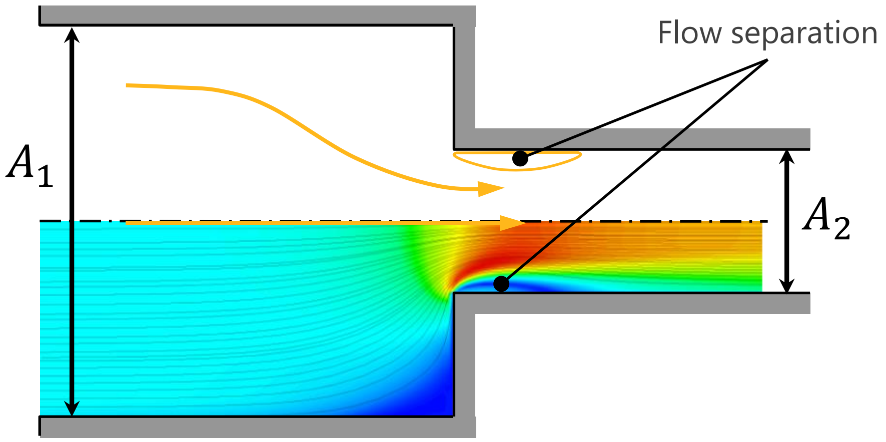


Smooth entrance schematics with overlaid numerical results

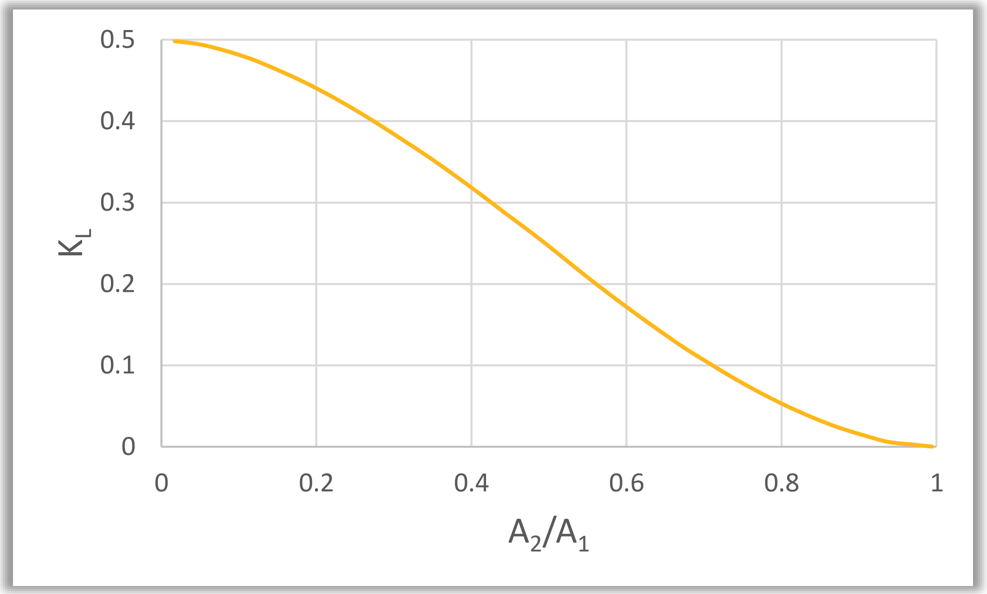


Sudden Contraction Losses

- Pipes and channels are often connected to large diameter pipes. As flow from a larger pipe enters a smaller pipe, a loss occurs due to the flow separation at the corners, like in the entrance region.
- The *K* factor is a function of the smaller (A_1) to larger (A_2) pipe cross-section areas. If $A_1 \gg A_2$, the K factor $K_L \approx 0.5$.



