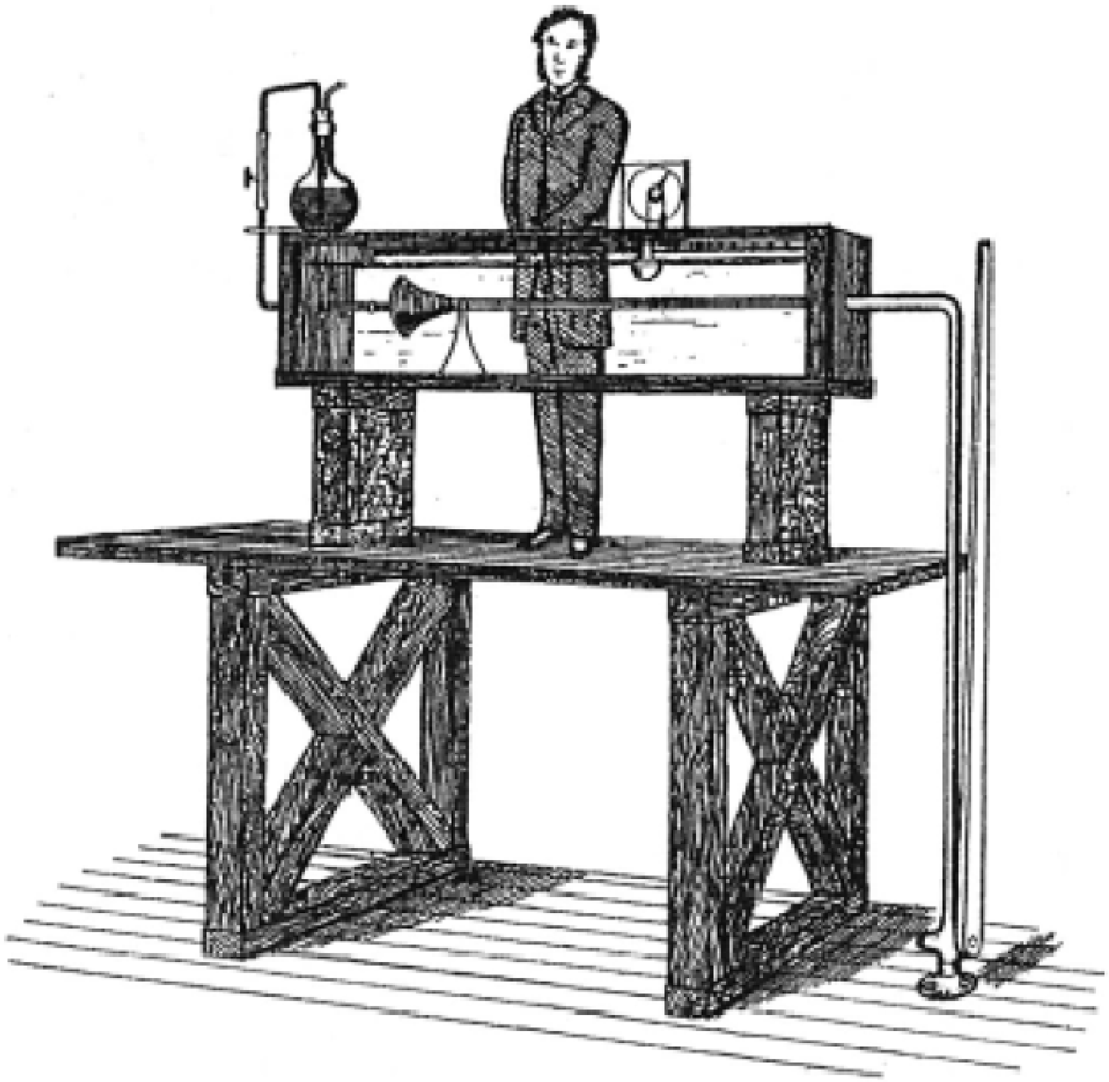
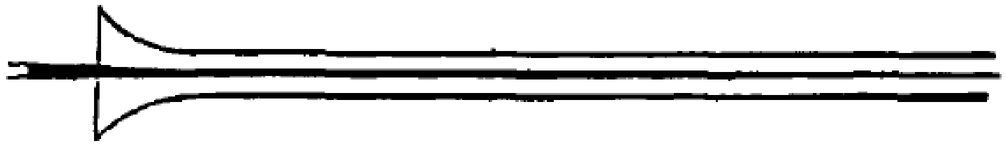
MOTI IN CONDOTTI



Osborne Reynolds e il suo esperimento

MOTO LAMINARE - MOTO TURBOLENTO



(a) Laminar flow

(b) Turbulent flow

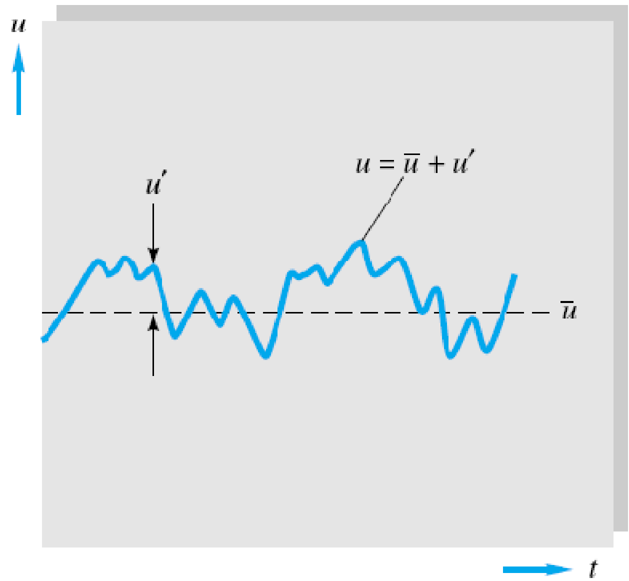
(c) Turbulent flow (observed by electric spark)

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

$Re \leq 2300$	*Moto Laminare*
$2300 \leq Re \leq 4200$	*Moto Transizionale*
$Re \geq 4200$	*Moto Turbolento*

MOTO TURBOLENTO
MOTO TRIDIMENSIONALE INSTAZIONARIO

$$\underline{V} = \underline{V}(t,x,y,z) = \begin{cases} u = u(t,x,y,z) \\ v = v(t,x,y,z) \\ w = w(t,x,y,z) \end{cases} \qquad p = p(t,x,y,z)$$

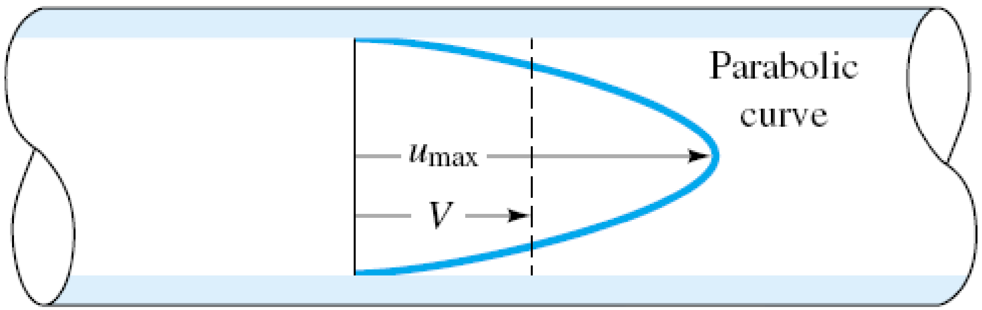


$$\overline{u} = \frac{1}{T}\int_0^T u\,dt \qquad u' = u - \overline{u} \qquad \overline{u'} = \frac{1}{T}\int_0^T (u - \overline{u})\,dt = \overline{u} - \overline{u} = 0$$

In modo analogo anche per ***v, w, p*** e possibile definire le grandezze medie e fluttuanti

Nel caso di moti turbolenti, si utilizzeranno sempre i valori medi delle grandezze

