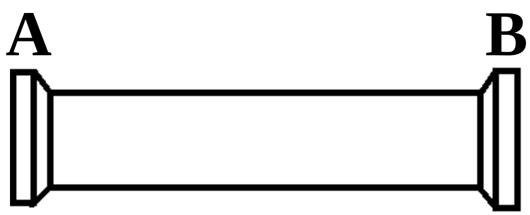
PRESSURE DROP AND LOSSES IN PIPE

When water (fluid) flows in a pipe, for example from point A to point B, pressure drop will occur due to the energy losses (major and minor losses).



Bernoulli equation:

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + z_B + \sum h_L$$

If pipe diameter is the same, the velocity remain constant along the pipe.

$$V_A = V_B = V$$

If the height is the same, the potential energy can be neglected.

$$z_A = z_B = z$$

Pressure drop could be determine as:

$$\frac{P_A - P_B}{\rho g} = \sum h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} + K \cdot \frac{V^2}{2g}$$

where f is a friction factor, and need to be determine.For laminar flow, $f = \frac{64}{\text{Re}}$

For turbulent flow, f need to be determined using Moody chart

The relative pipe roughness, $\frac{\varepsilon}{D}$ need to be measured.

COLEBROOK-WHITE EQUATION

This is an equation to find the value of friction factor, f , for turbulent flow.

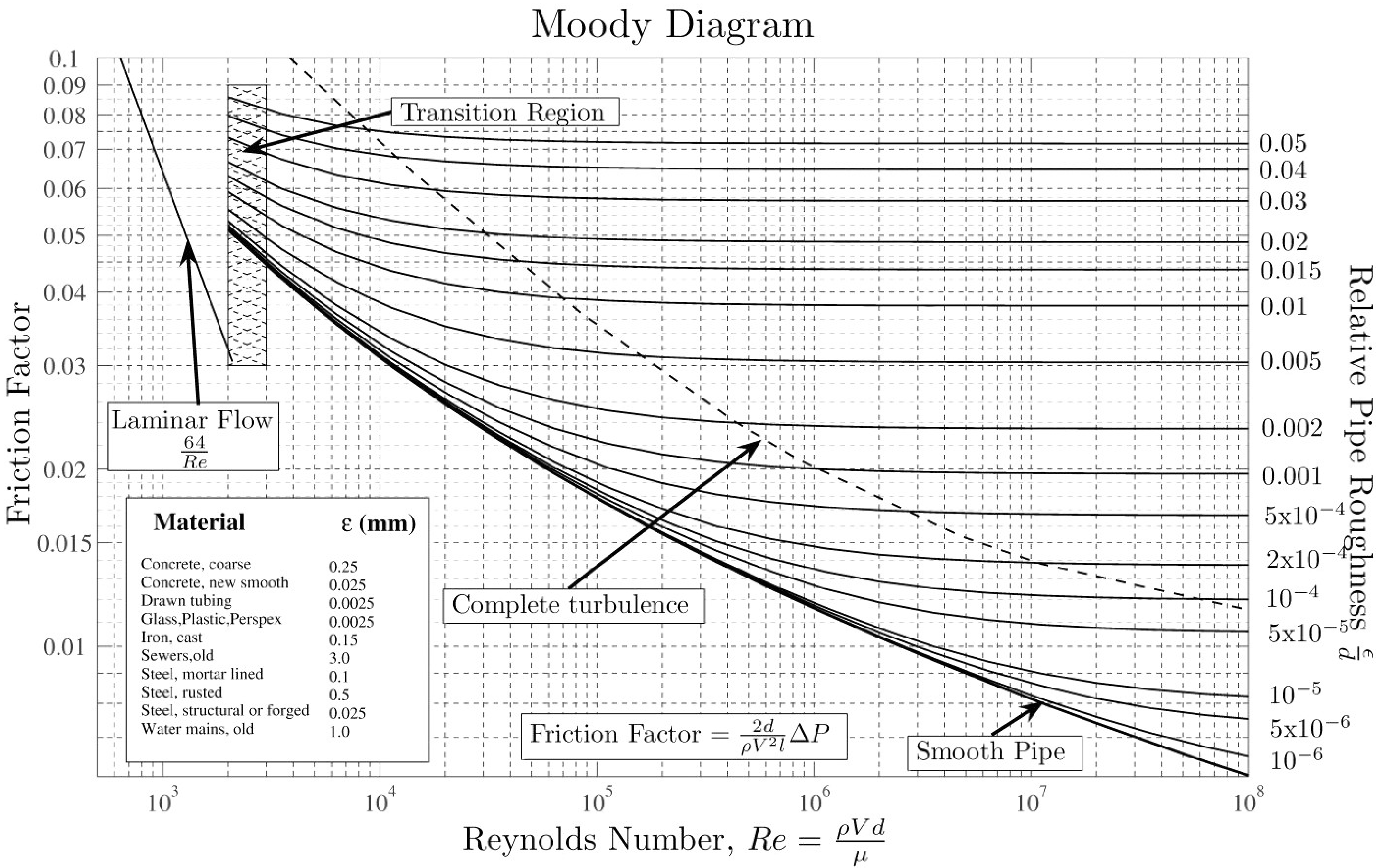
$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

