FLUID MECHANICS

LAB 8

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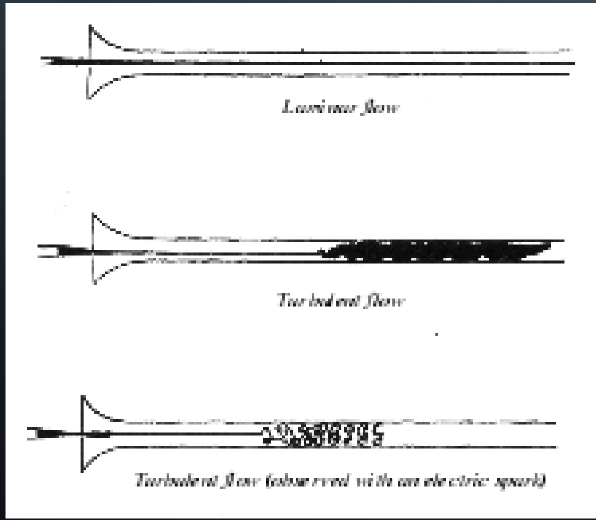
FLUID MECHANICS

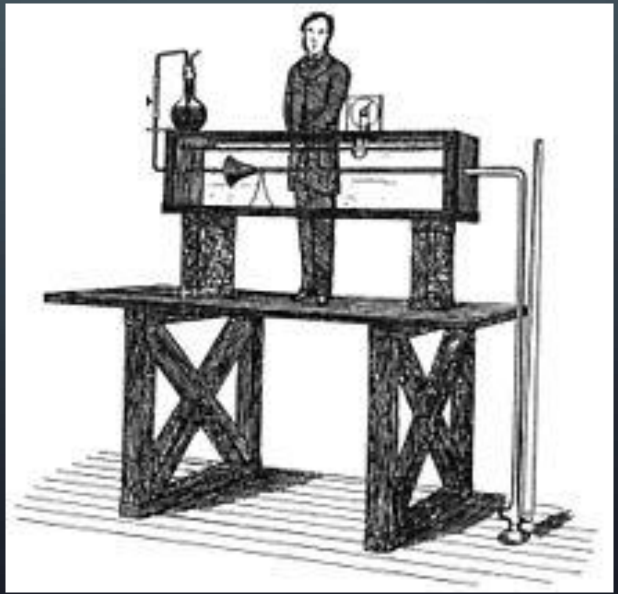
- Reynolds Number
- Bernoulli Equation
- Head Loss

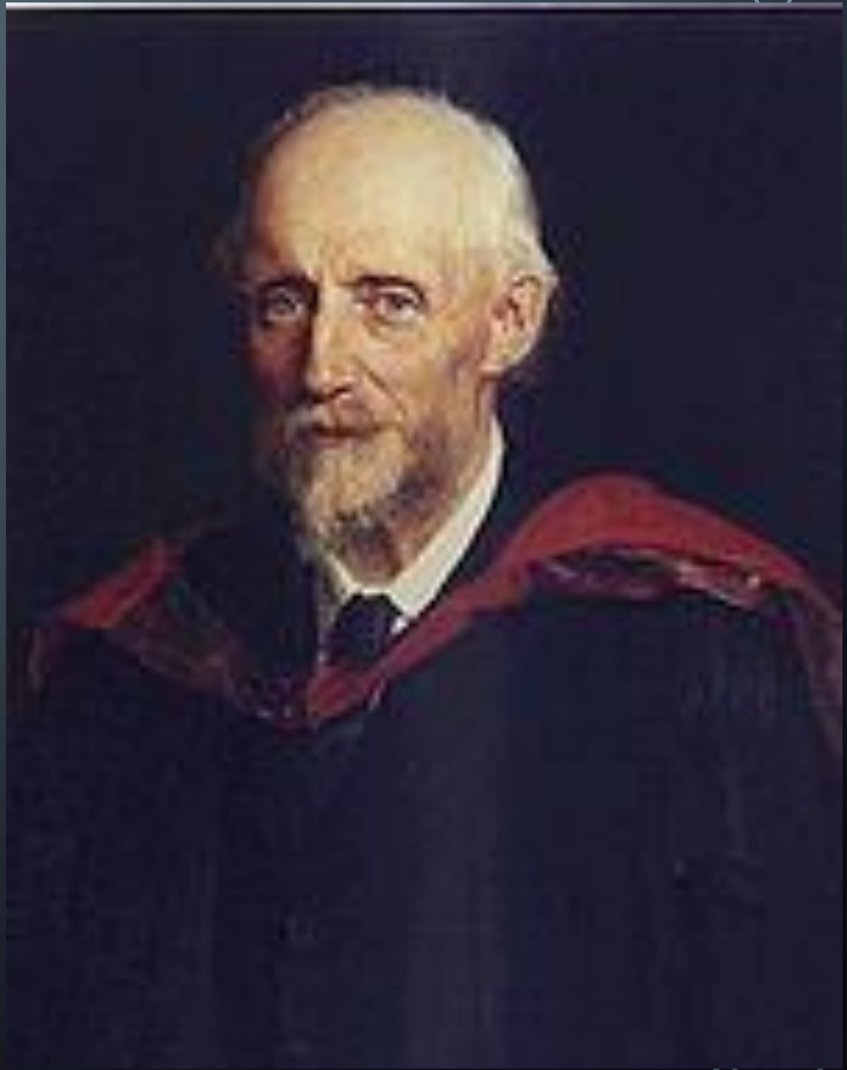
- Goal: To explore the basic principles of the fluid mechanics of: 1) The difference between laminar flow and turbulent flow in circular pipe through Reynolds experiment, and measure the corresponding Reynolds number; 2) The fluid velocity measurement in the circular pipe through the Pitot tube; 3) The head loss measurement due to the contraction at the inlet and the expansion at the outlet.

OSBORNE REYNOLDS

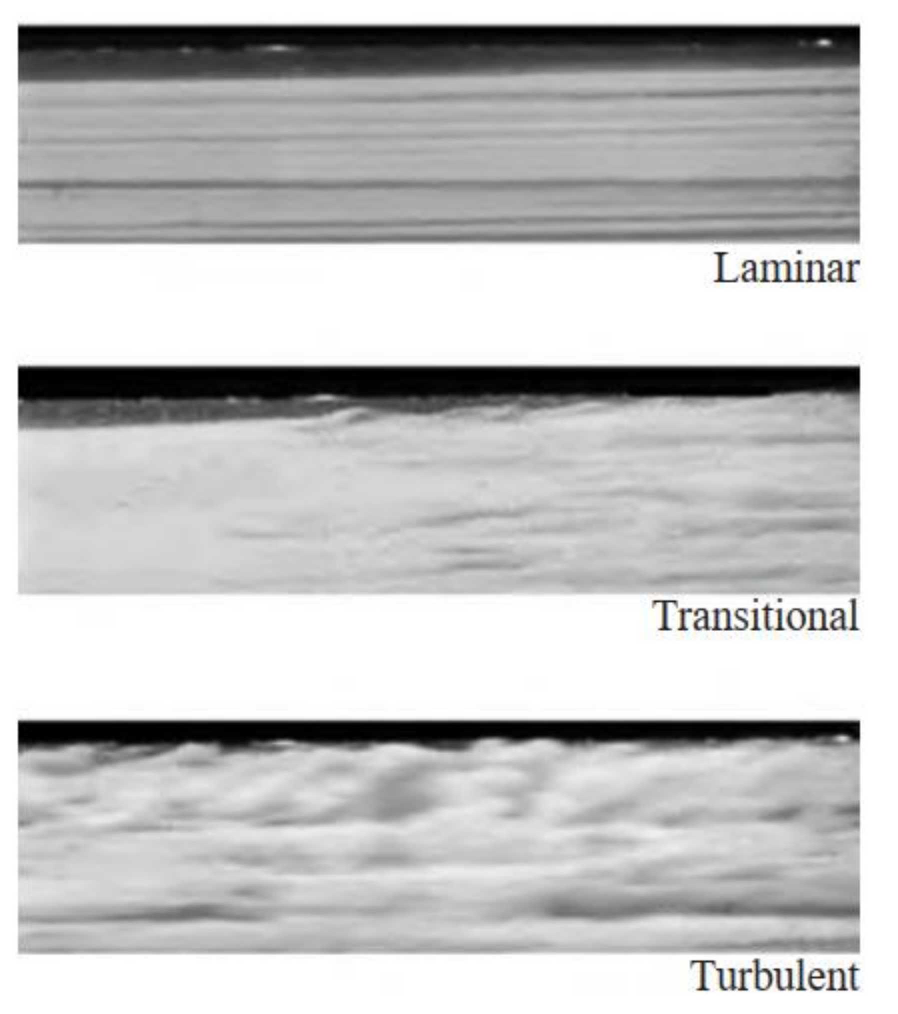
- British engineer and physicist
- Fellow of the Royal Society (1877)
- Heat transfer between solids and fluids
- 1883



