Energy in Steady Flow

5.1. Energies of a flowing fluid

Kinetic energy

mass $= m = \rho \forall$, $\forall$ = volume

Weight $= W = \gamma \forall = \rho g \forall$

Kinetic energy, $KE = \frac{1}{2} m V^2 = \frac{1}{2} \rho \forall V^2$

- kinetic energy per unit weight

$$\frac{KE}{W} = \frac{\frac{1}{2}\rho \forall V^2}{\rho g \forall} = \frac{V^2}{2g}$$

- kinetic energy per unit mass

$$\frac{KE}{m} = \frac{1/2 \rho \forall V^2}{\rho \forall} = \frac{V^2}{2}$$

- kinetic energy per unit volume

$$\frac{KE}{\forall} = \frac{1/2 \rho \forall V^2}{\forall} = \frac{\rho V^2}{2}$$

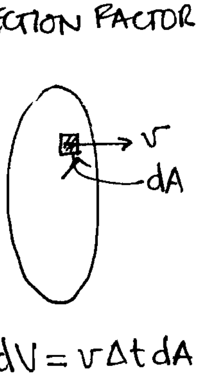
UNITS

$$\frac{KE}{W} = \frac{V^2}{2g} \rightarrow ft, m$$

$$\frac{KE}{m} = \frac{V^2}{2} \rightarrow \frac{ft^2}{s^2}, \frac{m^2}{s^2}$$

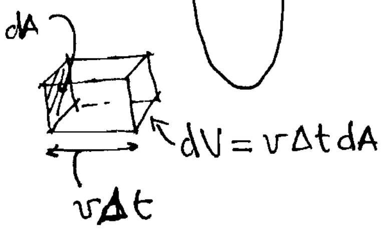
$$\frac{KE}{\forall} = \frac{\rho V^2}{2} \rightarrow \frac{lb}{ft^2}, \frac{N}{m^2}$$

- CORRECTION FACTOR FOR KINETIC ENERGY: not all particles have the same velocity V



← FOR A small element of area dA, the velocity is v, and the kinetic energy of the particles flowing through it in time Δt

$$d(KE) = \frac{1}{2} dm \cdot v^2 = \frac{1}{2} \rho dV v^2 = \frac{1}{2}\rho(v\Delta t dA) \cdot v^2$$



$$d\left(\frac{KE}{\Delta t}\right) = \frac{1}{2}\rho v^3 dA$$

↑ kinetic energy rate

TOTAL KINETIC ENERGY RATE:
$$\frac{KE}{\Delta t} = \int_A d\left(\frac{KE}{\Delta t}\right) = \frac{1}{2}\rho \int_A v^3 dA = KER_{true}$$

If the entire cross-section has $v = V$, then the total kinetic energy rate would be

$$\left(\frac{KE}{\Delta t}\right)_V = \frac{1}{2}\rho \int_A V^3 dA = \frac{1}{2}\rho V^3 \int_A dA = \frac{1}{2}\rho V^3 A = KER_{AVERAGE}$$

To relate KER_{TRUE} to $KER_{AVERAGE}$, introduce a KINETIC ENERGY CORRECTION FACTOR (α) so that

$$KER_{TRUE} = \alpha \cdot KER_{AVERAGE}$$

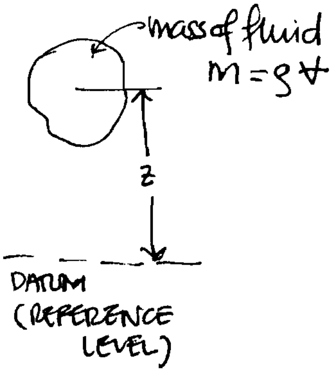
$$\cancel{\tfrac{1}{2}}\rho \int_A v^3 dA = \alpha \cdot \cancel{\tfrac{1}{2}}\rho V^3 \cdot A \Rightarrow \boxed{\alpha = \frac{1}{AV^3}\int_A v^3 dA}$$

RECALL, FROM CONTINUITY, that $V = \frac{Q}{A} = \frac{1}{A}\int_A v\, dA$

- NOTES:
  - $\alpha > 1$
  - the greater the variation of v, the larger the value of α
  - laminar flow in a pipe $\rightarrow$ $\alpha = 2$
  - turbulent flow in a pipe $\rightarrow$ $1.01 < \alpha < 1.15$ range
    $1.03 < \alpha < 1.06$ in most cases

  $\Rightarrow$ in turbulent flows, using $\alpha = 1.0$ introduces little error in the calculations

