HYDRAULICS

PIPE FLOW
SECTION 7

HEAD (ENERGY) LOSSES

INTRODUCTION

1. A pipe is a closed conduit which is used for carrying fluids under pressure.
2. Pipes are commonly circular in sections.
3. As the pipes carry fluids under pressure, the pipe always run full.
4. The fluid flowing in the pipe is always subjected to resistence due o shear forces between fluid particles and the boundary walls of the pipe and between the fluid particles themselves resulting from the viscosity of the fluid.
5. A certain amount of energy possesessed by the flowing fluid will be consumed in overcoming this resistence to the flow, there will always be some loss of energy in the direction of flow.

TYPE OF FLOW IN PIPE (1/2)

- There are two types of flow in the pipe:
  - Laminar flow, and
  - Turbulent flow.
- Based on the Osborne Reynold experiment (1883), the occurrence of a laminar and turbulent flow as governed by the relative magnitudes od the inertia and the viscous force.

$$R_e = \frac{\text{Inertia Force}}{\text{Viscous Force}} = \frac{F_t}{F_\upsilon}$$

$$R_e = \frac{\rho V L}{\mu}$$

Re = Reynold number
V = Characteristic (representative) velocity
L = Characteristic linear dimension
ρ = mass density of fluid
μ = viscosity of flowing fluid, and
υ = kinematic viscosity (μ/ρ)

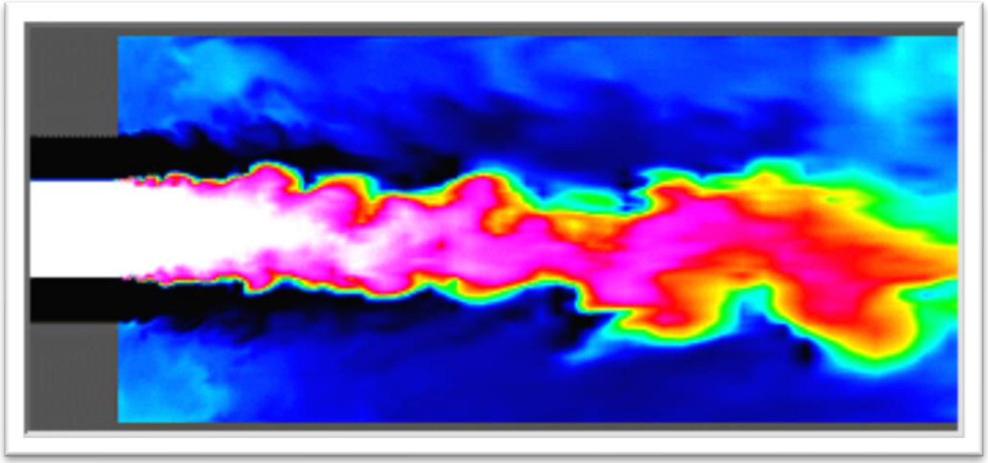
TYPE OF FLOW IN PIPE (2/2)

Based on the Reynold experiment, he decided that:

- Laminar flow occured when the Reynolds number less then 2.000, all turbulence entering the flow can be damped out by viscosity
- Turbulent flow occurred when Reynolds number greater then 4.000.
- When the Reynolds numbers between 2.000 and 4.000, the flow is in transition condition.

TYPE OF FLOW VISUALIZATION

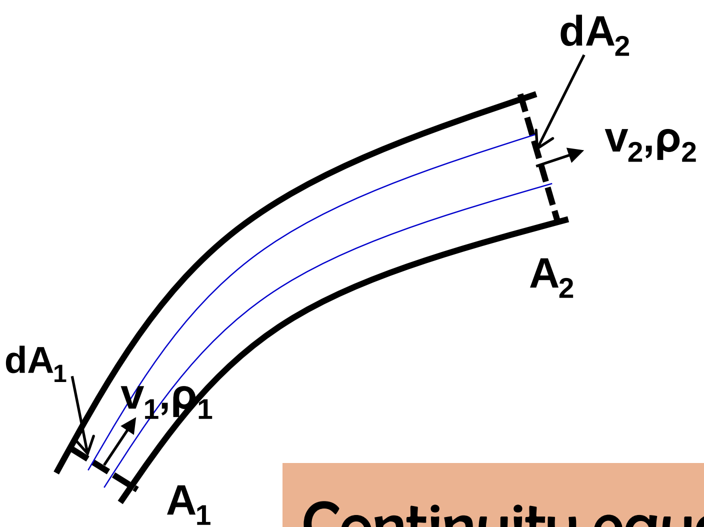
Laminar flow



Turbulent flow

CONTINUITY EQUATION

Consider to small section of flow in the tube, the mass flow entering the tube per second is equal to that flowing out from the tube per second, as there is no mass flow crossing the tube, then :