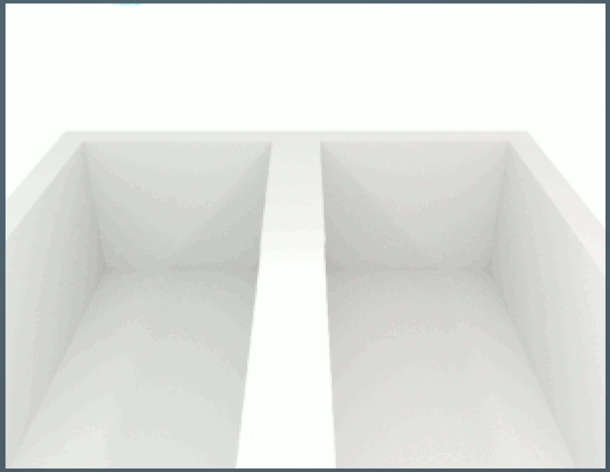




REYNOLDS NUMBER



REYNOLDS NUMBER



- Reynolds number

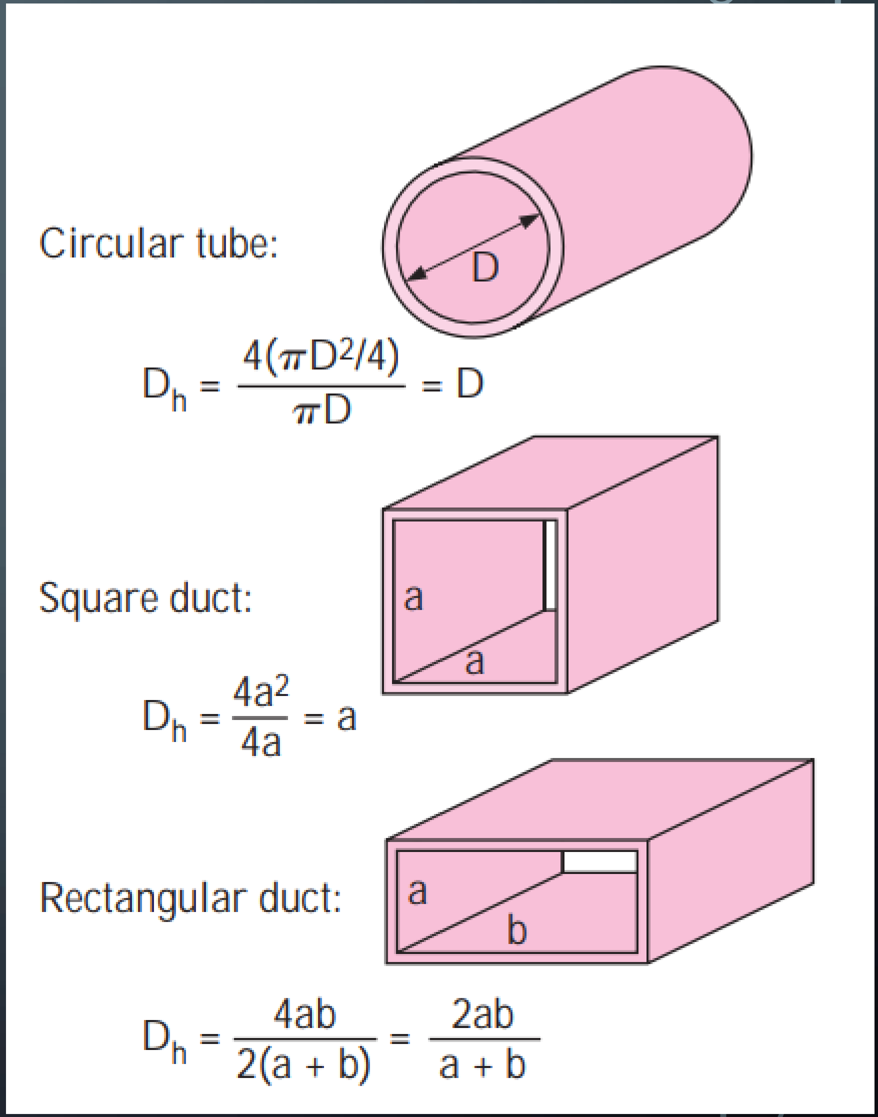
$$\mathrm{Re} = \frac{\rho V_{avg} D}{\mu} = \frac{V_{avg} D}{\nu}$$

- Critical Reynolds number internal flow in a circular pipe

$$\mathrm{Re}_{\mathrm{cr}} = 2300(2320, 2000)$$

- Hydraulic diameter

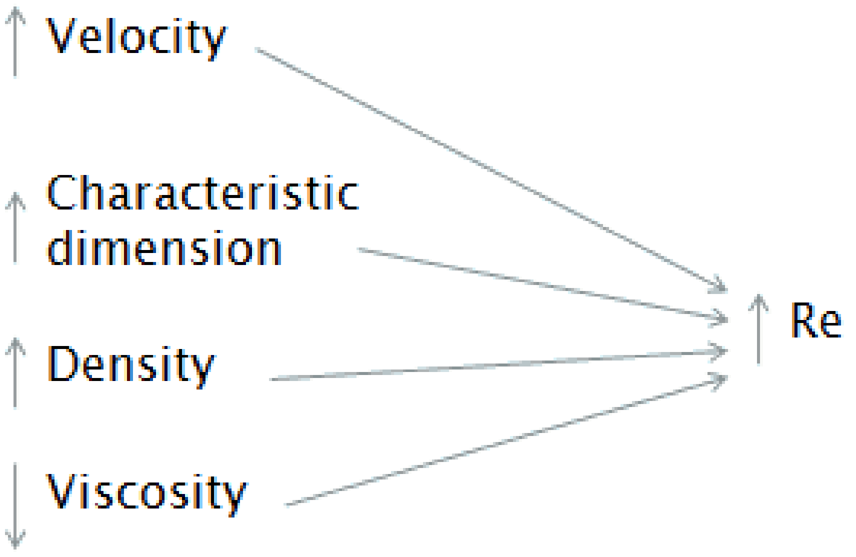
$$D_h = \frac{4A_c}{p}$$

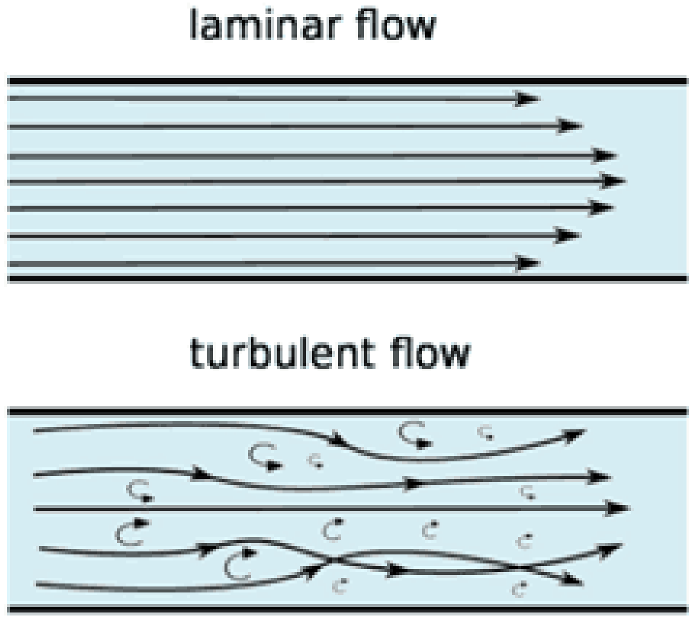


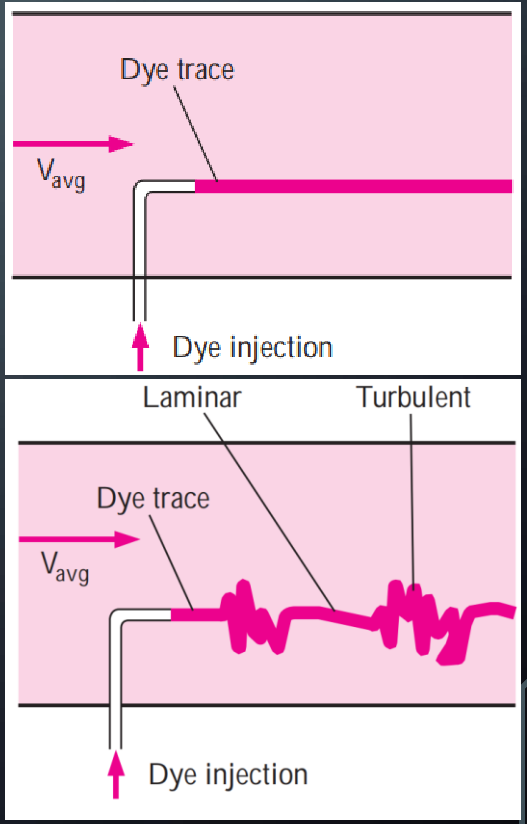
REYNOLDS NUMBER

$Re \lesssim 2300$	laminar flow
$2300 \lesssim Re \lesssim 4000$	transitional flow
$Re \gtrsim 4000$	turbulent flow

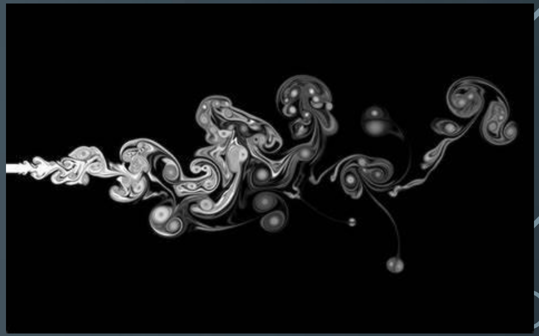
$$Re = \frac{\text{inertia forces}}{\text{viscous forces}} = \frac{\rho \,.\, V \,.\, D}{\mu}$$