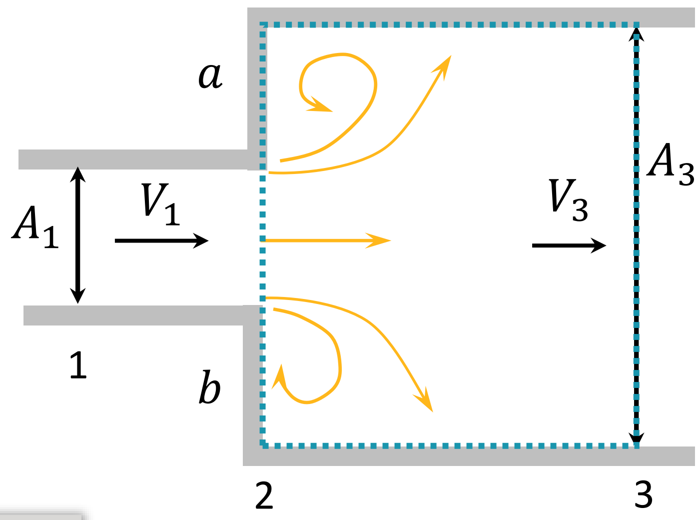
Sudden contraction schematics with overlaid numerical results



Sudden Expansion Losses (cont.)

- The opposite of a sudden contraction is a sudden expansion which is also a source of losses. As the fluid leaves the smaller pipe, it initially forms a jet-like flow which takes a few diameters to dissipate and fully developed flow to re-establish. A part of fluid kinetic energy is lost to dissipation in the process.
- This is one of the very few components where the *K* factor can be obtained through a simple analysis of conservation principles. Let's consider a control volume of the expansion region.

Assuming the flow is uniform at sections 1, 2 and 3, and the pressure is constant along walls (a, b) and the exit of the small pipe, the governing equations for the conservation of mass, momentum and energy are:

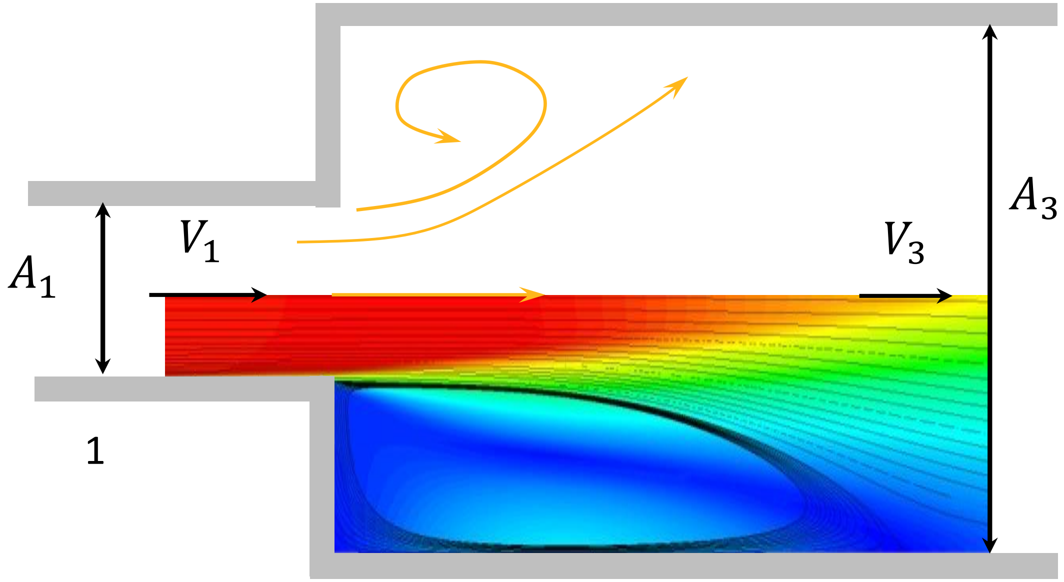


$$A_1 V_1 = A_3 V_3$$
$$p_1 A_3 - p_3 A_3 = \rho A_3 V_3 (V_3 - V_1)$$
$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} = \frac{p_3}{\rho g} + \frac{V_3^2}{2g} + h_l$$