<u>Potential energy</u> $\rightarrow$ DUE TO GRAVITY, $P.E. = mgh = \rho \forall g h$



$$\frac{P.E.}{weight} = \frac{P.E.}{W} = \frac{\rho \forall g h}{\rho g \forall} = h$$

$$\frac{P.E.}{mass} = \frac{\rho \forall g h}{\rho \forall} = gh$$

$$\frac{P.E.}{volume} = \frac{\rho \forall g h}{\forall} = \rho g h$$

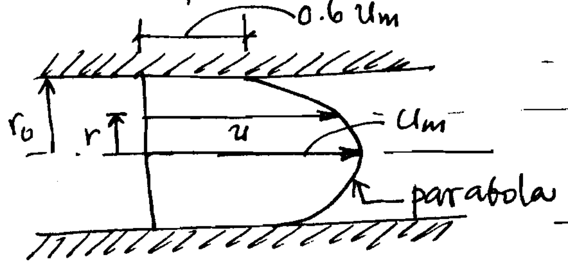
<u>Pressure head</u> From $p = \gamma h \Rightarrow h = \frac{p}{\gamma} = \text{length} \equiv \frac{\text{PRESSURE ENERGY}}{\text{WEIGHT}}$

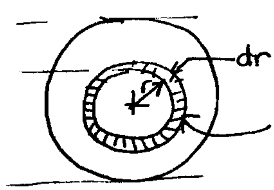
<u>Internal energy</u> molecular level (thermal) — SEE page 129

$\Delta i = c_v \Delta T$, c_v = specific heat at constant volume

EXERCISES

5.1.1. Assume the velocity profile for turbulent flow in a circular pipe to be approximate by a parabola from the axis to a point very close to the wall where the local velocity is $u = 0.6\,u_m$ where u_m is the maximum velocity at the axis (Figure X5.1.1). The equation for this parabola is $u = u_m[1 - 0.4(r/r_0)^2]$. Find α.





$A = \pi r_0^2$

$dA = 2\pi r dr$

$$u(r) = u_m[1 - 0.4(r/r_0)^2], \text{ check } \begin{cases} \text{when } r = r_0,\ u(r) = 0.6\,u_m \\ \text{when } r = 0,\ u(r) = u_m \end{cases}$$

$\frac{0.4}{4} = 0.10 = \frac{1}{10}$ $\quad 0.4 = \frac{4}{10} = \frac{2}{5}$

$$dQ = u(r)dA = u(r)2\pi r dr = 2\pi r u_m[1 - 0.4(r/r_0)^2]dr$$

$$Q = \int dQ = 2\pi u_m \int_0^{r_0}\left(r - \frac{0.4}{r_0^2}r^3\right)dr = 2\pi u_m\left(\frac{r^2}{2} - \frac{0.4}{4r_0^2}r^4\right)\Bigg|_0^{r_0}$$

$$= 2\pi u_m\left(\frac{r_0^2}{2} - \frac{r_0^4}{10 r_0^2}\right) = 2\pi u_m r_0^2\left(\frac{1}{2} - \frac{1}{10}\right) = 2\pi u_m r_0^2\,\frac{5-1}{10}$$

$$= \frac{8\pi u_m r_0^2}{10} = \frac{4}{5}\pi u_m r_0^2, \quad V = \frac{Q}{A} = \frac{\frac{4}{5}\pi u_m \cancel{r_0^2}}{\cancel{\pi r_0^2}} = \frac{4}{5}u_m$$

$$u^3 = u_m^3\left(1 - \frac{0.4}{r_0^2}r^2\right)^3$$

$$\int_A u^3 dA = \int_0^{r_0} u_m^3 \Big(\underbrace{1 - \frac{2}{5r_0^2}r^2}_{s}\Big)^3 2\pi r dr = \int_1^{3/5} u_m^3 s^3 \cancel{2}\pi \cdot \left(-\frac{5}{\cancel{4}_2} r_0^2 ds\right)$$

$$= -\frac{5}{2}u_m^3 r_0^2 \pi \int_1^{3/5} s^3 ds = -\frac{5}{2}u_m^3 r_0^2 \pi \frac{s^4}{4}\Bigg|_1^{3/5}$$

$$= -\frac{5}{8}u_m^3 r_0^2 \pi\left(\frac{81}{625} - 1\right) = -\frac{5}{8}u_m^3 r_0^2\left(\frac{-544}{625}\right)\pi$$

$$= +u_m^3 r_0^2 \pi \frac{68}{125} = \frac{68}{125}u_m^3 r_0^2 \pi$$

$s = 1 - \frac{2}{5r_0^2}r^2$

$ds = -\frac{4}{5r_0^2}r dr$

$r dr = -\frac{5}{4}r_0^2 ds$

For $r = 0$, $s = 1$

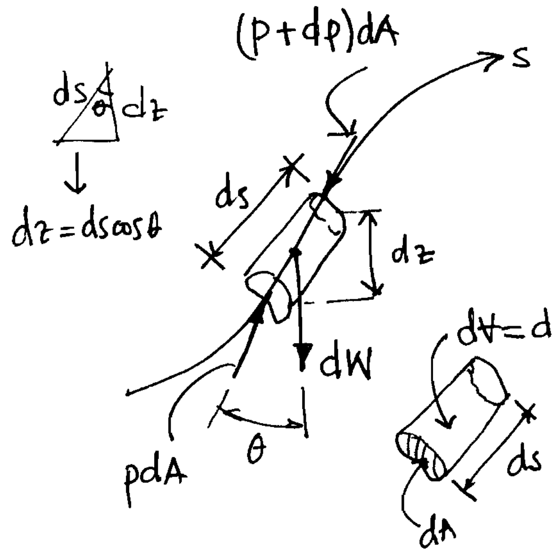
For $r = r_0$, $s = 1 - \frac{2}{5} = \frac{3}{5}$