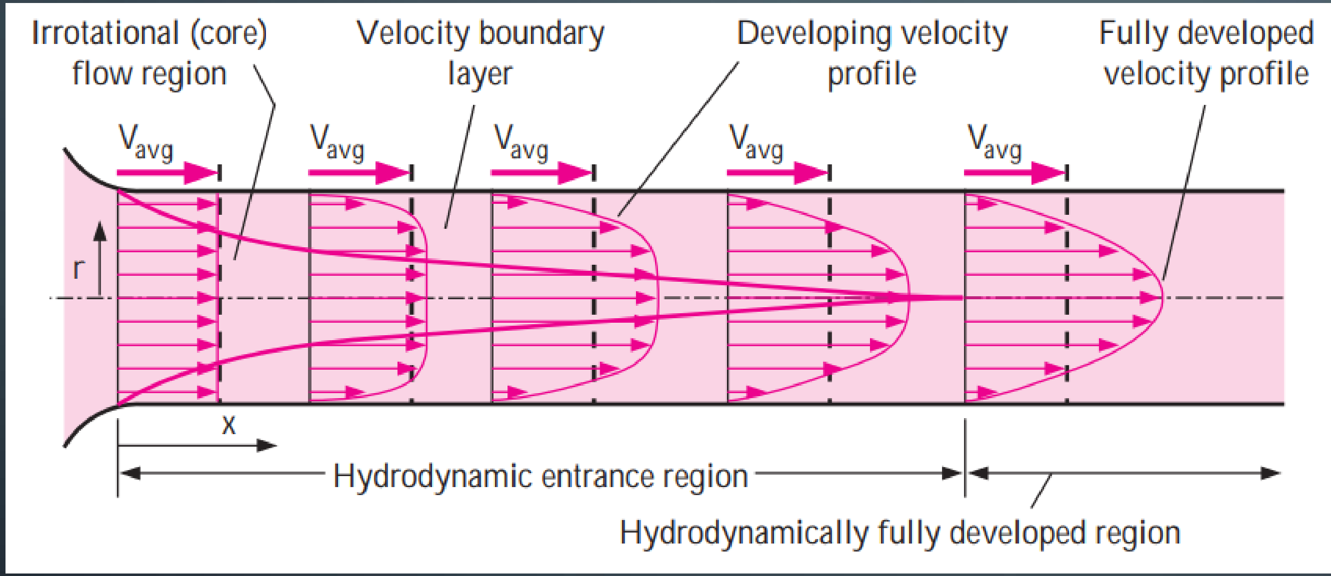


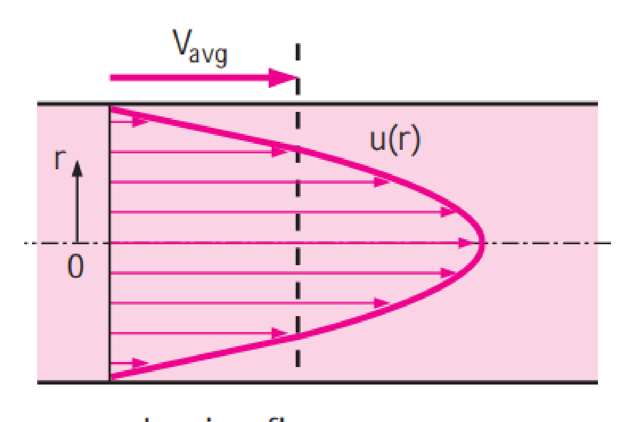




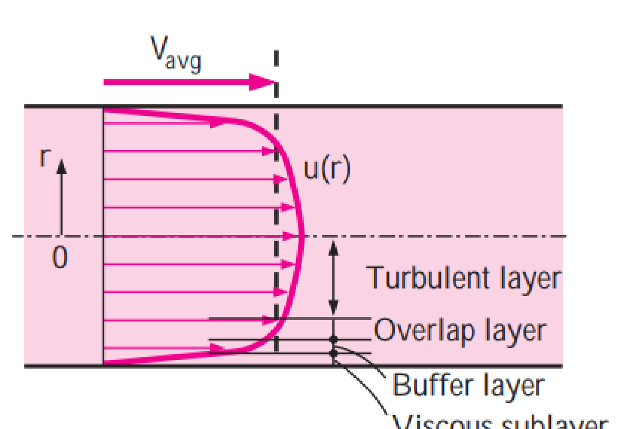
ENTRANCE REGION & VELOCITY PROFILE







Laminar flow



Turbulent flow

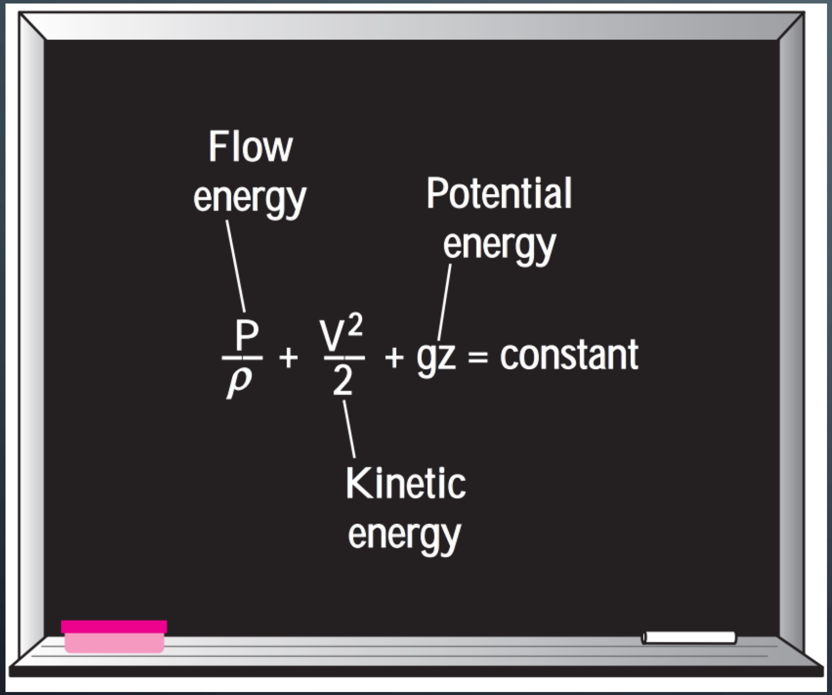
$$\frac{L_{h,laminar}}{D} \cong 0.05\mathrm{Re}; \quad \frac{L_{h,tubulent}}{D} \cong 1.359\mathrm{Re}^{1/4}$$

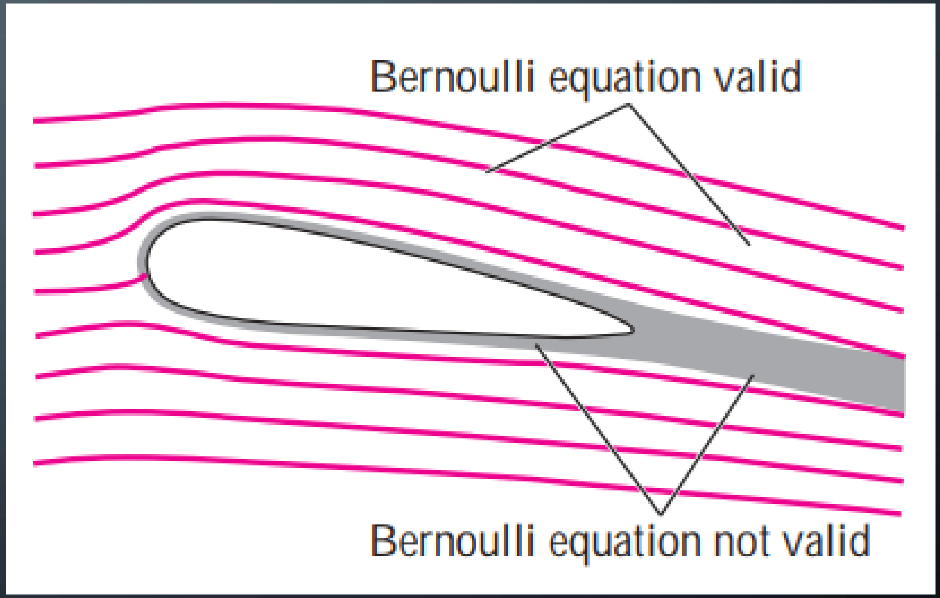
$$u(r) = 2V_{\mathrm{avg}}\left(1 - \frac{r^2}{R^2}\right)$$

BERNOULLI EQUATION

Conservation of mass, energy and momentum

The sum of the kinetic, potential, and flow energies of a fluid particle is constant along a streamline during steady flow when the compressibility and frictional effects are negligible.