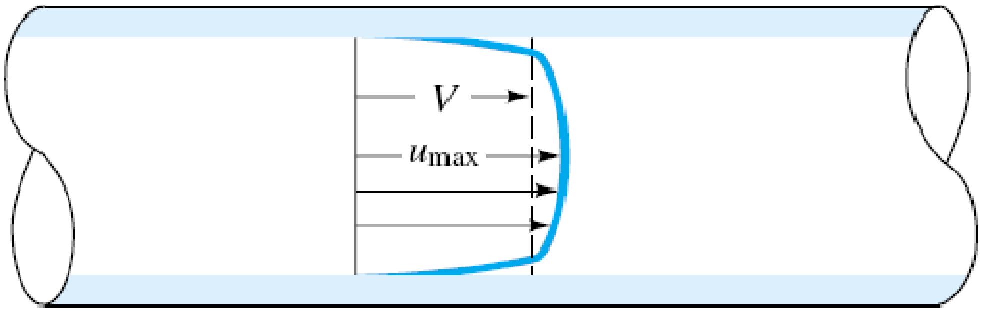
PROFILO DI VELOCITÀ



Moto Laminare

Re < 2300

V velocità media



Moto Turbolento

Re > 4200

Più unidimensionale

In moto turbolento $V \cong u_{max}$

PERDITE DI CARICO IN REGIME INCOMPRESSIBILE

<u>Equazione di conservazione massa</u>

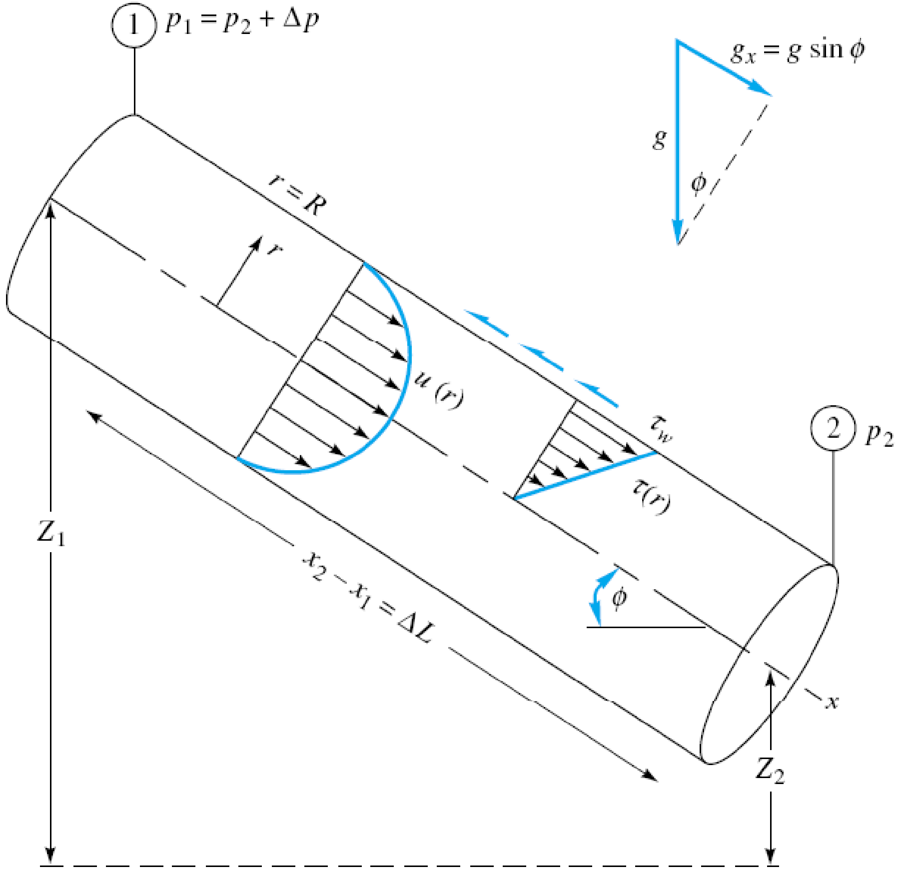
Moto unidimensionale stazionario

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

Moto incompressibile ($\rho =$ cost)

Sezione costante (A = cost)

$$\boxed{V_1 = V_2 = V = cost}$$



PERDITE DI CARICO IN REGIME INCOMPRESSIBILE

<u>Bilancio quantità di moto</u>

$$\dot{m}\,(\underline{V}_2 - \underline{V}_1) + p_1 A_1 \underline{n}_1 + p_2 A_2 \underline{n}_2 + \underline{S} = m\,\underline{g}$$

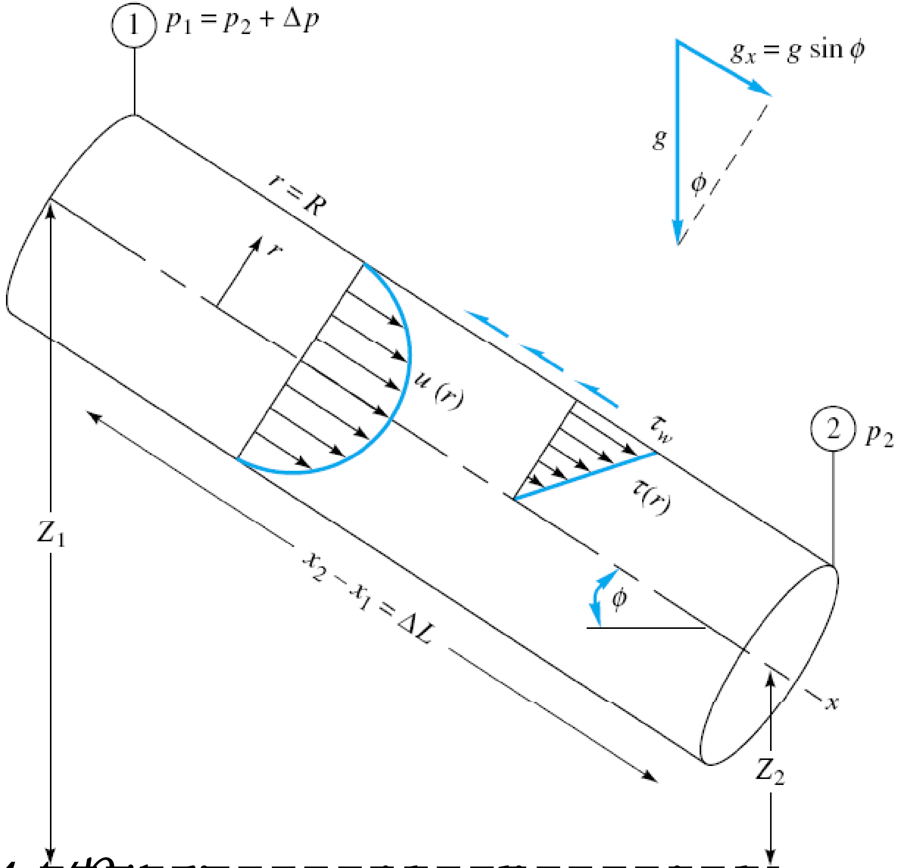
$$-\cancel{\dot{m}}V + \cancel{\dot{m}}V - p\cancel{A} + (\cancel{p} + \Delta p)\,A + S_x = \rho\, A \Delta L\, \underline{g}\cdot\underline{i}$$

$$S_x = \tau_p \wp \Delta L \qquad\qquad \tau_p \equiv \tau_w \textit{ in figura}$$

$$\Delta L\, \underline{g}\cdot\underline{i} = -g(z_1 - z_2) = -g\Delta z$$

posto $\quad |\underline{g}| \equiv g$

$$A dp + \rho\, g A \Delta z + \tau_p \wp \Delta L = 0$$



dividendo per A e indicando con $D_e = 4A/\wp$ il ***diametro idraulico equivalente***

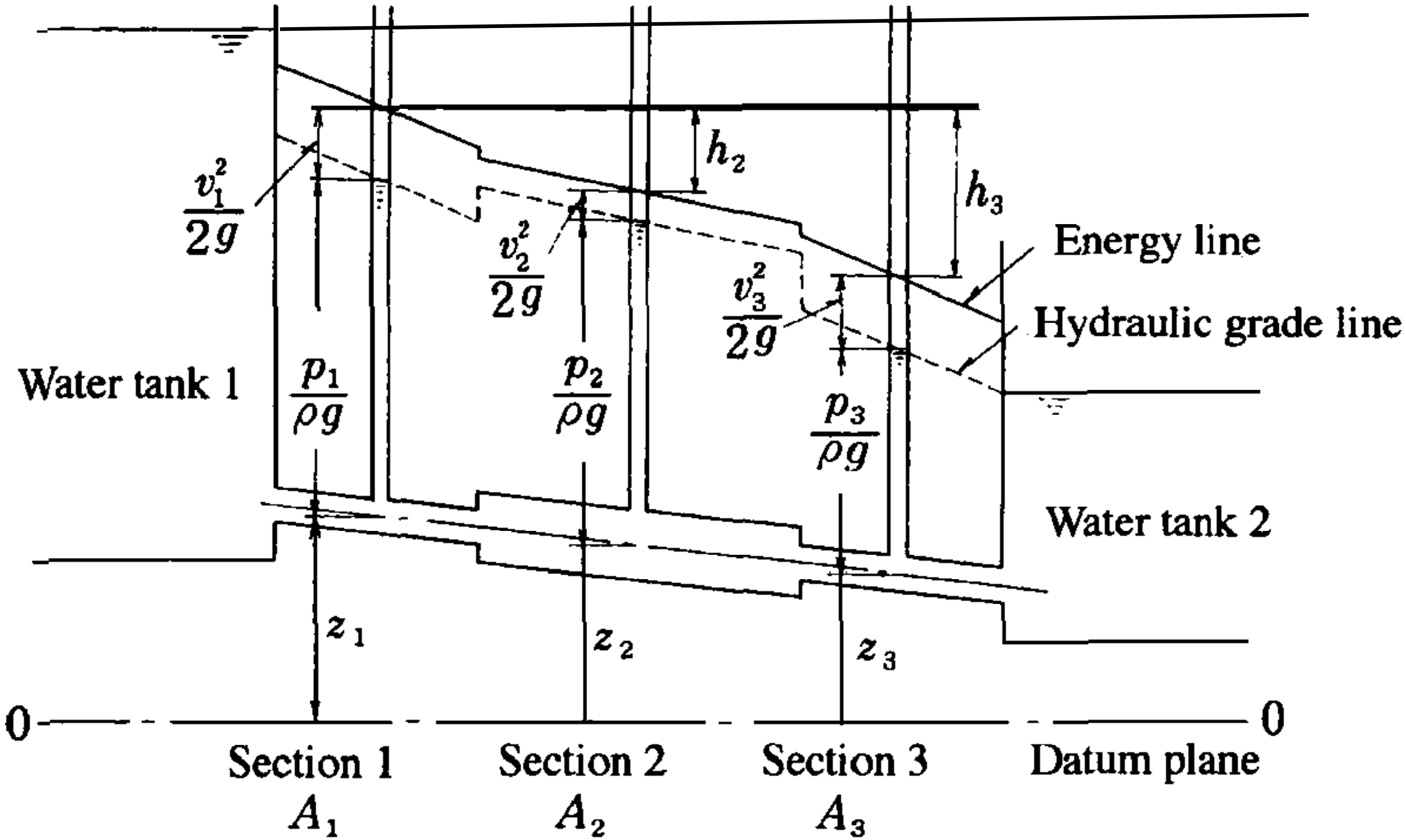
$$\Delta p + \rho\, g \Delta z + 4\,\tau_p \frac{\Delta L}{D_e} = 0 \quad \Rightarrow \quad \frac{\Delta p}{\rho\, g} + \Delta z = -\frac{4\,\tau_p}{\rho\, g}\frac{\Delta L}{D_e} = -h_f$$