$$\alpha = \frac{1}{AV^3}\int_A u^3 dA = \frac{\frac{68}{125}\cancel{u_m^3}\cancel{r_0^2}\cancel{\pi}}{\cancel{\pi r_0^2}\cdot\frac{64}{125}\cancel{u_m^3}} = \frac{68}{64}$$

$$\boxed{\alpha = \frac{68}{64} = 1.0625}$$

136 68
272
625   544   16
81   4
544   64

5.2. Equation for Steady Motion of an Ideal Fluid Along a Streamline, and Bernoulli's Theorem.



Consider element of fluid moving along streamline

- mass, $dm = \rho dV\!\!\!\!- = \rho dA ds$
- weight, $dW = dm.g = \rho g dV\!\!\!\!-$ $= \gamma dV\!\!\!\!- = \gamma dA.ds$
- acceleration in steady flow, $a_s = V\frac{dV}{ds}$
- Newton's 2nd law $\sum F_s = dm.a_s$

$$\Rightarrow \quad pdA - (p+dp)dA - dW\cos\theta = dm.a_s$$

$$\cancel{pdA} - \cancel{pdA} - dp\,dA - \gamma dA ds\cos\theta = \rho dA \cancel{ds} V \frac{dV}{\cancel{ds}}$$

Divide by dA $\rightarrow$ $$-dp - \gamma \underbrace{ds\cos\theta}_{dz} = \rho V dV$$

$$\Rightarrow \quad dp + \gamma dz + \rho V dV = 0$$

Divide by ρ $\rightarrow$ $$\boxed{\frac{dp}{\rho} + g dz + V dV = 0}$$ One-Dimensional Euler equation

Divide by g $\rightarrow$ $$\boxed{\frac{dp}{\gamma} + dz + \frac{V}{g} dV = 0}$$

NOTE: $d\left(\frac{V^2}{2}\right) = \frac{\cancel{2}VdV}{\cancel{2}} = VdV$, thus

For $$\boxed{\frac{dp}{\gamma} + dz + d\left(\frac{V^2}{2g}\right) = 0}$$

Integration of Euler's equation

- Compressible fluid $\rightarrow$ needs $\gamma = \gamma(p, T)$ – see 5.7/Ch. 13
- Incompressible fluid, γ = constant

$$\boxed{\frac{p}{\gamma} + z + \frac{V^2}{2g} = \text{constant (along a streamline)}} \Big\} \text{ ENERGY PER UNIT WEIGHT}$$

Bernoulli's theorem (after Daniel Bernoulli (1700-1782))

Other forms:

$$\boxed{\frac{p}{\rho} + gz + \frac{V^2}{2} = \text{constant (along streamline)}} \Big\} \text{ energy per unit mass}$$

$$\boxed{p + \gamma z + \tfrac{1}{2}\rho V^2 = \text{constant (along streamline)}} \Big\} \text{ energy per unit volume}$$

Bernoulli's constant

Assumptions:
1. Ideal fluid (negligible viscous effects)
2. Steady flow
3. Equation applies along a streamline, i.e., Bernoulli's constant changes (in general) from streamline to streamline
4. Fluid is incompressible (γ=constant, liquids)
5. No energy added to or removed from fluid along a given streamline.

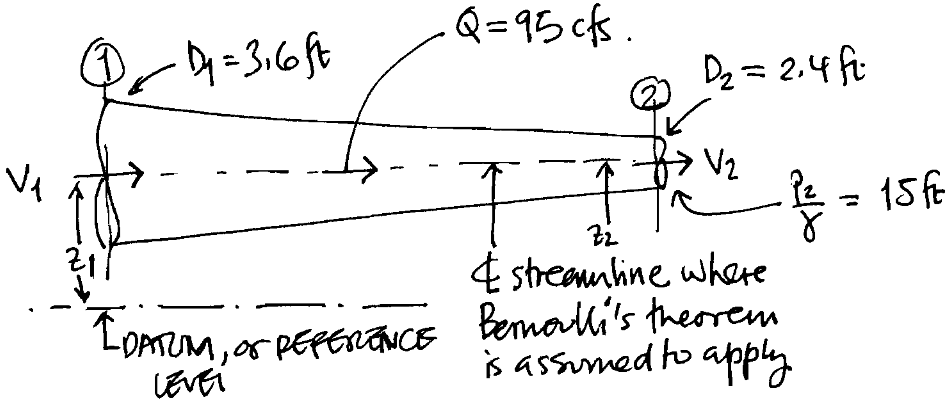
- Bernoulli's theorem can be applied to real fluids when viscosity effects are negligible
- For irrotational flows (see Section 14.2) Bernoulli's equation holds throughout the entire flow field, i.e., Bernoulli's constant is the same in all streamlines.