Steady, incopressible flow: $\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{constant}$

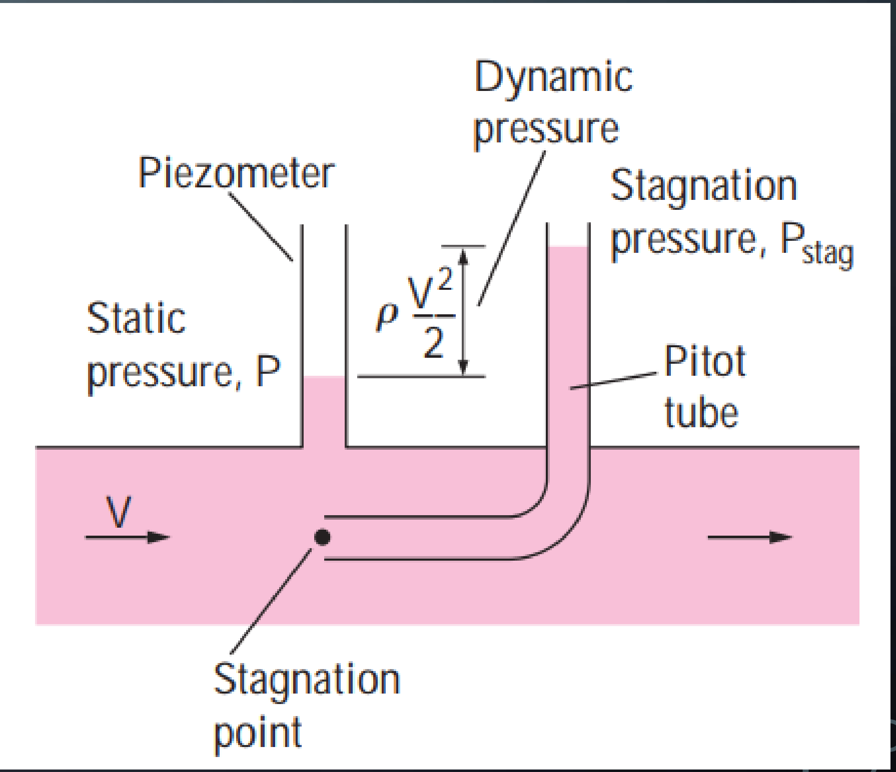
BERNOULLI EQUATION

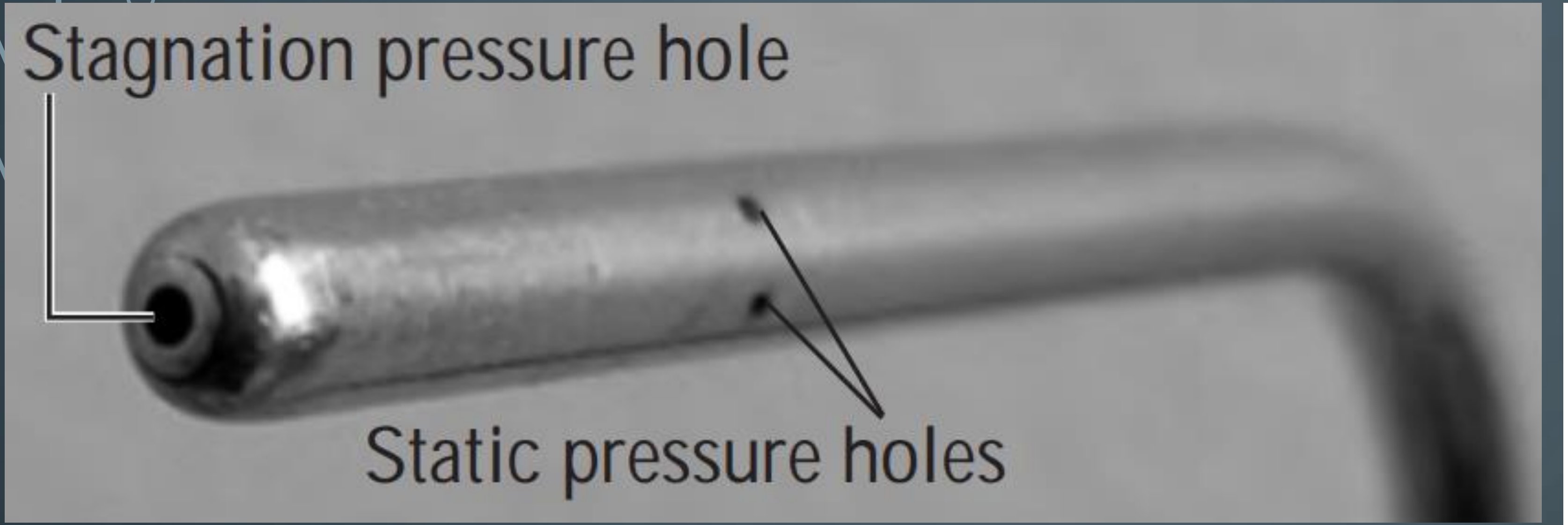
$$P + \rho\frac{V^2}{2} + \rho g z = \text{constant (along a streamline)}$$

- P: static pressure
- $\rho\frac{V^2}{2}$: dynamic pressure
- $\rho g z$: hydrostatic pressure

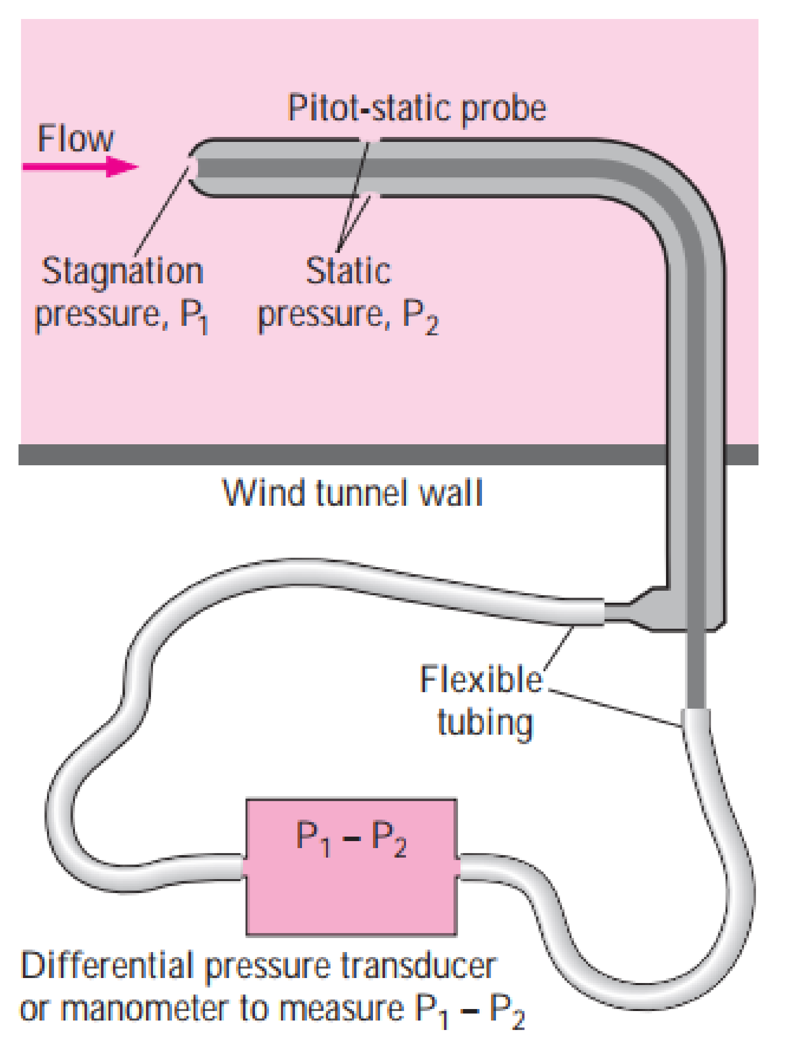
$$P_{\text{stag}} = P + \rho\frac{V^2}{2}$$

$$V = \sqrt{\frac{2(P_{\text{stag}} - P)}{\rho}}$$




Stagnation pressure hole
Static pressure holes


Pitot Tube
Santander


Flow
Pitot-static probe
Stagnation pressure, P_1
Static pressure, P_2
Wind tunnel wall
Flexible tubing
$P_1 - P_2$
Differential pressure transducer or manometer to measure $P_1 - P_2$

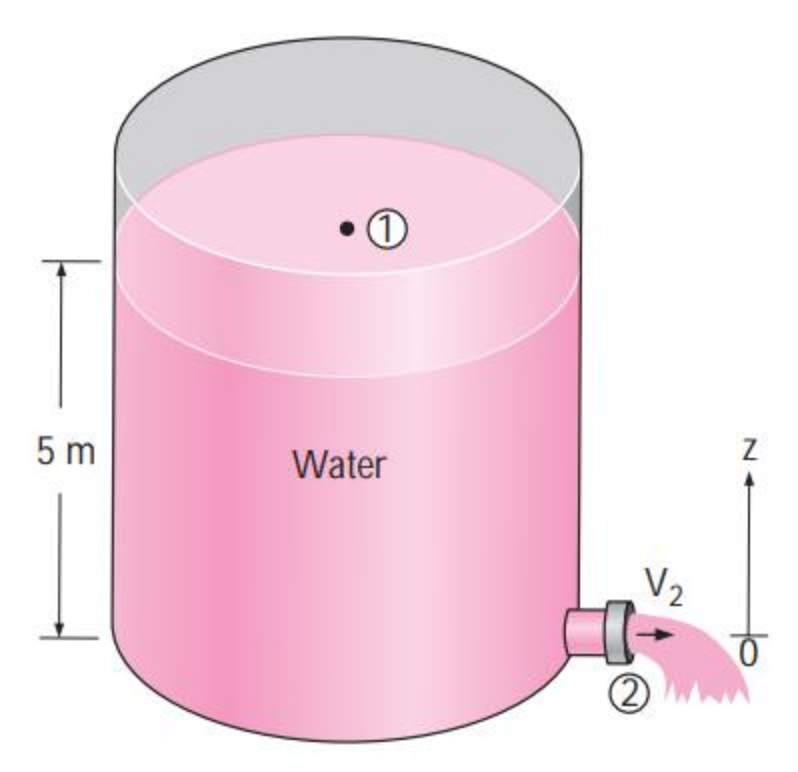
WATER DISCHARGE

- Bernoulli equation

$$\frac{\cancel{P_1}}{\cancel{\rho g}} + \frac{V_1^2}{2g} \xrightarrow{} 0 + z_1 = \frac{\cancel{P_2}}{\cancel{\rho g}} + \frac{V_2^2}{2g} + z_2 \xrightarrow{} 0 \quad \rightarrow \quad z_1 = \frac{V_2^2}{2g}$$