$$\rho_1 V_1 dA_1 = \rho_2 V_2 dA_2$$

V_1 and V_2 = mean flow velocity at section 1 and 2, respectively

dA_1 and A_2 = cross section area of the tube

ρ_1 and ρ_2 = mass density

Continuity equation: $A_1V_1 = A_2V_2 = Q$

Prepared by: SURIPIN, DR., IR., M.ENG

BERNOULLI EQUATION

Bernoulli equation:

$$z + \frac{p}{\rho g} + \frac{V^2}{2g} = \text{kons tan}$$

Where: Z : elevation head

$\frac{p}{\rho g}$: pressure head

$\frac{V^2}{2g}$: velocity head

Energy equation along the pipe:

$$z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g}$$

For a real fluid, energy losses should be considered, so:

$$z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + \sum h_f$$

LAWS OF FLUID FRICTION

- The frictional resistance offered to the low depends on type of flow.
- The frictional resistance in the laminar flow is:

1. Proportional to the velocity of flow
2. Independent of the pressure
3. Proportional to the area of surface in contact
4. Independent of the nature of the surface in contact
5. Greatly affected by variation of the temperature of the flowing fluid

- The frictional resistance of the turbulent flow is:

1. Proportional to $(velocity)^n$, n = 1.7 to 2.0
2. Independent of pressure
3. Slightly affected by variation of the temperature of the flowing fluid
4. Proportional to the area of surface in contact
5. Dependent on the nature of the surface in contact

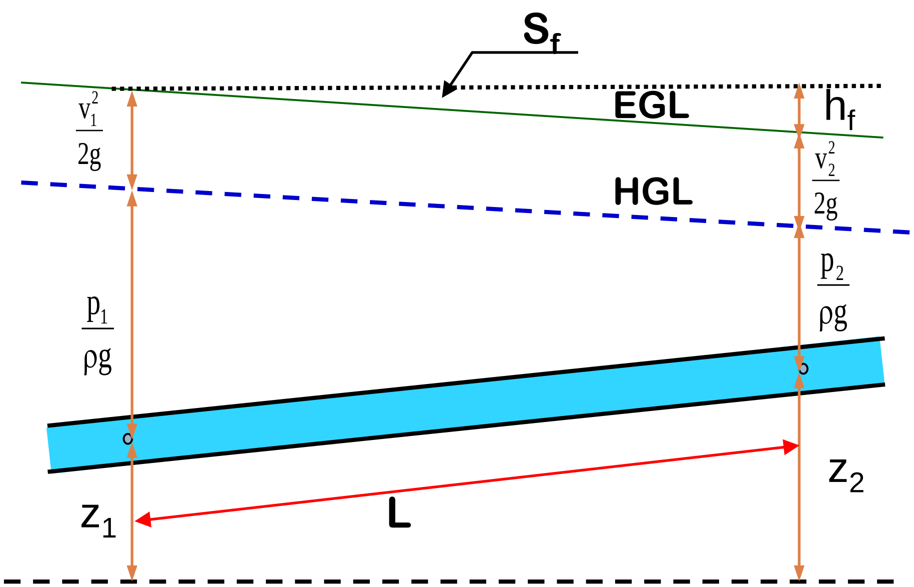
HEAD (ENERGY) LOSSES

1. The head or energy losses in flow in a pipe are made up of friction losses (major losses) and local losses (minor losses)
2. Major losses are caused by forces between the liquid and the solid boundary (distributed along the length of the pipe)
3. Minor losses are caused by disruptions to the flow at local features like bends and changes in cross section
4. The distribution of losses, and other components can be shown by two imaginary lines:
   1) The energy grade line (EGL) is drawn a vertical distance from the datum equal to the total head
   2) The hydraulic grade line (HGL) is drawn a vertical distance below the energy grade line equal to the velocity head

