Minor Losses In Pipe

HYDRAULICS CE 322

FRICTION LOSS EQUATION

$$hf = \frac{fLV^2}{2gD}$$

The most popular pipe flow equation was derived by Henry Darcy (1803 to 1858), Julius Weischbach(1806 to 1871), and the others about the middle of the nineteenth century.

- The equation takes the following form and is commonly known as the Darcy-Weisbach Equation.

Table 22.1 Roughness Heights ,e, for Certain Common Materials

Pipe Material	e (mm)	e (ft)
Brass	0.0015	0.000005
Concrete		
Steel forms, smooth	0.18	0.0006
Good joints, average	0.36	0.0012
Rough, visible form marks	0.60	0.002
Copper	0.0015	0.000005
Corrugated metal (CMP)	45	0.15
Iron (common in older water lines, except ductile or DIP, which is widely used today)		
Asphalt lined	0.12	0.0004
Cast	0.26	0.00085
Ductile; DIP—cement mortar lined	0.12	0.0004
Galvanized	0.15	0.0005
Wrought	0.045	0.00015
Polyvinyl chloride (PVC)	0.0015	0.000005
Polyethylene, high density (HDPE)	0.0015	0.000005
Steel		
Enamel coated	0.0048	0.000016
Riveted	0.9 ~ 9.0	0.003–0.03
Seamless	0.004	0.000013
Commercial	0.045	0.00015

Turbulent flow or laminar flow

Reynolds Number (NR) < 2000 laminar flow

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

Reynolds Number (NR) ≥ 4000 turbulent flow;

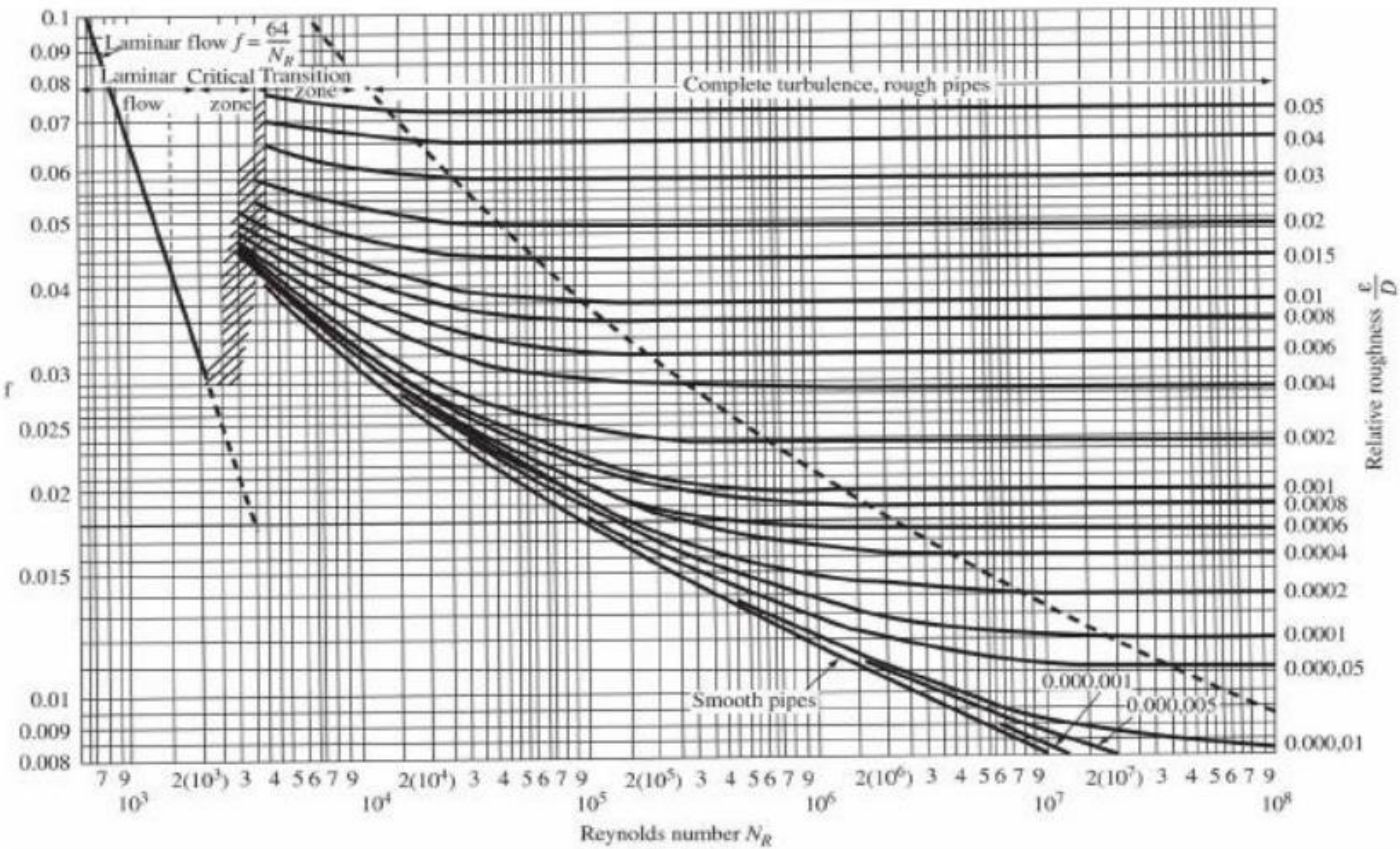
the value of friction factor (f) then becomes less dependent on the Reynolds Number but more dependent on **the relative roughness (e/D) of the pipe.**

Friction factor can be found in:

1. Graphical solution: Moody Diagram

2. Implicit equations : Colebrook-White Equation

Moody Diagram



Colebrook-White Equation:

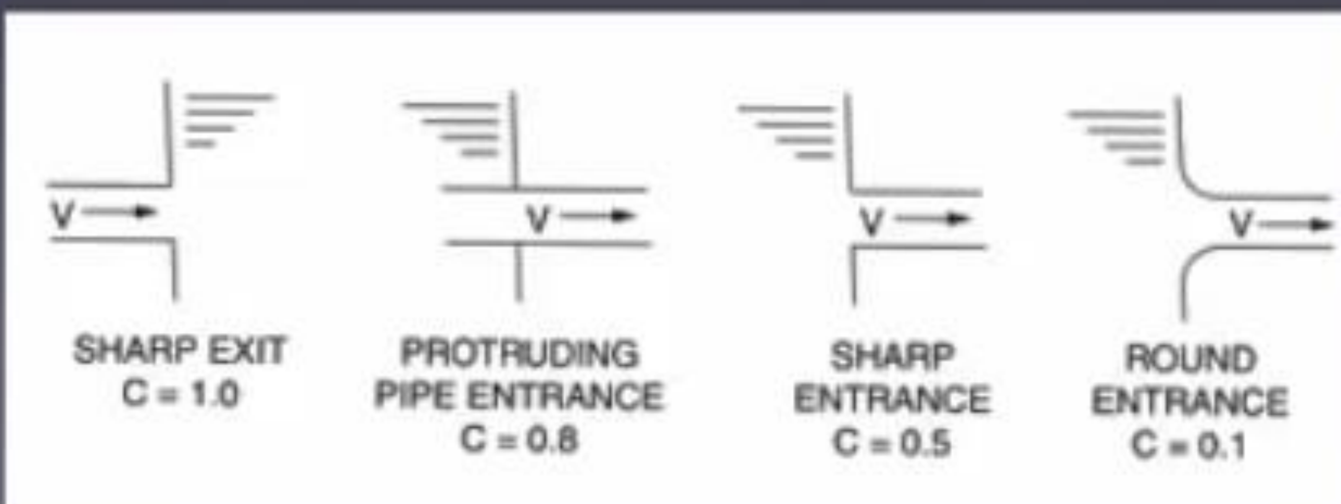
$$\frac{1}{\sqrt{f}} = -\log\left(\frac{\frac{e}{D}}{3.7} + \frac{2.51}{N_R\sqrt{f}}\right)$$

Minor Losses

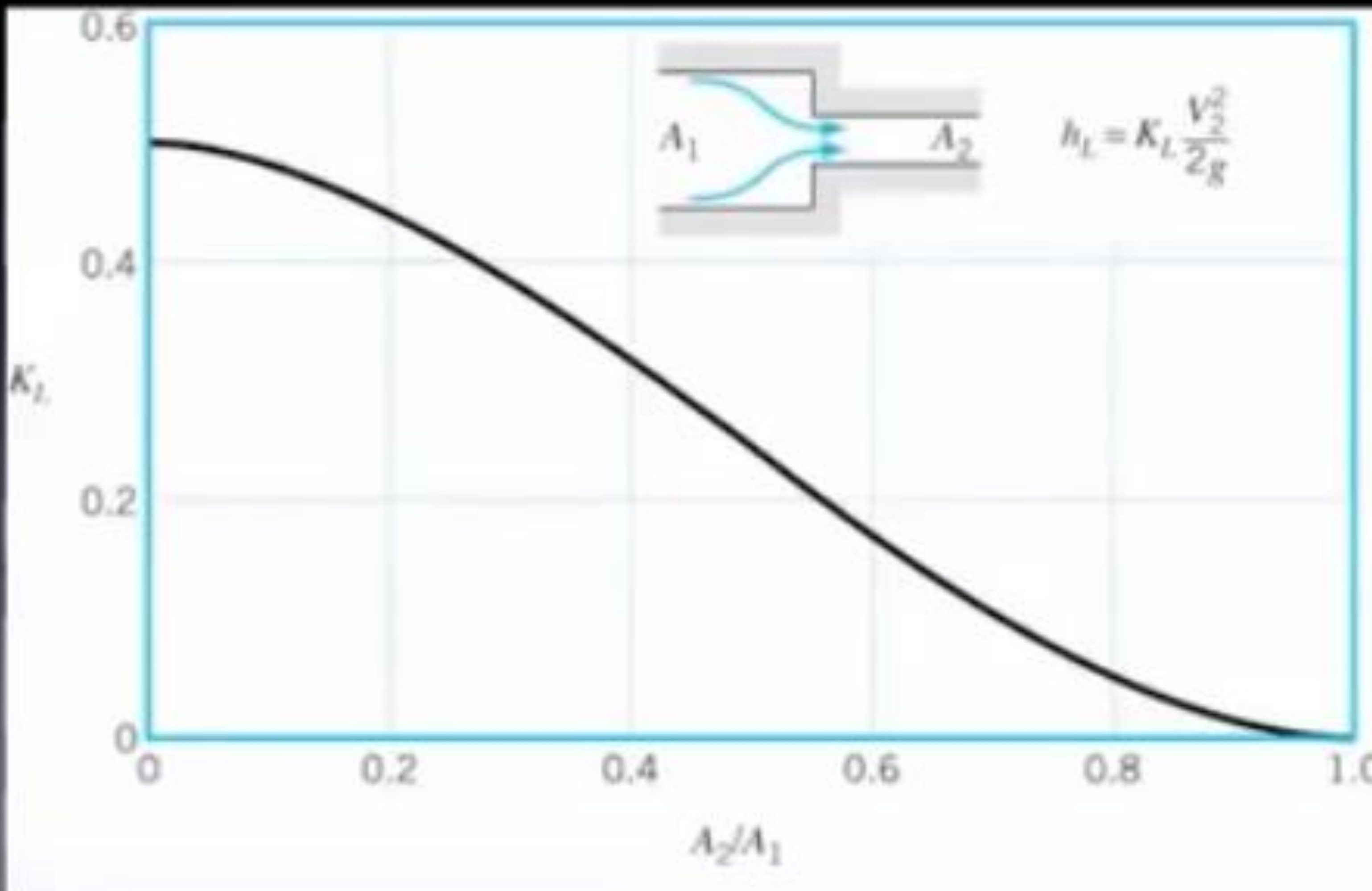
- valves, bends, tees, ...