f = Darcy friction factor, dimensionless
D = Inside diameter of pipe in meter
ε = Pipe surface roughness in meter
Re = Reynolds number, dimensionless

From this equation, Moody chart was developed.

Moody chart consist three (3) major parts;

1. Laminar region
2. Transition region
3. Turbulent region


Moody Diagram
Friction Factor
Reynolds Number, $Re = \frac{\rho V d}{\mu}$
Relative Pipe Roughness $\frac{\epsilon}{d}$
Transition Region
Laminar Flow
$\frac{64}{Re}$
Complete turbulence
Friction Factor $= \frac{2d}{\rho V^2 l}\Delta P$
Smooth Pipe
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.015
0.01
10^3
10^4
10^5
10^6
10^7
10^8
0.05
0.04
0.03
0.02
0.015
0.01
0.005
0.002
0.001
$5x10^{-4}$
$2x10^{-4}$
10^{-4}
$5x10^{-5}$
10^{-5}
$5x10^{-6}$
10^{-6}
Material
ε (mm)
Concrete, coarse 0.25
Concrete, new smooth 0.025
Drawn tubing 0.0025
Glass,Plastic,Perspex 0.0025
Iron, cast 0.15
Sewers,old 3.0
Steel, mortar lined 0.1
Steel, rusted 0.5
Steel, structural or forged 0.025
Water mains, old 1.0

Laminar region

The value of friction factor is proportional with Reynolds number.

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

A straight line could be plotted on the Moody chart.

Transition region

Friction will be affected with Reynolds number and internal pipe roughness.

Complete turbulent region

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

From equation above, high Reynolds number could lead to a very small value.

It is means that only internal pipe surface roughness would influence the friction value.

In Moody chart, the graph line would become a horizontal straight line.

Example

Water flows through 406.4 mm pipeline. It has 4.525 mm wall thickness. Flowrate is 11.36 m^3/min. Assuming a pipe roughness of 0.0508 mm, calculate the friction factor and head loss due to friction in 305 m of pipe length.

Flowrate, Q = 11.36 m^3/min = 0.189 m^3/s

Inner diameter = 406.4 – 2(9.525) = 387.35 mm = 0.38735 mm

$$\mathrm{Re} = \frac{\rho V D}{\mu} = 5.5 \times 10^5$$

$$\frac{\varepsilon}{D} = \frac{0.0000508}{0.38735} = 0.0001311 \approx 0.0001$$

From Moody chart, $f = 0.015$

$$\frac{P_A - P_B}{\rho g} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} = 1.54\,(\mathrm{m})$$

$$P_A - P_B = 15.2\,\mathrm{kPa}$$

Example

A concrete pipe, 2m inside diameter, is used to transport water from a pumping facility to a storage tank 5km away. Neglecting any difference in elevations, calculate the friction factor and pressure loss due to friction at a flow rate of 34,000m^3/h. Assume a pipe roughness of 0.05mm. If a delivery pressure of 4kPa must be maintained at the delivery point and the storage tank is at an elevation of 200m above that of the pumping facility, calculate the pressure required at the pumping facility at the given flow rate, using the Moody chart.

HAZEN-WILLIAMS EQUATION

A more popular approach to the calculation of head loss in water piping systems is the use of the Hazen-Williams equation.

In this method a coefficient *C* known as the Hazen-Williams *C* factor is used to account for the internal pipe roughness of efficiency.