MAJOR LOSSES

Based on the Bernoulli equation:

$$z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + h_f$$



Untuk pipa seragam, $v_1 = v_2$

Sehingga:

$$h_f = \frac{p_1 - p_2}{\rho g} + Z_1 - Z_2$$

$$hf = \frac{\tau_0 PL}{\rho g.A} \qquad \tau_0 = \rho g R \frac{h_f}{L}$$

$$\tau_0 = \rho g R S_f$$

Darcy-Weisbach: $$h_f = \frac{\lambda L V^2}{2gD}$$

λ is nondimensional constante

MINOR LOSSES

1. Loss of energy due to sudden enlargement: $h_L = \frac{(V_1 - V_2)^2}{2g}$

2. Loss of energy due to sudden contraction: $h_L = 0.5\frac{V^2}{2g}$

3. Loss of energy at the entrance to a pipe: $h_L = 0.5\frac{V^2}{2g}$

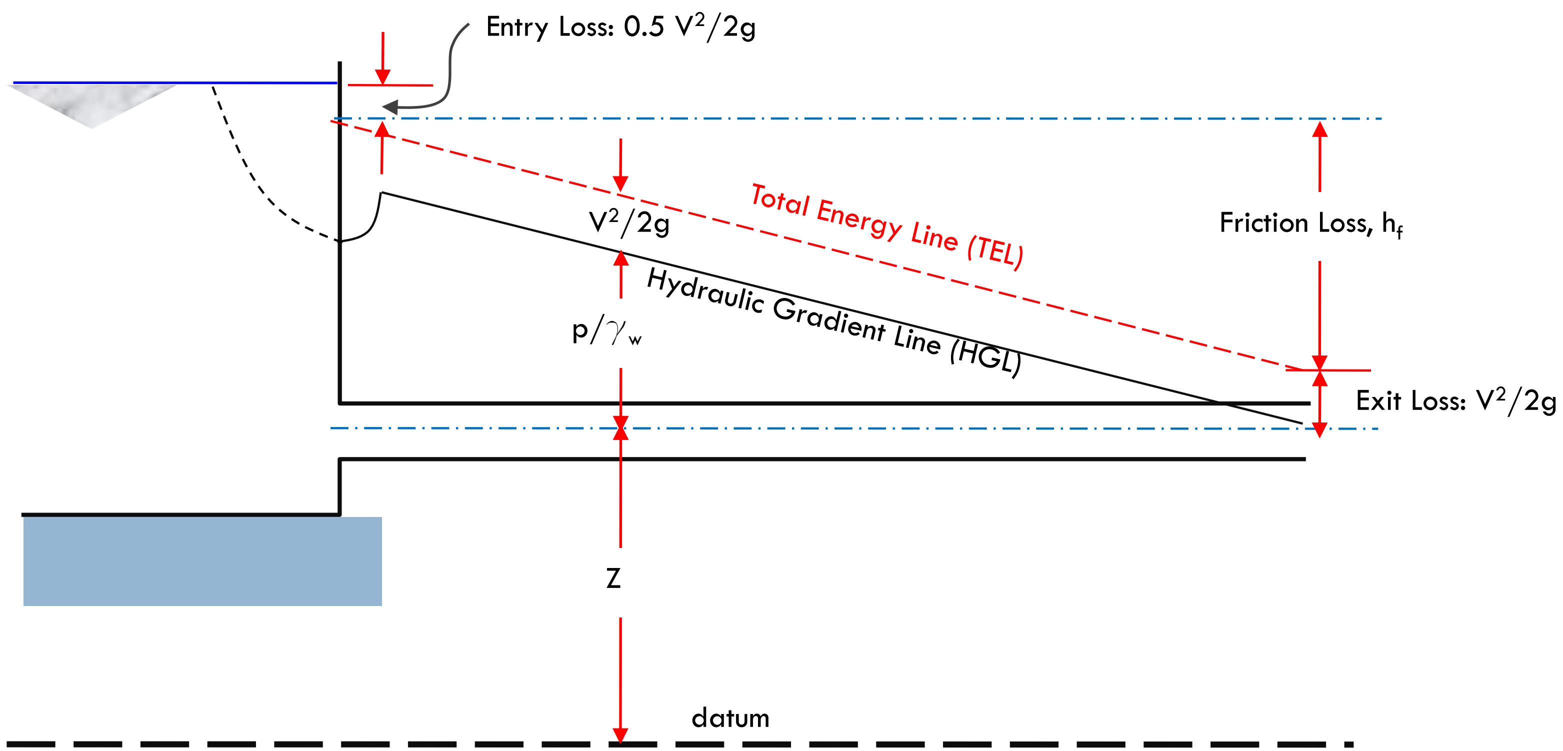
4. Loss of energy at the exit from a pipe: $h_L = \frac{V^2}{2g}$