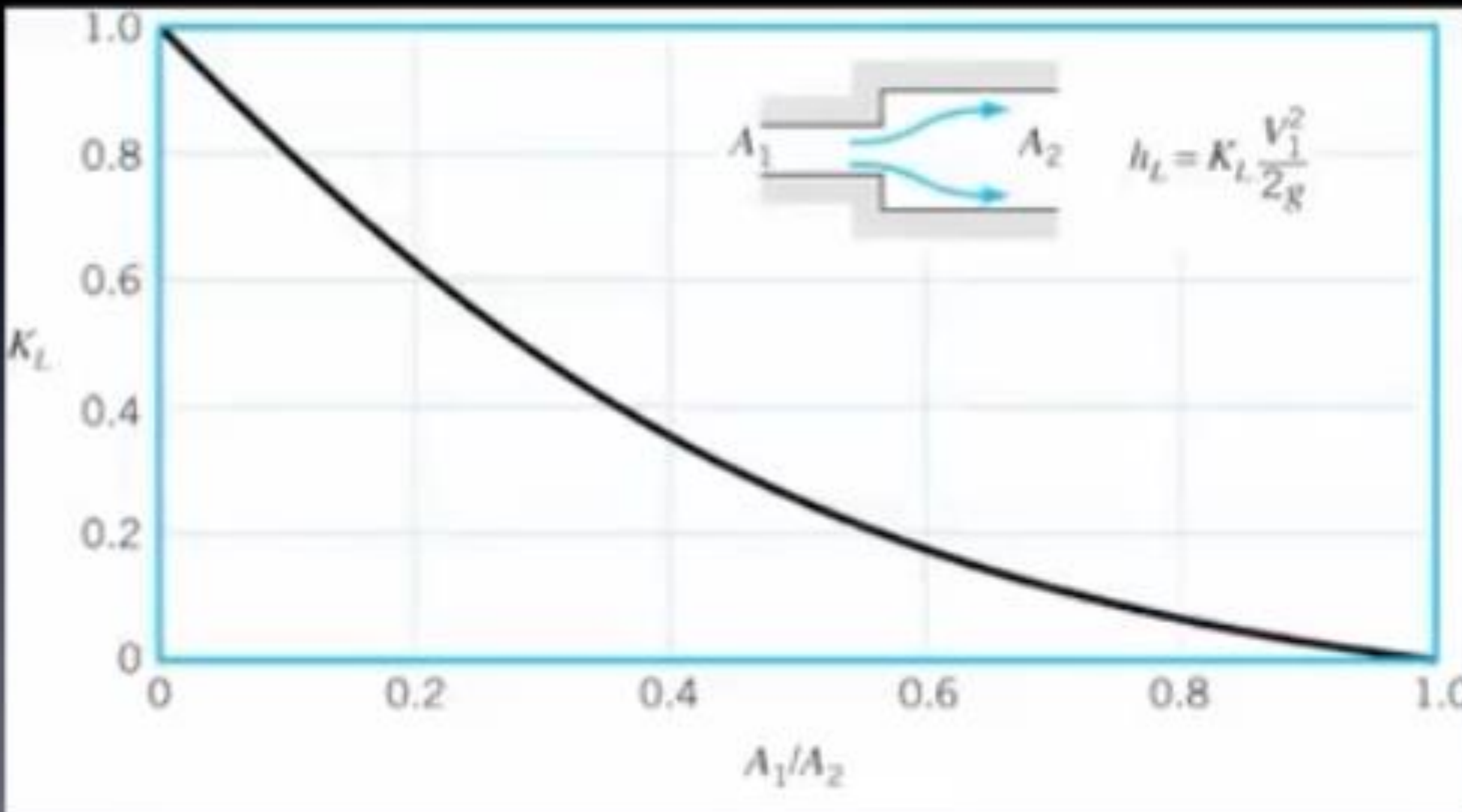
$$h_L = \sum K_L \frac{V^2}{2g}$$

1. Pipe Exits and Entrances



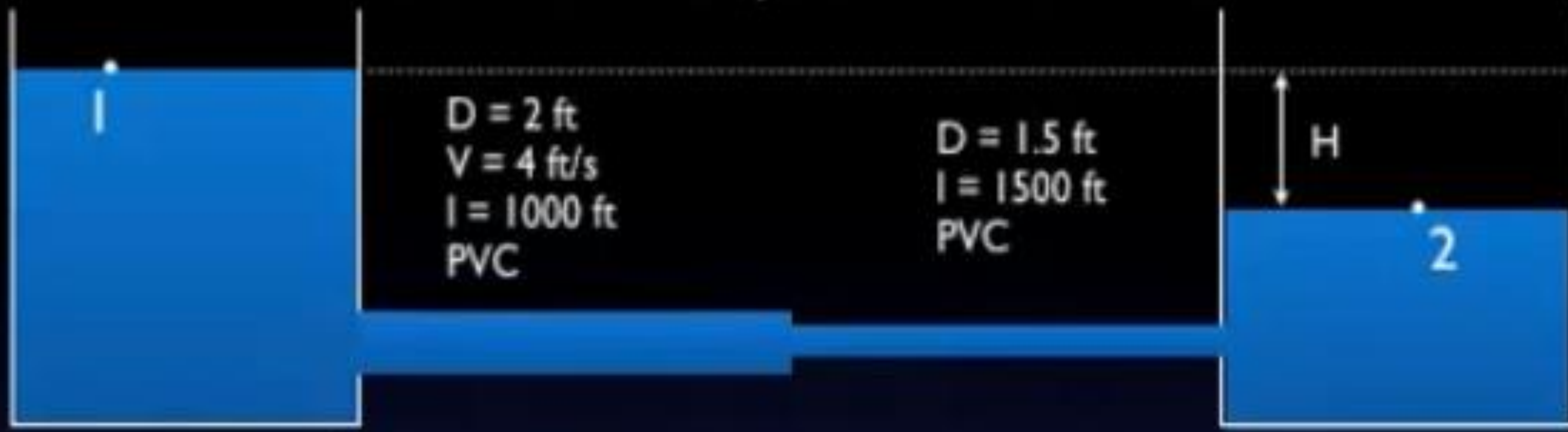
2. Contractions and Expansions





1.0
0.8
0.6
0.4
0.2
0
K_L
0
0.2
0.4
0.6
0.8
1.0
A_1/A_2
A_1
A_2
$h_L = K_L \frac{V_1^2}{2g}$

ex. determine H, consider all losses



$$\frac{P_1}{\gamma} + \frac{\alpha_1 v_1^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \frac{\alpha_2 v_2^2}{2g} + z_2 + h_L \qquad H = h_L$$

(terms P_1/γ, $\alpha_1 v_1^2/2g$, h_p, P_2/γ, $\alpha_2 v_2^2/2g$ crossed out → 0)

$$H = f_1 \frac{l_1 V_1^2}{D_1 2g} + f_2 \frac{l_2 V_2^2}{D_2 2g} + K_{L,en}\frac{V_1^2}{2g} + K_{L,ex}\frac{V_2^2}{2g} + K_{L,c}\frac{V_2^2}{2g}$$

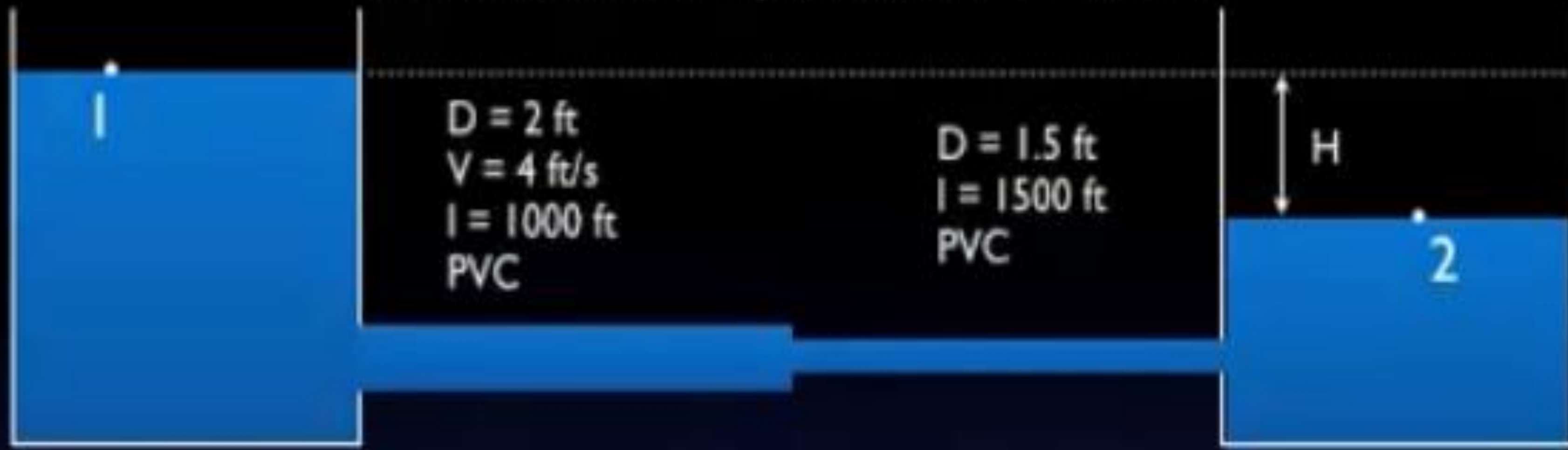
$$V_1 A_1 = V_2 A_2$$

$$K_{L,en} = 0.5 \quad K_{L,c} = 0.20$$

$$K_{L,ex} = 1.0$$

$$V_2 = \frac{A_1 V_1}{A_2} = \frac{D_1^2 V_1}{D_2^2} = \frac{2^2 \cdot 4}{1.5^2} = 7.11\ ft/s$$

ex. determine H, consider all losses



$$Re_1 = \frac{V_1 D_1}{\nu} = \frac{4 \cdot 2}{1.21 \times 10^{-5}} = 6.61 \times 10^5$$

$$Re_2 = \frac{V_2 D_2}{\nu} = \frac{7.11 \cdot 1.5}{1.21 \times 10^{-5}} = 8.81 \times 10^5$$

$f_1 = 0.0125$ $f_2 = 0.0120$

$$H = 0.0125\frac{1000 \cdot 4^2}{2 \cdot 2 \cdot 32.2} + 0.012\frac{1500 \cdot 7.11^2}{1.5 \cdot 2 \cdot 32.2}$$

$$+0.5\frac{4^2}{2 \cdot 32.2} + 1.0\frac{7.11^2}{2 \cdot 32.2} + 0.2\frac{7.11^2}{2 \cdot 32.2}$$

major losses

minor losses

$$H = 10.97 \qquad + 1.10$$

$$H = 12.1\ ft$$

often insignificant and ignore

"ignore minor losses"

MINOR LOSS

$$H_m = K \cdot \frac{V^2}{2g}$$

Losses caused by fittings, bends, valves etc.