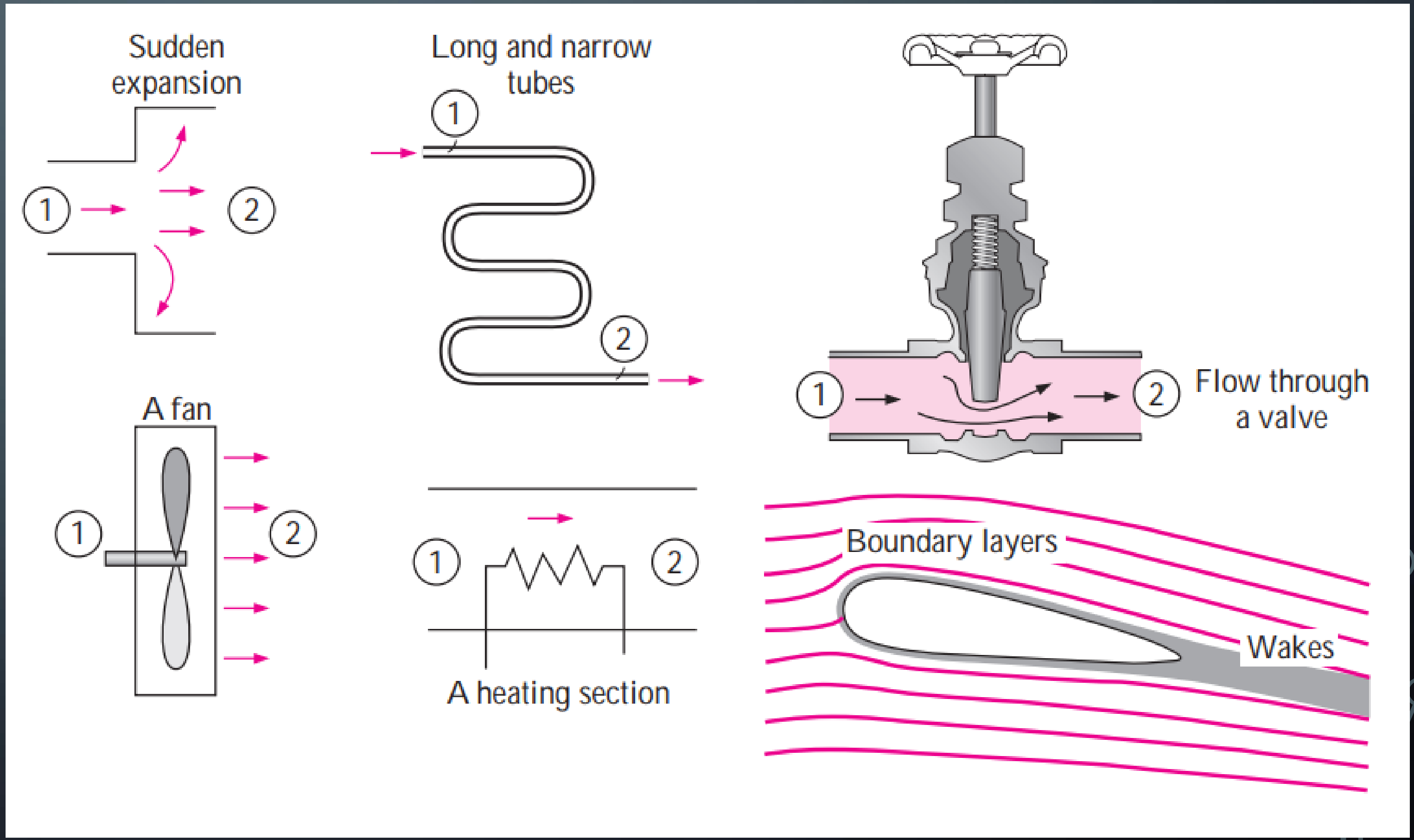
- Toricelli equation.

$$V_2 = \sqrt{2gz_1} = \sqrt{2(9.81\ \text{m/s}^2)(5\ \text{m})} = \mathbf{9.9\ m/s}$$



LIMITATIONS ON THE USE OF THE BERNOULLI EQUATION

- Steady flow
- Frictionless flow
- No shaft work
- Incompressible flow
- No heat transfer
- Flow along a streamline



PRESSURE DROP AND HEAD LOSS

- Pressure loss

$$\Delta P = f\frac{L}{D}\frac{\rho V_{\text{avg}}^2}{2}$$

- Darcy friction factor, circular pipe, laminar

$$f = \frac{64\mu}{\rho D V_{\text{avg}}} = \frac{64}{\text{Re}}$$

- Head loss (equivalent fluid height)

$$h_L = \frac{\Delta P_L}{\rho g} = f\frac{L}{D}\frac{V_{\text{avg}}^2}{2g}$$

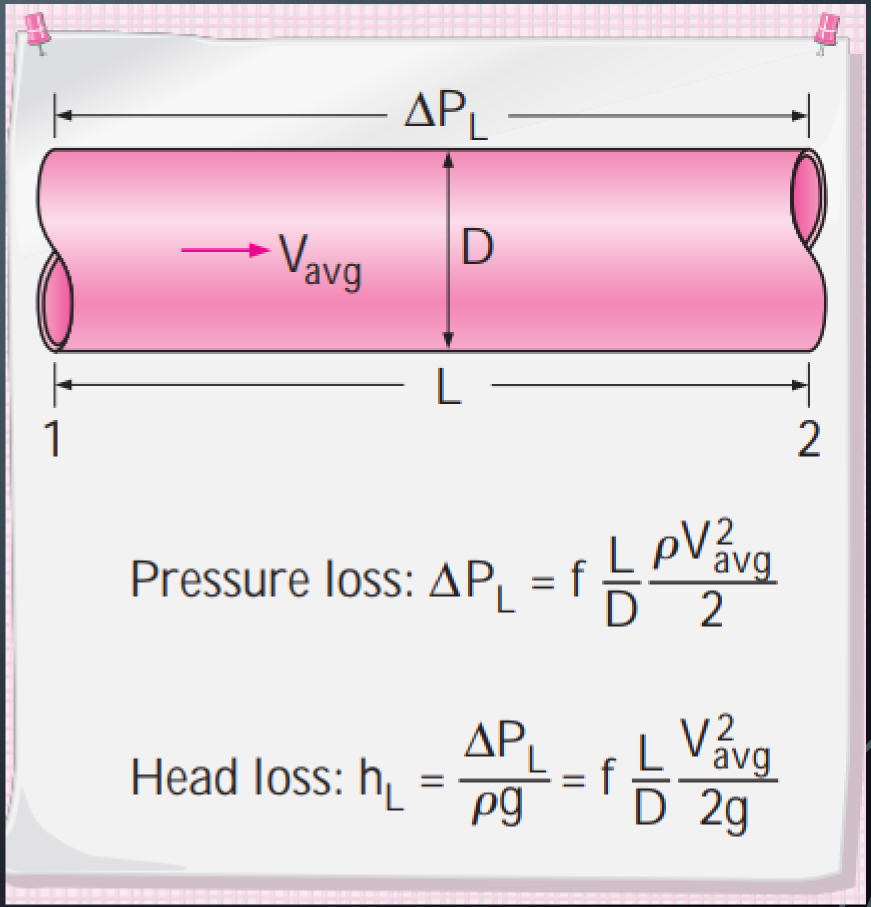
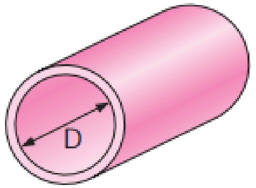
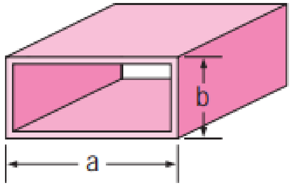
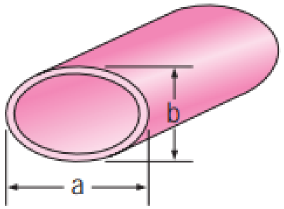
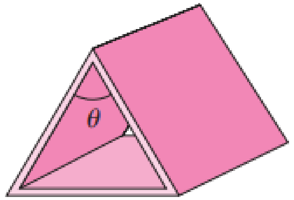


TABLE 8–1

Friction factor for fully developed *laminar flow* in pipes of various cross sections ($D_h = 4A_c/p$ and $\mathrm{Re} = V_{avg} D_h/\nu$)