5. Loss of energy due to gradual contraction or enlargement: $h_L = k\frac{(V_1 - V_2)^2}{2g}$

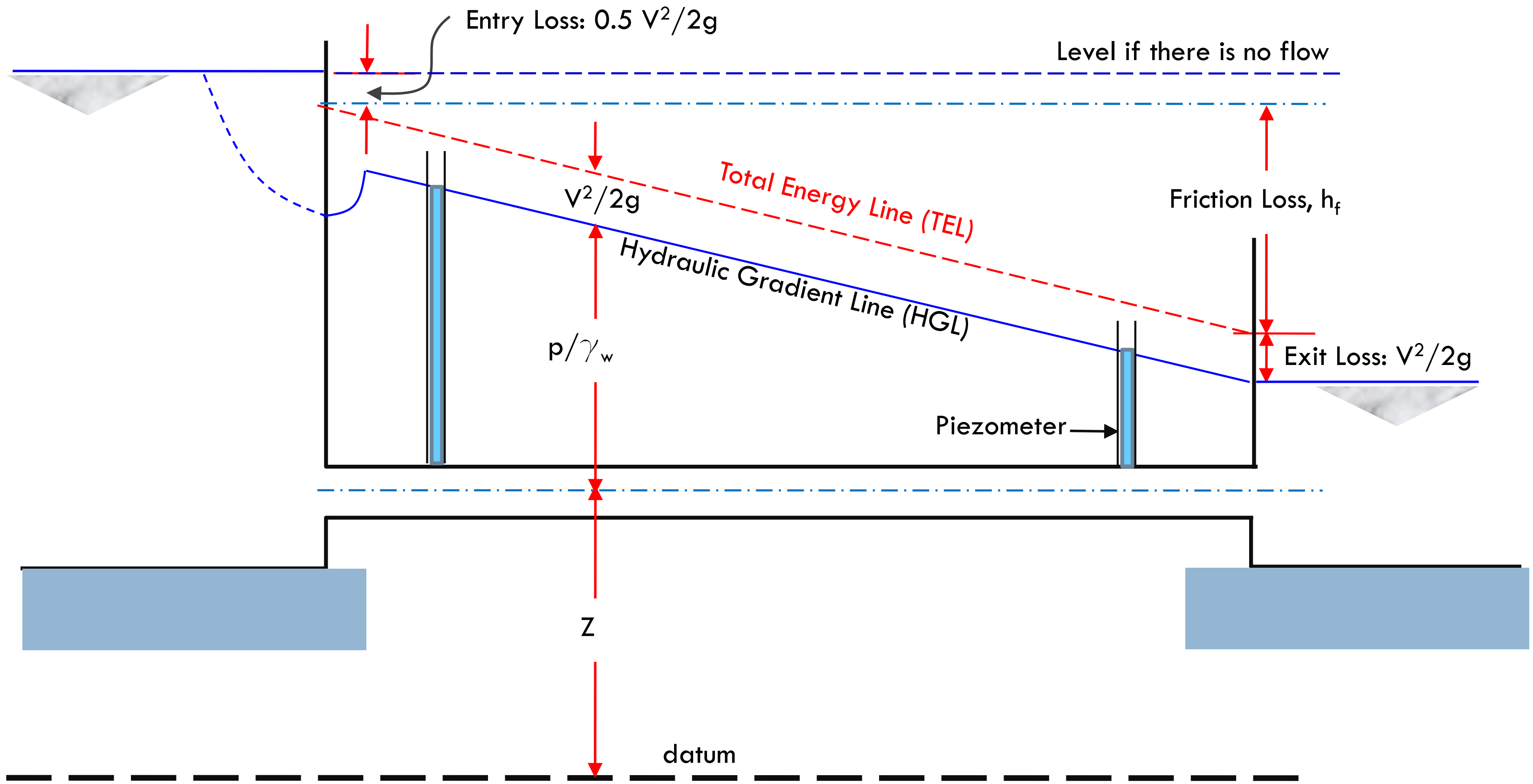
7. Loss of energy in the bends: $h_L = k\frac{V^2}{2g}$

