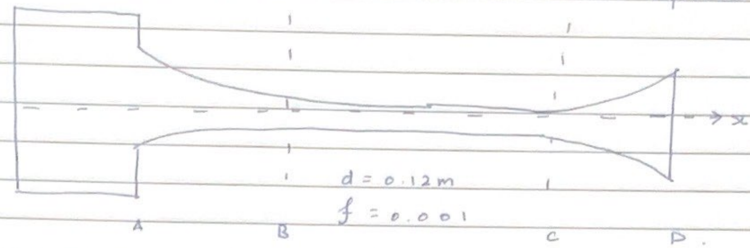
1.



$P_o = 600\,kPa$ $M_B = 0.52$ $T_D = 398.2\,K$

$T_o = 400\,K$ $P_D = 490\,kPa$.

$\therefore k = 1.4$, $C_p = 1004\,J\,kg^{-1}K^{-1}$, $R = 287\,J\,kg^{-1}K^{-1}$

a) From point A to B, using Isentropic Table, @ $M_B = 0.52$,

$\frac{P_B}{P_0} = 0.8317$, $P_B = 499.02\,kPa$

$\frac{T_B}{T_0} = 0.9487$, $T_B = 379.48\,K$.

$P = \rho R T \rightarrow \rho = \frac{P_B}{R T_B} = \frac{499\,020}{287 \times 379.48} = 4.582\,kg/m^3$.

$\therefore \dot{m} = \rho V A$ $a = \sqrt{\gamma R T_B} = \sqrt{1.4 \times 287 \times 379.48}$

$= (4.582)(203.05)\left(\frac{\pi D^2}{4}\right)$ $\approx 390.48\,m/s$

$= 197.6\,kg/s$ $V_B = a M_B = 0.52 \times 390.48$

$= 203.05\,m/s$.

b) Since no heat is lost in Isentropic & fanno flow, $T_{0A} = T_{0B} = T_{0C} = T_{0D}$

$\therefore \frac{T_D}{T_{0D}} = \frac{398.2}{400} = 0.9955$.

By Referring to Isentropic flow Table, $M_D = 0.15$

$\therefore \frac{P_D}{P_{0D}} = 0.9844. \Rightarrow P_{0D} = \frac{P_D}{0.9844} = \frac{490}{0.9844}$

$= 497.77\,kPa$.

c) $\Delta S = C_p \ln\left(\cancel{\frac{T_{0D}}{T_{0A}}}\right)^{0} - R \ln\left(\frac{P_{02}}{P_{01}}\right) = -287 \ln\left(\frac{497.77}{\cancel{490}\ 600}\right)$

$= \cancel{-4.5153\,J/kg \cdot K}$

$= 53.61\,J/kg \cdot K$

d) ~~At point D, using isentropic Table at~~ $\cancel{M_B = 0.52}$, ~~$M_D = 0.15$~~

~~$\frac{A_D}{A^*} = 3.9103 \rightarrow A^* = \frac{A_D}{3.9103} =$~~

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d) ~~$A_c = \frac{\pi D^2}{4} = \frac{\pi(0.12)^2}{4} = 0.0113$~~

By using fanno flow @ $M_B = 0.52$

$\frac{fL^*}{D_h} = 0.9174.$

$\frac{0.001(L_1^*)}{0.12} = 0.9174 \rightarrow L_1^* = 110.1m$

Since $P_D = P_{0D}$ (isentropic flow in nozzle)

$\therefore \frac{P_{02}}{P_0^*} = 1.3034 \rightarrow P_0^* = \frac{P_{02}}{1.3034} = 4.603 \times 10^5 Pa$