Unlike the Moody chart or the Colebrook-White equation, the Hazen-Williams equation does not require use of the Reynolds number or viscosity of water to calculate the head loss due to friction.

The Hazen-Williams equation for head loss is expressed as follows:

For SI unit:

$$h_L = \frac{10.67 \cdot L}{D^{4.87}} \cdot \left(\frac{Q}{C}\right)^{1.852}$$

h = Frictional head loss in m
L = Length of pipe in m
D = Inside diameter of pipe in m
Q = Flow rate in m^3/s
C = Hazen-Williams *C* factor or roughness coefficient, dimensionless.

For British unit:

$$h_L = \frac{4.73 \cdot L}{D^{4.87}} \cdot \left(\frac{Q}{C}\right)^{1.852}$$

h = Frictional head loss in ft
L = Length of pipe in ft
D = Inside diameter of pipe in ft
Q = Flow rate in ft^3/s
C = Hazen-Williams C factor or roughness coefficient, dimensionless.

Note:

Above equation can be rearrange a follows:

$$S = \frac{h_L}{L}$$

where S is the hydraulic slope

Commonly used values of the Hazen-Williams *C* factor for various applications.

Pipe material	*C* factor
Smooth pipes (all metal)	130 – 140
Cast iron (old)	100
Iron (worn/pitted)	60 – 80
Polyvinyl chloride (PVC)	150
Brick	100
Smooth wood	120
Smooth masonry	120
Vitrified clay	110

MANNING EQUATION

The Manning equation was originally developed for use in open channel flow of water. It is also sometimes used in pipe flow.

The Manning equation uses the Manning index, *n* or roughness coefficient.

For SI unit:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} \cdot \left(\frac{h_L}{L} \right)^{\frac{1}{2}}$$

Q = Flow rate, m^3/s
A = cross sectional area of pipe, m^2
R = hydraulic radius (D/4 for circular pipes flowing full)
n = Manning index, or roughness coefficient, dimensionless
D = Inside diameter of pipe, m
h_L = Friction loss, m
L = Length of pipe, m

For British unit:

$$Q = \frac{1.486}{n} AR^{\frac{2}{3}} \cdot \left(\frac{h_L}{L}\right)^{\frac{1}{2}}$$

Q = Flow rate, ft^3/s
A = cross sectional area of pipe, ft^2
R = hydraulic radius (D/4 for circular pipes flowing full)
n = Manning index, or roughness coefficient, dimensionless
D = Inside diameter of pipe, ft
h_L = Friction loss, ft
L = Length of pipe, ft

Example of Manning index

Pipe material	Resistance factor
PVC	0.009
Very smooth	0.010
Cement-lined ductile iron	0.012
New cast iron, welded steel	0.014
Old cast iron, brick	0.020
Badly corroded cast iron	0.035
Wood, concrete	0.016
Clay, new riveted steel	0.017
Canals cut through rock	0.040
Earth canals average condition	0.023
Rivers in good conditions	0.030

MINOR LOSSES

Minor losses in a water pipeline are classified as those pressure drops that are associated with piping components such as valves and fitting.

There are included:
Elbow and tees
Pipe diameter enlargement / reduction
Nozzle
Entrance / exit losses