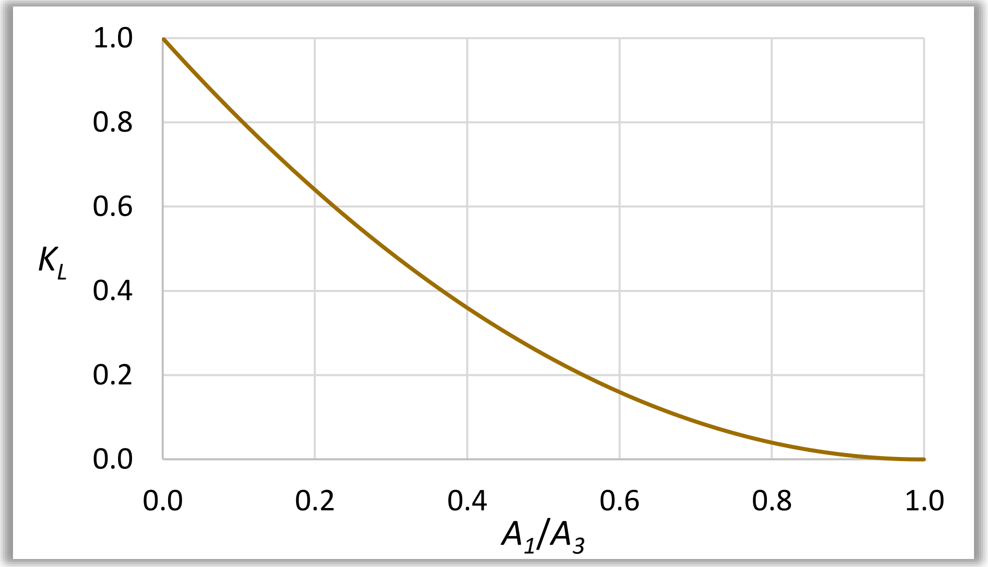
This, after re-arrangement, gives the *K* factor as:

$$K_L = \left(1 - \frac{A_1}{A_3}\right)^2$$

Sudden Expansion Losses (cont.)