NOTE:

$$\underbrace{\frac{p}{\gamma}}_{\text{pressure head}} + \underbrace{z}_{\text{ELEVATION}} + \underbrace{\frac{V^2}{2g}}_{\text{velocity head}} = \text{constant} = \underbrace{H}_{\text{TOTAL HEAD}}$$

EXERCISES.

5.2.1. Assume frictionless flow in a ~~large~~ long, horizontal conical pipe which has a diameter of 3.6 ft at the entrance and 2.4 ft at exit. The pressure head at the smaller end is 15 ft of water. If water flows through this cone at a rate of 95 cfs, find the velocities at the two ends and the pressure head at the larger end.



Find $V_1 = ?$, $V_2 = ?$, $P_1/\gamma = ?$

NOTE: since the pipeline is horizontal $z_1 = z_2$

Bernoulli's theorem at ①: $\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = H$

Bernoulli's theorem at ②: $\frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g} = H$

i.e., $\frac{P_1}{\gamma} + \cancel{z_1} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \cancel{z_2} + \frac{V_2^2}{2g}$ (since $z_1 = z_2$)

$$\frac{P_1}{\gamma} = \frac{P_2}{\gamma} + \frac{V_2^2 - V_1^2}{2g}$$

continuity: $Q = V_1 A_1 = V_2 A_2 \Rightarrow \cancel{V_1 \cdot \frac{\pi D_1^2}{4} = V_2 \frac{\pi D_2^2}{4} \Rightarrow V_1 D_1^2 = V_2 D_2^2}$

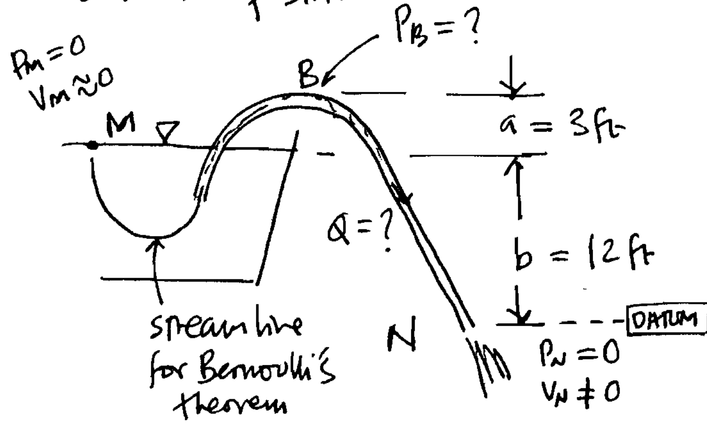
$$V_1 = \frac{Q}{A_1} = \frac{Q}{\pi D_1^2/4} = \frac{4Q}{\pi D_1^2} = \frac{4 \times 95}{\pi \times 3.6^2} = 9.33 \text{ fps}$$

$$V_2 = \frac{Q}{A_2} = \frac{Q}{\pi D_2^2/4} = \frac{4Q}{\pi D_2^2} = \frac{4 \times 95}{\pi \times 2.4^2} = 20.99 \text{ fps}$$

then,

$$\frac{P_1}{\gamma} = 15 + \frac{20.99^2 - 9.33^2}{2 \times 32.2} = 20.49 \text{ ft}.$$

5.2.2. Assume the flow to be frictionless in the siphon shown in Fig. X5.2.2., where $a = 3$ ft, $b = 12$ ft. Find the rate of discharge in cfs and the pressure head at B if the pipe has a uniform diameter of 3 in.



NOTES:

1 - We assume a continuous supply of water in the reservoir to ensure steady state conditions

2 — at point M, in the free surface, the gage pressure is zero, $P_M = 0$.

3 - the area of the flow at point M is assumed to be so large compared to the area of the pipe that $V_M \approx 0$, i.e., $Q = V_M A_M = VA$, where V, A = velocity and area of pipe, respectively. We have $A_M \gg A \Rightarrow \frac{A_M}{A} \gg 1$. Since $\frac{A_M}{A} = \frac{V}{V_M} \Rightarrow \frac{V}{V_M} \gg 1$ or $V \gg V_M$. So, we take $V_M \approx 0$.