$\frac{P_{0a}}{P_0^*} = \frac{497.77}{460.3} = 1.0814.$

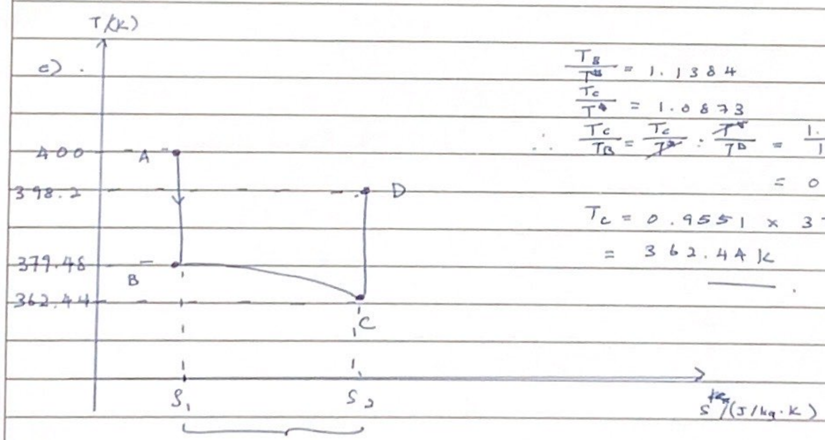
By fanno flow table at Subsonic Regime, $M_C = 0.72$

$\frac{fL_2^*}{D} = 0.1721 \rightarrow \frac{0.001 L_2^*}{0.12} = 0.1721$

$L_2^* = 20.65m$

$\therefore L = L_1^* - L_2^* = 110.1 - 20.65 = 89.45m$ #

e).



$\frac{T_B}{T^*} = 1.1384$

$\frac{T_C}{T^*} = 1.0873$

$\therefore \frac{T_C}{T_B} = \frac{T_C}{T^*} \div \frac{T^*}{T_B} = \frac{1.0873}{1.1384}$

$= 0.9551$

$T_C = 0.9551 \times 379.48$

$= 362.44K$

$\Delta S = 53.61.$

#

Notes

For Isentropic flow, $T_{01} = T_{02}$ & $P_{01} = P_{02}$

For fanno-Line, $T_{01} = T_{02}$ BUT $P_{01} \neq P_{02}$

For Ray-Leigh flow, $T_{01} \neq T_{02}$ & $P_{01} \neq P_{02}$

Remember this & be fine.

To ~~Safe~~ Save time, use $\Delta S = C_p \ln\left(\frac{T_{02}}{T_{01}}\right) - R \ln\left(\frac{P_{02}}{P_{01}}\right)$

(w/o Rayleigh flow, $T_{02} = T_{01}$ hence first term is cancelled off) #

2a) $u = ay^3 + by + c$

3 Assumptions

① No slip $\rightarrow$ $u = 0$, $y = 0$

$0 = c \quad \therefore \quad c = 0$

② Continuity ⇨ free stream, $u = V$, $y = \delta$

$\therefore \quad V = a\delta^3 + b\delta \quad$ — (1)

③ No shear force, when $y = \delta$, $\frac{\partial u}{\partial y} = 0$

$\frac{\partial u}{\partial y} = 3ay^2 + b = 0$

$\therefore \quad 3a\delta^2 + b = 0 \quad$ — (2)

from (2) $\quad b = -3a\delta^2$ — (3)

Substituting (3) into (1) $\quad V = a\delta^3 + (-3a\delta^2)(\delta)$

$= a\delta^3 - 3a\delta^3 = -2a\delta^3$ — (4)

from (4) $\quad a = -\frac{V}{2\delta^3}$

from (3) $\quad \therefore b = -3a\delta^2 = 3\left(\frac{V}{2\delta^3}\right)\delta^2 = \frac{3}{2}\left(\frac{V}{\delta}\right)$

Replacing a, b, c into the main Eqn

~~$\frac{u}{V} = -\frac{1}{2}y^3 + \frac{3}{2}$~~

$\frac{u}{V} = -\frac{1}{2}\left(\frac{y}{\delta}\right)^3 + \frac{3}{2}\left(\frac{y}{\delta}\right)$ #

~~$= -\frac{1}{2}\delta^3$~~

$= -\frac{1}{2}\eta^3 + \frac{3}{2}\eta \quad \left(\text{where } \eta = \frac{y}{\delta}\right)$

~~b) $\frac{\delta^*}{\delta} = \frac{1}{\delta}\int_0^\delta \left(1 + \frac{1}{2}\eta^3 - \frac{3}{2}\eta\right.$~~

b) $\frac{\delta^*}{\delta} = \frac{1}{\delta}\int_0^\delta \left(1 + \frac{1}{2}\left(\frac{y}{\delta}\right)^3 - \frac{3}{2}\left(\frac{y}{\delta}\right)\right) dy$

