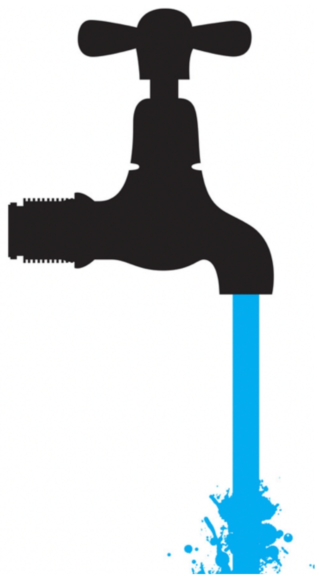
FLOW IN PIPE

When water comes out of a faucet, it has a certain velocity. The velocity can be calculated using the idea of Torricelli's theorem.

$$V = \sqrt{2gh}$$



When the faucet is fitted with a short rubber hose, the water comes out with a velocity that is slightly less than the velocity of the water leaving the faucet.

When a long rubber hose is used, there is a possibility that the water coming out will be slowed down.

This indicates there is a loss of energy in the flow.

Therefore, Bernoulli equation need to be modify.
From previous chapter, Bernoulli equation written as:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 = \text{constant}$$

In this case, we assume that the flow is steady and uniform, and there is no energy loss along the flow.

In the situation where we need to take into account the loss of energy, the Bernoulli equation needs to be written like this.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + \text{Losses}$$

Energy loss can be divided into two main types namely major losses and minor losses.

Major losses are associated with frictional energy loss that is caused by the viscous effects of the fluid and roughness of the pipe wall. Major losses create a pressure drop along the pipe since the pressure must work to overcome the frictional resistance.

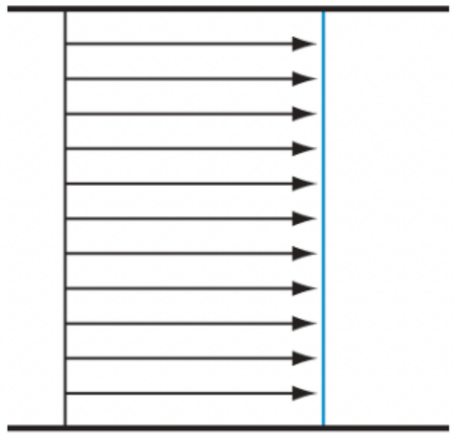
Minor losses represent additional energy dissipation in the flow, usually caused by secondary flows induced by curvature or recirculation, the existence of parts in the pipe system and the design of the pipe system itself.

Thus, Bernoulli equation can be written as :

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + \text{Major losses} + \text{Minor losses}$$

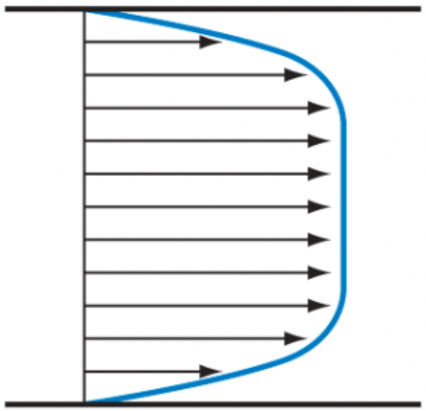
MAJOR LOSS

Velocity profile in ideal flow can be shown like this.



There is no “no-slip condition” phenomenon on the pipe wall. Fluid molecules flow with the same velocity in all parts.

But the velocity profile in real flow is like this. The phenomenon of “no-slip condition” occurs and the maximum velocity occurs in the middle of the pipe.



The friction that occurs between the molecules and the pipe wall causes energy loss to occur in the fluid flow. The longer the pipe, the higher the energy loss due to friction. That's why we can observe the water coming out from the long rubber pipe is slow compared to the velocity of the water coming out directly from the faucet.

The formula for calculating major loss is as follows:

$$\text{Major loss} = f\frac{L}{D}\frac{V^2}{2g}$$

f : Friction factor

L : Length of pipe

D : Diameter of pipe

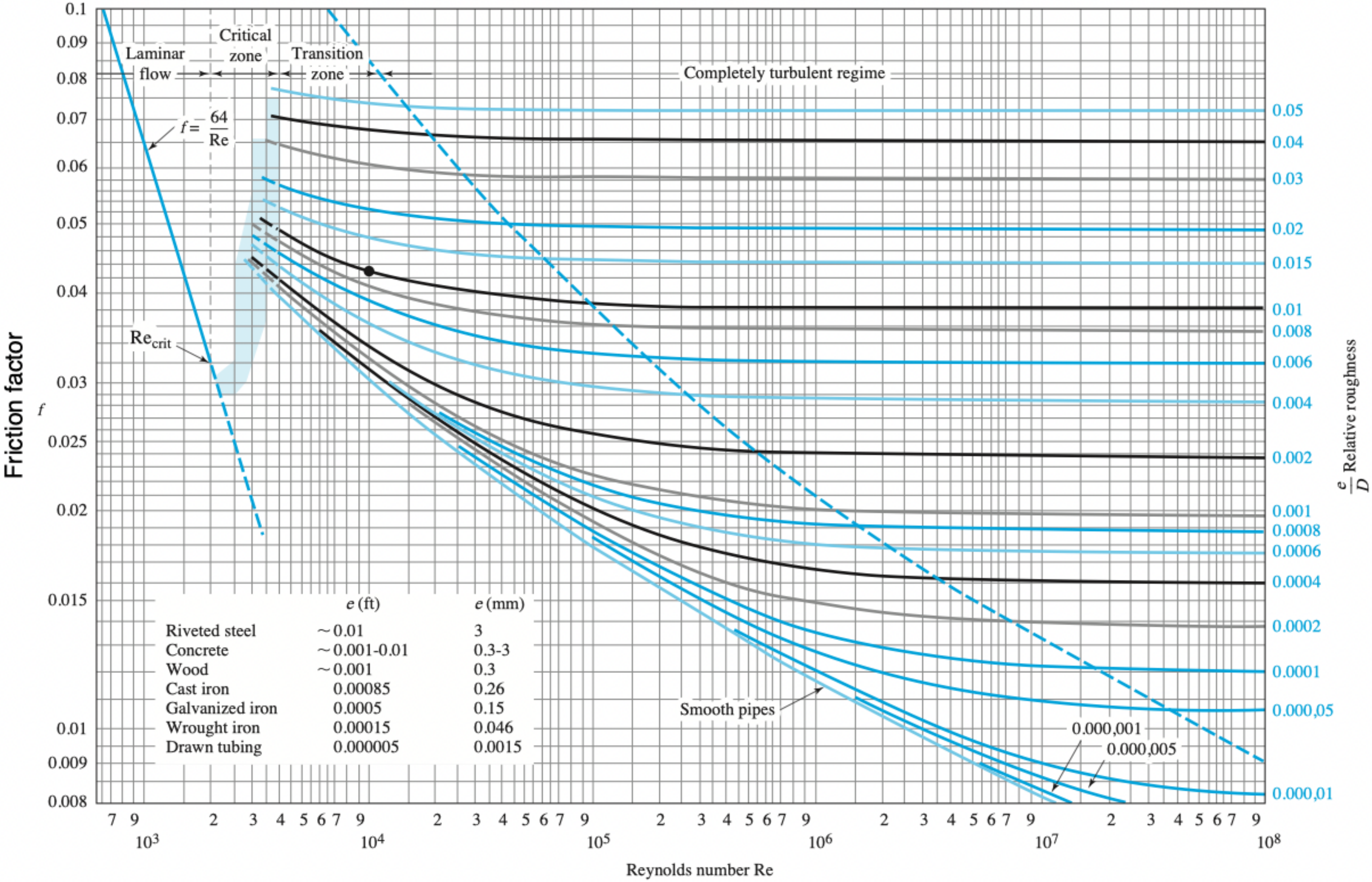
V : The velocity of the fluid flowing in the pipe

For laminar flow:

$$f = \frac{64}{Re}$$

For turbulent flow:

We need to refer to Moody chart. It is dependence on the relative roughness value



Friction factor
f
Laminar flow
Critical zone
Transition zone
Completely turbulent regime
f = 64/Re
Re_crit
Smooth pipes
0.000,001
0.000,005
e/D Relative roughness
Reynolds number Re
e (ft)
e (mm)
Riveted steel ~0.01 3
Concrete ~0.001-0.01 0.3-3
Wood ~0.001 0.3
Cast iron 0.00085 0.26
Galvanized iron 0.0005 0.15
Wrought iron 0.00015 0.046
Drawn tubing 0.000005 0.0015
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.000,05
0.000,01

Example:

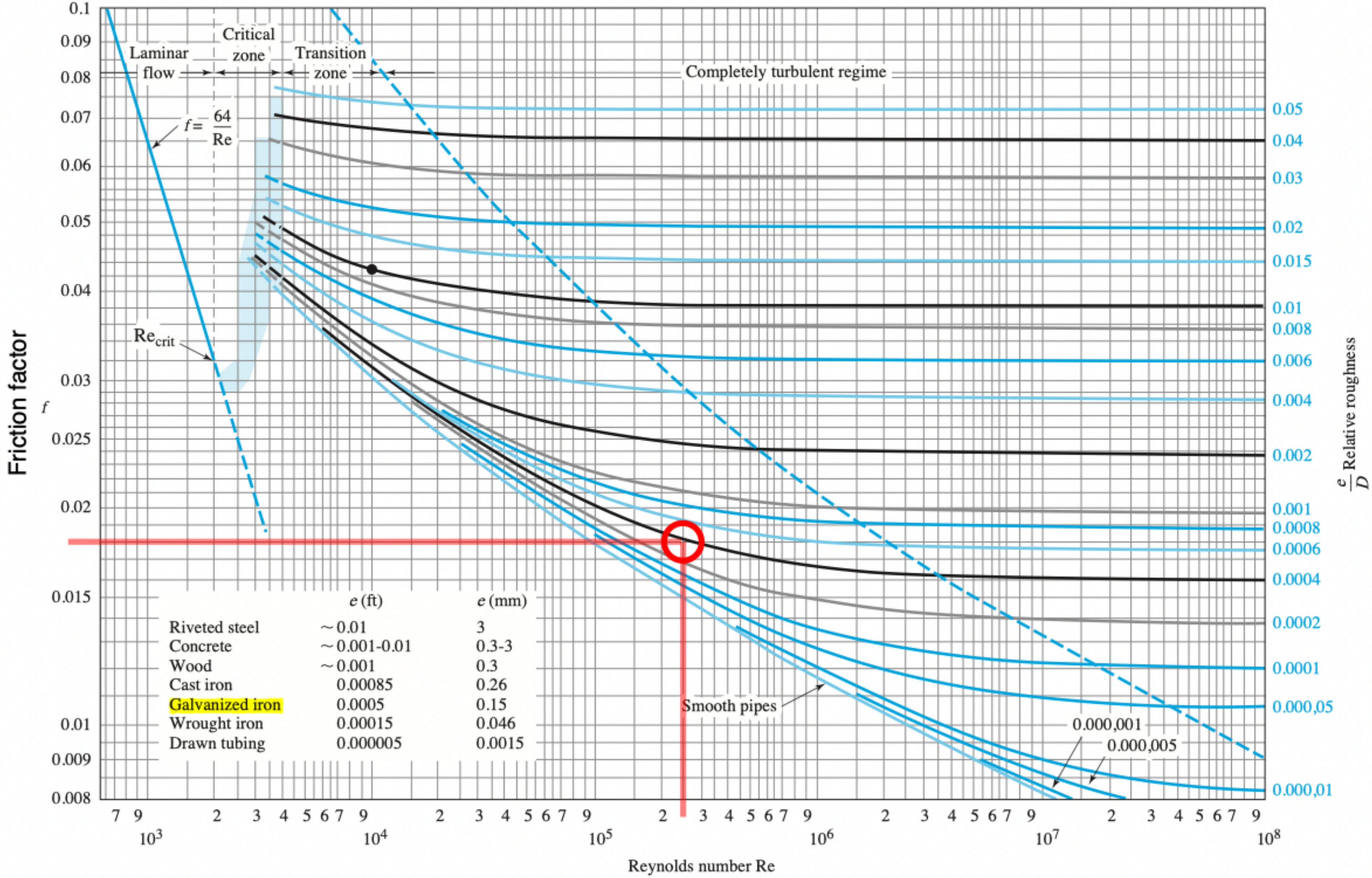
Galvanized iron pipe, normally has a surface roughness of 0.15 mm.
Diameter of galvanized iron pipe is 0.375 m.

$$\frac{e}{D} = \frac{0.15\,mm}{375\,mm} = 0.0004$$

Let say, the Reynolds number is 2.5×10^5.

$$Re = \frac{\rho V D}{\mu}$$

The value of friction factor is 0.018 (dimensionless).



	e (ft)	e (mm)
Riveted steel	~0.01	3
Concrete	~0.001-0.01	0.3-3
Wood	~0.001	0.3
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Drawn tubing	0.000005	0.0015

Point to ponder:

Determine the value of the Reynolds number first because laminar and turbulence flow have different methods of determining the value of the friction factor.

Make sure you know the type of pipe material and pipe diameter. This will give a different relative roughness value.

Determine the diameter of the pipe. Even if the pipe type is the same pipe material, different diameters will give different Reynolds number values.

MINOR LOSS

Minor losses represent additional energy dissipation in the flow, usually caused by secondary flows induced by curvature or recirculation, the existence of parts in the pipe system and the design of the pipe system itself.