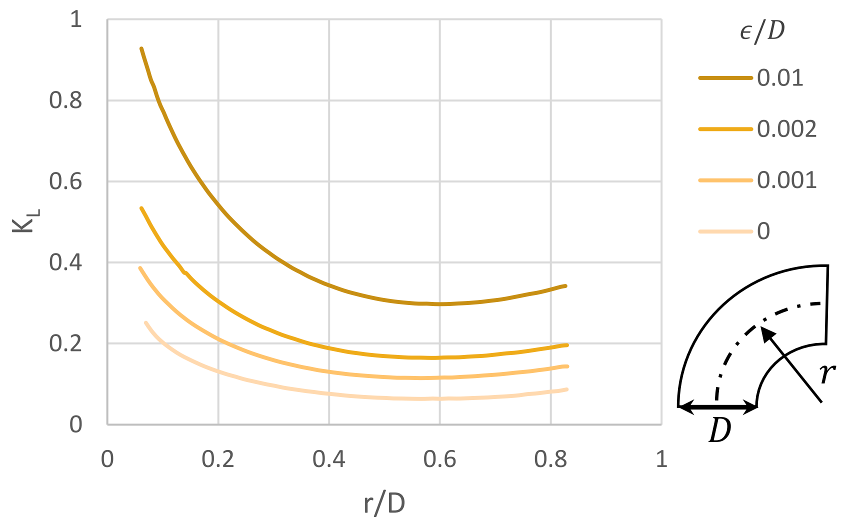


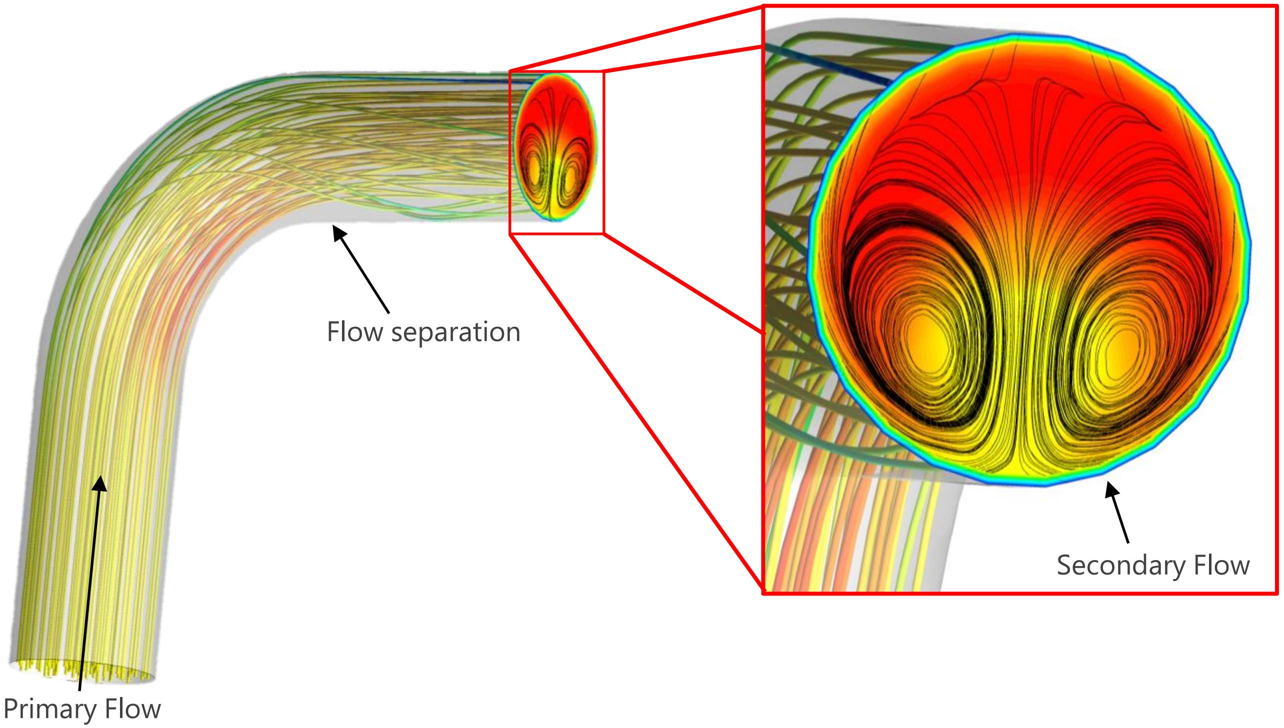
Sudden expansion schematics with overlaid numerical results