$= \int_0^1 \left(1 + \frac{1}{2}\eta^3 - \frac{3}{2}\eta\right) d\eta$

$= \left[\eta + \frac{1}{8}\eta^4 - \frac{3}{4}\eta^2\right]_0^1$

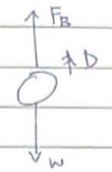
$= \left[1 + \frac{1}{8} - \frac{3}{4}\right] = 0.3750$

$\therefore \frac{\delta}{\delta^*} = \frac{1}{0.375} = 2.67$ #

Notes

- Remember the 3 assumptions. Once final Equation is found, check back to see if it fits the Assumptions
- This question is quite standard so remember the method to score this part 8 =)

b) At terminal Velocity (For steel first)



By N2L

$$F_B + D = W \quad (F_{net} = 0 \text{ hence upwards = Downward Force}) \quad (1)$$

F_B = weight of water Displaced

$$= \rho_w \cdot V_s g = \rho_w \left(\tfrac{4}{3}\pi R_s^3\right) g$$

$$= \tfrac{4}{3}\pi \rho_w R_s^3 g$$

$$D = \tfrac{1}{2}\rho v^2 A C_D = \tfrac{1}{2}\rho_w v^2 (\pi R_s^2) C_D$$

$$W = \rho_s \left(\tfrac{4}{3}\pi R_s^3\right) g = \tfrac{4}{3}\pi \rho_s R_s^3 g$$

Combining together to form (1)

$$\tfrac{4}{3}\cancel{\pi}\rho_w R_s^{\cancel{3}} g + \tfrac{1}{2}\rho_w v^2 (\cancel{\pi R_s^2}) C_D = \tfrac{4}{3}\cancel{\pi}\rho_s R_s^{\cancel{3}} g$$

$$\tfrac{4}{3}\rho_w R_s g + \tfrac{1}{2}\rho_w v^2 C_D = \tfrac{4}{3}\rho_s R_s g$$

$$\cancel{\tfrac{4}{3}\rho_w R_s - \tfrac{4}{3}} \quad \tfrac{4}{3}\rho_s R_s g - \tfrac{4}{3}\rho_w R_s g = \tfrac{1}{2}\rho_w v^2 C_D.$$

$$\therefore R_s = \left(\tfrac{1}{2}\rho_w v^2 C_D\right) \Big/ \left(\tfrac{4}{3}\rho_s \cancel{R_s} g - \tfrac{4}{3}\rho_w g\right)$$

$$= \frac{3\rho_w v^2 C_D}{\cancel{4}(8\rho_s - 8\rho_w)g}$$

$\therefore$ ~~$\frac{R_s}{R}$~~

Doing the Same for aluminium Ball

$$R_a = \frac{3\rho_w v^2 C_D}{(8\rho_a - 8\rho_w)g}$$

$$\therefore \frac{R_s}{R_a} = \frac{3\rho_w v^2 C_D}{(8\rho_s - 8\rho_w)g} \cdot \frac{(8\rho_a - 8\rho_w)g}{3\rho_w v^2 C_D}$$

$$= \frac{\rho_a - \rho_w}{\rho_s - \rho_w} \#$$

} Since ρ_w, v & C_D are constant for Both Al & steel ball #.

By Newton 2nd Law

~~$F_B + D$~~

$$W - F_B - D = m\frac{dv}{dt} + v\cancel{\frac{dm}{dt}}^{\,0}$$

$$\frac{dv}{dt} = \frac{1}{m}(W - F_B - D) \qquad m = \tfrac{4}{3}\pi\rho_s R_s^3$$

$$= \frac{1}{m}\left(\tfrac{4}{3}\cancel{\pi}\cancel{\rho_s R_s^3} g - \tfrac{4}{3}\cancel{\pi}\rho_w R_s^3 g - \tfrac{1}{2}\rho_w v^2 \cancel{\pi}\cancel{R_s^2} C_D\right)$$

$$= \left[g - \frac{\rho_w g}{\rho_s} - \frac{3}{8}\frac{\rho_w C_D v^2}{\rho_s R_s}\right]$$

This part I am unsure but this is my answer for the finals.