BILANCIO DELLA QUANTITÀ DI MOTO

$$dp + \rho V dV + \rho g dz + 4\tau_p \frac{dx}{D_e} = 0$$

$$\frac{p_1}{g\rho} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{g\rho} + \frac{V_2^2}{2g} + z_2 + h_2 = \frac{p_3}{g\rho} + \frac{V_3^2}{2g} + z_3 + h_3$$

con h_2, h_3 dette perdite di carico



PERDITE DI CARICO IN REGIME INCOMPRESSIBILE

$$\Delta p + \rho g \Delta z + 4\tau_p \frac{\Delta L}{D_e} = 0 \quad >>> \quad \frac{\Delta p}{\rho g} + \Delta z = - \frac{4\tau_p}{\rho g}\frac{\Delta L}{D_e} = - h_f$$

Da un analisi del fenomeno si vede che

$$\tau_p = F(\rho, V, \mu, D_e, \varepsilon)$$

Mediante il **Teorema di Buckingham** si ottiene:

$$f = \frac{8\tau_p}{\rho V^2} = F(Re, \frac{\varepsilon}{D_e}) \qquad con \;\; Re = \frac{\rho V D_e}{\mu}$$

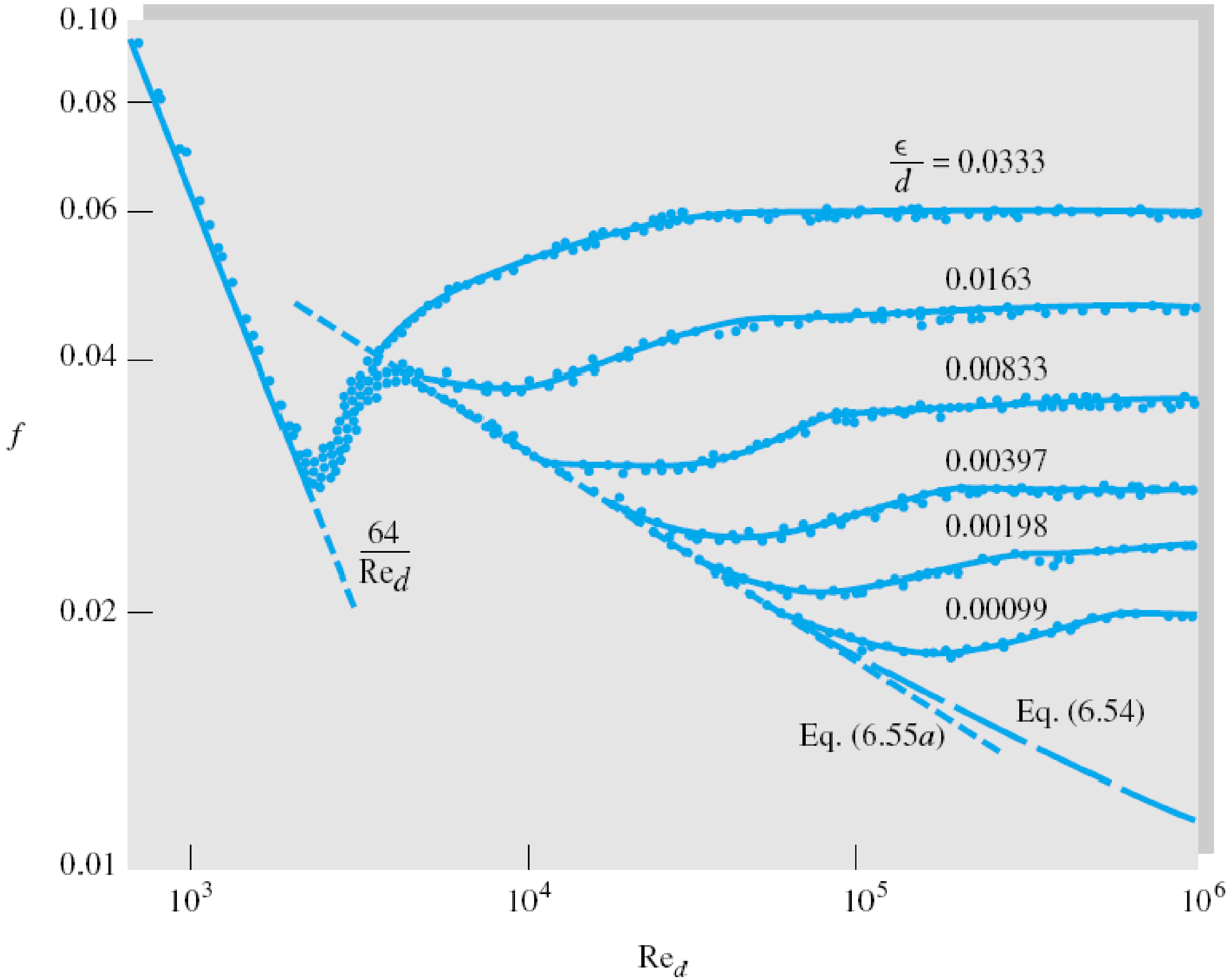
f ***coefficiente di Darcy ;*** $h_f = f \frac{L}{D_e}\frac{V^2}{2g}$