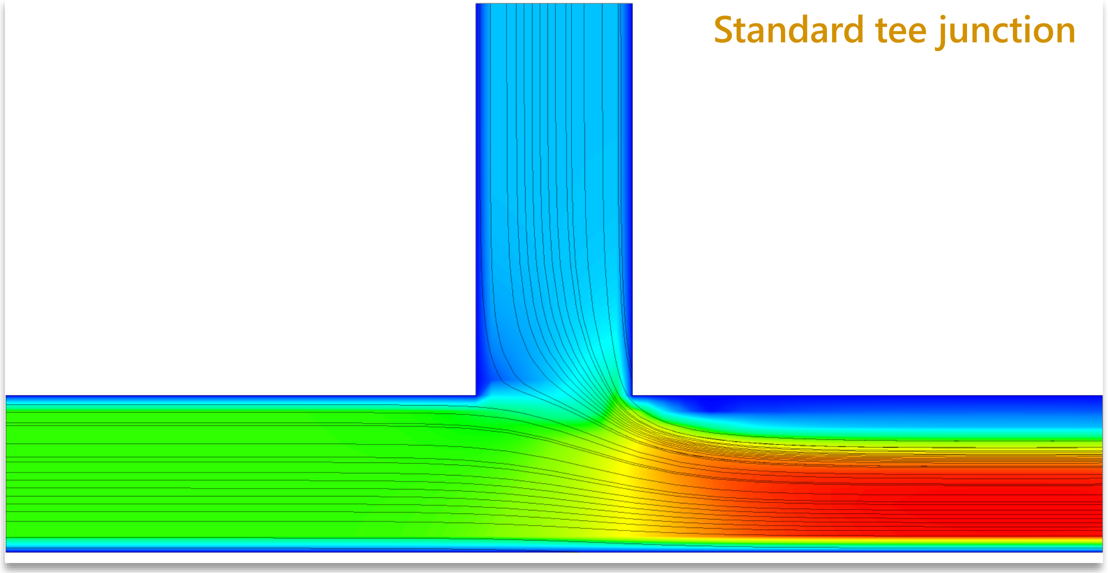
Pipe Bends

- Pipe bends introduce additional head losses compared to straight pipes due to flow separation and development of secondary flows. The K factor for pipe bends is obtained experimentally or from CFD models.
- The chart below shows that the loss can be reduced by increasing the radius of the bend. This, however, comes at the expense of making the bend longer which may pose a problem in fitting it into a confined space.