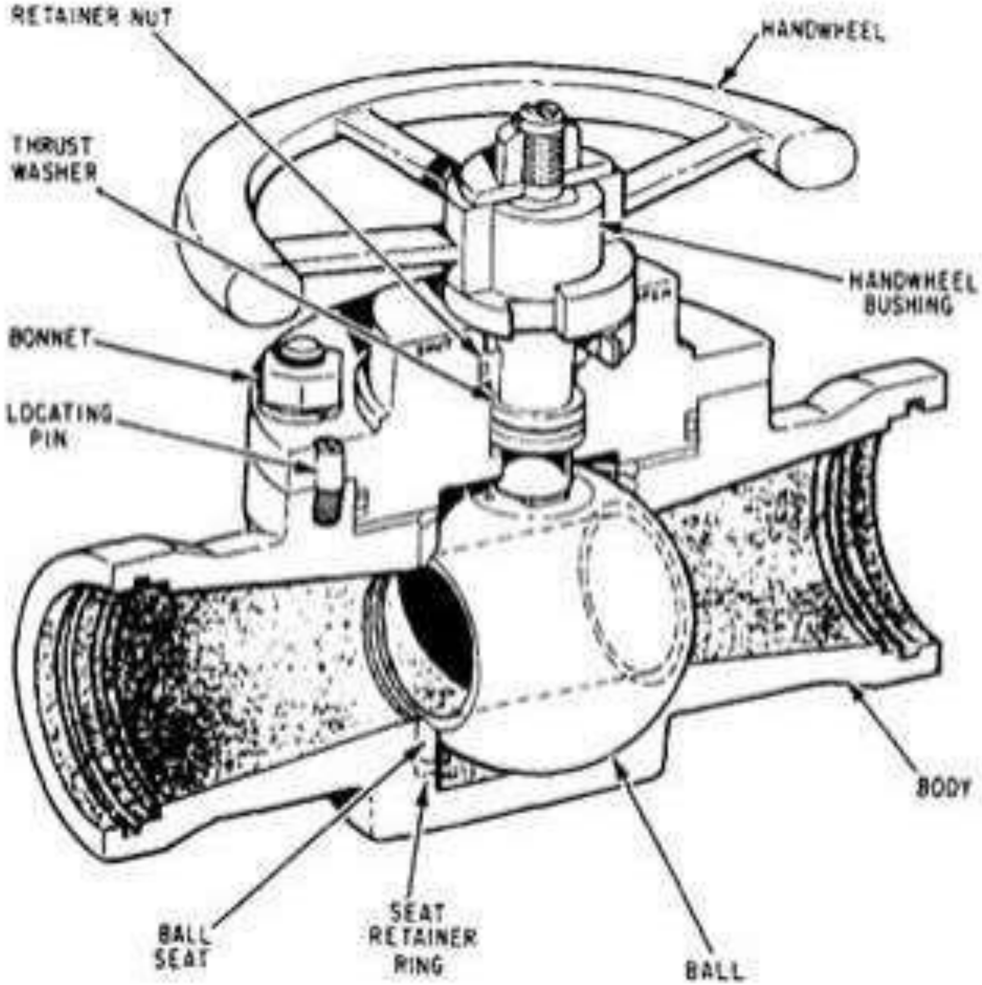
Each type of loss can be quantified using a loss coefficient (K).

Losses are proportional to velocity of flow and geometry of device.

- In addition to head loss due to friction, there are always other head losses due to pipe expansions and contractions, bends, valves, and other pipe fittings. These losses are usually known as **minor losses (h_{Lm})**.

- In case of a long pipeline, the minor losses maybe negligible compared to the friction losses, however, in the case of short pipelines, their contribution may be significant.

- Losses caused by fittings, bends, valves, etc…


RETAINER NUT
HANDWHEEL
THRUST WASHER
HANDWHEEL BUSHING
BONNET
LOCATING PIN
BODY
BALL SEAT
SEAT RETAINER RING
BALL


1
2
3
4
5
11
12
13
14
6
10
9
8
7

- Minor in comparison to friction losses which are considered major.
- Losses are proportional to – velocity of flow, geometry of device.

$$h_L = K\ (v^2 / 2g)$$

- The value of K is typically provided for various devices.
- Energy lost – units – N.m/N or lb-ft/lb
- K - loss factor - has no units (dimensionless).

MINOR LOSSES DUE TO : →

$$h_{Lm} = K \frac{V^2}{2g}$$

where ,

h_{Lm} = minor loss

K = minor loss coefficient

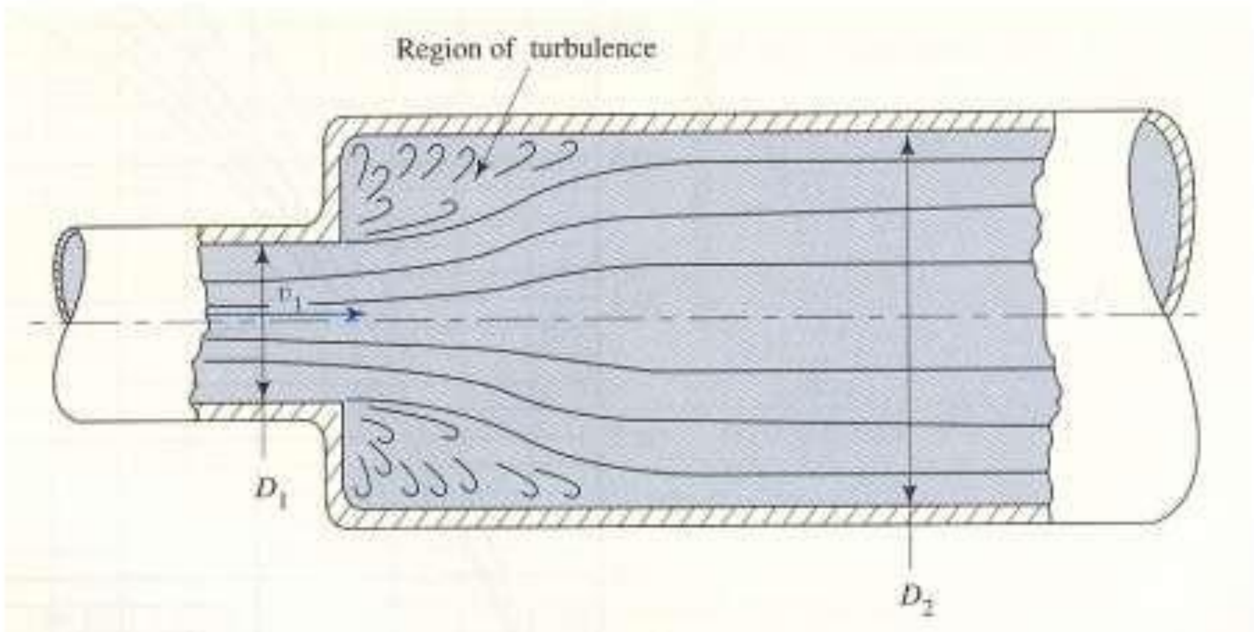
V = mean flow velocity

Type	K
Exit (pipe to tank)	1.0
Entrance (tank to pipe)	0.5
90 elbow	0.9
45 elbow	0.4
T-junction	1.8
Gate valve	0.25 - 25