8. Loss of energy in various pipe fitting: $h_L = k\frac{V^2}{2g}$

TOTAL ENERGY LINE (TEL) DAN HYDRAULIC GRADIENT LINE (HGL)



TOTAL ENERGY LINE (TEL) DAN HYDRAULIC GRADIENT LINE (HGL)



Prepared by: SURIPIN, DR., IR., M.ENG

CONTOH 1

1. pipa dengan diameter 22,5 cm dan panjang 1.580 m mempunyai kemiringan 1:200 untuk 790 m pertama dan 1:100 untuk 790 m berikutnya. Tekanan pada ujung atas 1,1 kg/cm2 dan di ujung bawah 0,55 kg/cm. Ambil f=0,032. Tentukan debit yang melalui pipa?

Jawaban:

Ambil garis referensi berada di ujung bawah pipa, sehingga tinggi tekan di ujung atas pipa adalah:

$$Z_1 = \frac{790}{200} + \frac{790}{100} = 3{,}95 + 7{,}90 = 11{,}85 \text{ m}$$

Dengan menggunakan persamaan Bernoulli antara ujung atas dan ujung bawah diperoleh:

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_f$$

CONTOH 1 (LANJUTAN.....)

$V_1 = V_2 = V$

$$h_f = \frac{fLV^2}{2gD} = \frac{0{,}032x1580xV^2}{2x9{,}81x0{,}225} = 11{,}45V^2$$

$$\frac{1{,}1x10^4}{1000} + \frac{V^2}{2g} + 11{,}85 = \frac{0{,}55x10^4}{1000} + \frac{V^2}{2g} + 0 + 11{,}45V^2$$

$11{,}45V^2 = 17{,}35$

$$V = \sqrt{\frac{17{,}35}{11{,}45}} = 1{,}23 \text{ m/s.}$$

$Q = AxV \rightarrow Q = \frac{\pi D^2}{4} V$

$$Q = \frac{\pi 0{,}225^2}{4} 1{,}23$$

$= 0{,}089 \text{ m}^3\text{/s.}$

CONTOH 2

2. Dua pipa masing-masing dengan panjang 300 m dihubungkan dengan reservoir sehingga terjadi aliran dengan debit 0,085 m^3/s. Jika diameter kedua pipa berturut-turut 30 cm dan 15 cm, tentukan rasio kehilangan tinggi tekan antara kedua pipa dipasang paralel dan dipasang seri! Abaikan kehilangan tekan minor.

Jawaban:

Pada pipa dipasang paralel, debit masing-masing pipa adalah Q_1 dan Q_2, sehingga

$$0,085 = Q_1 + Q_2 \qquad \text{(i)}$$

$$(h_f)_p = \frac{fLQ_1^2}{2g\left(\frac{\pi}{4}\right)^2 D_1^5} = \frac{fLQ_2^2}{2g\left(\frac{\pi}{4}\right)^2 D_2^5} \qquad \text{(ii)}$$

$$\frac{Q_1^2}{0,3^5} = \frac{Q_2^2}{0,15^5} \rightarrow Q_1 = 5,657\,Q_2 \qquad \text{(iii)}$$

CONTOH 2 (lanjutan .....)

Kombinasi (i) dan (iii) menghasilkan:

6,657 Q_2 = 0,085

Q_2 = 0,0128 m³/s.