Minor losses termed as:

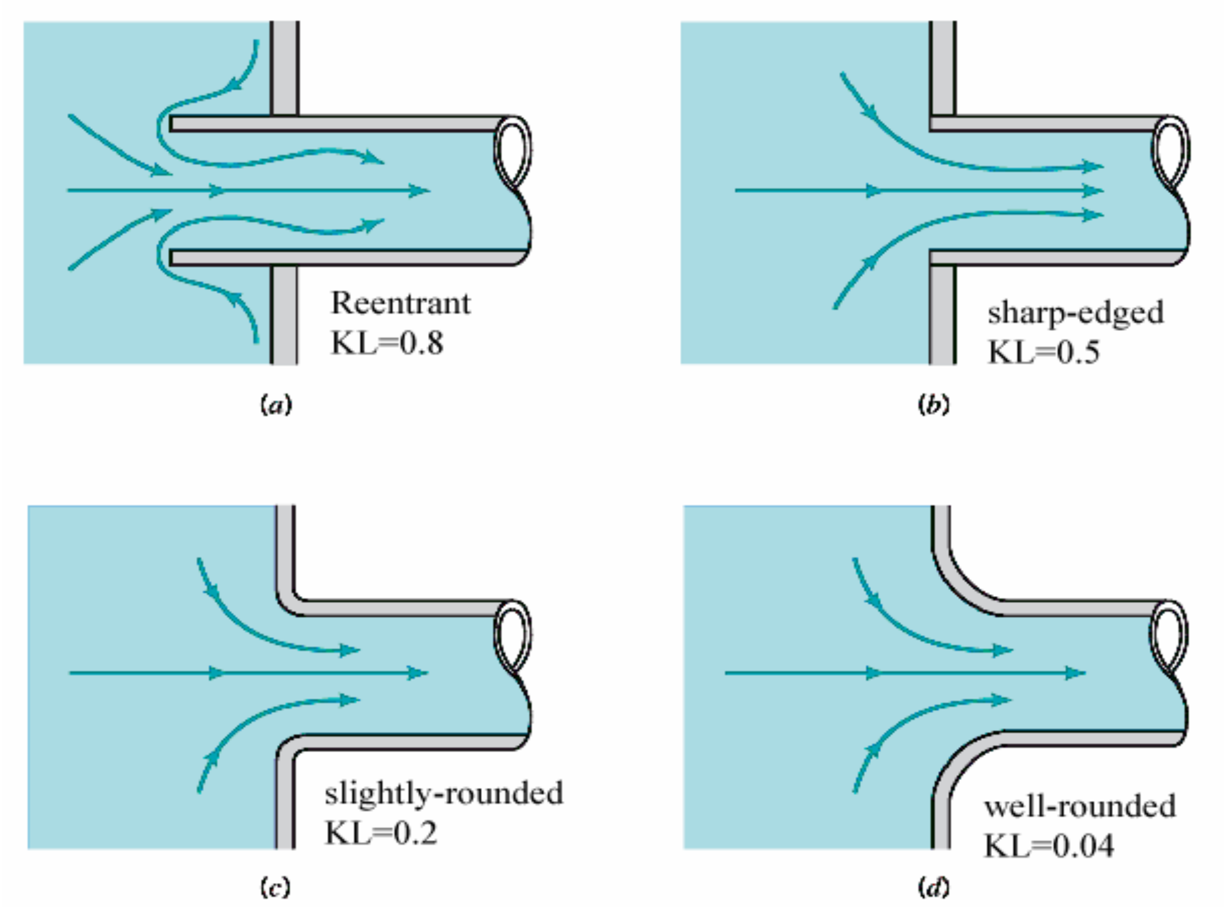
$$Minor\ loss = K\frac{V^2}{2g}$$

Where K is the loss coefficient (for specific part / area).