Table 6.2: Typical K values

SUDDEN ENLARGEMENT

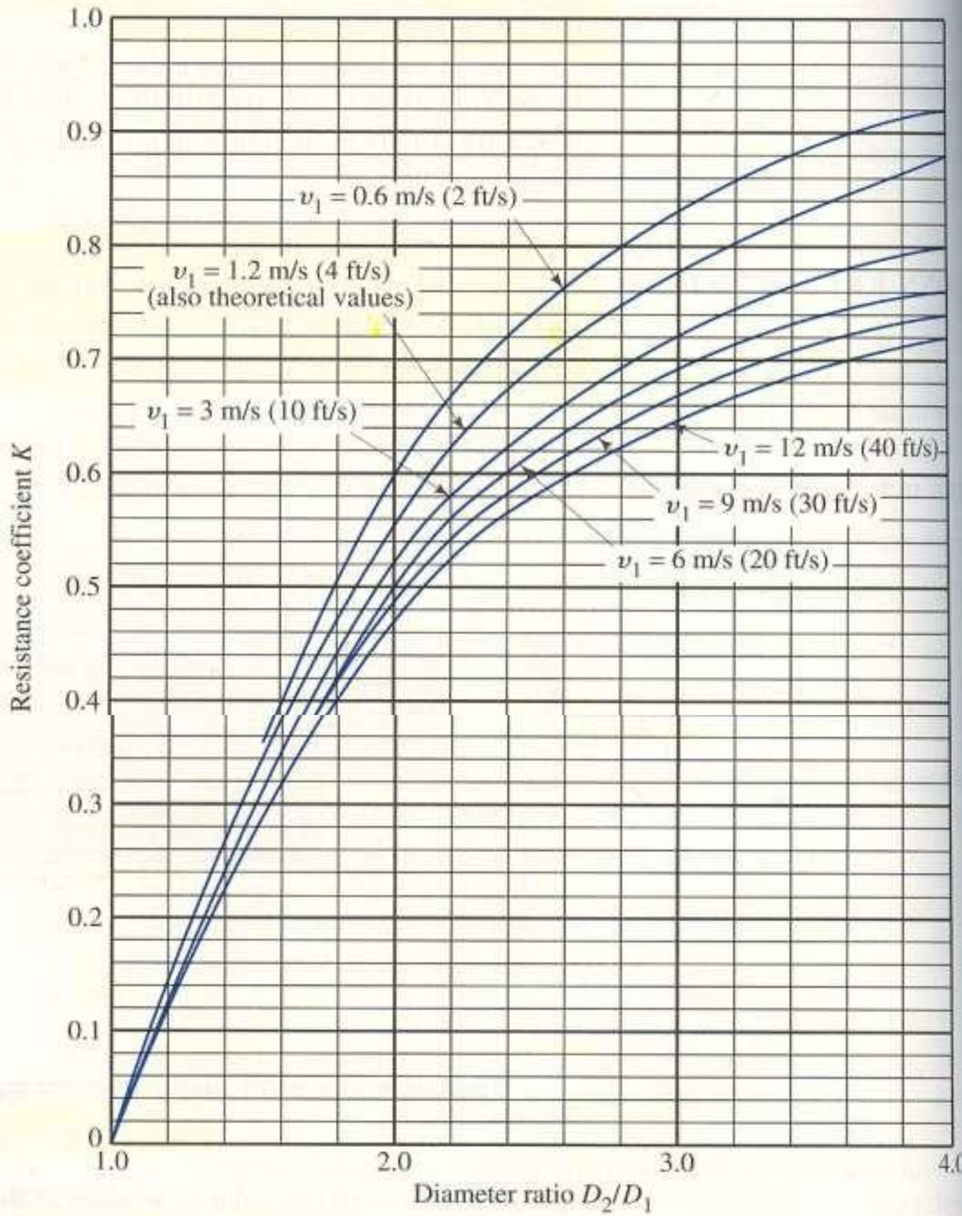
- As fluid flows from a smaller pipe into a larger pipe through sudden enlargement, its velocity abruptly decreases; causing turbulence that generates an energy loss.
- The amount of turbulence, and therefore the amount of energy, is dependent on the ratio of the sizes of the two pipes.


Region of turbulence
D_1
D_2

- **Energy lost is because of turbulence.** Amount of turbulence depends on the differences in pipe diameters.

$$h_L = K\,(v^2/2g)$$

- The values of K have been experimentally determined and provided in Figure 10.2 and Table 10.1.



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Resistance coefficient K
v_1 = 0.6 m/s (2 ft/s)
v_1 = 1.2 m/s (4 ft/s)
(also theoretical values)
v_1 = 3 m/s (10 ft/s)
v_1 = 12 m/s (40 ft/s)
v_1 = 9 m/s (30 ft/s)
v_1 = 6 m/s (20 ft/s)
1.0
2.0
3.0
4.0
Diameter ratio D_2/D_1

BLE 10.1 Resistance coefficient—sudden enlargement

D_2/D_1	Velocity v_1 0.6 m/s 2 ft/s	1.2 m/s 4 ft/s	3 m/s 10 ft/s	4.5 m/s 15 ft/s	6 m/s 20 ft/s	9 m/s 30 ft/s	12 m/s 40 ft/s
[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	0.11	0.10	0.09	0.09	0.09	0.09	0.08
[illegible]	0.26	0.25	0.23	0.22	0.22	0.21	0.20
[illegible]	0.40	0.38	0.35	0.34	0.33	0.32	0.32
[illegible]	0.51	0.48	0.45	0.43	0.42	0.41	0.40
[illegible]	0.60	0.56	0.52	0.51	0.50	0.48	0.47
[illegible]	0.74	0.70	0.65	0.63	0.62	0.60	0.58
[illegible]	0.83	0.78	0.73	0.70	0.69	0.67	0.65
[illegible]	0.92	0.87	0.80	0.78	0.76	0.74	0.72
[illegible]	0.96	0.91	0.84	0.82	0.80	0.77	0.75
[illegible]	1.00	0.96	0.89	0.86	0.84	0.82	0.80
[illegible]	1.00	0.98	0.91	0.88	0.86	0.83	0.81

urce: King, H. W., and E. F. Brater. 1963. *Handbook of Hydraulics*. 5th ed. New York: McGraw-Hill. Table 6-7.

D2/D1 = 1.0 -> 10.0 -> to infinity

- Analytical expression of K - If the velocity v_1 < 1.2 m/s or 4 ft/s, the K values can be given as :

› $K = [\ 1-(A_1/A_2)\ ]^2 = [\ 1-(D_1/D_2)^2\ ]^2$

Example 1

- Determine energy loss when 100 L/min of water moved from 1" copper tube to 3" copper tube.
- **Procedure** - Find velocity of flow and then find K.

- $D_1 = 25.3$ mm
- $A_1 = 0.0005017 \, m^2$

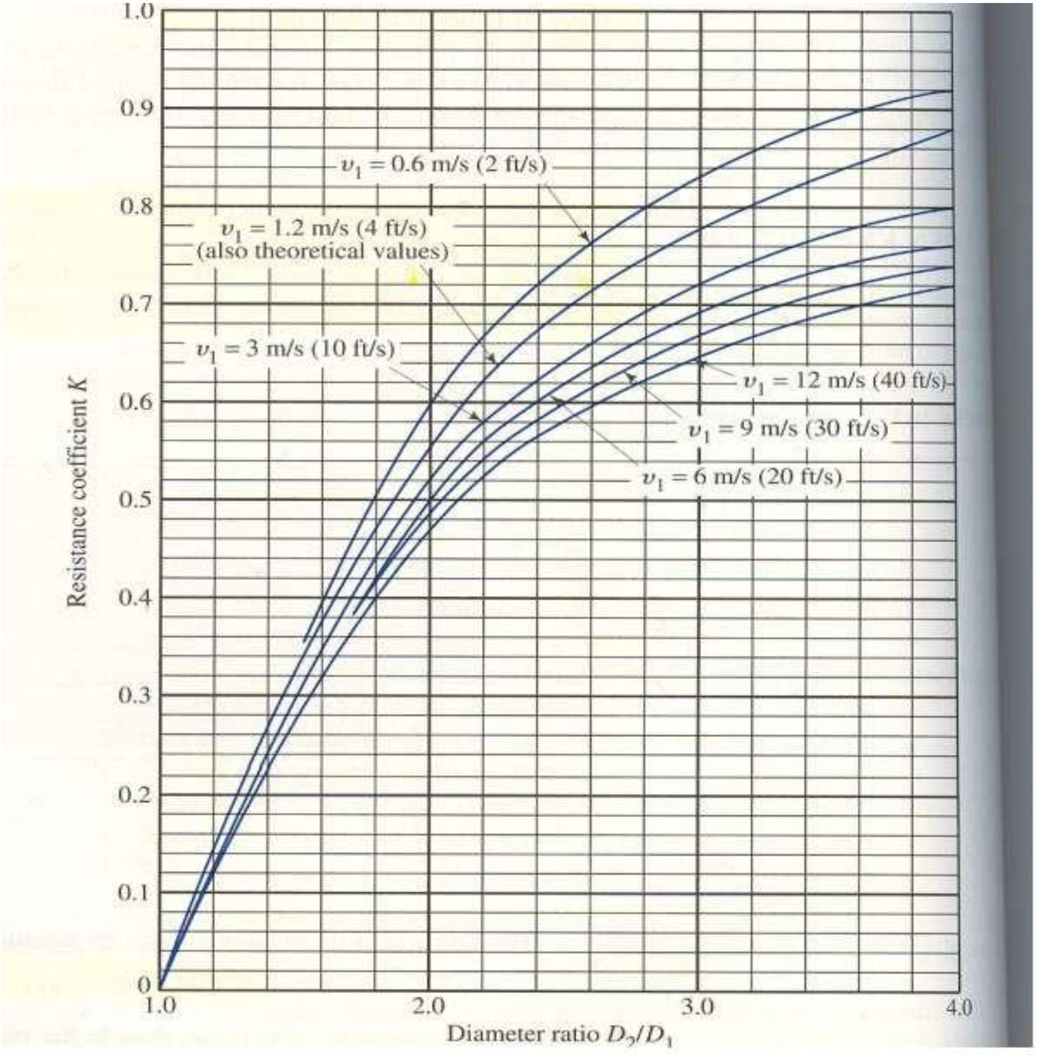
- $D_2 = 73.8$ mm
- $A_2 = 0.004282 \, m^2$

- $V_1 = Q_1/A_1 = [(100 \text{ L/min})/(60{,}000)] / 0.0005017 = 3.32$ m/s

(convert L/min to m^2/s)

$D_2/D_1 = 2.92$

Use graph – Figure 2



– $K = 0.72$

Therefore,

– $h_L = 0.72 * (3.32)^2 / 2 * 9.81 = 0.40\ m$

Example problem 2

- **Determine the pressure difference between the two pipes of the previous problem**

$$p_1/\gamma + z_1 + v_1^2/2g - h_L = p_2/\gamma + z_2 + v_2^2/2g$$

rearrange

$$p_1 - p_2 = \gamma[(z_2 - z_1) + (v_2^2 - v_1^2)/2g + h_L)]$$

$v_2 = Q/A_2 = 0.39\ m/s$

$$p_1 - p_2 = \gamma[(z_2 - z_1) + (v_2^2 - v_1^2)/2g + h_L)]$$

$$p_1 - p_2 = 9.81\ [\ 0 + ((0.39)^2 - (3.32)^2)/(2*9.81) + 0.40]$$

Only minor loss is considered because of short pipe length.

$$p_1 - p_2 = -1.51\ kPa$$

$$p_2 > p_1.$$

SUDDEN CONTRACTION

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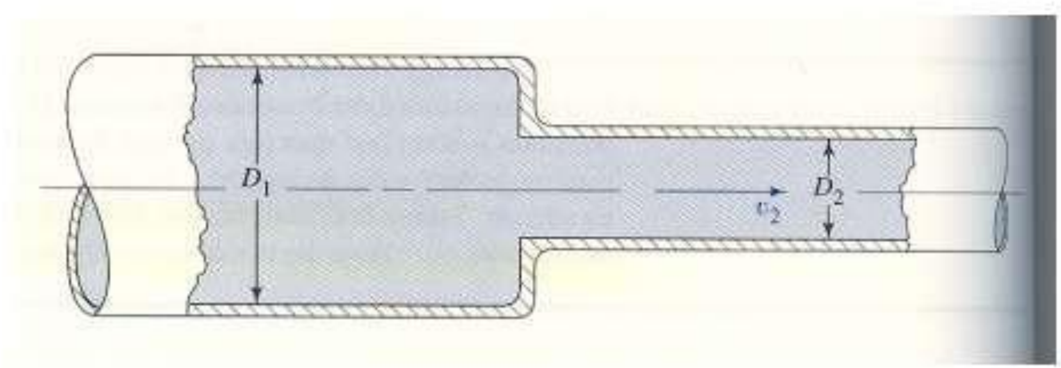


Loss is given by –

$$h_L = K(v_2^2/2g)$$

Note that the loss is related to the velocity in the second (smaller) pipe!