$\therefore$ let V_T be terminal velocity.

$$dt = \frac{1}{g - \frac{\rho_w g}{\rho_s} - \frac{3}{8}\frac{\rho_w C_D v^2}{\rho_s R_s}} dv$$

$$t = \int_0^{\frac{1}{2}V_T} f(v)\, dv \quad \left(\text{where } f(v) = \frac{1}{g - \frac{\rho_w g}{\rho_s} - \frac{3}{8}\frac{\rho_w C_D v^2}{\rho_s R_s}}\right).$$

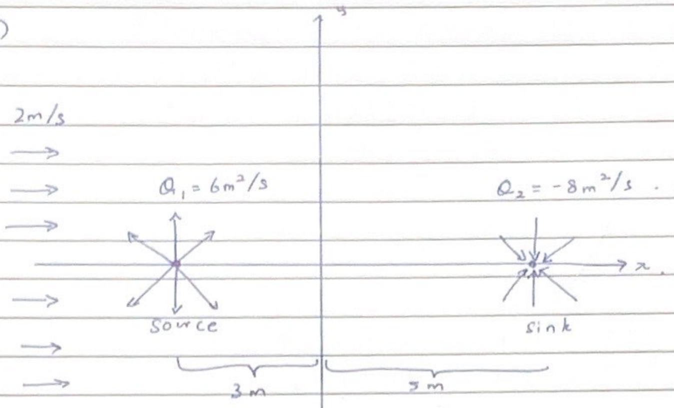
once t is found

$$dv = g(v)\, dt \quad \left(\text{where } g(v) = g - \frac{\rho_w g}{\rho_s} - \frac{3}{8}\frac{\rho_w C_D v^2}{\rho_s R_s}\right)$$

$$v = \int_0^t g(v)\, dt = h(v).$$

$$S = \int_0^t h(v)\, dt \#$$

3a)



Resolving it to x & y - axis, assume the stagnation point will become (x_o, y_o)

In x - Direction (Think of it this way, V_x due to Q_1 will be -ve when $x_o < -3$ & $x_o > -3$ is +ve as $\rightarrow$ is +ve).

$\Sigma V_x = 0$

$= 2 + \frac{Q_1}{2\pi(x_0+3)} + \cancel{\frac{Q_2}{2\pi(x_0-5)}} \; \frac{Q_2}{2\pi(5-x_0)}$ (same logic applies for sink).

$= 2 + \frac{6}{2\pi(x_0+3)} + \frac{8}{2\pi(5-x_0)}$ -

$\frac{6(5-x_0)+8(x_0+3)}{2\pi(x_0+3)(5-x_0)} = -2$

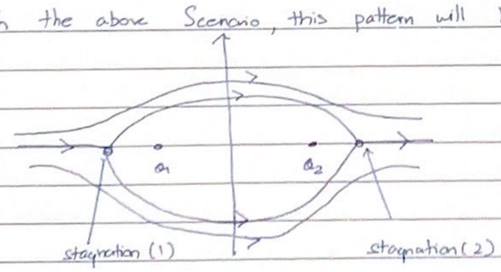
$6(5-x_0)+8(x_0+3) = 2\pi(x_0+3)(x_0-5)$

$30 - 6x_0 + 8x_0 + 24 = 2\pi(x_0^2 - 2x_0 - 15)$

$2\pi x_0^2 - (4\pi+2)x_0 - (30\pi+54) = 0$.

$\therefore x_0 = 6.1530$ or $x_0 = -3.8346$.

In the above Scenario, this pattern will be formed (Rankine Body)



$\therefore y_{01} = y_{02} = 0$

$\therefore$ The two coordinates are $(6.1530, 0)$ & $(-3.8346, 0)$

#

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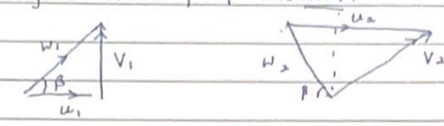
$\rho_{oil} = 900\ kg/m^3$, $\omega = 2000\ RPM$

$= 209.44\ rad/s$

$h = 0.04m$, $r_i = 0.12m$

$Q = 0.45 m^3/s$, $P = 200kW$

Assuming idealized pump condition.