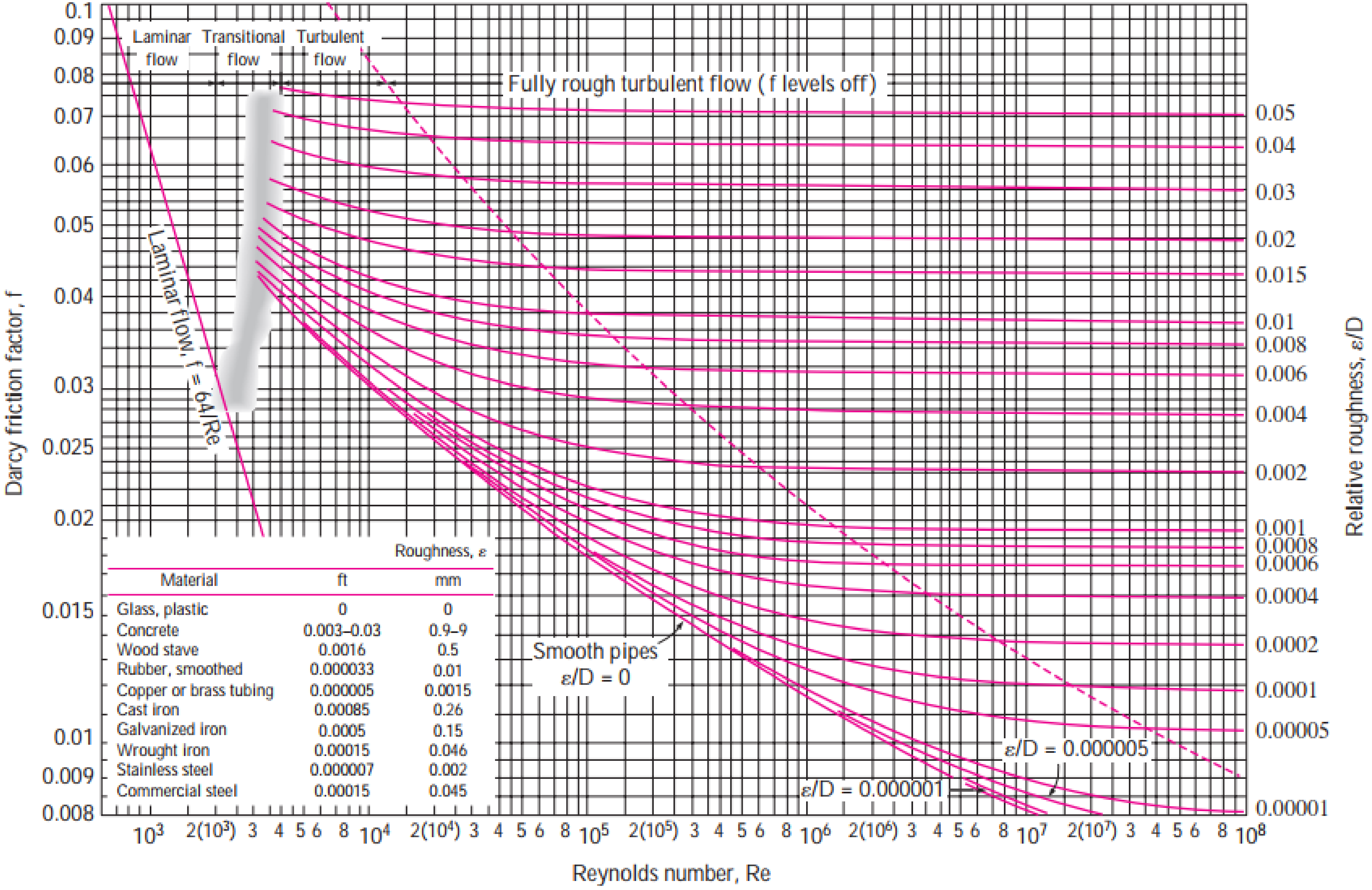
Tube Geometry	a/b or $\theta°$	Friction Factor f
Circle 	—	64.00/Re
Rectangle 	a/b	
	1	56.92/Re
	2	62.20/Re
	3	68.36/Re
	4	72.92/Re
	6	78.80/Re
	8	82.32/Re
	∞	96.00/Re
Ellipse 	a/b	
	1	64.00/Re
	2	67.28/Re
	4	72.96/Re
	8	76.60/Re
	16	78.16/Re
Isosceles triangle 	θ	
	10°	50.80/Re
	30°	52.28/Re
	60°	53.32/Re
	90°	52.60/Re
	120°	50.96/Re

MOODY CHART

The friction factor in fully developed turbulent pipe flow depends on the Reynolds number and the relative roughness ε/D

- Colebrook equation

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$



	Roughness, ε	
Material	ft	mm
Glass, plastic	0	0
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

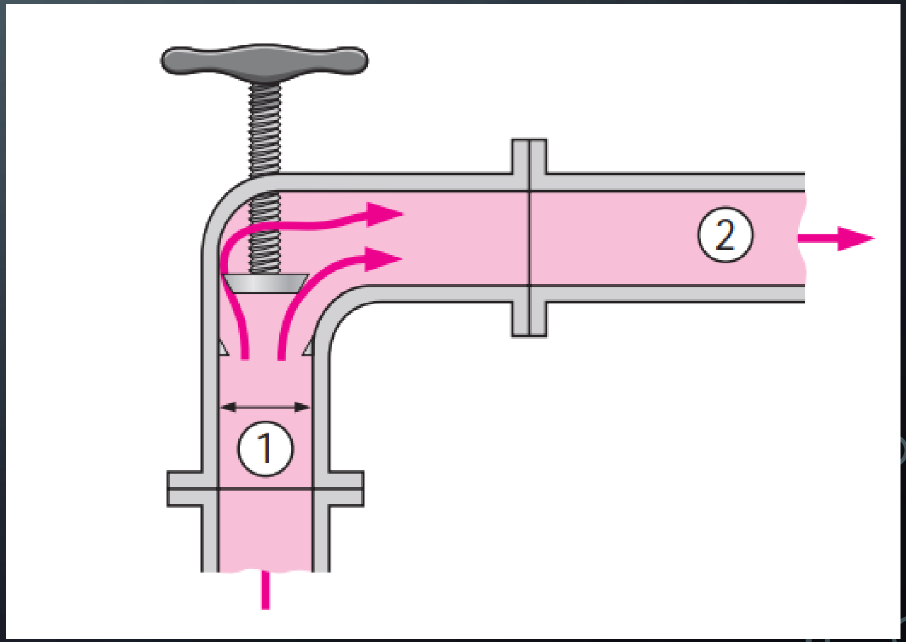
MINOR LOSSES

- Minor loss

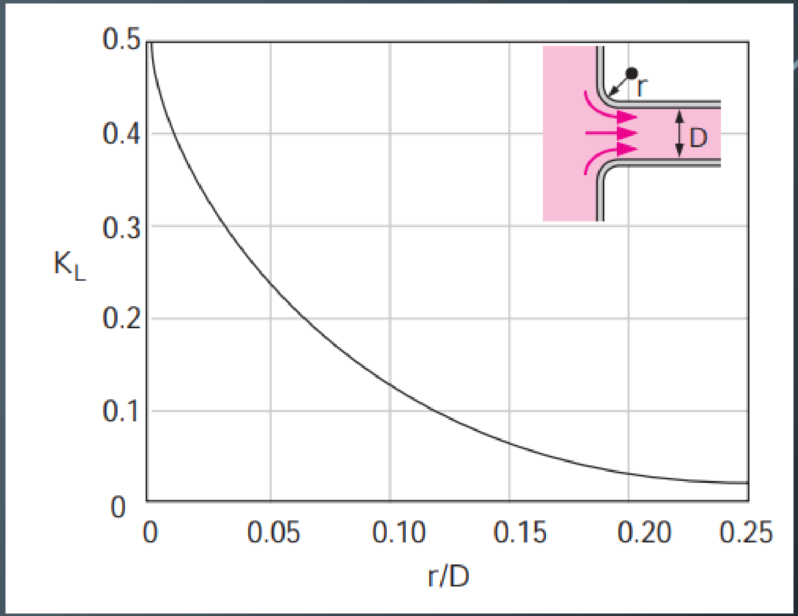
$$h_L = K_L \frac{V^2}{2g}$$

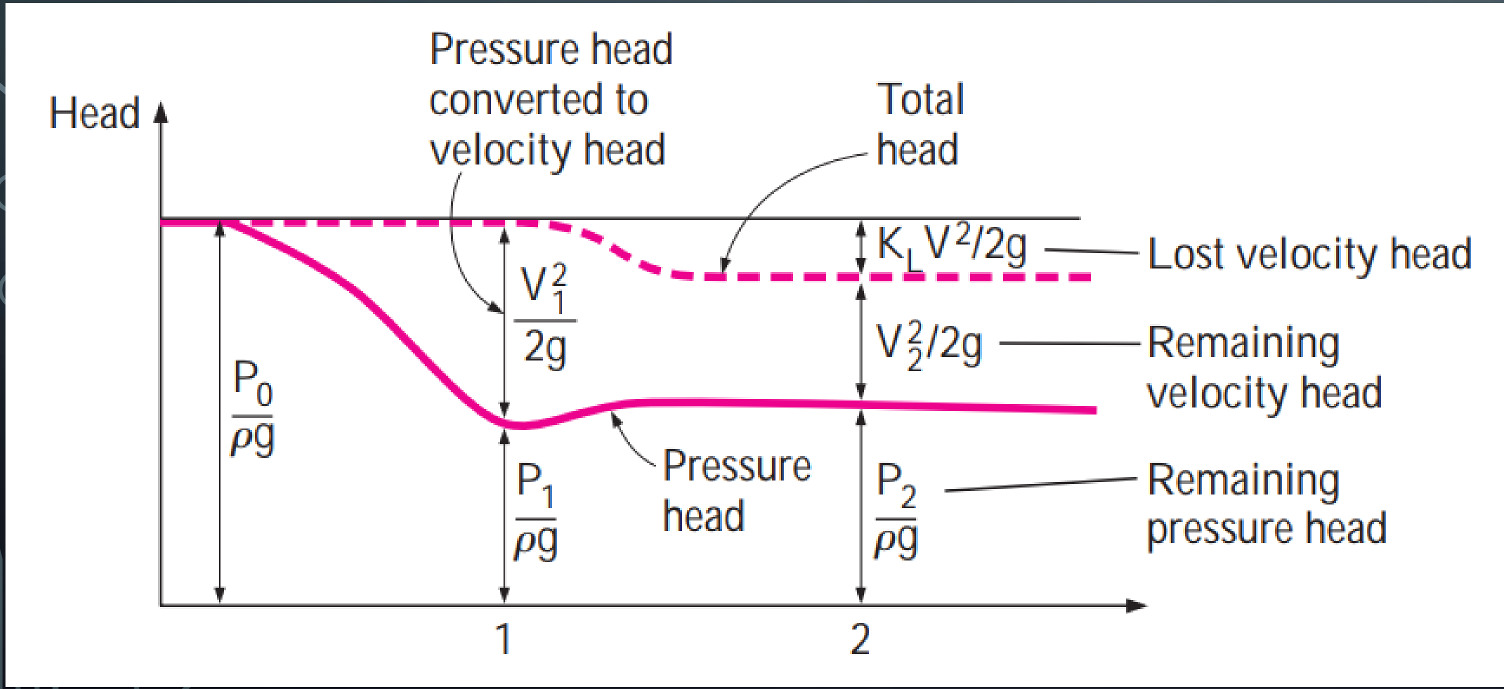
- Fittings, Valves, Bends…
- Total head loss