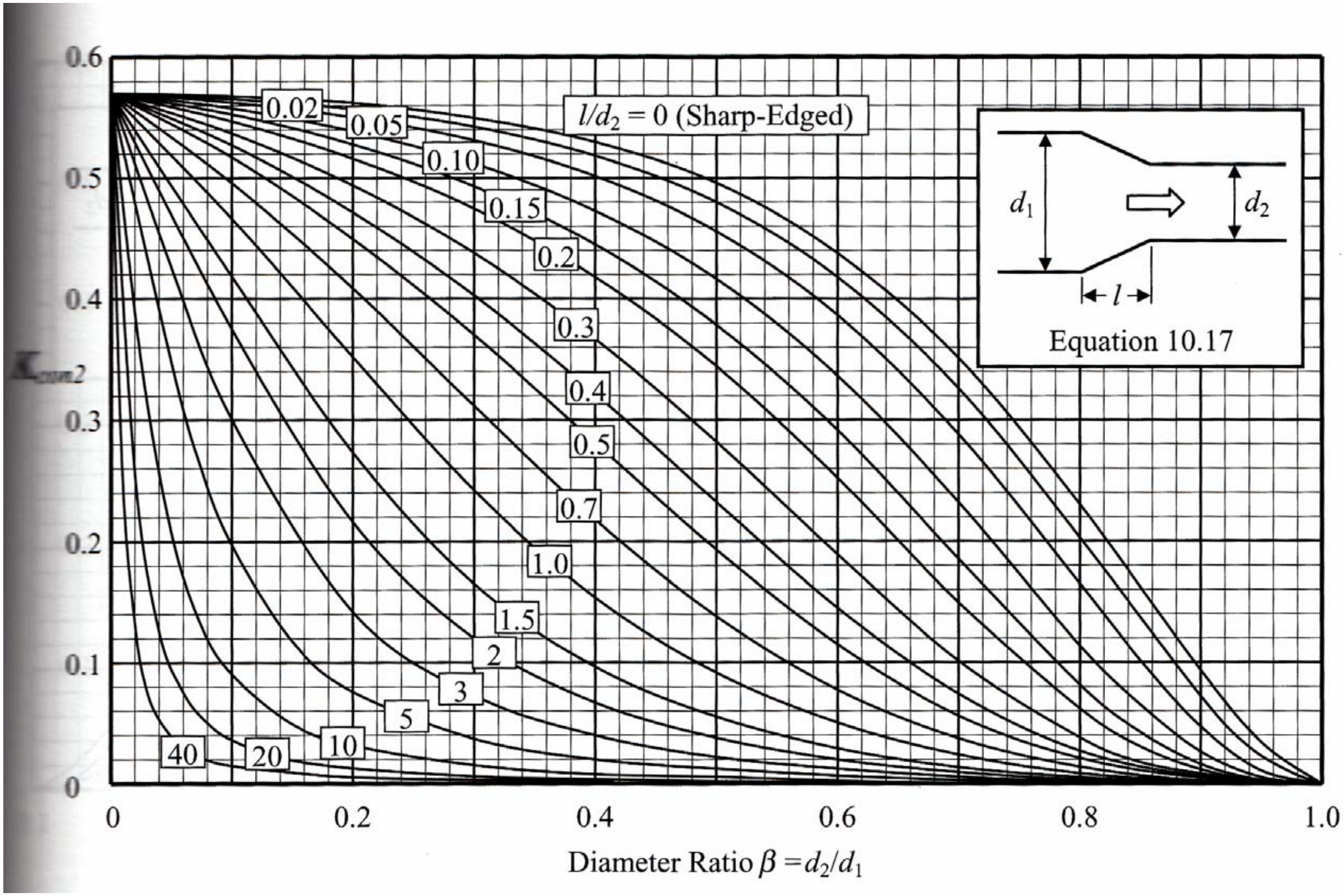
They are relatively small compared to friction loss in a straight length of pipe.