The loss is associated with the contraction of flow and turbulence –

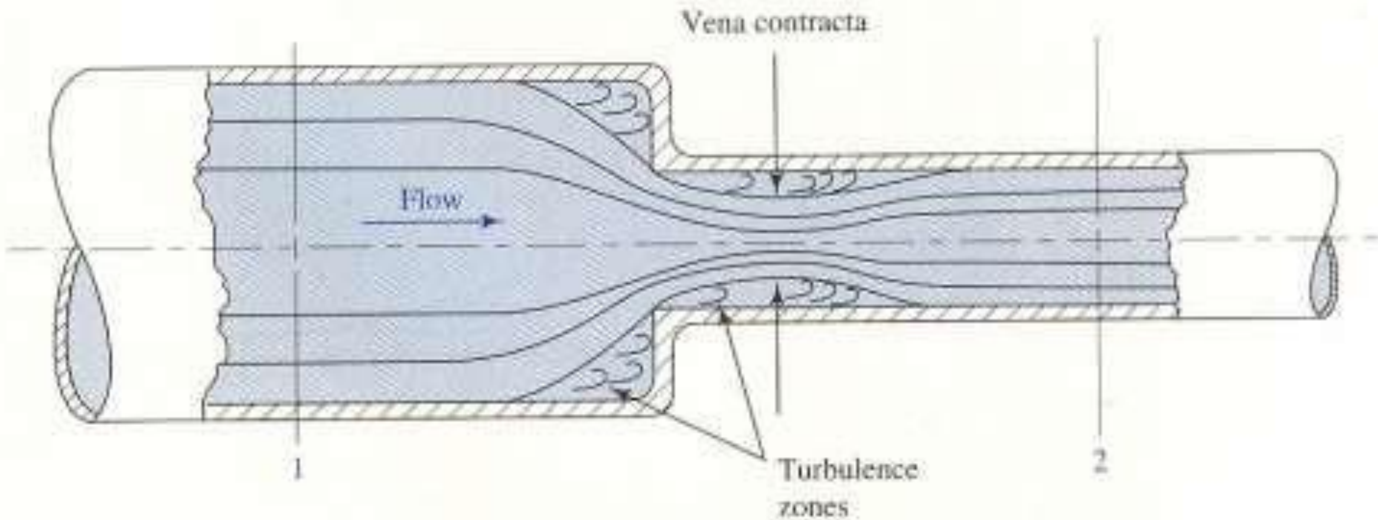
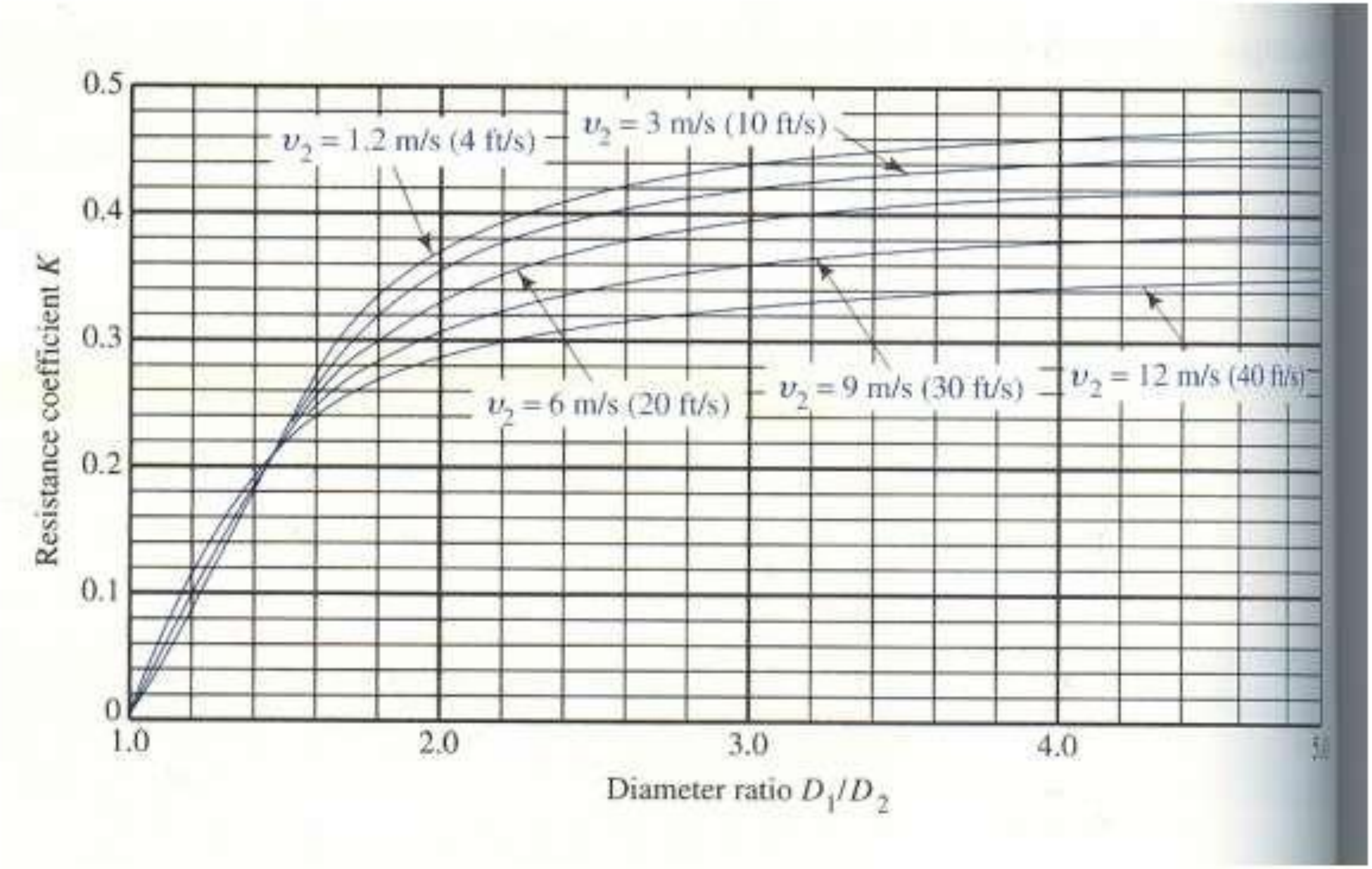


FIGURE 10.8 Vena contracta formed in a sudden contraction.

- The section at which the flow is the narrowest – Vena Contracta
- At vena contracta, the velocity is maximum.

K can be computed using **Figure 10.7 and table 10.3** –
Again based on diameter ratio and velocity of flow