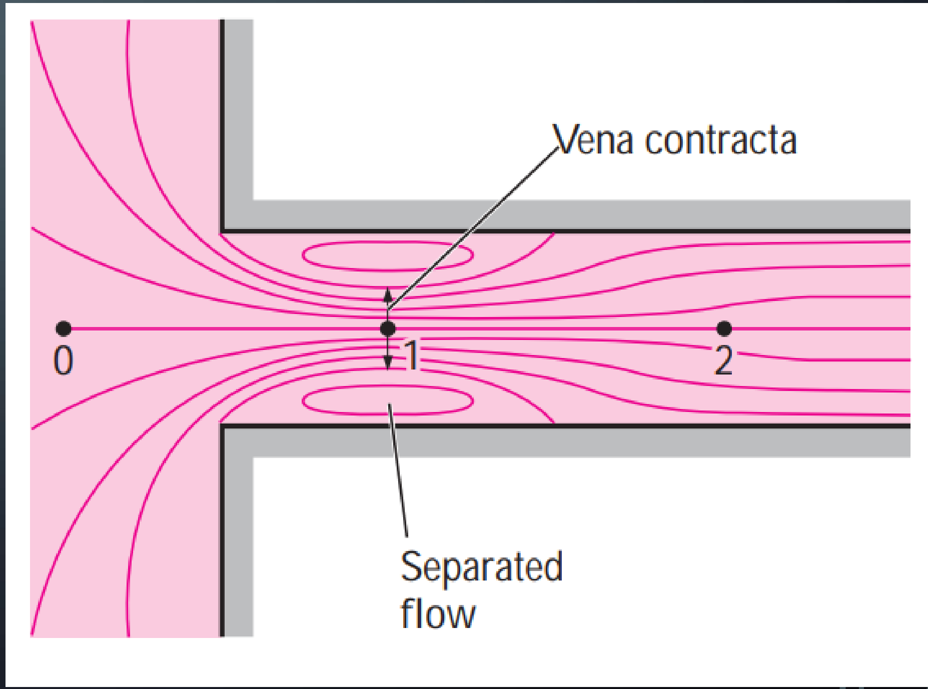
$$h_{L,\text{total}} = \sum_i f_i \frac{L_i}{D_i} \frac{V_i^2}{2g} + \sum_j K_{L,j} \frac{V_j^2}{2g}$$