4 - First we apply Bernoulli's theorem on a streamline, through the pipe, connecting points M and N

$$\frac{P_M}{\gamma} + z_M + \frac{V_M^2}{2g} = \frac{P_N}{\gamma} + z_N + \frac{V_N^2}{2g}$$

with: $P_M = 0$ $\quad$ $P_N = 0$

$z_M = b = 12$ ft $\quad$ $z_N = 0$ (location of DATUM)

$V_M \approx 0$ $\quad$ $V_N = ?$

$$0 + 12 + 0 = 0 + 0 + \frac{V_N^2}{2 \times 32.2} \Rightarrow V_N^2 = 2 \times 32.2 \times 12 = 772.8$$

$$\underline{V_N = 27.79 \text{ fps}}$$

5 - Since point B has the same diameter as point N: $Q = \frac{\pi D_B^2}{4} V_B = \frac{\pi D_N^2}{4} V_N$

$\Rightarrow V_B = V_N = 27.79$ fps. Then, we apply Bernoulli's theorem between M and B (or between B and N), with $z_B = a + b = 15$ ft

$$\frac{P_M}{\gamma} + z_M + \frac{V_M^2}{2g} = \frac{P_B}{\gamma} + z_B + \frac{V_B^2}{2g} \Rightarrow 0 + 12 + 0 = \frac{P_B}{\gamma} + 15 + \frac{27.79^2}{2 \times 32.2} \Rightarrow \frac{P_B}{\gamma} = -14.99 \text{ ft}$$

Important conclusions from Exercise 5.2.2.

- We assume steady state in our solution. Implications:

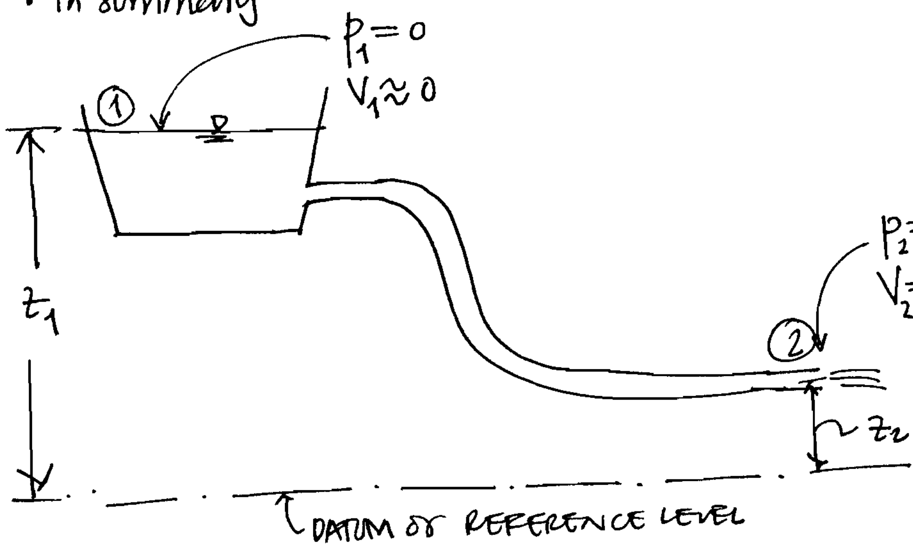
  1 – continuous supply of water. This may not always be the case, e.g., if your water supply is a tank of finite dimensions, it will run out of water after some time, i.e., the flow will be unsteady

  NOTE: Unsteady flow problems are presented in Chapter 12.

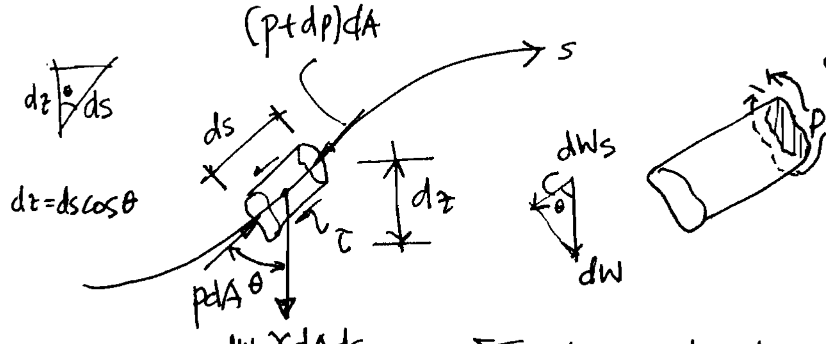
- Large reservoir area ⇒ velocity at the free surface is zero. This is a commonly used assumption in solving steady flow problems.

- Free surface and discharge point pressure — if the discharge point is open to the atmosphere — in both cases we take $P_{gage} = 0$.

- In summary



5.3. Equation for steady motion of a real fluid along a streamline



dA = AREA of ELEMENT
P = perimeter around dA

shear force on element:

$F_s = \tau P ds$

$\Sigma F_s = dm a_s$, with $dm = \rho dA ds$, $a_s = V\frac{dV}{ds}$

$$-dW_s + pdA - (p+dp)dA - \tau P ds = \rho dA ds\, V\frac{dV}{ds}$$

$$-dW_s + \cancel{pdA} - \cancel{pdA} - dp dA - \tau P ds = \rho dA ds\, V\frac{dV}{ds}$$

$$-\gamma dA ds \cos\theta - dp dA - \tau P ds = \rho dA \cancel{ds}\, V\frac{dV}{\cancel{ds}}$$

divide by dA $\rightarrow$ $$-\gamma dz - dp - \frac{\tau P ds}{dA} = \rho V dV$$

divide by γ, rearrange $\rightarrow$ $$\frac{dp}{\gamma} + dz + d\left(\frac{V^2}{2g}\right) = -\frac{\tau P ds}{\gamma dA}$$