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

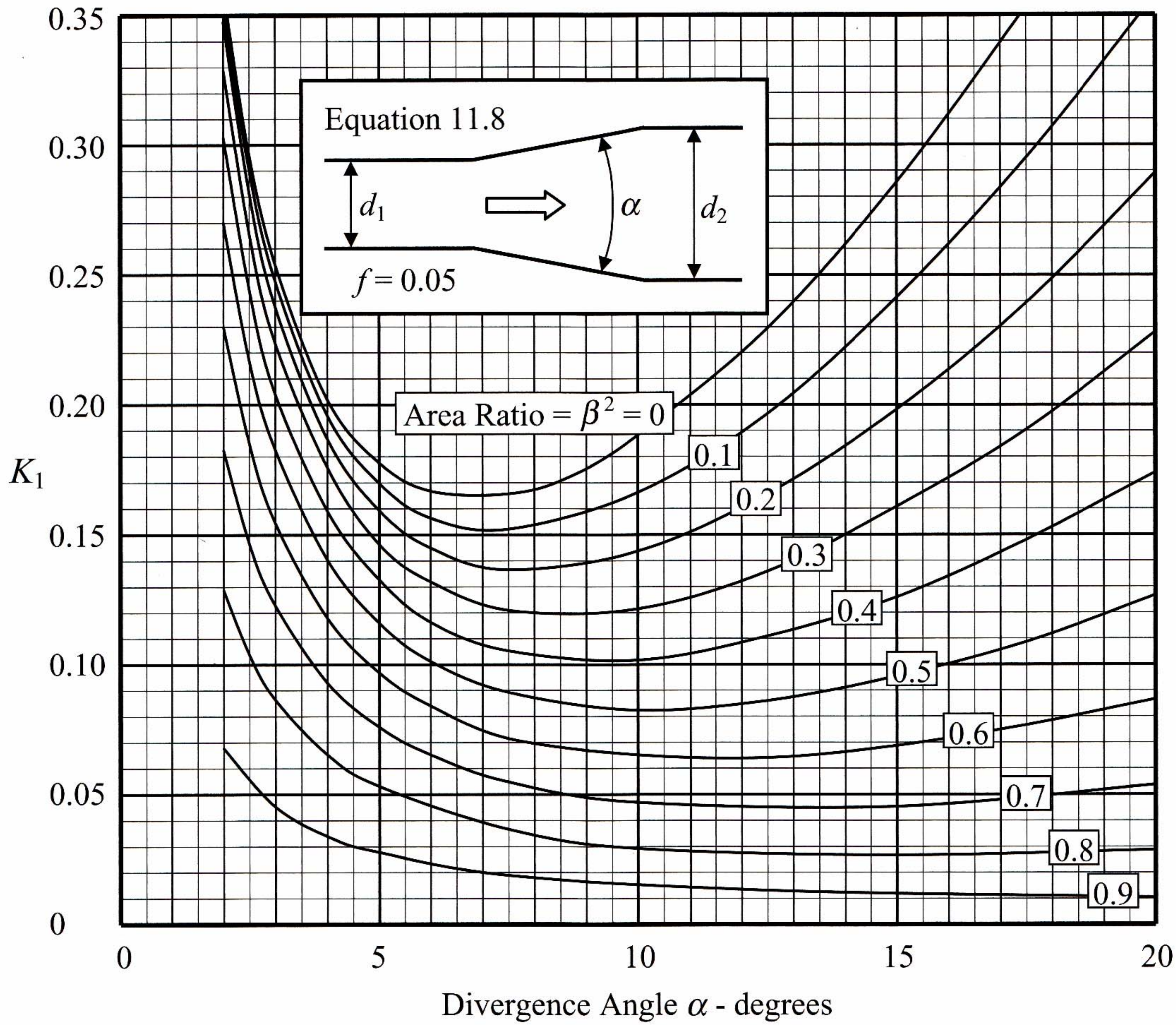
Where *K* is a resistance factor.

It must be noted that this way calculating the minor losses is valid only in turbulent flow. No data are available for laminar flow.

Some engineers use the equivalent length to determine minor losses.



K_{con2}
0.6
0.5
0.4
0.3
0.2
0.1
0
$l/d_2 = 0$ (Sharp-Edged)
0.02
0.05
0.10
0.15
0.2
0.3
0.4
0.5
0.7
1.0
1.5
2
3
5
10
20
40
d_1
d_2
l
Equation 10.17
0
0.2
0.4
0.6
0.8
1.0
Diameter Ratio $\beta = d_2/d_1$



Equation 11.8
d_1
α
d_2
$f = 0.05$
Area Ratio = β^2 = 0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
K_1
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
5
10
15
20
Divergence Angle α - degrees