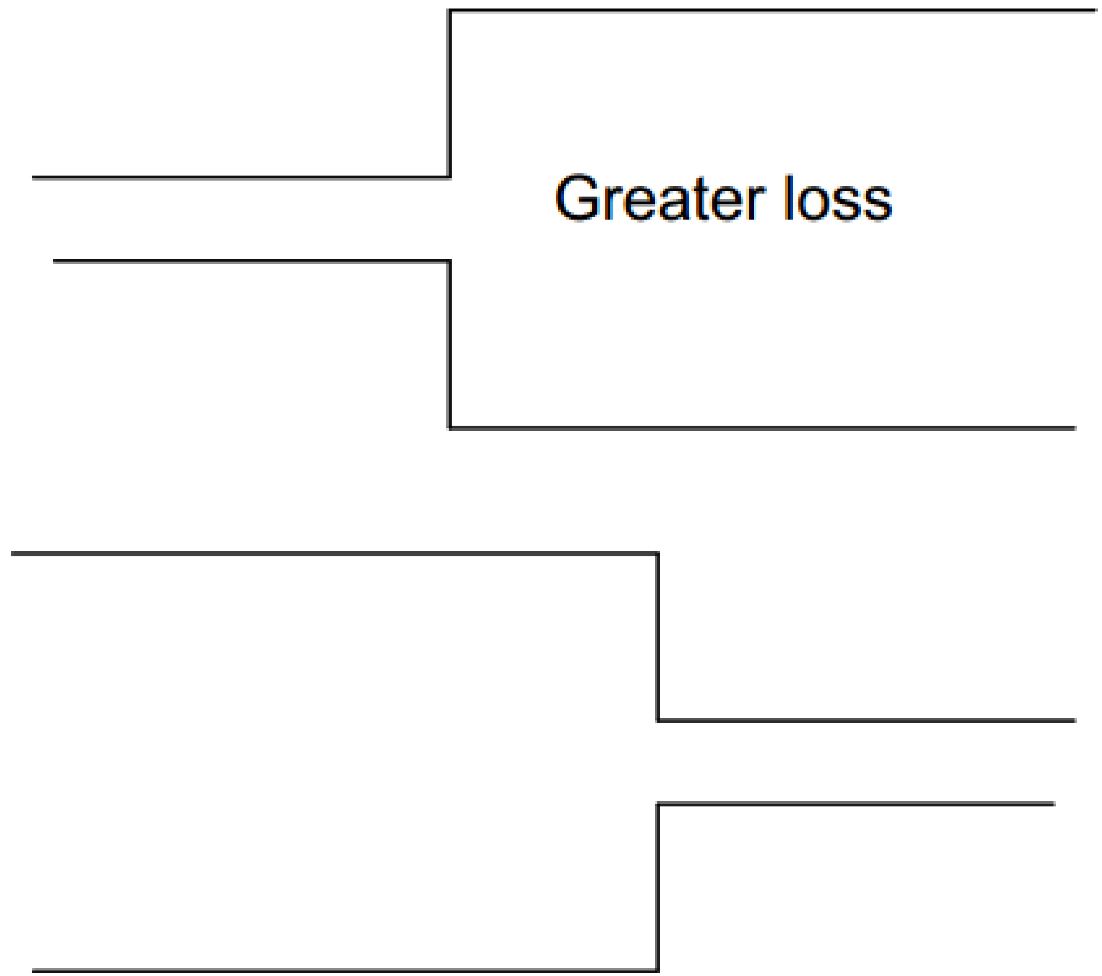


ABLE 10.3 Resistance coefficient—sudden contraction

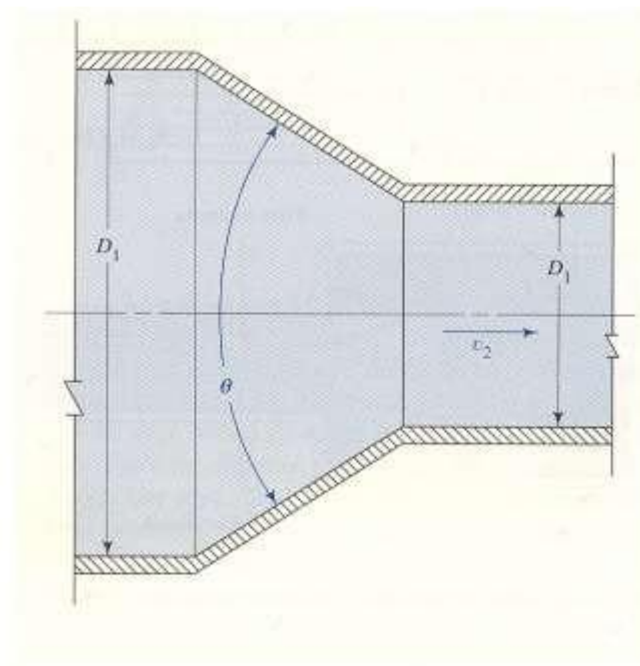
	Velocity v_2								
D_1/D_2	0.6 m/s 2 ft/s	1.2 m/s 4 ft/s	1.8 m/s 6 ft/s	2.4 m/s 8 ft/s	3 m/s 10 ft/s	4.5 m/s 15 ft/s	6 m/s 20 ft/s	9 m/s 30 ft/s	12 m/s 40 ft/s
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06
1.2	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.10	0.11
1.4	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.20
1.6	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24
1.8	0.34	0.34	0.34	0.33	0.33	0.32	0.31	0.29	0.27
2.0	0.38	0.37	0.37	0.36	0.36	0.34	0.33	0.31	0.29
2.2	0.40	0.40	0.39	0.39	0.38	0.37	0.35	0.33	0.30
2.5	0.42	0.42	0.41	0.40	0.40	0.38	0.37	0.34	0.31
3.0	0.44	0.44	0.43	0.42	0.42	0.40	0.39	0.36	0.33
4.0	0.47	0.46	0.45	0.45	0.44	0.42	0.41	0.37	0.34
5.0	0.48	0.47	0.47	0.46	0.45	0.44	0.42	0.38	0.35
10.0	0.49	0.48	0.48	0.47	0.46	0.45	0.43	0.40	0.36
∞	0.49	0.48	0.48	0.47	0.47	0.45	0.44	0.41	0.38

Source: King, H. W., and E. F. Brater, 1963. *Handbook of Hydraulics*, 5th ed. New York: McGraw-Hill, Table 6-9.

- Energy losses for sudden contraction are less than those for sudden enlargement.

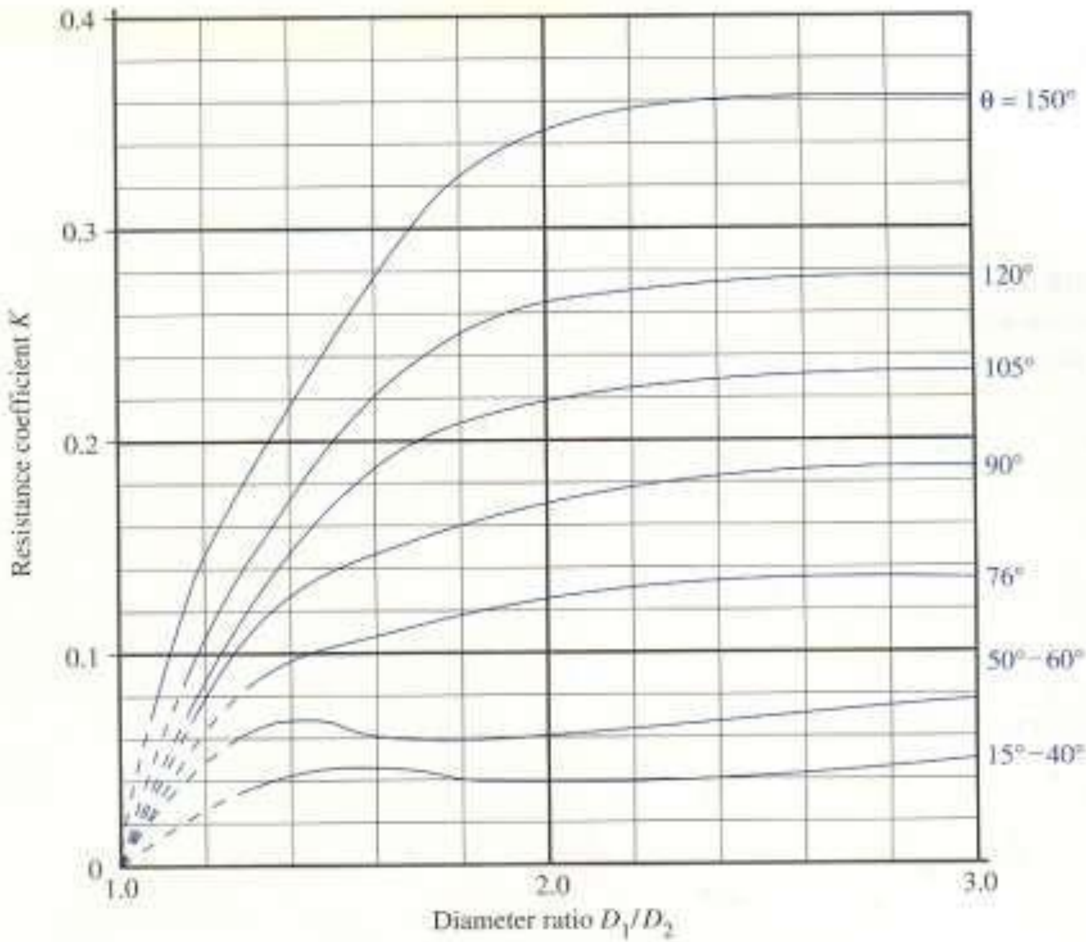

Greater loss

Gradual Contraction

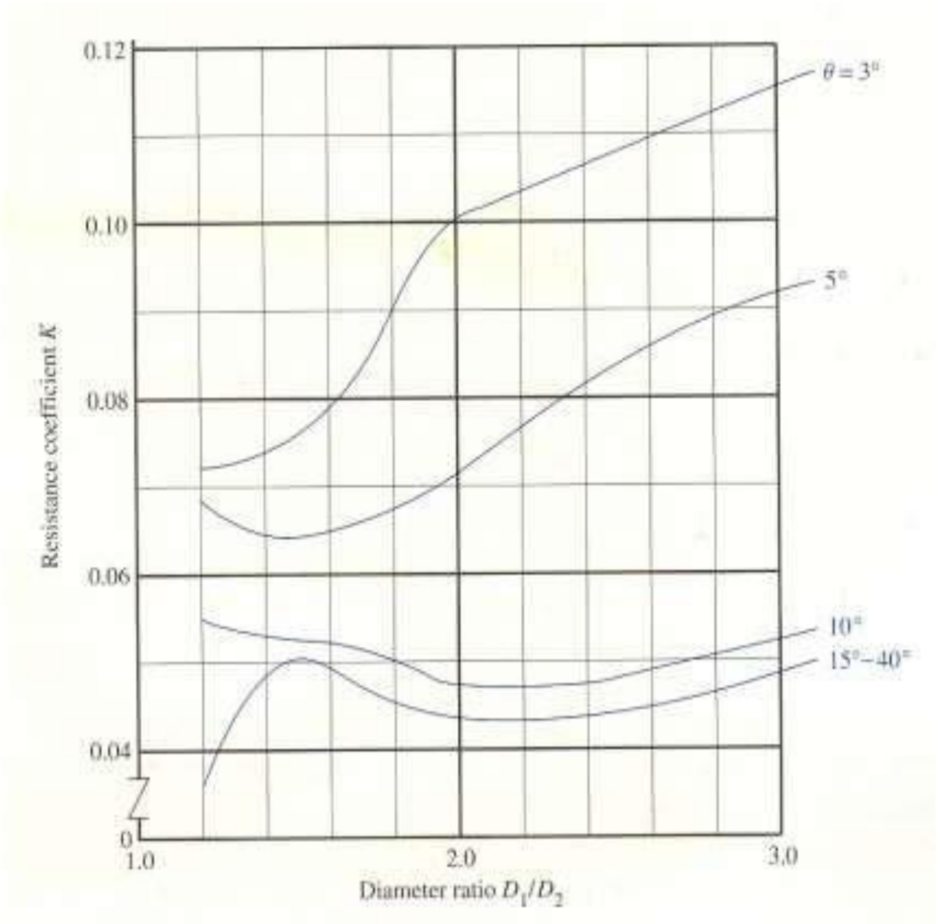


$$h_L = K(v_2^2 / 2g)$$

K is given by **Figs 10.10 and 10.11**



0.4
0.3
0.2
0.1
0
1.0
2.0
3.0
Resistance coefficient K
Diameter ratio D_1/D_2
θ = 150°
120°
105°
90°
76°
50°−60°
15°−40°



Why – the plot values includes both the effect flow separation and friction!

EXIT LOSS

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– The tank water is assumed to be stationery, that is, the velocity is zero.