NOTE: dA = AREA of element, constant, replace by A $\Rightarrow$ Eq. (5.11) in book

$$\frac{dp}{\gamma} + dz + d\left(\frac{V^2}{2g}\right) = -\frac{\tau P}{\gamma A} ds$$

Integrating this equation:

- Compressible fluids: need equation of state (see 5.7, Ch. 13)
- Incompressible fluids: γ = constant

Integration:

$$\frac{p_2}{\gamma} - \frac{p_1}{\gamma} + z_2 - z_1 + \frac{V_2^2}{2g} - \frac{V_1^2}{2g} = -\frac{\tau P L}{\gamma A} \Rightarrow$$

$$\left(\frac{p_1}{\gamma} + z + \frac{V_1^2}{2g}\right) - \frac{\tau P L}{\gamma A} = \frac{p_2}{\gamma} + z + \frac{V_2^2}{2g}$$

RECALL ASSUMPTIONS:
1 – steady flow
2 – incompressible fluid
3 – along a streamline
4 – no energy added or removed

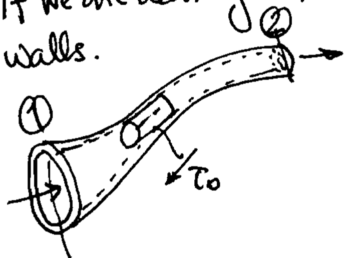
Compare this equation with Bernoulli's theorem

$$\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - \frac{\tau P L}{\gamma A} = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$ ← FOR REAL FLUIDS

$$\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$ ← FOR IDEAL FLUIDS (Bernoulli)

THIS TERM REPRESENTS THE LOSS OF ENERGY PER UNIT WEIGHT DUE TO FLUID FRICTION BETWEEN 1 & 2

If we are dealing with a closed conduit $\Rightarrow \tau = \tau_0$, shear stress on the walls.



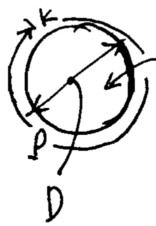
The energy loss TERM is

$$\boxed{h_f = \frac{\tau_0 P L}{\gamma A}}$$ ← wall friction head loss

$$\boxed{\underbrace{\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g}}_{H_1 = \text{TOTAL HEAD AT } 1} - h_f = \underbrace{\frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g}}_{H_2 = \text{TOTAL HEAD AT } 2}} \quad \text{or} \quad \boxed{H_1 - h_f = H_2}$$

H_1: INITIAL HEAD; h_f: loss as heat; H_2: FINAL HEAD

For a circular pipe



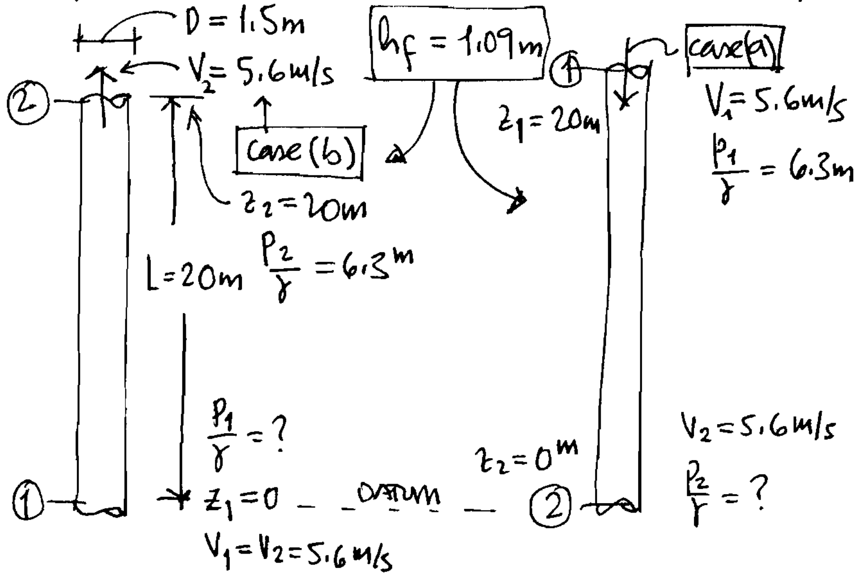
$A = \frac{\pi D^2}{4}$

$P = \pi D$

$$h_f = \frac{\tau_0 P L}{\gamma A} = \frac{\tau_0 \cancel{\pi} D L}{\gamma \cancel{\pi} D^2/4} = \frac{4\tau_0 L}{\gamma D}$$

Exercises

5.3.2. A vertical pipe of 1.5 m diameter and 20 m long has a pressure head of 6.3 m of water at its upper end. When the flow of water through it is such that the mean velocity is 5.6 m/s, the pipe friction is $h_f = 1.09$ m. Find the pressure head at the lower end of the pipe when the flow is (a) downward; (b) upward.