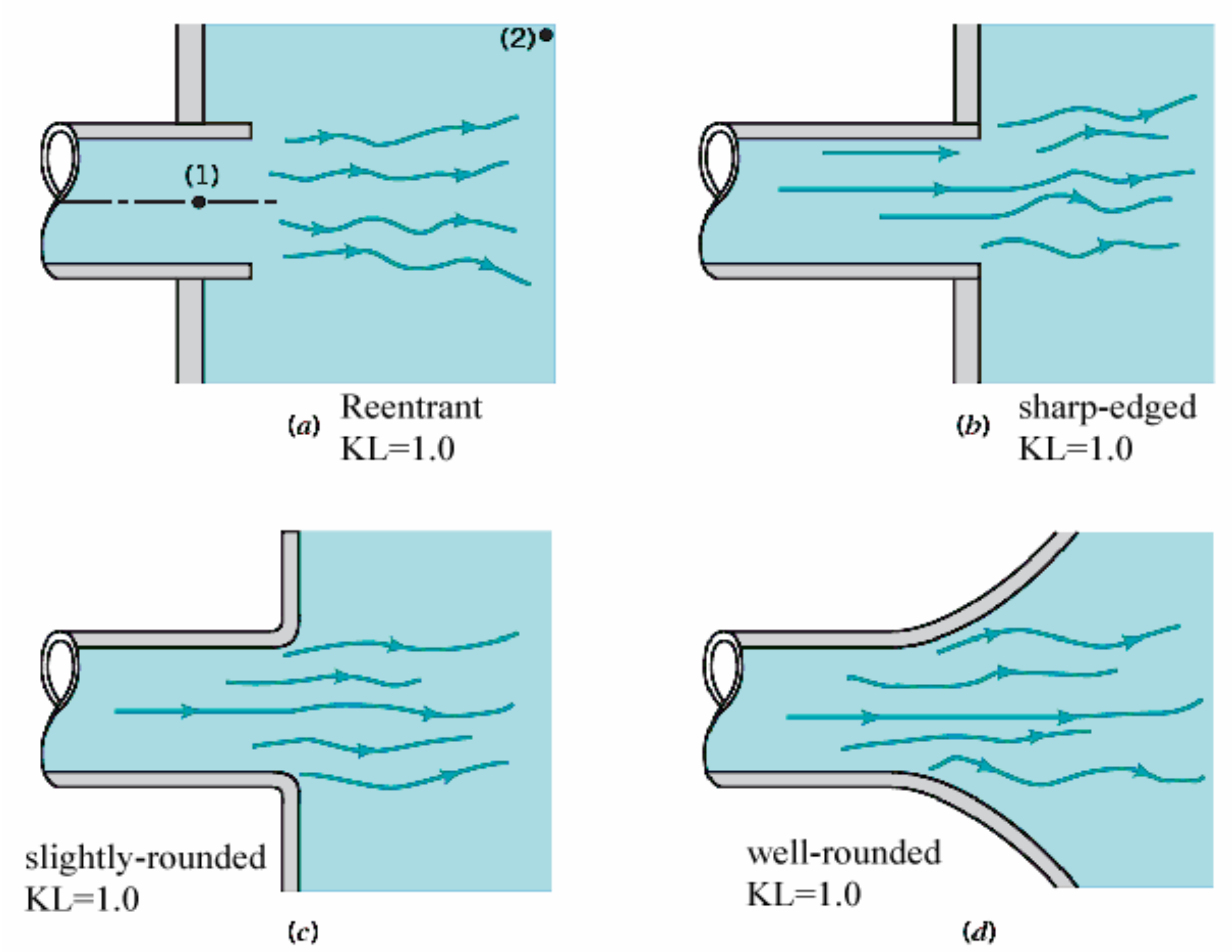
Normally, minor loss occurs at these points:

1. Pipe inlet and outlet
2. Pipe sudden contraction and sudden expansion
3. Pipe bending
4. Connector such as valve and filter

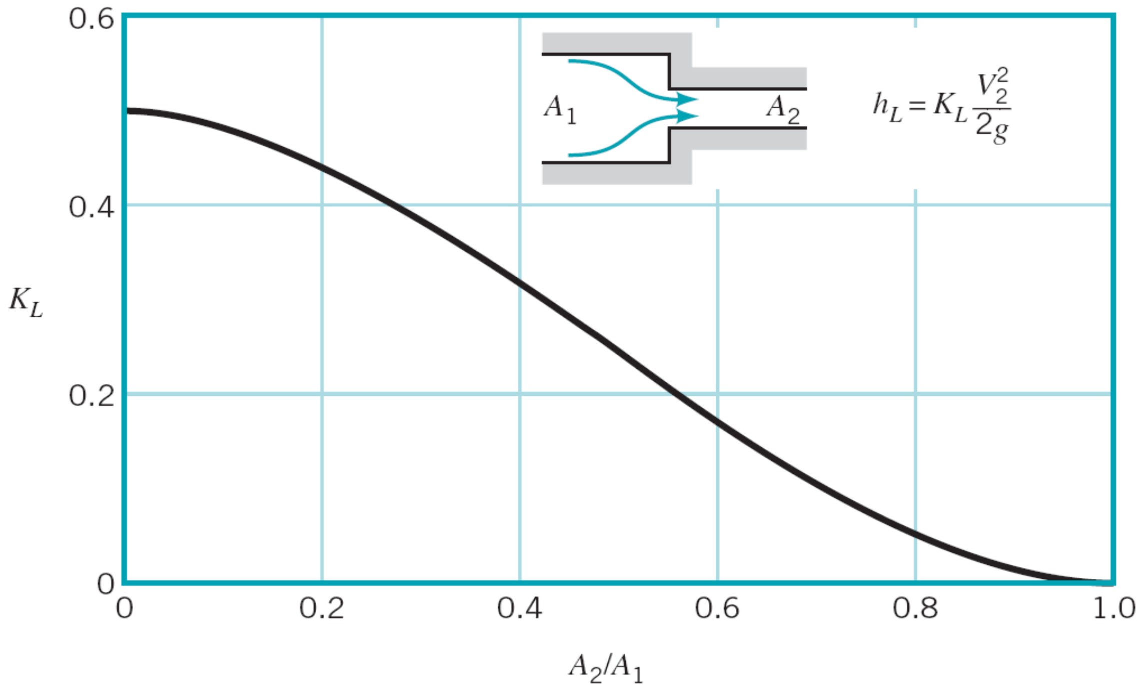
Entrance flow conditions and loss coefficient.