$u_1 = r\omega_1 = (0.12)(209.44) = 25.1328 m/s$

$V_1 = V_n = \frac{Q}{2\pi r b} = \frac{0.45}{2\pi(0.04)(0.12)} = 14.92 m/s$.

$\cancel{\text{Since } P_w = \omega T \eta = \rho Q (u_2 V_{t2} - u_1 V_{t1}) \eta}$

$\cancel{= (900)}$

Since $\eta P_w = \omega T = \rho Q (u_2 V_{t2} - \cancel{u_1 V_{t1}}^{\to 0})$

$10^3 \times 0.8 (200) = (900)(0.45)(u_2 V_{t2})$ — (1)

$u_2 = r_o \omega_1 = 209.44 r_o$

$\cancel{V_{t2} = \frac{Q}{2\pi r b} = \frac{0.45}{2\pi r_o (0.04)} = 1.79 \frac{1}{r_o}}$.

$V_{n2} = \frac{Q}{2\pi r b} = \frac{0.45}{2\pi r_o (0.04)} = 1.79 \frac{1}{r_o}$

$V_{t2} = u_2 - V_{n2} \cot\beta$

$= 209.44 r_o - (1.79) \frac{1}{r_o} \cdot \cancel{\tan^{-1}} \left(\frac{1}{\tan 25}\right)$

$= 209.44 r_o - 3.84 \frac{1}{r_o}$ — (2)

Sub (2) into (1) $10^3 \times 0.8 (200) \cancel{k} = (900)(0.45)(209.44 r_o)(209.44 r_o - 3.84 \frac{1}{r_o})$

$160\ 000 = 1.776 \times 10^7 r_o^2 - 3.2572 \times 10^5$

$r_o^2 = 0.0272 \rightarrow r_o = 0.1654m$ #

Might need to check the interpretation of the qn.

ii)

$u_2 = r_2 \omega$

$= (209.44)(0.1654)$

$= 34.64 m/s$

$V_{in} = 14.92 m/s$ $\quad V_{2n} = \frac{Q}{2\pi r b} = \frac{0.45}{2\pi (0.1654)(0.04)}$

$= 10.83 m/s$

$V_{t2} = u_2 - V_{2n} \cot\beta = 34.64 - 10.83 \frac{1}{\tan(25)}$

$= 11.42 m/s$

$\therefore \eta P_w = \rho Q (u_2 V_{t2} - u_1 V_{t1})$

$= (900)(0.45)\left[(34.64)(11.42) - (25.1328)(V_{t1})\right]$

$= 1.6 \times 10^5$

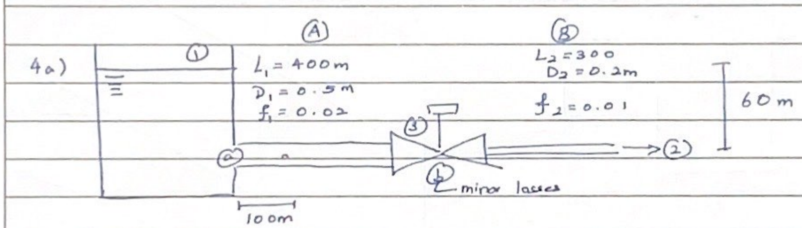
$\therefore V_{t1} = 0.021 m/s$

$\therefore u_1 = 25.1328 m/s$.

$u_1 - V_{t1} = 25.11 m/s$.

$\therefore \beta_1 = \tan^{-1}\left(\frac{14.92}{25.11}\right) = 30.72°$ #

4a)



By Bernoulli Eqn

$$\cancel{\frac{P_1}{\rho g}} + \cancel{\frac{V_1^2}{2g}}^{0} + z_1 = \cancel{\frac{P_2}{\rho g}} + \frac{V_2^2}{2g} + \cancel{z_2}^{0} + \cancel{\frac{L}{g}\frac{dv}{dt}}^{0 \text{ (steady state)}} + f\left(\frac{L}{D}\right)\frac{V^2}{2g} + h_L$$

$(P_1 = P_2 = P_{atm})$

$$60 = \frac{V_2^2}{2g} + (0.02)\left[\frac{400}{0.5}\right]\left[\frac{V_1^2}{2g}\right] + 0.01\left[\frac{300}{0.2}\right]\left[\frac{V_2^2}{2g}\right] + (0.5)\frac{V_1^2}{2g} + \frac{V_2^2}{2g}(0.5). \quad —(1)$$

By Mass-Continuity Eqn at Pipe A & B.