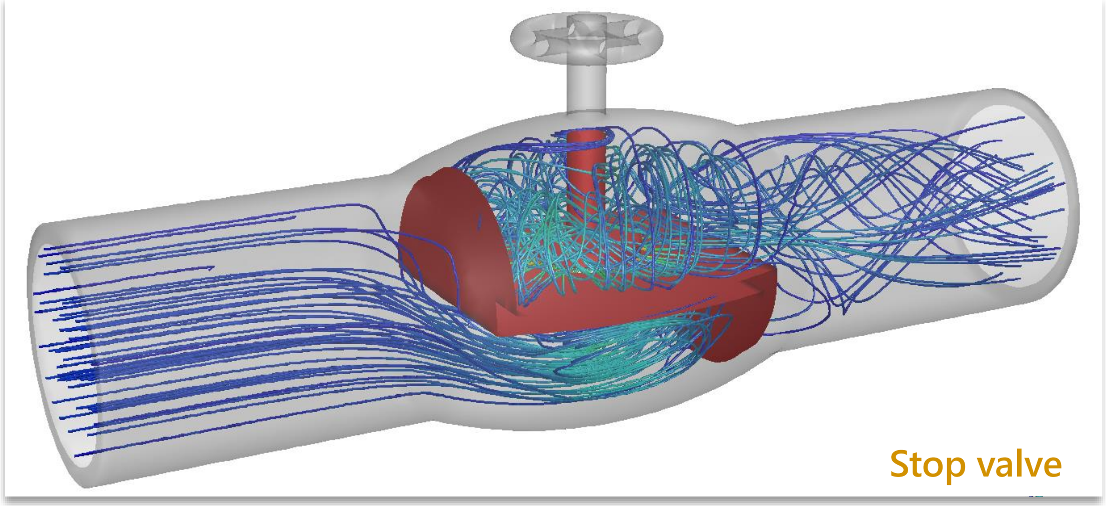




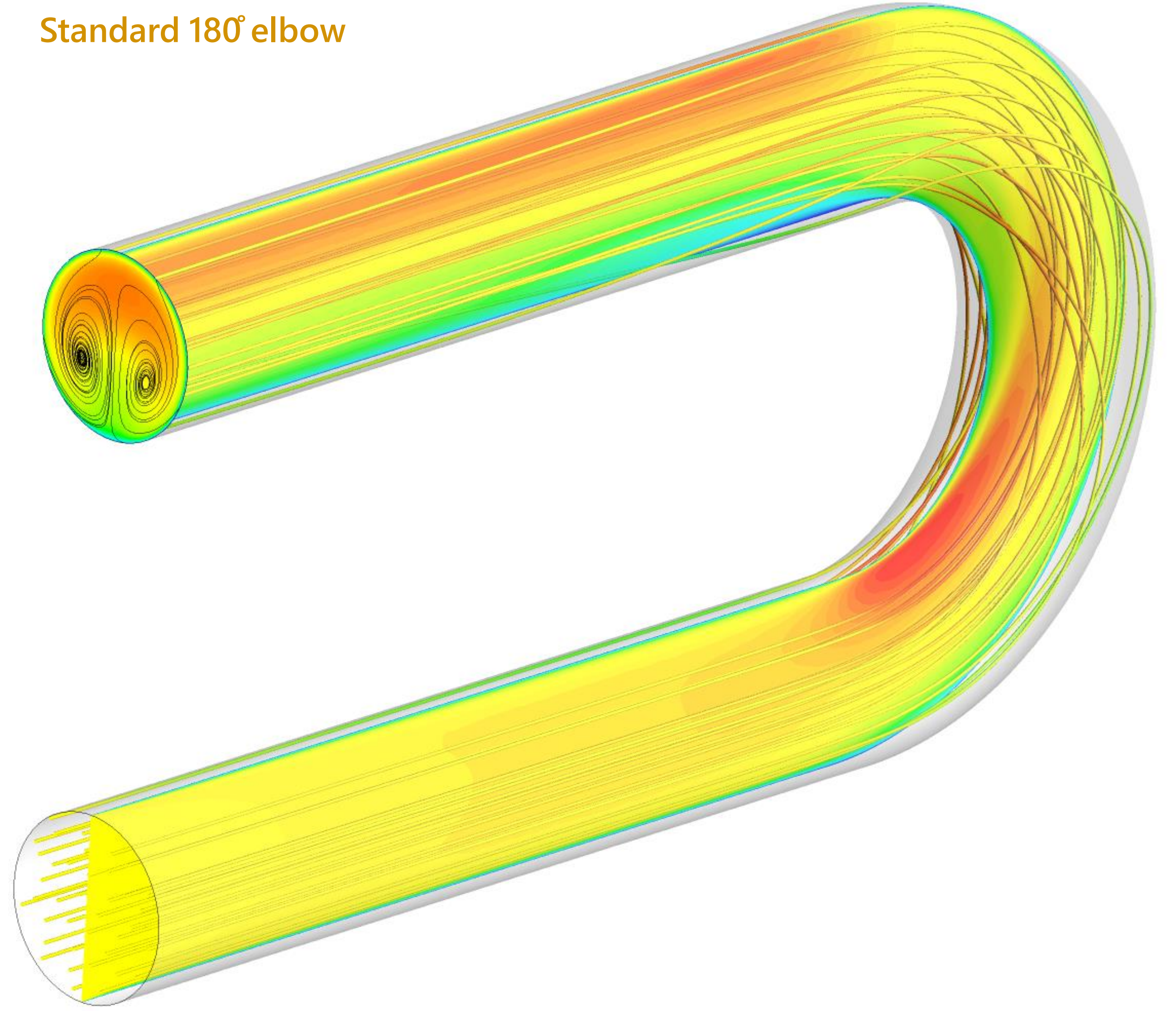
Losses in Other Pipe Components



Standard tee junction



Stop valve



Standard 180° elbow

Losses in Other Pipe Components (cont.)

Fitting	Loss Coefficient, *K*
Rounded entrance to a circular pipe	0.2 (slightly rounded)
Sharp-edged entrance to a circular pipe	0.5
Pipe exit into a tank	1
90º miter bend with guide vanes	0.2
Standard 90º elbow	0.7
Standard 180º elbow	1.5
Standard tee	2.0
Gate valve (fully open)	0.15
Globe valve (fully open)	10
Ball valve (fully open)	0.05

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Summary

- A discussion of the minor losses for internal flows was introduced here.
- Minor losses for a range of geometries were examined.
- Depending on a pipe system, minor losses can actually be significant contributors to the total head loss.

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