Exit flow conditions and loss coefficient.

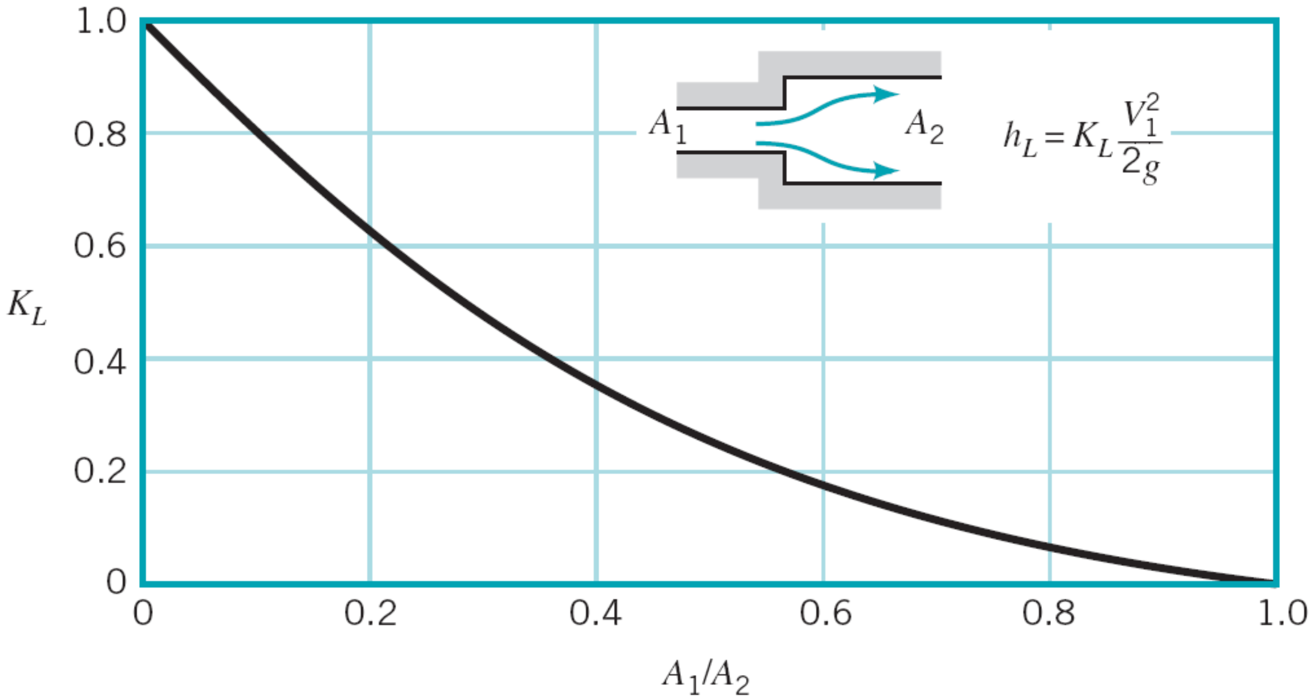


Sudden contraction



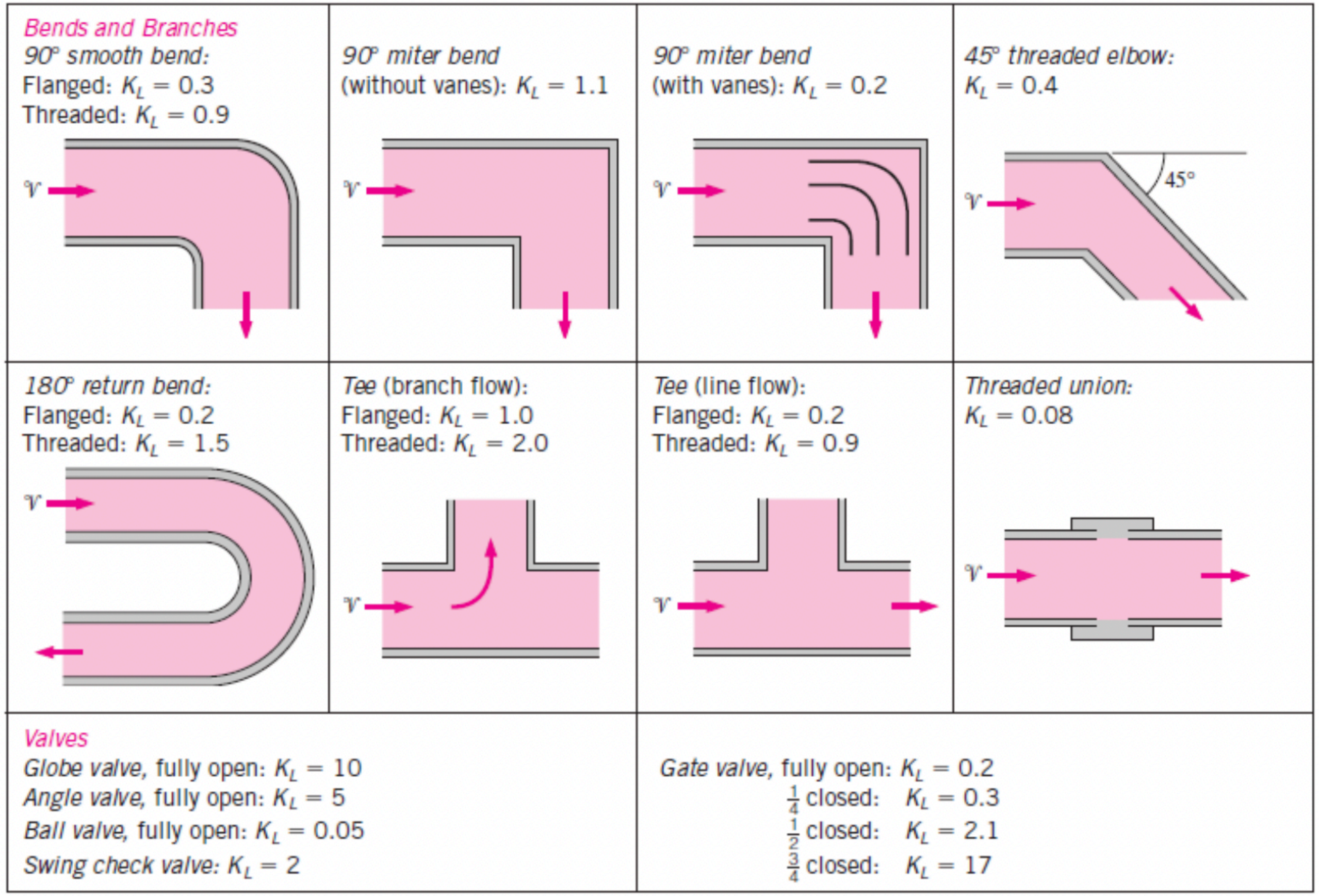
$$K = \left(1 - \frac{A_2}{A_1}\right)^2$$

Sudden expansion



$$K = \left(1 - \frac{A_1}{A_2}\right)^2$$

Pipe bending



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: $K_L = 17$	

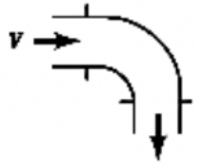
*These are representative values for loss coefficients. Actual values strongly depend on the design and manufacture of the components and may differ from the given values considerably (especially for valves). Actual manufacturer's data should be used in the final design.

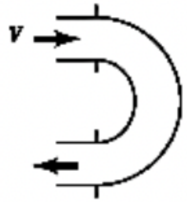
Note: These value will be given in exam question.

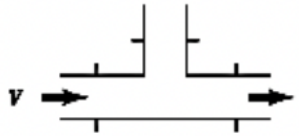
Valve and filter.

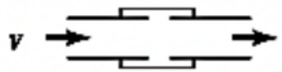
Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$

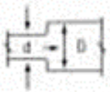
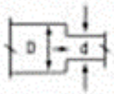
Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210

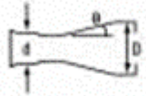
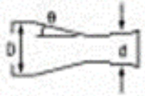
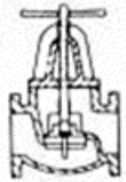
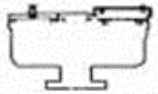
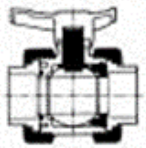