TABLE 1.6 Friction Loss in Valves—Resistance Coefficient *K*

		Nominal pipe size, in											
Description	L/D	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$–3	4	6	8–10	12–16	18–24
Gate valve	8	0.22	0.20	0.18	0.18	0.15	0.15	0.14	0.14	0.12	0.11	0.10	0.10
Globe valve	340	9.20	8.50	7.80	7.50	7.10	6.50	6.10	5.80	5.10	4.80	4.40	4.10
Angle valve	55	1.48	1.38	1.27	1.21	1.16	1.05	0.99	0.94	0.83	0.77	0.72	0.66
Ball valve	3	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
Plug valve straightway	18	0.49	0.45	0.41	0.40	0.38	0.34	0.32	0.31	0.27	0.25	0.23	0.22
Plug valve 3-way through-flow	30	0.81	0.75	0.69	0.66	0.63	0.57	0.54	0.51	0.45	0.42	0.39	0.36
Plug valve branch flow	90	2.43	2.25	2.07	1.98	1.89	1.71	1.62	1.53	1.35	1.26	1.17	1.08
Swing check valve	50	1.40	1.30	1.20	1.10	1.10	1.00	0.90	0.90	0.75	0.70	0.65	0.60
Lift check valve	600	16.20	15.00	13.80	13.20	12.60	11.40	10.80	10.20	9.00	8.40	7.80	7.22
Standard elbow													
90°	30	0.81	0.75	0.69	0.66	0.63	0.57	0.54	0.51	0.45	0.42	0.39	0.36
45°	16	0.43	0.40	0.37	0.35	0.34	0.30	0.29	0.27	0.24	0.22	0.21	0.19
Long radius 90°	16	0.43	0.40	0.37	0.35	0.34	0.30	0.29	0.27	0.24	0.22	0.21	0.19
Standard tee													
Through-flow	20	0.54	0.50	0.46	0.44	0.42	0.38	0.36	0.34	0.30	0.28	0.26	0.24
Through-branch	60	1.62	1.50	1.38	1.32	1.26	1.14	1.08	1.02	0.90	0.84	0.78	0.72
Mitre bends													
$\alpha = 0$	2	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02
$\alpha = 30$	8	0.22	0.20	0.18	0.18	0.17	0.15	0.14	0.14	0.12	0.11	0.10	0.10
$\alpha = 60$	25	0.68	0.63	0.58	0.55	0.53	0.48	0.45	0.43	0.38	0.35	0.33	0.30
$\alpha = 90$	60	1.62	1.50	1.38	1.32	1.26	1.14	1.08	1.02	0.90	0.84	0.78	0.72

SIMPLIFICATION OF MAJOR LOSS CALCULATION

Head loss due to friction;

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

From continuity equation,

$$Q = AV = \frac{\pi D^2}{4} V \quad \Rightarrow \quad V = \frac{4Q}{\pi D^2} \quad \Rightarrow \quad V^2 = \frac{16Q^2}{\pi^2 D^4}$$

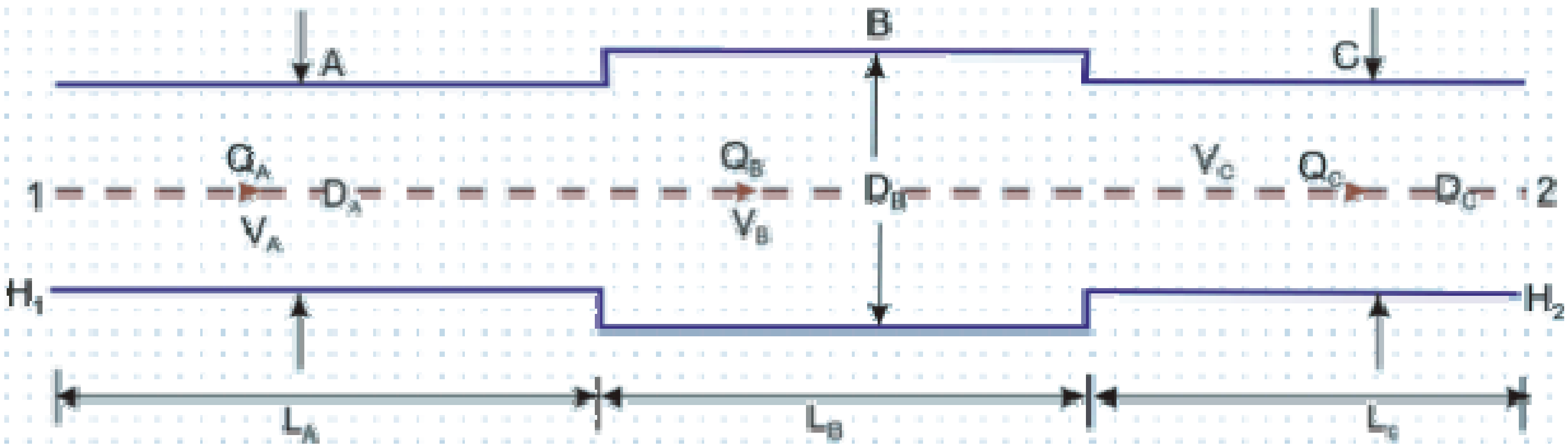
Head loss equation can be written as:

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} = f \cdot \frac{L}{D^5} \cdot \frac{16}{2g\pi^2} \cdot Q^2$$

$$h_L = K \cdot Q^2$$

Usually, for turbulent flow, $h_L = K \cdot Q^2$

<u>Major losses in series pipe</u>



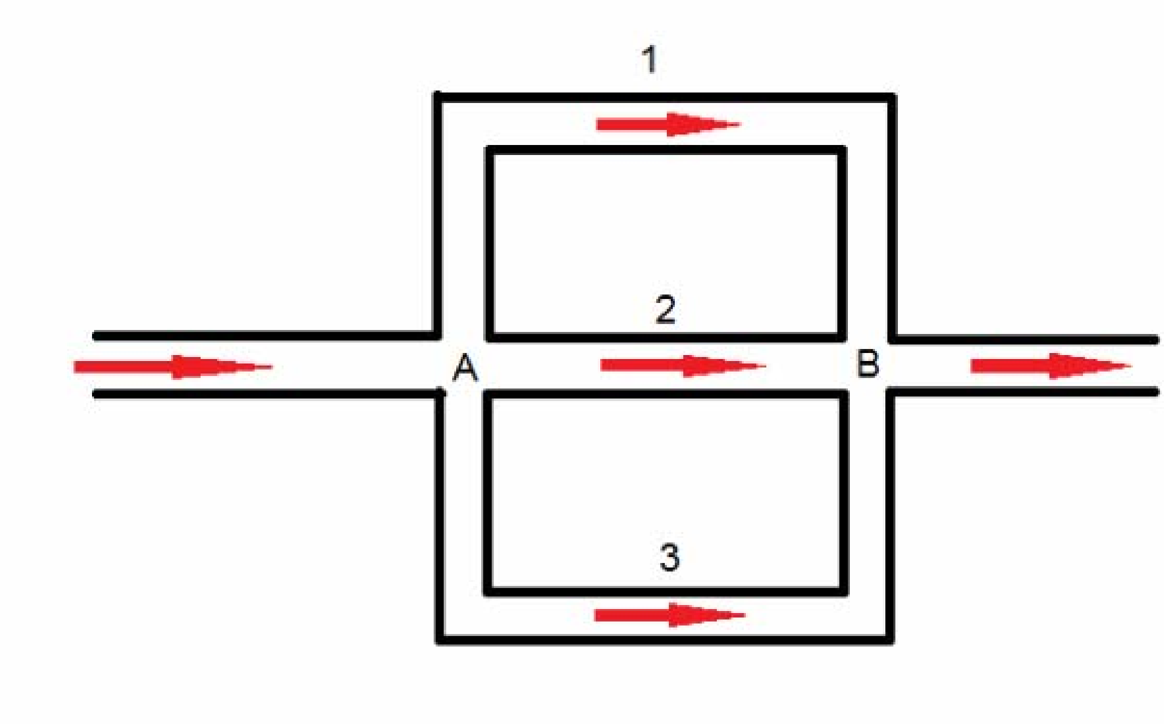
Flow rate is constant

$$Q = Q_A = Q_B = Q_C$$

Major losses keep increasing

$$\sum h_L = h_A + h_B + h_C = (K_A + K_B + K_c) \cdot Q^2$$

Major losses in parallel pipe



Flow rate is constant at inlet and outlet (only)

$$Q_A = Q_B$$

However, flow rate for pipe 1, 2 and 3 are different.

$$Q_A = Q_B = Q_1 + Q_2 + Q_3$$

Major losses are constant for pipe 1, 2 and 3.

$$\sum h_L = h_1 = h_2 = h_3$$

$$h_L = KQ^2 \quad \Rightarrow \quad Q = \sqrt{\frac{h_L}{K}}$$

$$Q_A = Q_B = Q_1 + Q_2 + Q_3$$

$$\sqrt{\frac{h_L}{K}} = \sqrt{\frac{h_L}{K_1}} + \sqrt{\frac{h_L}{K_2}} + \sqrt{\frac{h_L}{K_3}}$$

$$\frac{1}{\sqrt{K}} = \frac{1}{\sqrt{K_1}} + \frac{1}{\sqrt{K_2}} + \frac{1}{\sqrt{K_3}}$$