con $\Delta L = L$

Queste perdite di carico si chiamano DISTRIBUITE

In condotti circolari $D_e = D = d$

ESPERIMENTI DI NIKURADSE

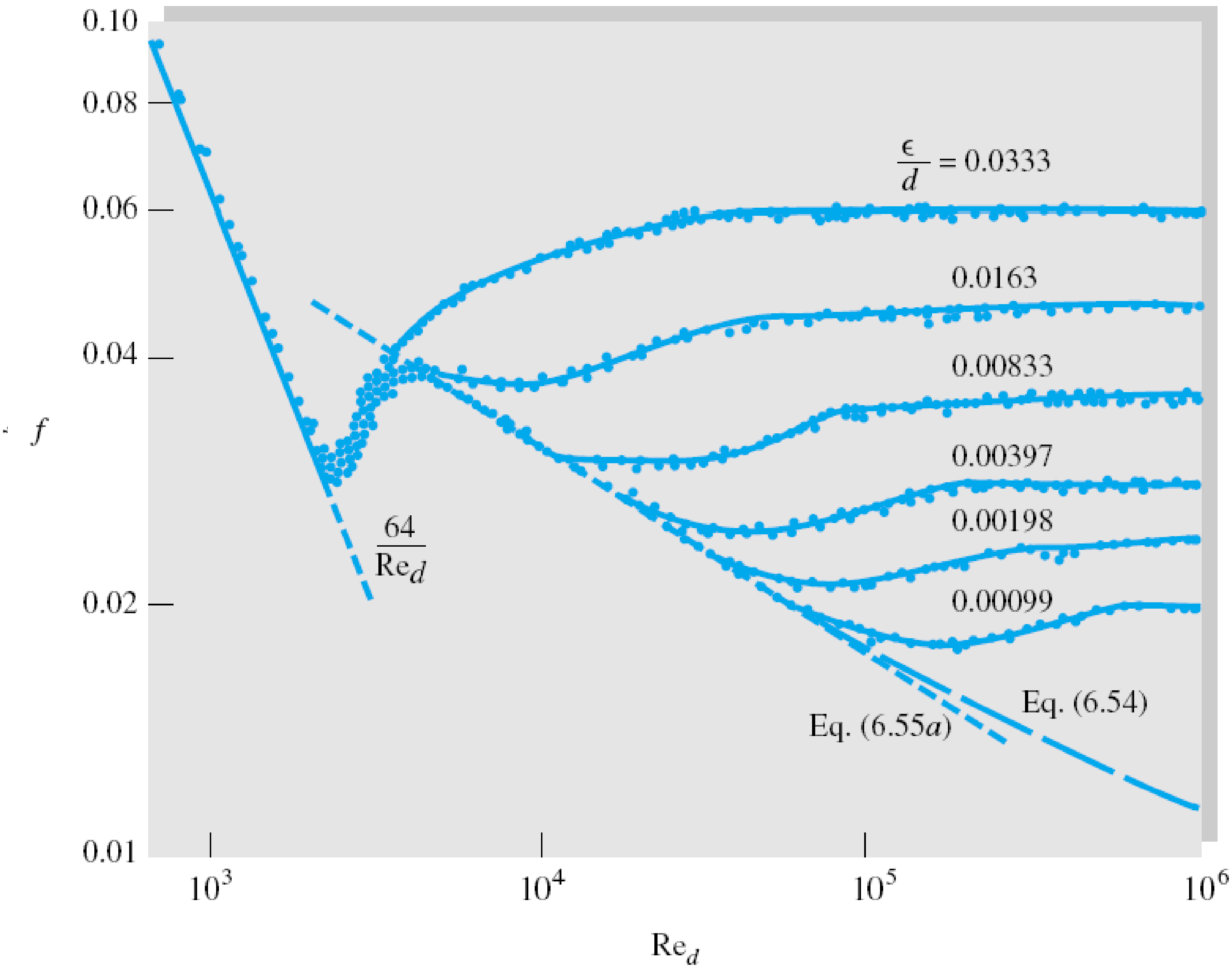


FORMULA DI COLEBROOK E WHITE

$$\frac{1}{f^{1/2}} = -2.0 \log \left(\frac{\epsilon/d}{3.7} + \frac{2.51}{\mathrm{Re}_d f^{1/2}} \right)$$

$$\mathrm{Re}_d = \frac{\rho V De}{\mu}$$

La formula di Colebrook e White si traduce nell'<u>abaco di Moody</u>


0.10
0.08
0.06
0.04
0.02
0.01
f
$\frac{\epsilon}{d}$ = 0.0333
0.0163
0.00833
0.00397
0.00198
0.00099
$\frac{64}{Re_d}$
Eq. (6.54)
Eq. (6.55a)
10^3
10^4
10^5
10^6
Re_d

TIPICHE SCABREZZE

		ε		
Material	Condition	ft	mm	Uncertainty, %
Steel	Sheet metal, new	0.00016	0.05	± 60
	Stainless, new	0.000007	0.002	± 50
	Commercial, new	0.00015	0.046	± 30
	Riveted	0.01	3.0	± 70
	Rusted	0.007	2.0	± 50
Iron	Cast, new	0.00085	0.26	± 50
	Wrought, new	0.00015	0.046	± 20
	Galvanized, new	0.0005	0.15	± 40
	Asphalted cast	0.0004	0.12	± 50
Brass	Drawn, new	0.000007	0.002	± 50
Plastic	Drawn tubing	0.000005	0.0015	± 60
Glass	—	Smooth	Smooth	
Concrete	Smoothed	0.00013	0.04	± 60
	Rough	0.007	2.0	± 50
Rubber	Smoothed	0.000033	0.01	± 60
Wood	Stave	0.0016	0.5	± 40

PERDITE DI CARICO CONCENTRATE

Le perdite di carico concentrate si hanno in:

- *Ingressi. o uscite. di condotti*
- *Variazioni di sezione repentine*
- *Variazioni di sezione graduali*
- *Curve, condotti a T, in generale tutte le connessioni di condotti*
- *Valvole (aperte, o parzialmente chiuse)*

Coefficiente di perdita

$$K = \frac{h_m}{V^2/(2g)} = \frac{\Delta p}{\frac{1}{2}\rho V^2}$$

VALORI DI *K*

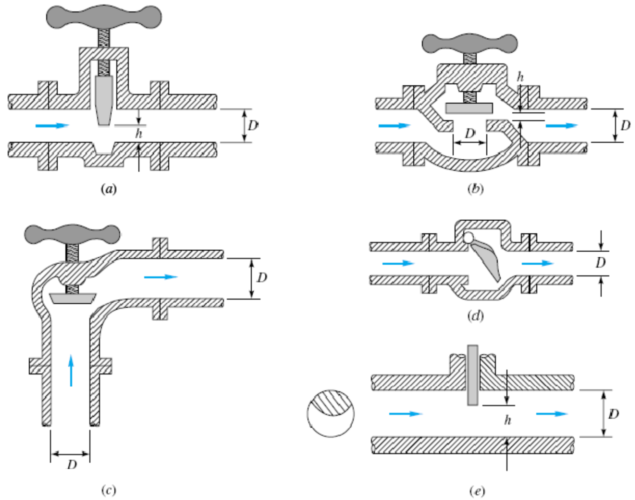
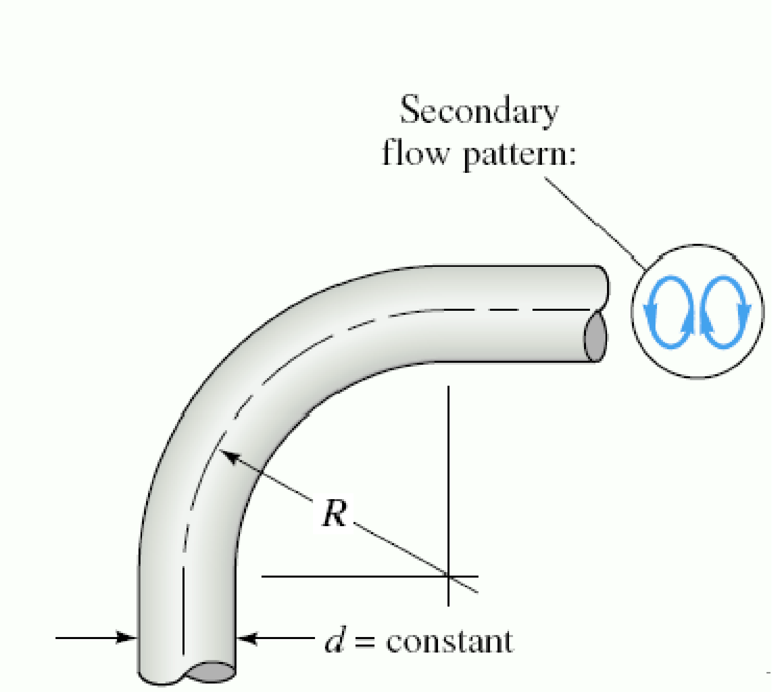
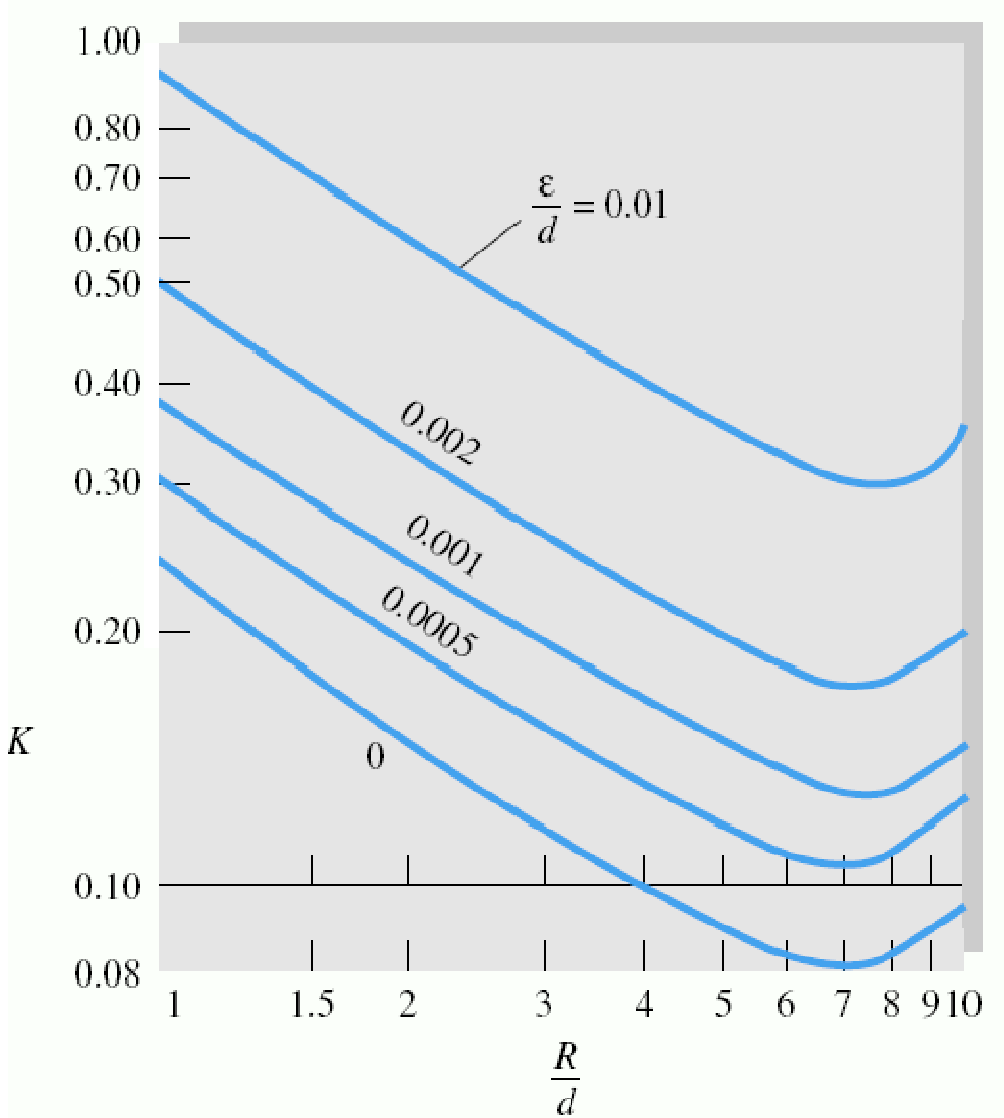