Fitting Type		K
Pipe Entry Losses		
Square Inlet		0.50
Re-entrant Inlet		0.80
Slightly Rounded Inlet		0.25
Bellmouth Inlet		0.05
Pipe Intermediate Losses		
Elbows R/D < 0.6 	45°	0.35
	90°	1.10
Long Radius Bends (R/D > 2) 	$11\frac{1}{4}$°	0.05
	$22\frac{1}{2}$°	0.10
	45°	0.20
	90°	0.50
Tees		
(a) Flow in line		0.35
(b) Line to branch flow		1.00
Sudden Enlargements 		
Ratio	d/D	
	0.9	0.04
	0.8	0.13
	0.7	0.26
	0.6	0.41
	0.5	0.56
	0.4	0.71
	0.3	0.83
	0.2	0.92
	<0.2	1.00
Sudden Contractions 		
Ratio	d/D	
	0.9	0.10
	0.8	0.18
	0.7	0.26
	0.6	0.32
	0.5	0.38
	0.4	0.42
	0.3	0.46
	0.2	0.48
	<0.2	0.50

Fitting Type		K
Gradual Enlargements 		
Ratio d/D q = 10° typical		
	0.9	0.02
	0.7	0.13
	0.5	0.29
	0.3	0.42
Gradual Contractions 		
Ratio d/D q = 10° typical		
	0.9	0.03
	0.7	0.08
	0.5	0.12
	0.3	0.14
Valves		
Gate Valve (fully open) 		0.20
Reflux Valve 		2.50
Globe Valve 		10.00
Butterfly Valve (fully open) 		0.20
Angle Valve 		5.00
Foot Valve with strainer 		15.00
Air Valves 		zero
Ball Valve 		0.10
Pipe Exit Losses		
Square Outlet		1.00
Rounded Outlet		1.00

PIPE SYSTEM

A pipe system is a set of pipe line (single or multiple) that deliver fluid from one place to another and has various components that help to achieve that purpose.

In this syllibus, the basic components are pump and turbine.

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy. In simple word, a pump is a component that gives energy to a fluid flow.

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. In simple word, a turbine is a component that absorbs energy from a fluid flow.

Bernoulli equation can be written as:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 + H_P = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_T + \text{Major losses} + \text{Minor losses}$$

H_P:Head of pump

H_T:Head of turbine

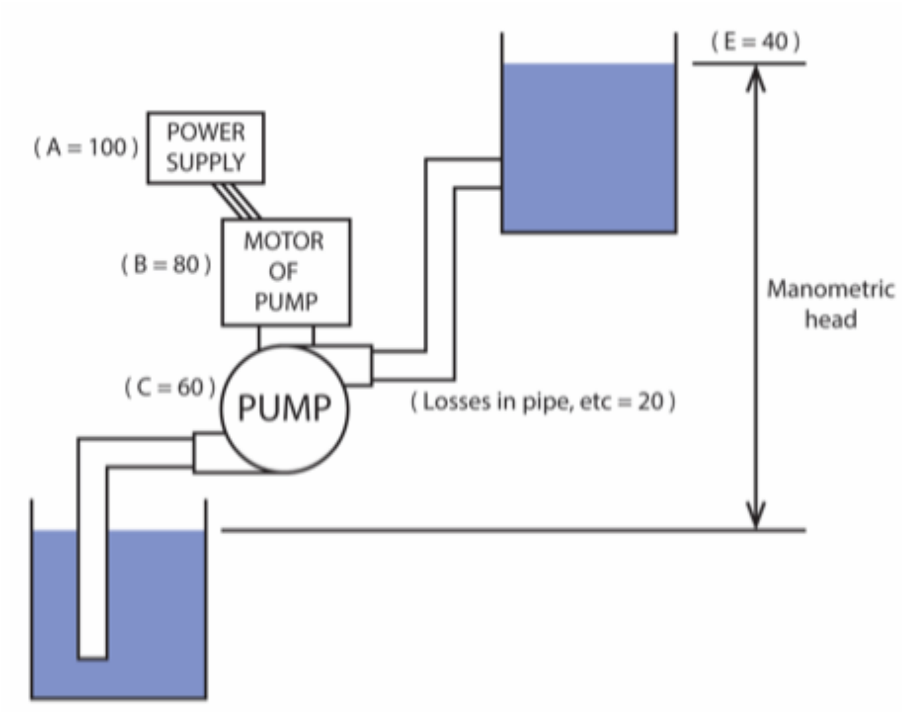
Unit for both, head of pump and head of turbine is in meter.

Energy losses for pump and turbine were concluded as the efficiency for pump and turbine.

$$\text{Efficiency} = \frac{\text{Power out}}{\text{Power in}}$$

$$\text{Power} = \rho g Q \cdot H$$

The head of a pump is a physical quantity that expresses the pump’s ability to lift a given volume of fluid, usually expressed in meters of water column, to a higher level from the point where the pump is positioned.



The head of turbine is the height difference between where the water enters into the hydro system and where it leaves it, measured in metres.