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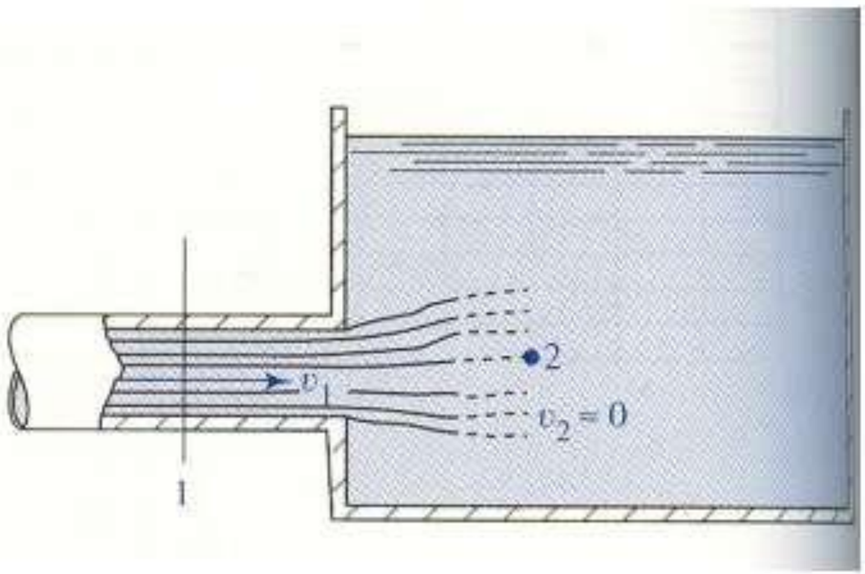
$$K = 1.0$$



$$h_L = 1.0 * (v_1^2 / 2g)$$

Gradual Enlargement

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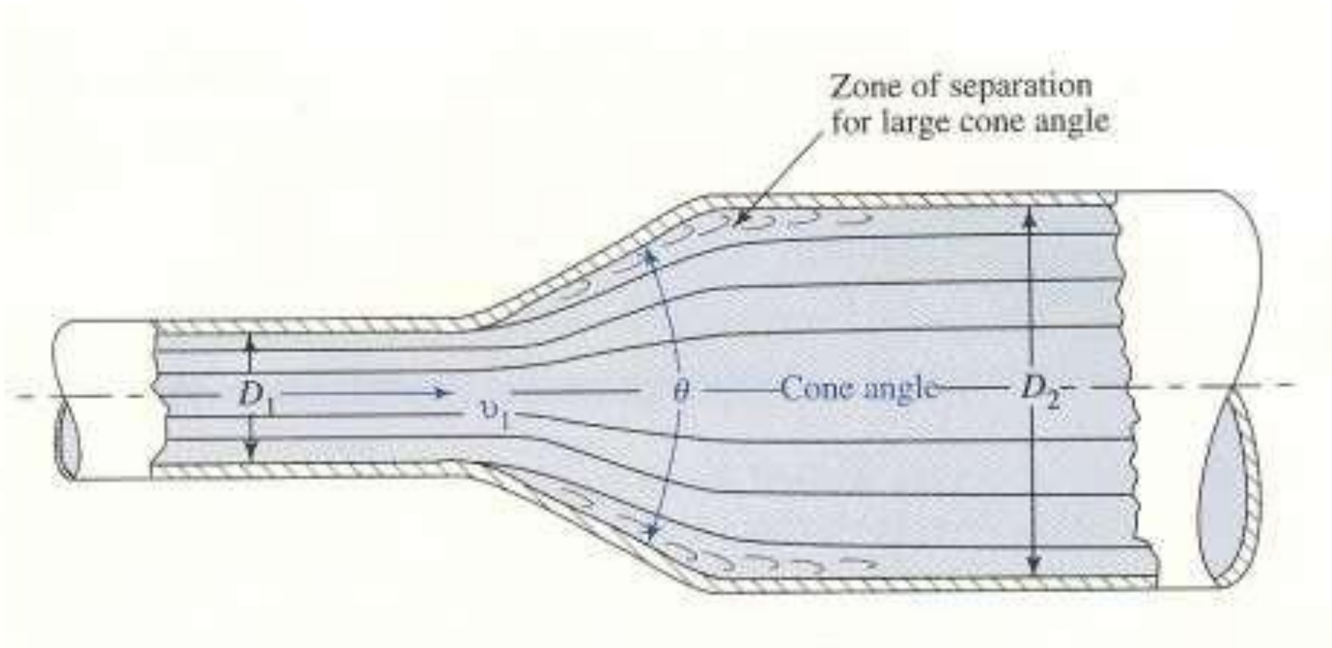
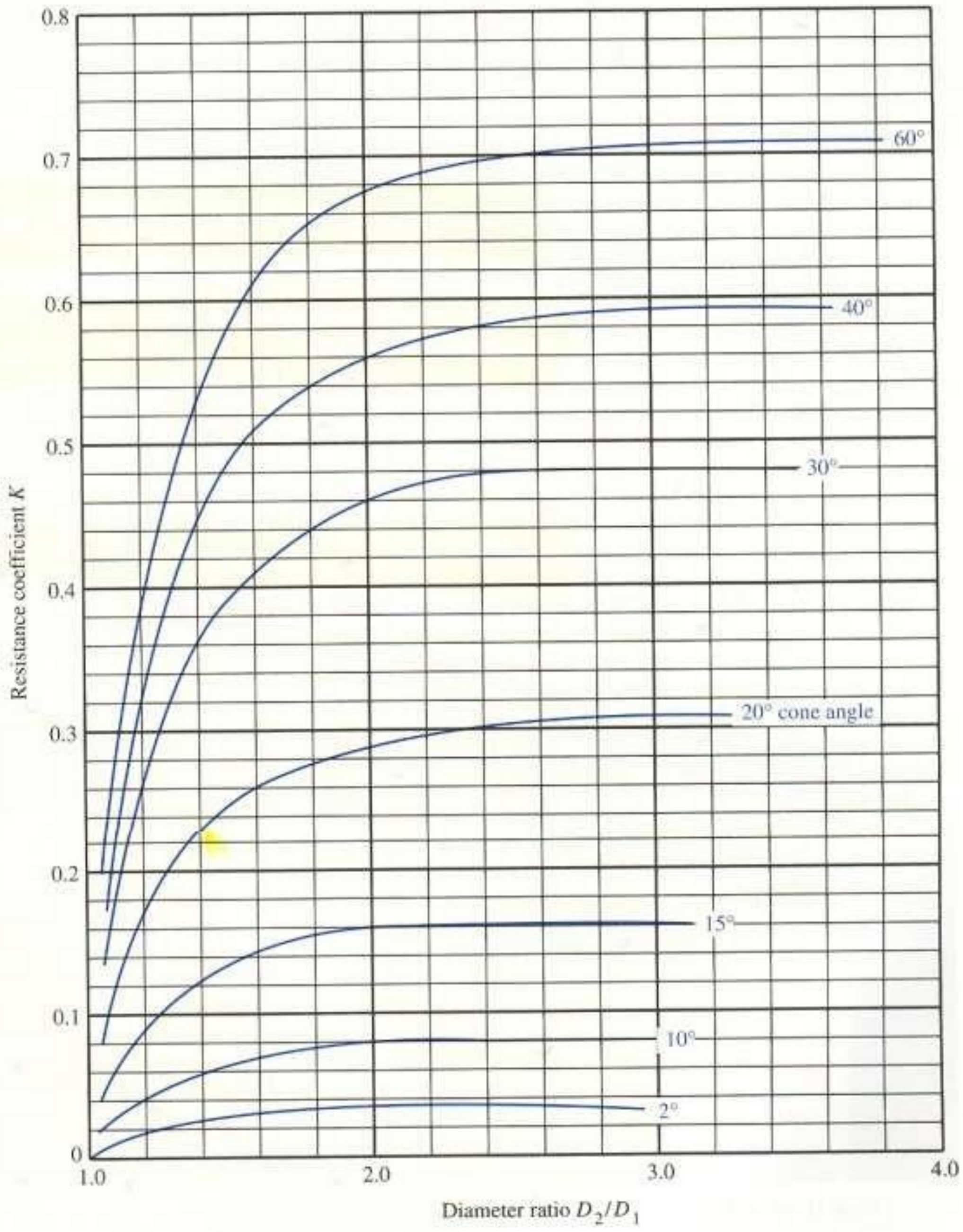
– The loss again depends on the ratio of the pipe diameters and the angle of enlargement.



$$h_L = K(v_1^2 / 2g)$$

K can be determined from Fig 10.5 and table 10.2 -



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Resistance coefficient K
60°
40°
30°
20° cone angle
15°
10°
2°
1.0
2.0
3.0
4.0
Diameter ratio D_2/D_1

TABLE 10.2 Resistance coefficient—gradual enlargement

	Angle of Cone θ											
D_2/D_1	2°	6°	10°	15°	20°	25°	30°	35°	40°	45°	50°	60°
1.1	0.01	0.01	0.03	0.05	0.10	0.13	0.16	0.18	0.19	0.20	0.21	0.23
1.2	0.02	0.02	0.04	0.09	0.16	0.21	0.25	0.29	0.31	0.33	0.35	0.37
1.4	0.02	0.03	0.06	0.12	0.23	0.30	0.36	0.41	0.44	0.47	0.50	0.53
1.6	0.03	0.04	0.07	0.14	0.26	0.35	0.42	0.47	0.51	0.54	0.57	0.61
1.8	0.03	0.04	0.07	0.15	0.28	0.37	0.44	0.50	0.54	0.58	0.61	0.65
2.0	0.03	0.04	0.07	0.16	0.29	0.38	0.46	0.52	0.56	0.60	0.63	0.68
2.5	0.03	0.04	0.08	0.16	0.30	0.39	0.48	0.54	0.58	0.62	0.65	0.70
3.0	0.03	0.04	0.08	0.16	0.31	0.40	0.48	0.55	0.59	0.63	0.66	0.71
∞	0.03	0.05	0.08	0.16	0.31	0.40	0.49	0.56	0.60	0.64	0.67	0.72

Source: King, H. W., and E. F. Brater. 1963. *Handbook of Hydraulics*, 5th ed. New York: McGraw-Hill, Table 6-8.