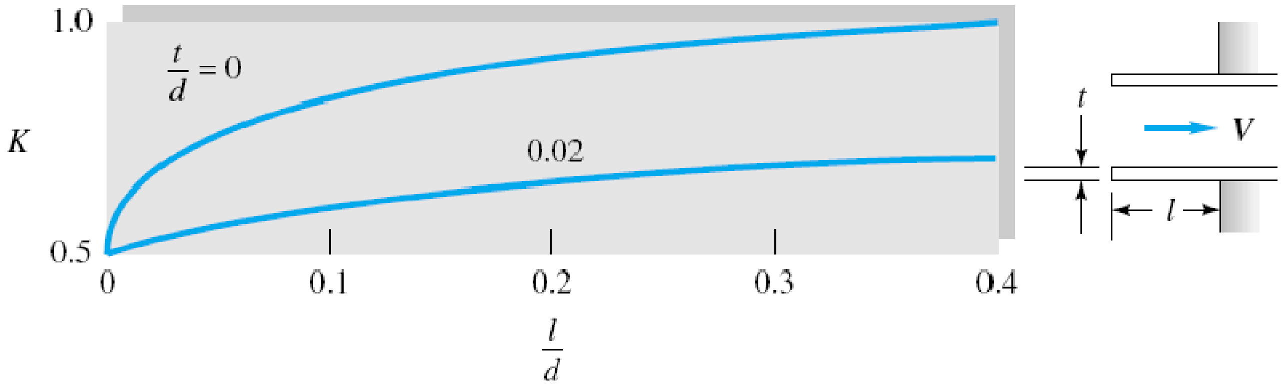
Fig. 6.17 Typical commercial valve geometries: (*a*) gate valve; (*b*) globe valve; (*c*) angle valve; (*d*) swing-check valve; (*e*) disk-type gate valve.

	Nominal diameter, in								
	Screwed				Flanged				
	1/2	1	2	4	1	2	4	8	20
Valves (fully open):									
Globe	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	0.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Swing check	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Elbows:									
45° regular	0.39	0.32	0.30	0.29					
45° long radius					0.21	0.20	0.19	0.16	0.14
90° regular	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
90° long radius	1.0	0.72	0.41	0.23	0.40	0.30	0.19	0.15	0.10
180° regular	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20
180° long radius					0.40	0.30	0.21	0.15	0.10
Tees:									
Line flow	0.90	0.90	0.90	0.90	0.24	0.19	0.14	0.10	0.07
Branch flow	2.4	1.8	1.4	1.1	1.0	0.80	0.64	0.58	0.41

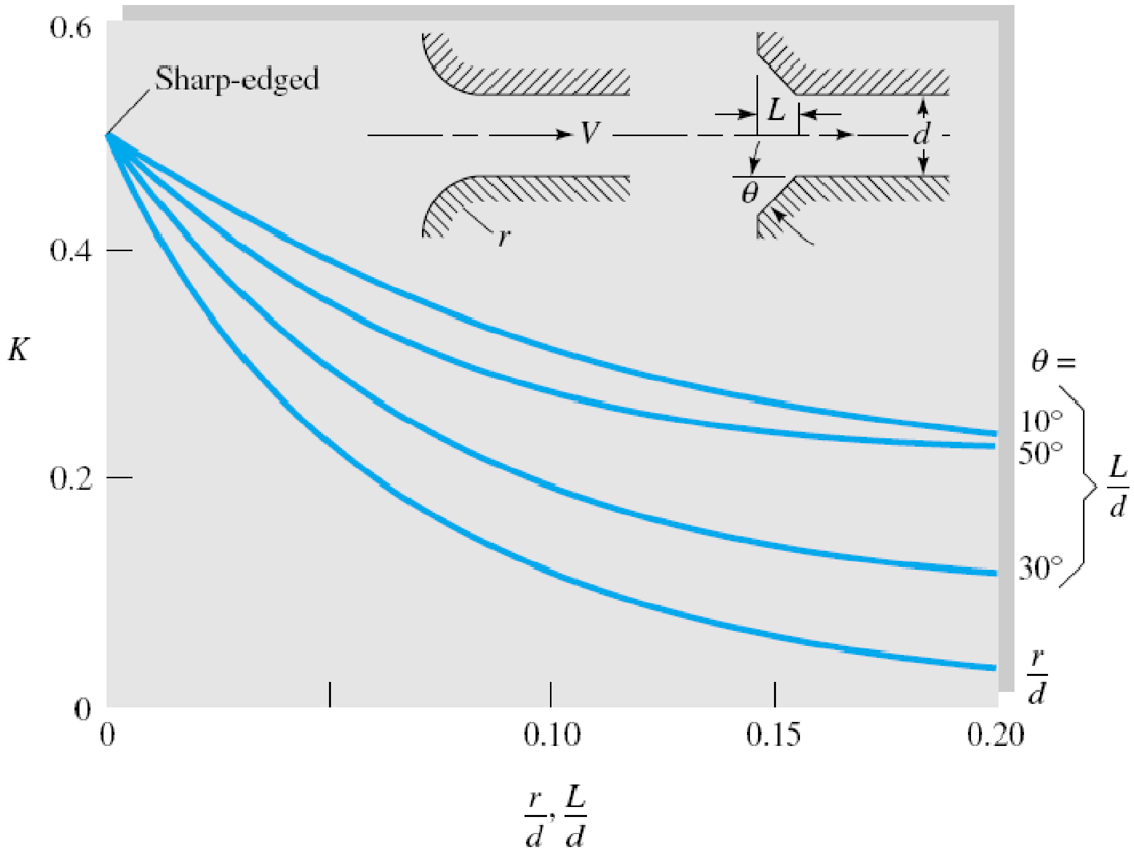
CURVE


Secondary
flow pattern:
R
d = constant


1.00
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.08
K
ε/d = 0.01
0.002
0.001
0.0005
0
1
1.5
2
3
4
5
6
7
8
9
10
R/d