Sehingga $$(h_f)_p = \frac{fx300x0{,}0128^2}{2g\left(\frac{\pi}{4}\right)^2 0{,}15^5} = \frac{fx644{,}09}{2g\left(\frac{\pi}{4}\right)^2}$$

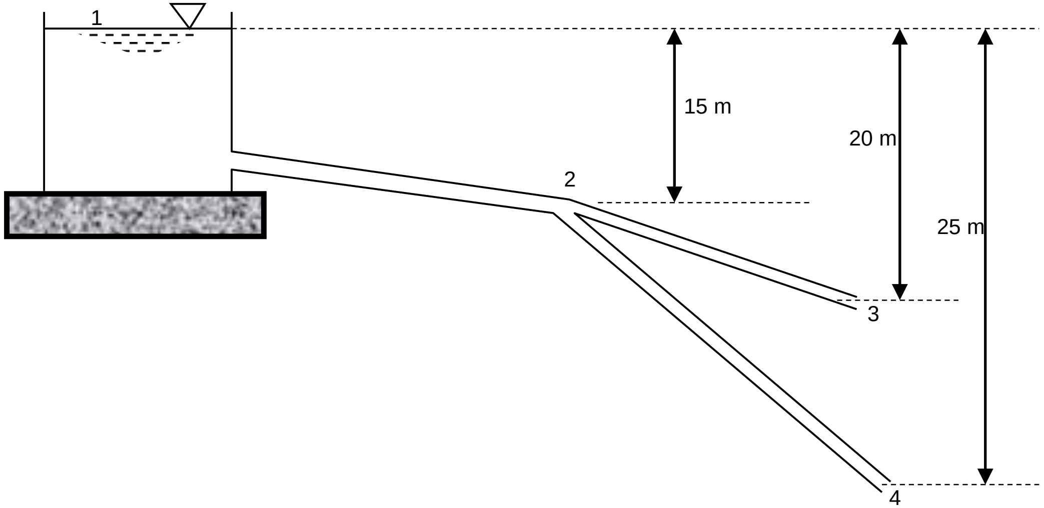
Pada pipa dipasang seri:

$$(h_f)_s = \frac{fLV_1^2}{2gD_1} + \frac{fLV_2^2}{2gD_2} = \frac{fLQ_1^2}{2g\left(\frac{\pi}{4}\right)^2 D_1^5} + \frac{fLQ_2^2}{2g\left(\frac{\pi}{4}\right)^2 D_2^5} = \frac{fx300x0{,}085^2}{2g\left(\frac{\pi}{4}\right)^2 0{,}3^5} + \frac{fx300x0{,}085^2}{2g\left(\frac{\pi}{4}\right)^2 0{,}15^5} = \frac{fx29x435{,}19}{2g\left(\frac{\pi}{4}\right)^2}$$

Sehingga: $$\frac{(h_f)_p}{(h_f)_s} = \frac{\dfrac{fx644{,}09}{2g\left(\frac{\pi}{4}\right)^2}}{\dfrac{fx29.435{,}19}{2g\left(\frac{\pi}{4}\right)^2}} = 0{,}0188, \text{ atau } \frac{(h_f)_s}{(h_f)_p} = 45{,}7.$$

CONTOH 3

3. Air mengalir dari waduk melalui pipa dengan diameter 15 cm sepanjang 150 m ke titik yang berada 15 m di bawah muka air waduk. Pada titik ini pipa bercabang menjadi dua, masing-masing berdiameter 10 cm, salah satunya sepanjang 50 m mengalirkan air ke udara pada ketinggian 18 m di bawah muka air waduk, dan satunya sepanjang 75 m mengalirkan air ke udara pada titik 25 di bawah muka air waduk. Ambil harga koefisien gesekan 0,032. Hitung debit dari masing-masing pipa. Abaikan kehilangan tinggi tekan pada percabangan.



CONTOH 3 (lanjutan .....)

Jawaban:

Misal tekanan di titik (2) adalah p, dan tekanan atmosfir 10,33 m air. Persamaan Bernoulli untuk titik (1) dan (2):

$$10{,}33 + 15 = \frac{p}{\gamma} + \frac{V_1^2}{2g} + \frac{0{,}032x150xV_1^2}{2gx0{,}15} \quad \rightarrow \quad \frac{p}{\gamma} = 25{,}33 - 1{,}971V_1^2 \qquad \text{(i)}$$

Persamaan Bernoulli untk titik (2) dan (3):

$$\frac{p}{\gamma} + \frac{V_2^2}{2g} + 5 = 10{,}33 + \frac{0{,}032x50xV_2^2}{2gx0{,}10} \quad \rightarrow \quad \frac{p}{\gamma} = 5{,}33 + 0{,}305V_2^2 \qquad \text{(ii)}$$