$\cancel{V_A} V_A A_A = V_B A_B$

$\left(\frac{\pi D_A^2}{4}\right)(V_A) = \left(\frac{\pi D_B^2}{4}\right)(V_B) \Rightarrow V_1 = 0.16 V_2 \quad —(2)$

Sub (2) into (1)

$\cancel{60 = \frac{V_2^2}{2(9.81)} + 0}$ $\quad 60 = 0.051 V_2^2 + 0.021 V_2^2 + 0.765 V_2^2 + 6.53 \times 10^{-4} V_2^2 + 0.0255 V_2^2$

$V_2^2 = 69.513 \longrightarrow V_2 = 8.34 m/s$ #

b) For Maximum water pressure,

$P_h = \rho c (v - v_2) \rightarrow$ Since $v_2 = 0$

$= (1000)(800)(8.34)$

$= \cancel{6.67}\ 6.672 \text{ MPa}$ #

c) By Bernoulli Eqn again P_∞

$$\cancel{\frac{P_1}{\rho g}} + \cancel{\frac{V_1^2}{2g}} + z_1 = \cancel{\frac{P_3}{\rho g}} + \frac{V_3^2}{2g} + \cancel{z_3} + \frac{L}{g}\frac{dv}{dt} + f\left(\frac{L}{D}\right)\left(\frac{V_1^2}{2g}\right) + h_L$$

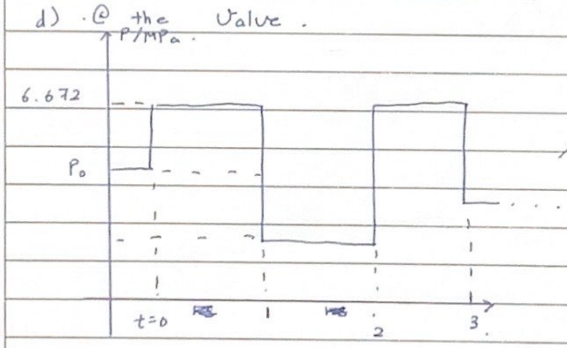
$P_1 = P_3 = P_\infty$

$$60 = \frac{V_A^2}{2g} + \frac{L}{g}\frac{dv}{dt} + f\left(\frac{L}{D}\right)\left(\frac{V_A^2}{2g}\right) + h_L$$

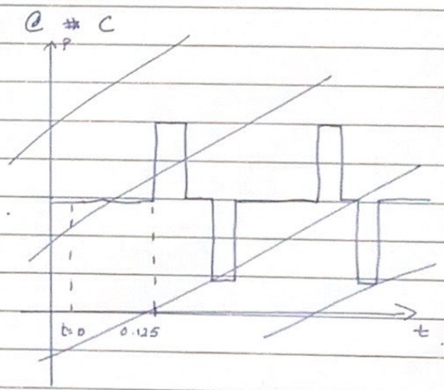
$$= 0.051 V_A^2 + 40.77\frac{dv}{dt} + 0.815 V_A^2 + 0.0255 V_A^2.$$

$$\frac{dv}{dt} = -0.0219 V_A^2 + 1.47$$ #

d) @ the Valve.

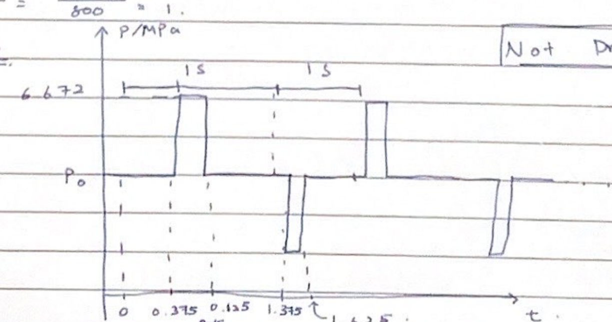


@ C



$\frac{2L}{c} = \frac{2\times400}{800} = 1.$

@ C



Not Drawn to Scale

e) Surge tanks or Surge chambers. It should be close to the Valve to reduce Damage (Lecture Notes) #