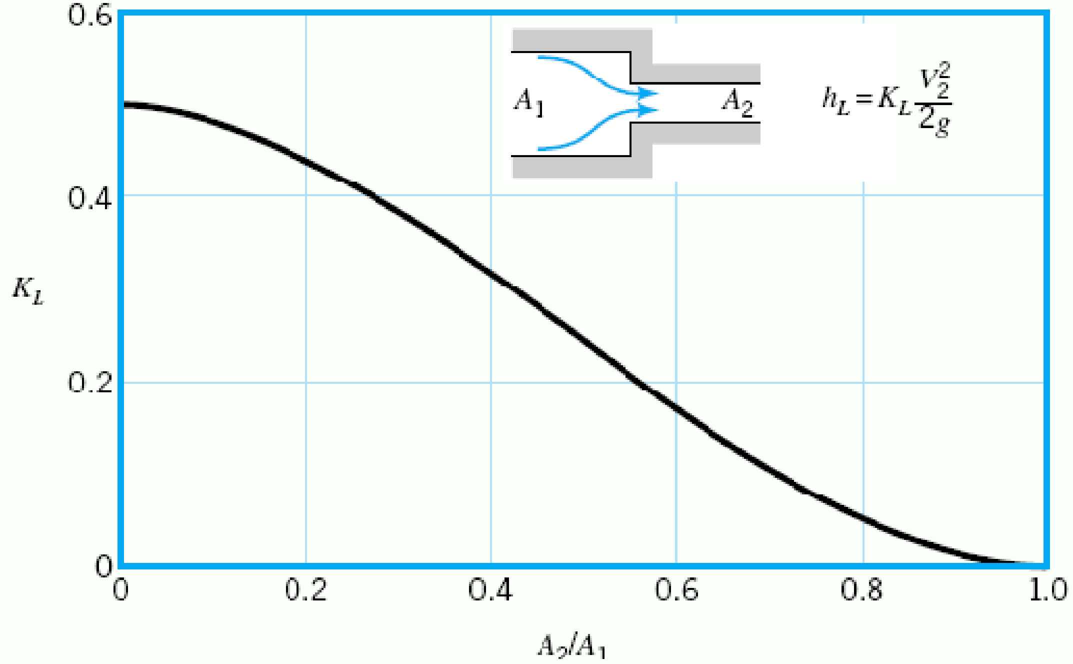


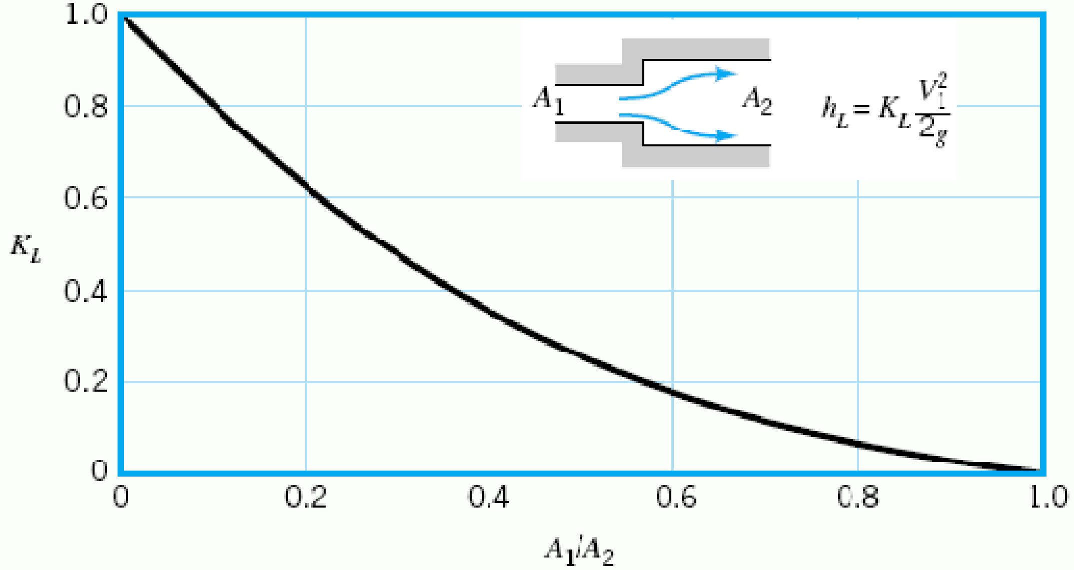
1.0
0.5
K
t/d = 0
0.02
0
0.1
0.2
0.3
0.4
l/d
t
V
l



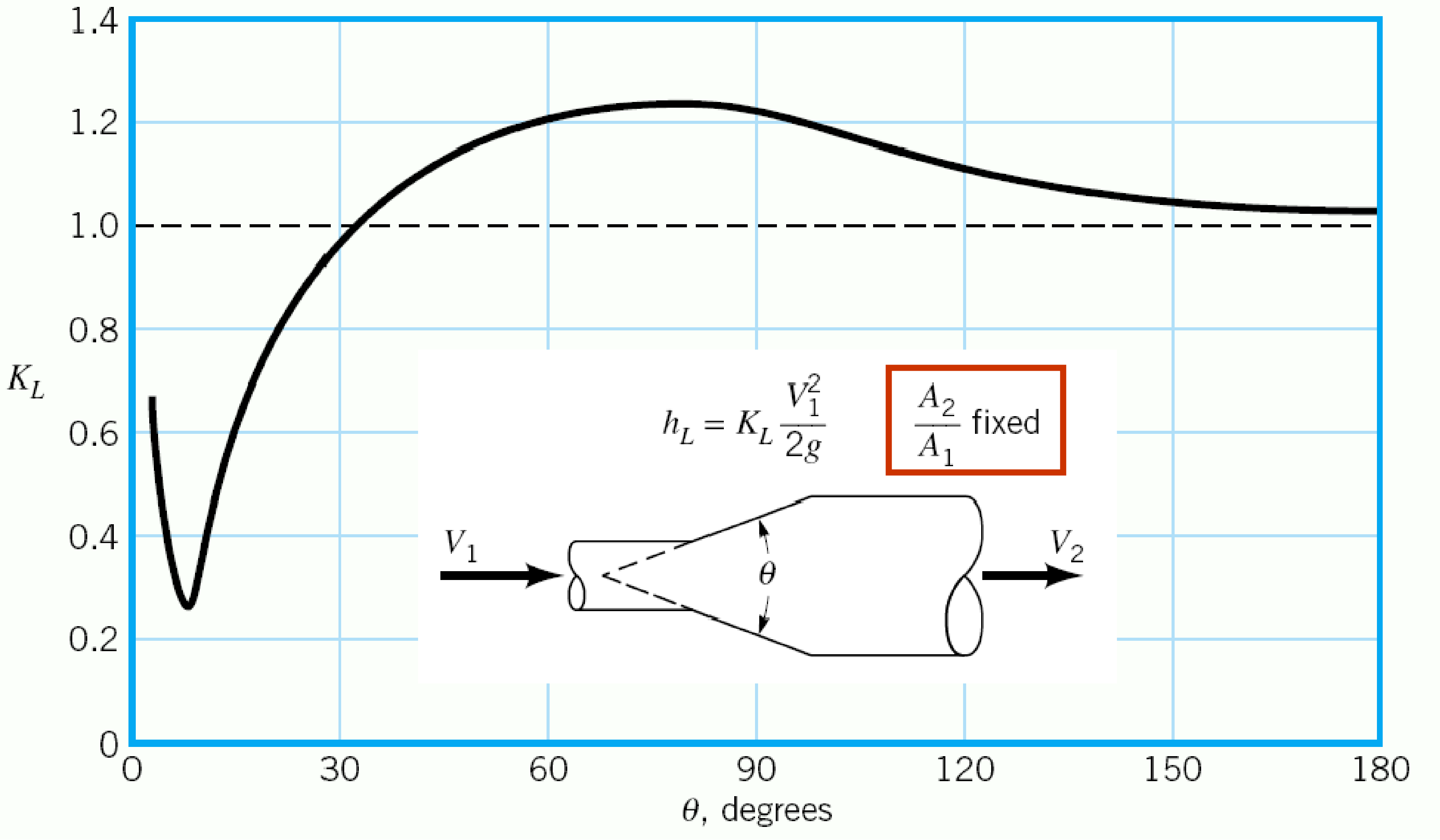
0.6
0.4
0.2
0
K
Sharp-edged
V
L
d
θ
r
θ =
10°
50°
30°
L/d
r/d
0
0.10
0.15
0.20
r/d, L/d

VARIAZIONI DI SEZIONE REPENTINE

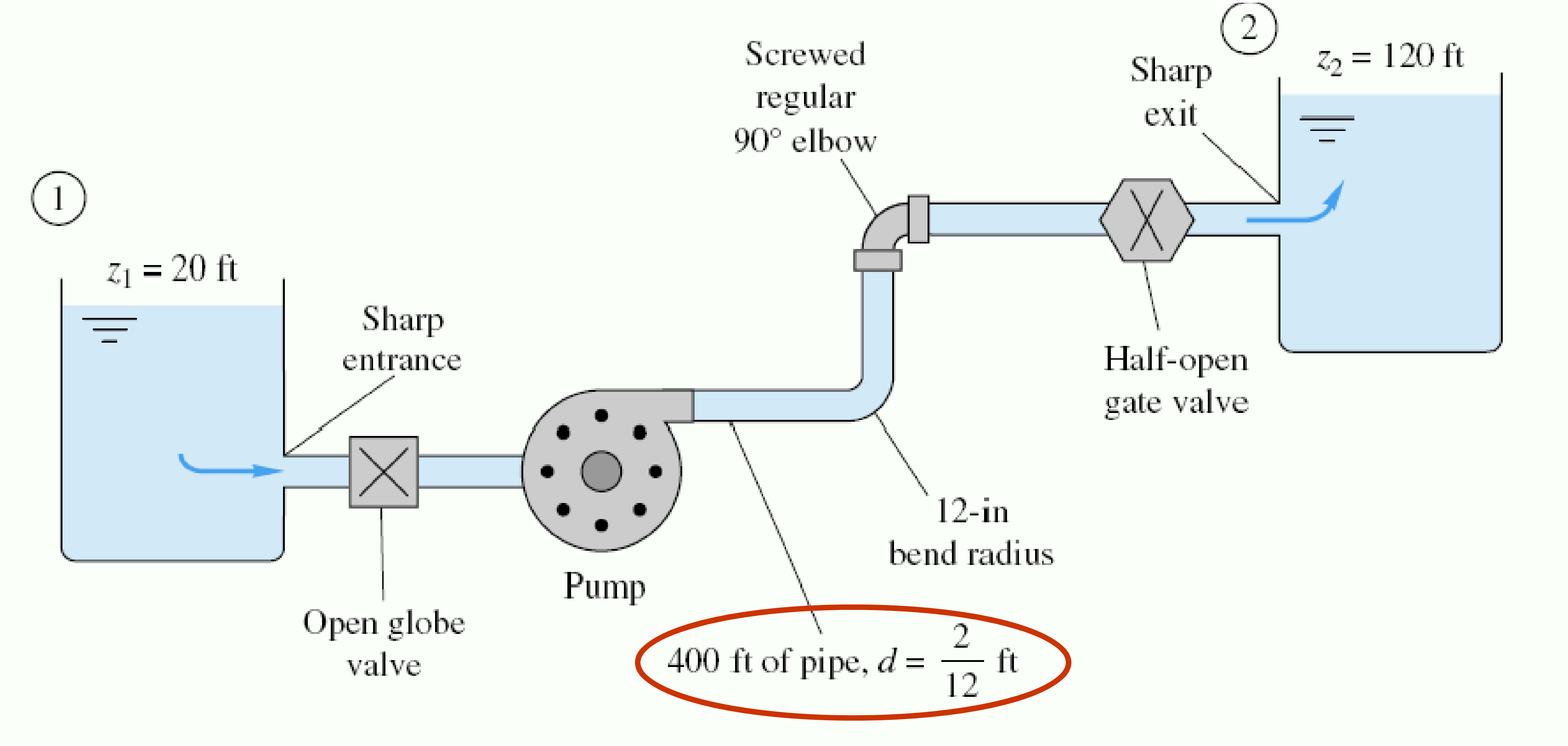




ALLARGAMENTI GRADUALI DI SEZIONE



EXAMPLE Determinare la prevalenza e la potenza della pompa



$\rho = 1.94$ slugs/ft^3

$Q = 0.2$ ft^3/s

$\nu = 0.000011$ ft^2/s.