Persamaan Bernulli untuk titik (2) dan (4):

$$\frac{p}{\gamma} + \frac{V_3^2}{2g} + 10 = 10{,}33 + \frac{0{,}032x75xV_3^2}{2gx0{,}10} \quad \rightarrow \quad \frac{p}{\gamma} = 0{,}33 + 0{,}714V_3^2 \qquad \text{(iii)}$$

Dengan persamaan kontnuitas diperoleh:

$$A_1xV_1 = A_2V_2 + A_3V_3 \quad \rightarrow \quad 9V_1 = 4(V_2 + V_3) \qquad \text{(iv)}$$

CONTOH 3 (lanjutan .....)

Dengan persamaan (i) s/d (iv) permaslahan dapat diselesaikan sbb.:

Asumsikan $V_3 = nV_2$

$$V_1 = \frac{4}{9}(n+1)V_2$$

Dari (i) dan (ii)

$$25{,}33 - 1{,}971V_1^2 = 5{,}33 + 0{,}305V_2^2$$

$$20 = \left(1{,}971x\frac{16}{81}(n+1)^2 + 0{,}305\right)V_2^2$$

$$20 = (0{,}389\ n^2 + 0{,}779\ n + 0{,}694)V_2^2 \qquad \text{(v)}$$

Dari (ii) dan (iii)

$$5{,}33 + 0{,}305V_2^2 = 0{,}33 + 0{,}714V_3^2$$

$$5 = (0{,}714n^2 - 0{,}305)V_2^2 \qquad \text{(vi)}$$

Bagi (v) dengan (vi):

$$4 = \frac{0{,}389\ n^2 + 0{,}779\ n + 0{,}694}{0{,}714n^2 - 0{,}305}$$

$$2{,}856n^2 - 1{,}220 = 0{,}389\ n^2 + 0{,}779\ n + 0{,}694$$

$$2{,}467n^2 - 0{,}779 - 1{,}914 = 0$$

Jadi n = 1,053

CONTOH 3 (lanjutan .....)

Dari (vi) diperoleh :

V_2 = 3,207 m/s.

V_3 = 1,053x3,207 = 3,377 m/s.

$$Q_2 = \left(\frac{\pi}{4} x 0{,}1^2 x 3{,}207\right) = 0{,}0252 \text{ m}^3\text{/s.}$$

$$Q_3 = \left(\frac{\pi}{4} x 0{,}1^2 x 3{,}377\right) = 0{,}0265 \text{ m}^3\text{/s.}$$

Sehingga $Q_1 = Q_2 + Q_3$

$$Q_1 = 0{,}0252 + 0{,}0265$$

$$= 0{,}0517 \text{ m}^3\text{/s.}$$

ASSIGNMENTS

1. Sistem pipa tersusun dari pipa 1.500 m dengan diameter 30 cm, 1.000 m diameter 40 cm, dan 500 m diameter 30 cm dihubungkan secara seri. Konversikan sistem kedalam a). ekivalen panjang pipa seri dengan diameter 40 cm, b). ekivalen diameter pipa dengan panjang 3.600 m.
2. Penduduk suatu kota berjumlah 1.000.000 jiwa akan dilayani air bersih yang bersumber dari waduk yang berjarak 7,5 km dari kota. Kebutuhan air diproyeksikan 150 lt/jiwa/hari, setengah diantaranya akan disuplai dalam 8 jam. Elevasi waduk kondisi penuh +200,00 m dan kondisi paling rendah +125,00 m. Kehilangan energi total sistem sampai titik terjauh sebesar 25,00 m dan tinggi tekan di konsumen yang dipersayaratkan minimal 12,00 m. Tentukan diameter pipa. Ambil faktor gesekan f=0,04.
3. Pipa dengan panjang 6.000 m dan diameter 70 cm menghubungka 2 (dua) reservoir A dan B, yang mempunyai perbedaan elevasi muka air sebesar 30 m. Di pertengahan pipa antara A dan B terdapat percabangan yang mengalirkan ke reservoir C. Dengan mengambil f = 0,025, hitung debit ke reservoir B jika:
   a) Tidak ada aliran ke reservoir C.
   b) Aliran ke reservoir C sebesar 0,25 m^3/s.