(a) $\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_f = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g} \Rightarrow \frac{P_1}{\gamma} + 0 + \cancel{\frac{5.6^2}{2 \times 9.81}} - 1.09 = 6.3 + 20 + \cancel{\frac{5.6^2}{2 \times 9.81}}$

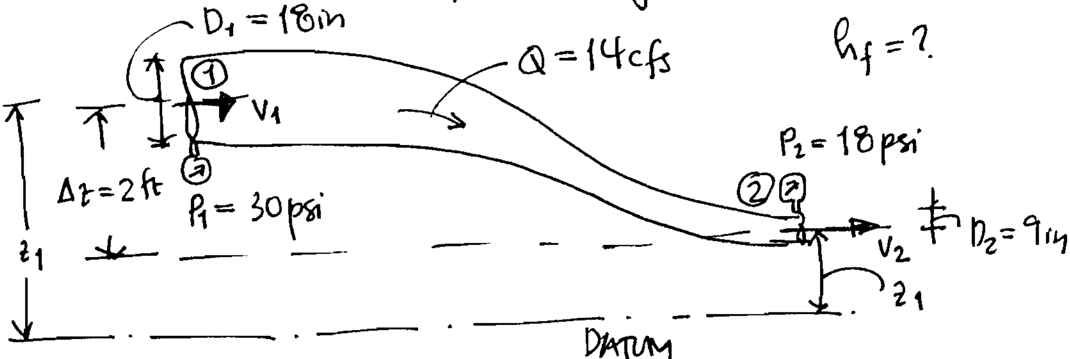
$\frac{P_1}{\gamma} = 26.30 + 1.09 = 27.39^m$

(b) $\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_f = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g} \Rightarrow 6.3 + 20 + \cancel{\frac{5.6^2}{2 \times 9.81}} - 1.09 = \frac{P_2}{\gamma} + 0 + \cancel{\frac{5.6^2}{2 \times 9.81}}$

$\frac{P_2}{\gamma} = 26.3 - 1.09 = 25.21^m$

Exercises (continued)

5.3.6. Water flows through a pipe at 14 cfs. At a point where the pipe is 18 in, the pressure is 30 psi; at a second point, further along the flow path and 2 ft lower than the first, the diameter is 9 in and the pressure is 18 psi. Find the pipe friction head loss between the two points. Neglect other head losses.



$D_1 = 18in = \frac{\cancel{18}^{3}}{\cancel{12}_{2}} ft = 1.5ft$, $V_1 = \frac{4Q}{\pi D_1^2} = \frac{4\times14}{\pi\times(1.5)^2} = 7.92$ fps

$D_2 = 9in = \frac{\cancel{9}^{3}}{\cancel{12}_{4}} ft = 0.75ft$, $V_2 = \frac{4Q}{\pi D_2^2} = \frac{4\times14}{\pi\times(0.75)^2} = 31.69$ fps

$P_1 = 30psi = 30\times144 \frac{lb}{ft^2} = 4320\ lb/ft^2$ $\gamma = 62.4\ lb/ft^3$

$P_2 = 18psi = 18\times144 \frac{lb}{ft^2} = 2592\ lb/ft^2$

$z_2 = z_1 + \Delta z = z_1 + 2ft \Rightarrow z_2 - z_1 = 2ft$

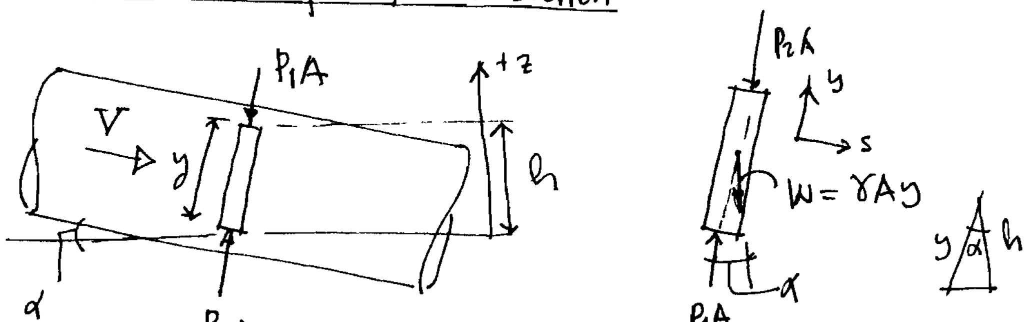
ENERGY EQUATION: $\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_f = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$

$$-h_f = \frac{P_2 - P_1}{\gamma} + \underbrace{z_2 - z_1}_{2ft} + \frac{V_2^2 - V_1^2}{2g} = \frac{2592 - 4320}{62.4} + 2 + \frac{31.69^2 - 7.92^2}{2\times32.2}$$

$$\boxed{h_f = 11.07\ ft}$$

5.4. Pressure in Fluid Flow

Pressure in conduits of uniform x-section



$h = y\cos\alpha$

$\Sigma F_y = 0$ (no motion ⊥ flow)