$\epsilon/d = 0.001$.

$\rho = 1000\ Kg/m^3$

Q = 0.2 x 0,3048 x 0.3048 x 0.3048 =

= 5.663E-3 m3/s

ν = 0.000011*0.3048*0.3048=1.02E-6 m2/s

EXAMPLE

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \left(\frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2\right) + h_f + \sum h_m - h_p$$

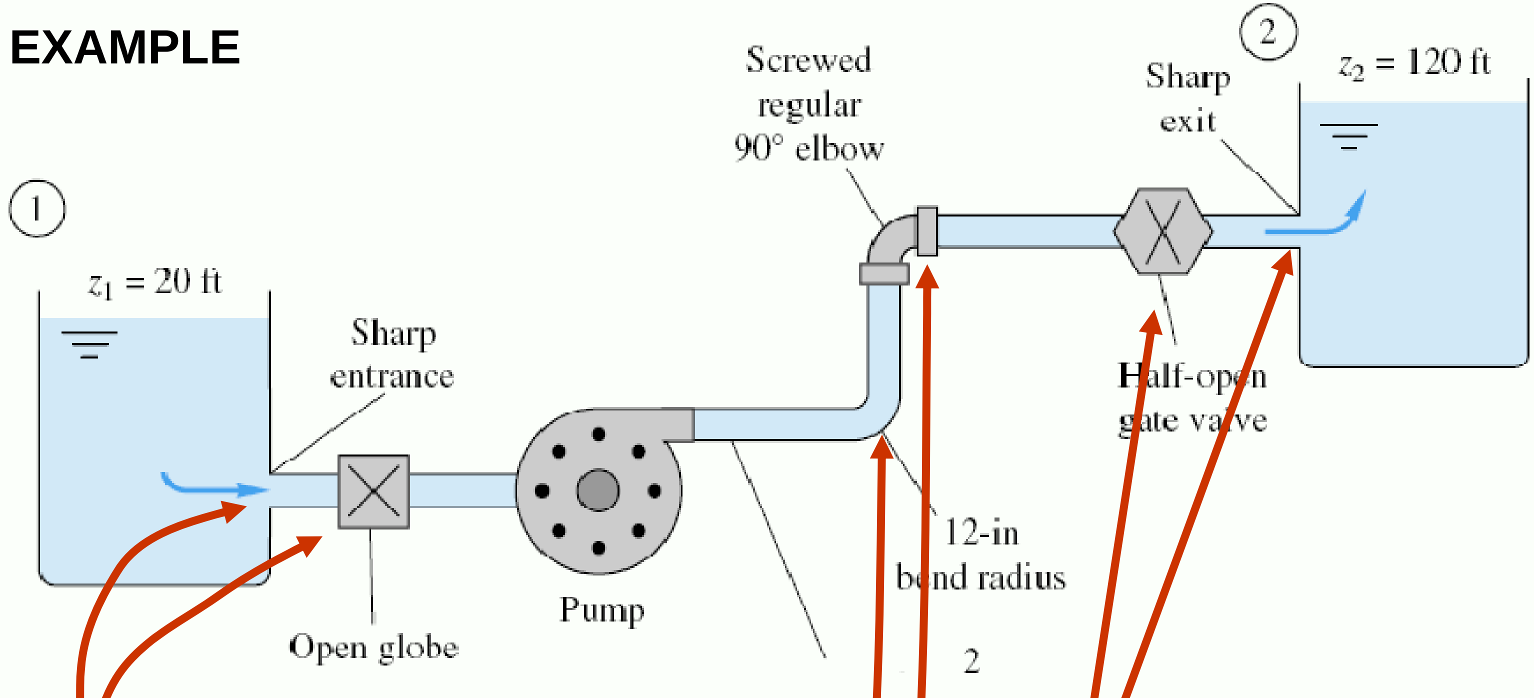
since $p_1 = p_2$ and $V_1 = V_2 \approx 0$,

$$h_p = z_2 - z_1 + h_f + \sum h_m = 120 \text{ ft} - 20 \text{ ft} + \frac{V^2}{2g}\left(\frac{fL}{d} + \sum K\right)$$

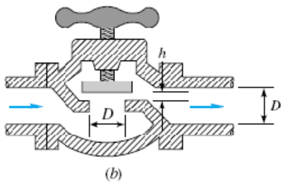
$$V = \frac{Q}{A} = \frac{0.2 \text{ ft}^3/\text{s}}{\frac{1}{4}\pi(\frac{2}{12} \text{ ft})^2} = 9.17 \text{ ft/s} = 2.79\ m/s$$

$$\text{Re}_d = \frac{Vd}{\nu} = \frac{9.17(\frac{2}{12})}{0.000011} = 139{,}000$$

EXAMPLE



Loss	K
Sharp entrance (Fig. 6.21)	0.5
Open globe valve (2 in, Table 6.5)	6.9
12-in bend (Fig. 6.20)	0.15
Regular 90° elbow (Table 6.5)	0.95
Half-closed gate valve (from Fig. 6.18*b*)	2.7
Sharp exit (Fig. 6.21)	1.0
	$\Sigma K = 12.2$



EXAMPLE

Re = 139 000

For $\epsilon/d = 0.001$, from the Moody chart read $f = 0.0216$.

$$h_p = 120\text{ ft} - 20\text{ ft} + \frac{V^2}{2g}\left(\frac{fL}{d} + \sum K\right) = 100\text{ ft} + \frac{(9.17\text{ ft/s})^2}{2(32.2\text{ ft/s}^2)}\left[\frac{0.0216(400)}{\frac{2}{12}} + 12.2\right]$$

$$= 100\text{ ft} + 84\text{ ft} = 184\text{ ft} \quad \text{pump head} = 56.08\text{ m}$$

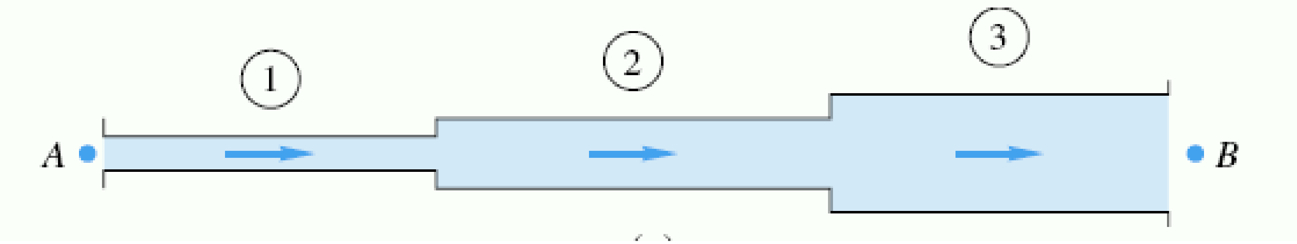
$$P = \rho g Q h_p = [1.94(32.2)\text{ lbf/ft}^3](0.2\text{ ft}^3\text{/s})(184\text{ ft}) = 2300\text{ ft}\cdot\text{lbf/s}$$

The conversion factor is 1 hp = 550 ft · lbf/s.

$$P = \frac{2300}{550} = 4.2\text{ hp}$$

$$P = \rho g Q h_p = 1000 \times 9.81 \times 5.663\text{E-3} \times 56.08 = 3115W = 3.115kW$$