MINOR LOSSES

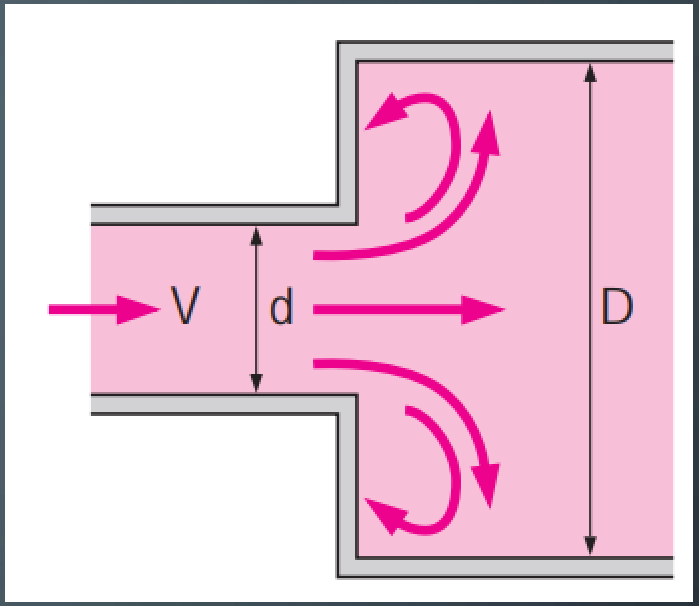




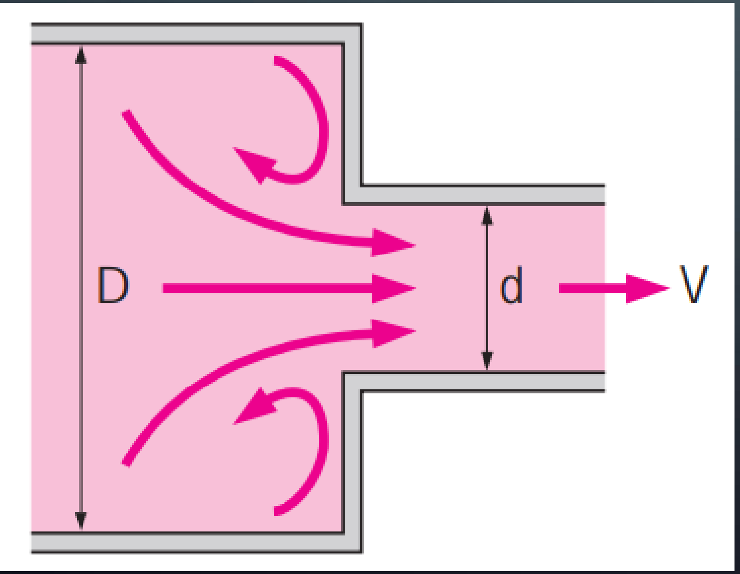


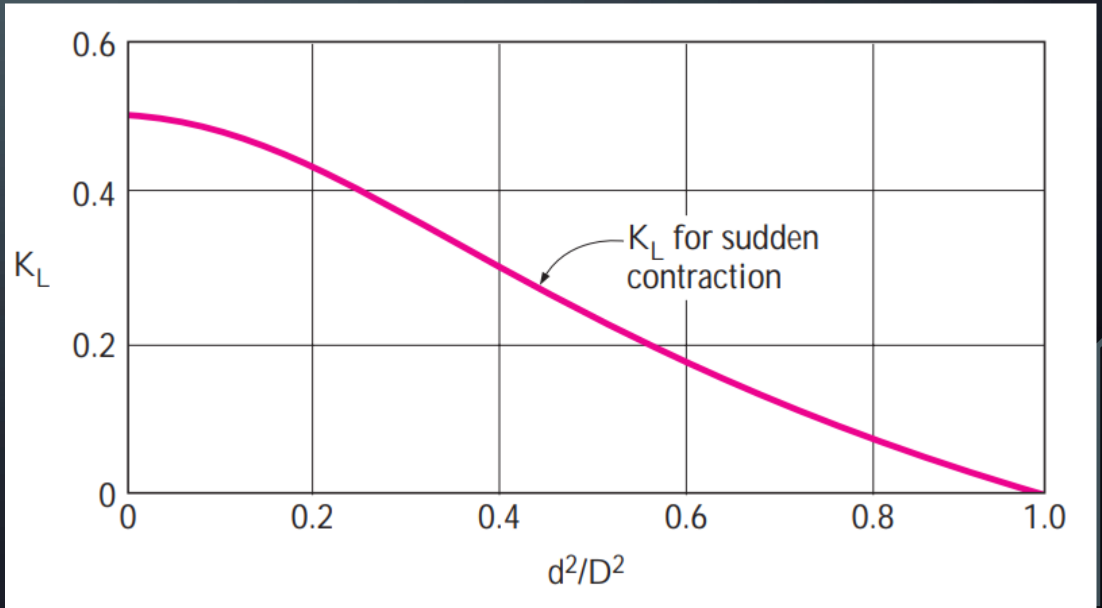
MINOR LOSSES

- Sudden expansion

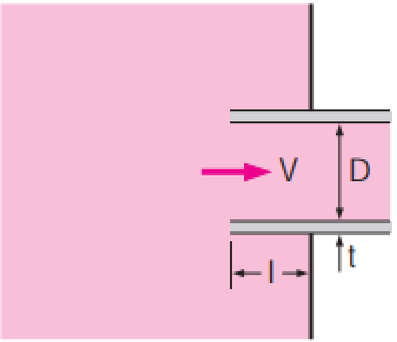
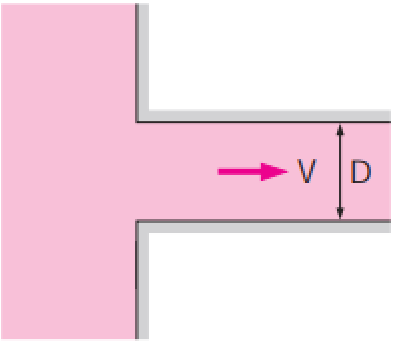
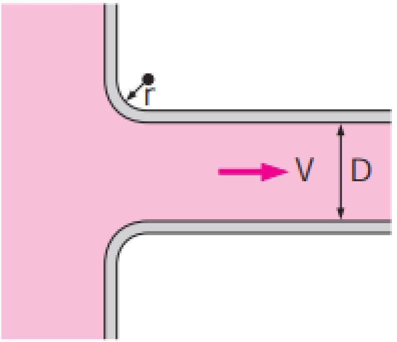
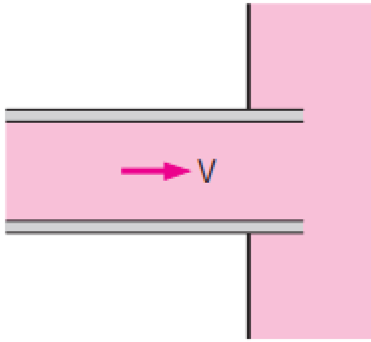
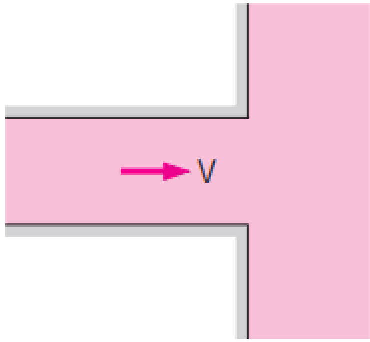
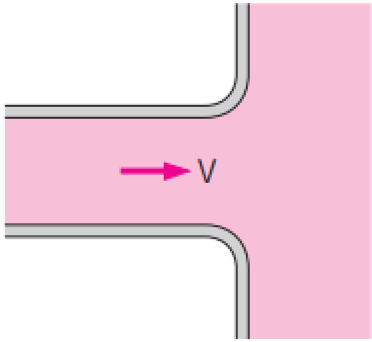


$$K_L = \left(1 - \frac{A_{small}}{A_{large}}\right)^2 = \left(1 - \frac{d^2}{D^2}\right)^2$$





Loss coefficients K_L of various pipe components for turbulent flow (for use in the relation $h_L = K_L V^2/(2g)$, where V is the average velocity in the pipe that contains the component)*

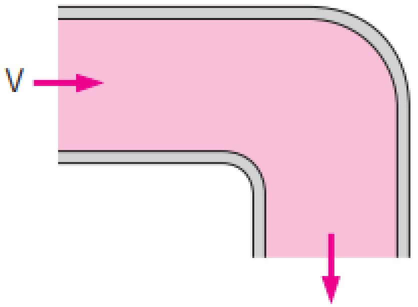
Pipe Inlet *Reentrant:* $K_L = 0.80$ ($t \ll D$ and $l \approx 0.1D$)  	*Sharp-edged:* $K_L = 0.50$  	*Well-rounded* ($r/D > 0.2$): $K_L = 0.03$ *Slightly rounded* ($r/D = 0.1$): $K_L = 0.12$ (see Fig. 8–36) 
Pipe Exit *Reentrant:* $K_L = \alpha$  	*Sharp-edged:* $K_L = \alpha$  	*Rounded:* $K_L = \alpha$ 

Note: The kinetic energy correction factor is $\alpha = 2$ for fully developed laminar flow, and $\alpha \approx 1$ for fully developed turbulent flow.

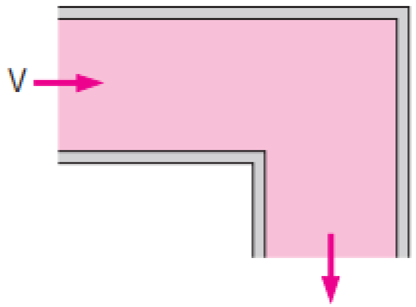
Sudden Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Bends and Branches

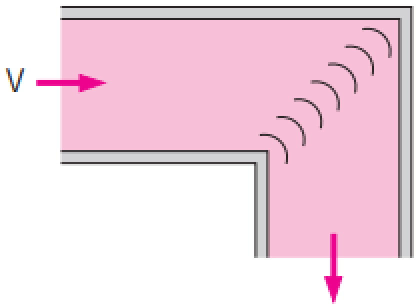
90° smooth bend:
Flanged: $K_L = 0.3$
Threaded: $K_L = 0.9$



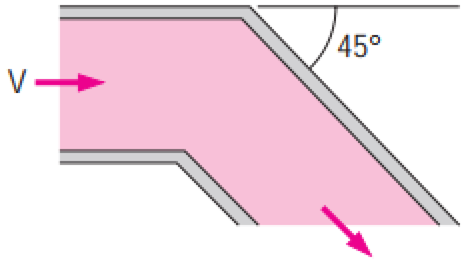
90° miter bend
(without vanes): $K_L = 1.1$



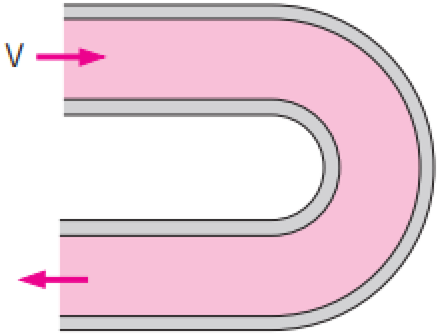
90° miter bend
(with vanes): $K_L = 0.2$



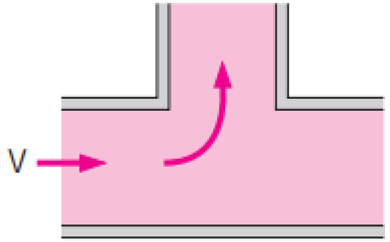
45° threaded elbow:
$K_L = 0.4$



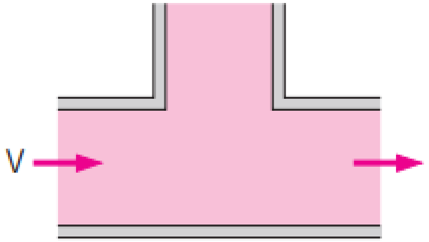
180° return bend:
Flanged: $K_L = 0.2$
Threaded: $K_L = 1.5$



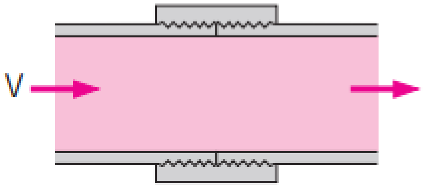
Tee (branch flow):
Flanged: $K_L = 1.0$
Threaded: $K_L = 2.0$



Tee (line flow):
Flanged: $K_L = 0.2$
Threaded: $K_L = 0.9$



Threaded union:
$K_L = 0.08$

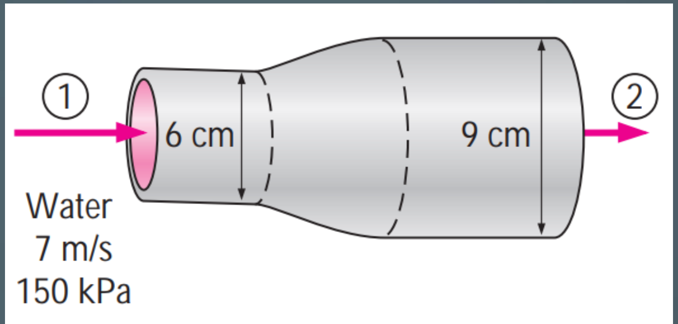


Valves

Globe valve, fully open: $K_L = 10$
Angle valve, fully open: $K_L = 5$
Ball valve, fully open: $K_L = 0.05$
Swing check valve: $K_L = 2$

Gate valve, fully open: $K_L = 0.2$
$\frac{1}{4}$ closed: $K_L = 0.3$
$\frac{1}{2}$ closed: $K_L = 2.1$
$\frac{3}{4}$ closed: $K_L = 17$

STUDIO

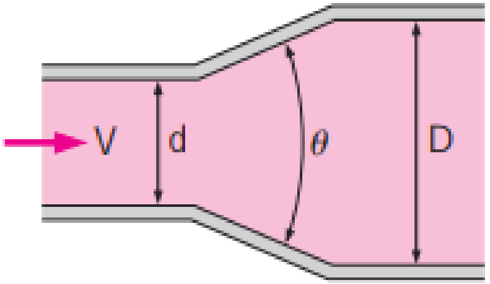


A 6-cm-diameter horizontal water pipe expands gradually to a 9-cm-diameter pipe. The walls of the expansion section are angled 30° from the horizontal. The average velocity and pressure of water before the expansion section are 7 m/s and 150 kPa, respectively. Determine the head loss in the expansion section and the pressure in the larger-diameter pipe.

Gradual Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Expansion:

$K_L = 0.02$ for $\theta = 20°$
$K_L = 0.04$ for $\theta = 45°$
$K_L = 0.07$ for $\theta = 60°$



Contraction (for $\theta = 20°$):

$K_L = 0.30$ for $d/D = 0.2$
$K_L = 0.25$ for $d/D = 0.4$
$K_L = 0.15$ for $d/D = 0.6$
$K_L = 0.10$ for $d/D = 0.8$