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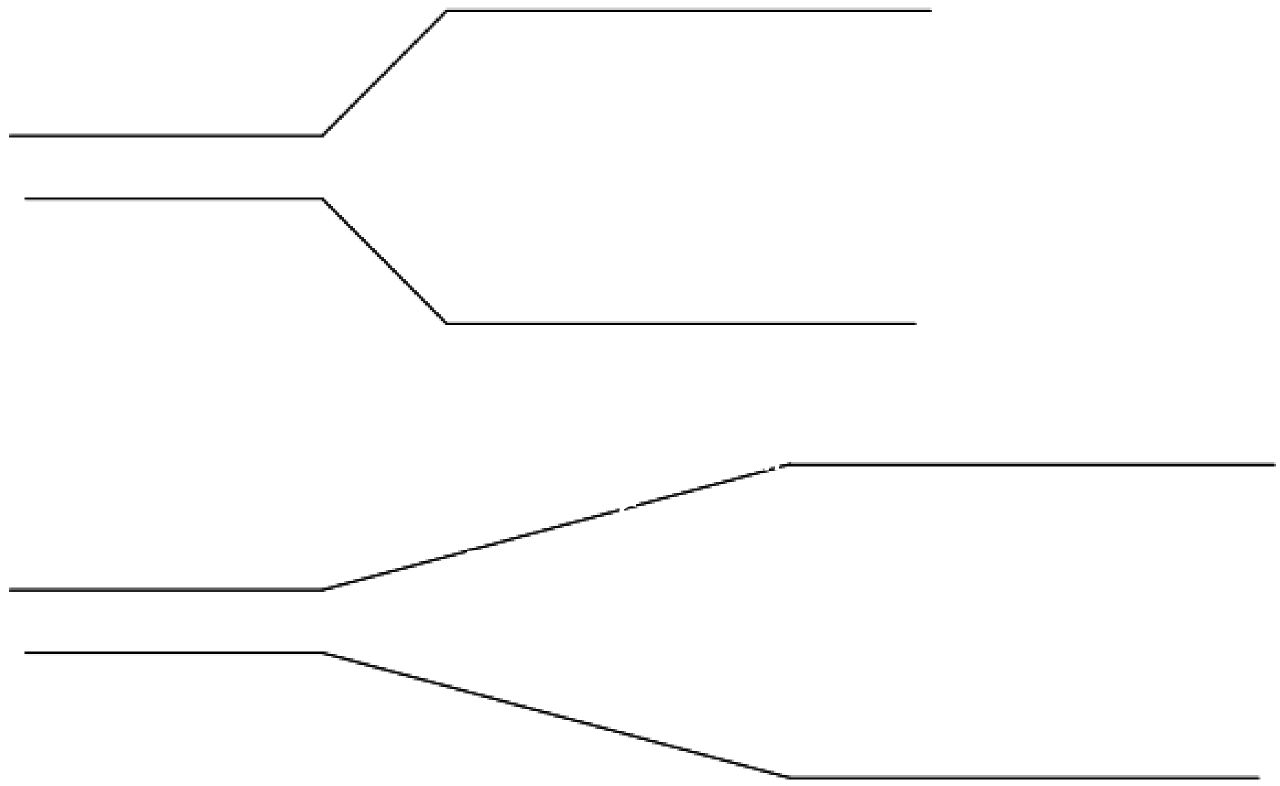
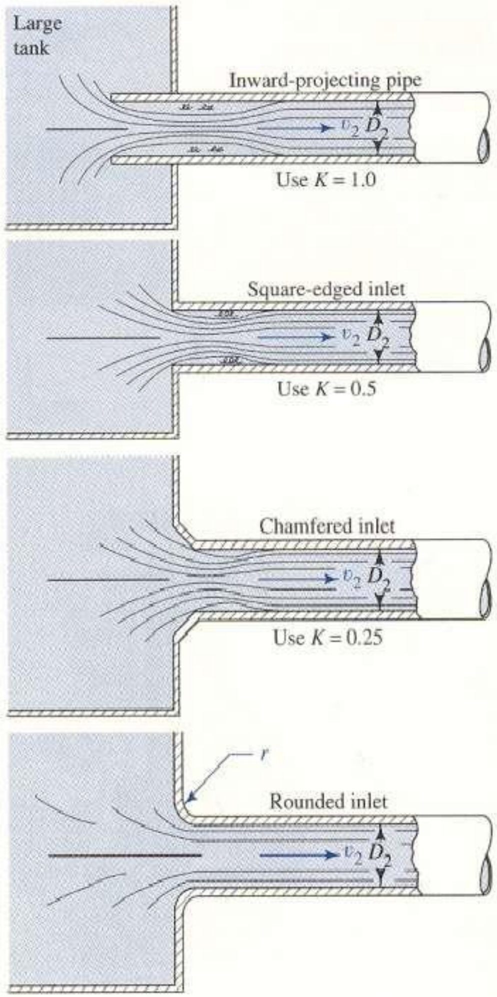
– If angle decreases – minor losses decrease, but you also need a longer pipe to make the transition – that means more FRICTION losses - therefore there is a tradeoff!



Minimum loss including minor and friction losses occur for angle of 7 degrees – OPTIMUM angle!

Entrance Losses



r/D_2	K
0	0.50
0.02	0.28
0.04	0.24
0.06	0.15
0.10	0.09
>0.15	0.04 (Well-rounded)

Resistance Coefficients for Valves & Fittings

$$h_L = K\ (v^2 / 2g)$$

$$K = (L_e / D) * f_t$$

Le

fT

FLOW THROUG H PIPES IN SERIES

- When two or more pipes of different diameters or roughness are connected in such a way that the fluid follows a single flow path throughout the system, the system represents a series pipeline.

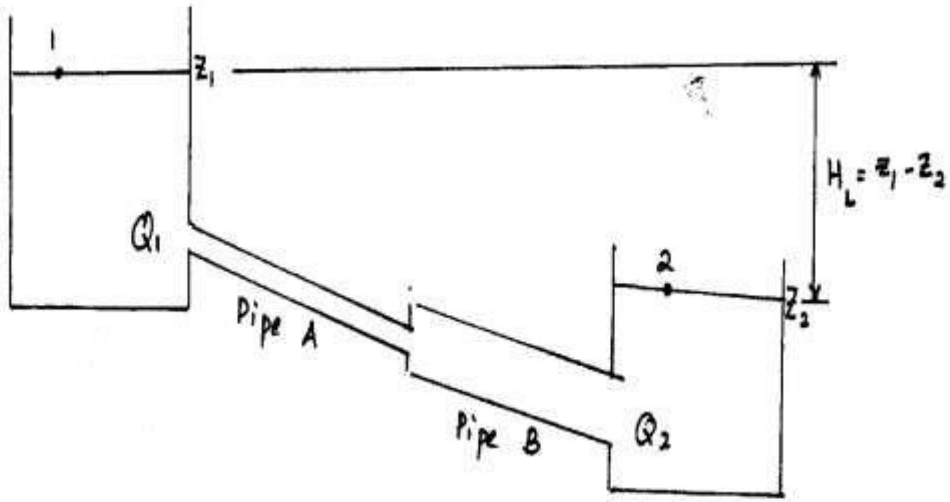


Figure 6.11: Pipelines in series

- Referring to Figure 6.11, the Bernoulli equation can be written between points 1 and 2 as follows;

$$\frac{P_1}{\rho g} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + z_2 + \frac{V_2^2}{2g} + H_{L1-2}$$

where ,

ρ = pressure head

= elevation head

= velocity head

= total energy lost between point 1 and 2

- Realizing that and then equation (6.14) reduces to

-

- The total head losses are a combination of the all the friction losses and the sum of the individual minor losses.

- Since the same discharge passes through all the pipes, the continuity equation can be written as;

FLOW THROUGH PIPES IN PARALLEL

- A combination of two or more pipes connected between two points so that the discharge divides at the first junction and rejoins at the next is known as pipes in parallel. Here the head loss between the two junctions is the same for all pipes.

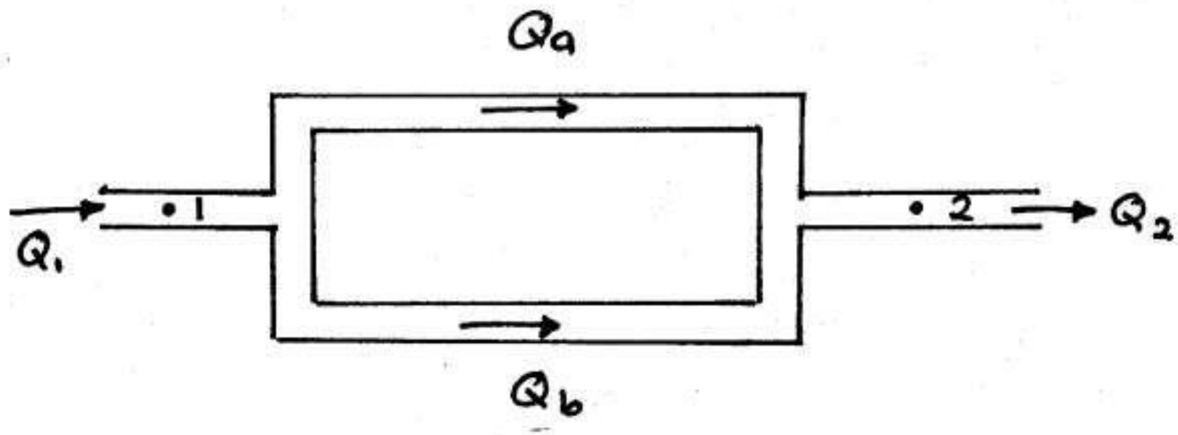


Figure 6.12: Pipelines in parallel

- Applying the continuity equation to the system;

(6.19)

- The energy equation between point 1 and 2 can be written as;

$$\frac{P_1}{\rho g} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + z_2 + \frac{V_2^2}{2g} + H_L$$

- The head losses throughout the system are given by;

(6.20)

- Equations (6.19) and (6.20) are the governing relationships for parallel pipe line systems. The system automatically adjusts the flow in each branch until the total system flow satisfies these equations.

HYDRAULIC GRADE LINE AND TOTAL ENERGY LINE

- The plot of the sum of pressure head and dynamic head along the flow path is known as energy line.
-

- The line will dip due to losses. For example in straight constant area pipe the line will slope proportional to the head drop per m length. There will be sudden dips if there are minor losses due to expansions, fittings etc..

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– Hydraulic grade line will be at a lower level and the difference between the ordinates will equal the dynamic head i.e. $u^2/2g$.

–

– This line will also dip due to frictional losses. Flow will be governed by hydraulic grade line.

- Introduction of a pump in the line will push up both the lines. Specimen plot is given in Fig. 7.15.1(pump is not indicated in figure).

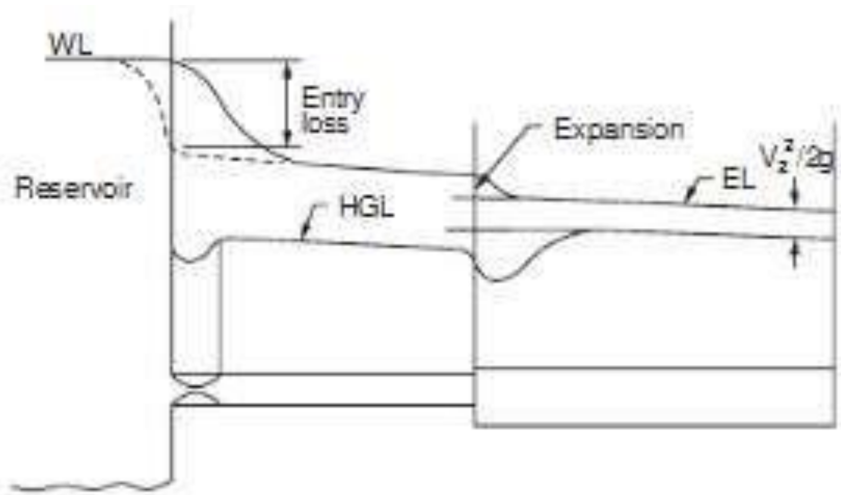

Figure 7.15.1 Energy and Hydraulic grade lines