EXAMPLE



$$Q_1 = Q_2 = Q_3 = \text{const}$$

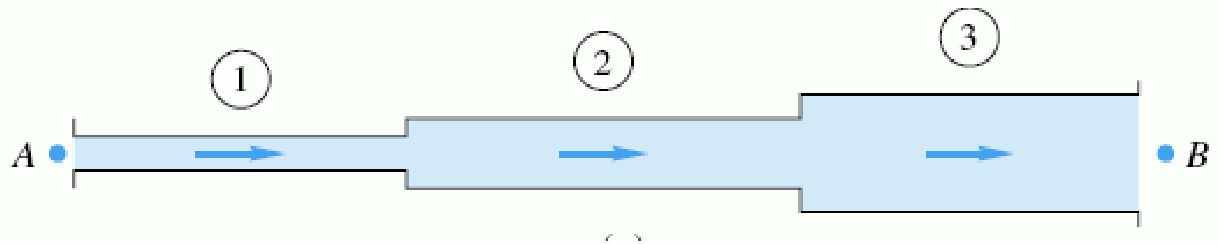
$$V_1 d_1^2 = V_2 d_2^2 = V_3 d_3^2$$

$$\Delta h_{A\to B} = \Delta h_1 + \Delta h_2 + \Delta h_3$$

$$\Delta h_{A\to B} = \frac{V_1^2}{2g}\left(\frac{f_1 L_1}{d_1} + \sum K_1\right) + \frac{V_2^2}{2g}\left(\frac{f_2 L_2}{d_2} + \sum K_2\right) + \frac{V_3^2}{2g}\left(\frac{f_3 L_3}{d_3} + \sum K_3\right)$$

$$\Delta h_{A\to B} = \frac{V_1^2}{2g}(\alpha_0 + \alpha_1 f_1 + \alpha_2 f_2 + \alpha_3 f_3)$$

EXAMPLE



Given is a three-pipe series system, The total pressure drop is p_A - p_B =150,000 Pa, and the elevation drop is z_A -z_B = 5 m. The pipe data are:

Pipe	L, m	d, cm	ϵ, mm	ϵ/d
1	100	8	0.24	0.003
2	150	6	0.12	0.002
3	80	4	0.20	0.005

The fluid is water, ρ = 1000 kg/m^3 and ν = 1.02 x10^6 m^2/s. Calculate the flow rate ***Q*** in m^3/h through the system.

EXAMPLE

Pipe	L, m	d, cm	ϵ, mm	ϵ/d
1	100	8	0.24	0.003
2	150	6	0.12	0.002
3	80	4	0.20	0.005

$$\Delta h_{A\to B} = \frac{p_A - p_B}{\rho g} + z_A - z_B = \frac{150{,}000}{1000(9.81)} + 5\ \text{m} = 20.3\ \text{m}$$

$$V_2 = \frac{d_1^2}{d_2^2} V_1 = \frac{16}{9} V_1 \qquad V_3 = \frac{d_1^2}{d_3^2} V_1 = 4V_1$$

$$\text{Re}_2 = \frac{V_2 d_2}{V_1 d_1}\text{Re}_1 = \frac{4}{3}\text{Re}_1 \qquad \text{Re}_3 = 2\ \text{Re}_1$$

Neglecting minor losses

Begin by estimating f_1, f_2, and f_3 from the Moody-chart fully rough regime

$$f_1 = 0.0262 \qquad f_2 = 0.0234 \qquad f_3 = 0.0304$$

$$\Delta h_{A\to B} = \frac{V_1^2}{2g}\left[1250 f_1 + 2500\left(\frac{16}{9}\right)^2 f_2 + 2000(4)^2 f_3\right]$$

$$V_1^2 \approx 2g(20.3)/(33 + 185 + 973). \qquad V_1 = 0.58\ \text{m/s}$$

EXAMPLE

$f_1 = 0.0262 \qquad f_2 = 0.0234 \qquad f_3 = 0.0304 \qquad V_1 = 0.58$ m/s

$\text{Re}_1 \approx 45{,}400 \qquad \text{Re}_2 = 60{,}500 \qquad \text{Re}_3 = 90{,}800$

Hence, from the Moody chart,

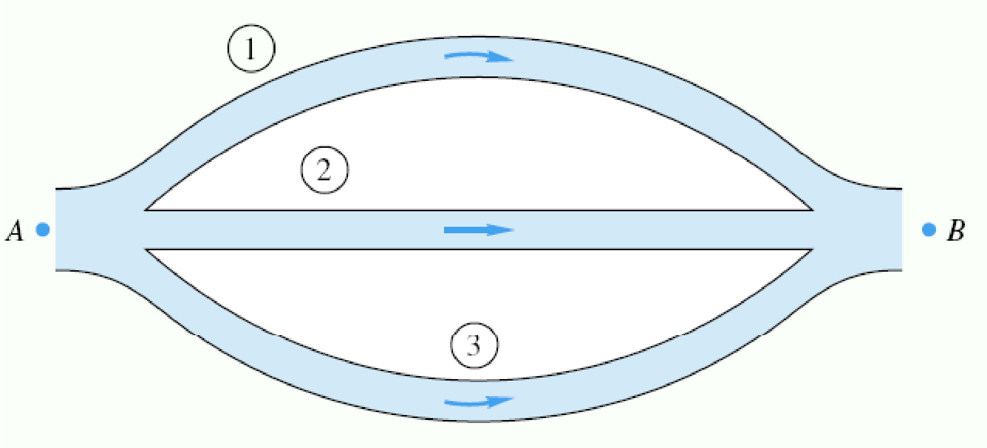
$$f_1 = 0.0288 \qquad f_2 = 0.0260 \qquad f_3 = 0.0314$$

$$V_1 = 0.565 \text{ m/s} \qquad Q = \tfrac{1}{4}\pi d_1^2 V_1 = 2.84 \times 10^{-3} \text{ m}^3/\text{s}$$

$$Q_1 = 10.2 \text{ m}^3/\text{h}$$

A second iteration gives $Q = 10.22$ m^3/h, a negligible change.

EXAMPLE



$$\Delta h_{A \to B} = \Delta h_1 = \Delta h_2 = \Delta h_3$$

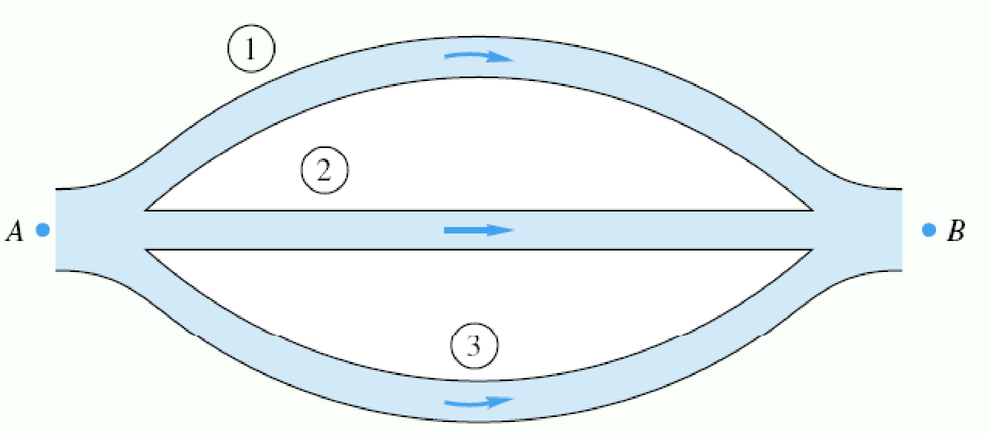
$$Q = Q_1 + Q_2 + Q_3$$

$$h_f = f(L/d)(V^2/2g) = fQ^2/C,$$

$$C = \pi^2 g d^5 / 8L,$$

$$h_f = \frac{Q^2}{\left(\sum \sqrt{C_i/f_i}\right)^2} \quad \text{where } C_i = \frac{\pi^2 g d_i^5}{8L_i}$$

EXAMPLE



Pipe	L, m	d, cm	ϵ, mm	ϵ/d
1	100	8	0.24	0.003
2	150	6	0.12	0.002
3	80	4	0.20	0.005

The pipes are connected in parallel

Total head loss of 20.3 m.

Compute the total flow rate Q, neglecting minor losses.

EXAMPLE

$$20.3 \text{ m} = \frac{V_1^2}{2g} 1250 f_1 = \frac{V_2^2}{2g} 2500 f_2 = \frac{V_3^2}{2g} 2000 f_3$$

Guess fully rough flow in pipe 1: $f_1 = 0.0262$, $V_1 = 3.49$ m/s; hence $\text{Re}_1 = V_1 d_1/\nu = 273{,}000$.

From the Moody chart read $f_1 = 0.0267$; recompute $V_1 = 3.46$ m/s, $Q_1 = 62.5$ m^3/h.

Next guess for pipe 2: $f_2 \approx 0.0234$, $V_2 \approx 2.61$ m/s; then $\text{Re}_2 = 153{,}000$, and hence $f_2 = 0.0246$, $V_2 = 2.55$ m/s, $Q_2 = 25.9$ m^3/h.

Finally guess for pipe 3: $f_3 \approx 0.0304$, $V_3 \approx 2.56$ m/s; then $\text{Re}_3 = 100{,}000$, and hence $f_3 = 0.0313$, $V_3 = 2.52$ m/s, $Q_3 = 11.4$ m^3/h.

$$Q = Q_1 + Q_2 + Q_3 = 62.5 + 25.9 + 11.4 = 99.8 \text{ m}^3/\text{h}$$

These three pipes carry 10 times more flow in parallel than they do in series.