$P_1A - \gamma A y \cos\alpha - P_2A = 0 \Rightarrow P_1 - P_2 = \gamma h$ (hydrostatic)

conclusions:

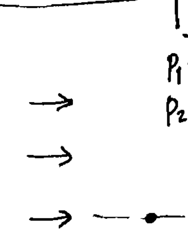
1- In any plane ⊥ direction of flow ⇒ p is hydrostatic

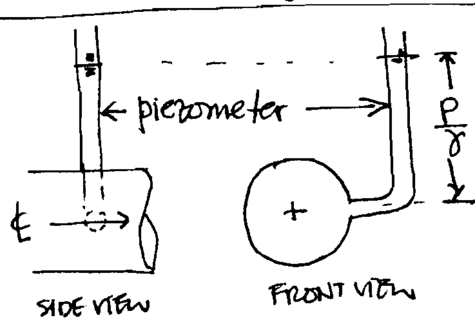
2- average pressure ≡ pressure at the centroid

3 – pressure lowest near top of conduit (most likely place for cavitation to occur)

$\boxed{\text{Static pressure}}$

p = static pressure, measured with piezometric tube





$\boxed{\text{STAGNATION PRESSURE}}$

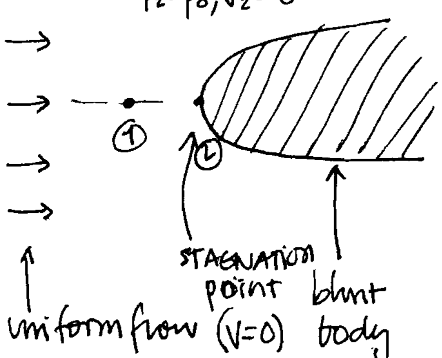
apply Bernoulli → $\frac{p}{\gamma} + \cancel{z_1} + \frac{V^2}{2g} = \frac{p_0}{\gamma} + \cancel{z_2} + 0$

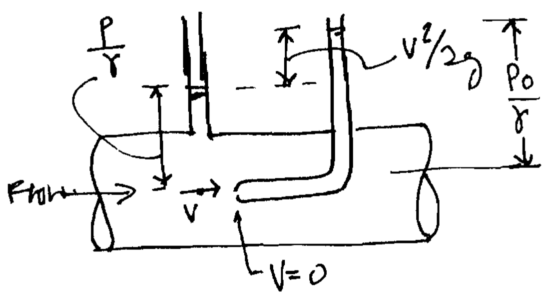
$P_1 = P,\ V_1 = V,\ z_1 = z_2$

$P_2 = P_0,\ V_2 = 0$

$$\boxed{P_0 = p + \gamma\frac{V^2}{2g} = p + \rho\frac{V^2}{2}} \leftarrow \text{STAGNATION pressure}$$

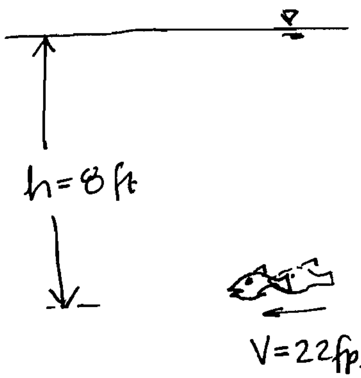
measured with a Pitot tube

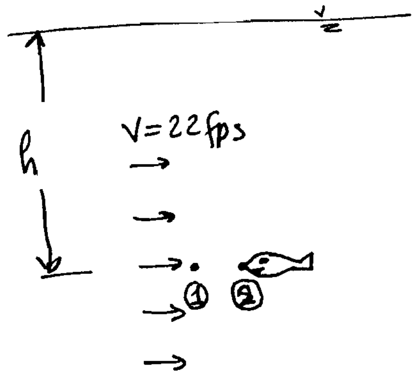




EXERCISES

5.4.3. Find the stagnation pressure on the nose of a fish swimming at 22 fps in fresh water ($\gamma = 62.4$ lb/ft^3) when it is 8 ft below the surface.





observing from side of quiescent water

observing while moving with fish (fish looks stationary, flow moves past fish at 22 fps)

point 2, stagnation point

$P_1 = \gamma h$; $V_1 = V = 22$ fps

$P_2 = p_o$, $V_2 = 0$

$z_1 = z_2$

$\Rightarrow$ Bernoulli

$$\frac{p}{\gamma} + \frac{V^2}{2g} = \frac{p_o}{\gamma}$$

$$p_o = p + \rho\frac{V^2}{2} = \gamma h + \frac{\gamma}{g}\frac{V^2}{2} = \gamma\left(h + \frac{V^2}{2g}\right)$$

$$= 62.4\frac{\text{lb}}{\text{ft}^3}\left(8\text{ft} + \frac{(22\text{ft/s})^2}{2\times 32.2\text{ft/s}^2}\right) = 968.16\frac{\text{lb}}{\text{ft}^2} =$$

$$= \frac{968.16}{144}\frac{\text{lb}}{\text{in}^2} = 6.72\text{ psi}$$

Pitot tube/application of stagnation pressure