N_{ca} = Capillary no. = $\frac{\text{viscous force}}{\text{surface tension force}} = \frac{\mu V L}{\sigma L} = \frac{\mu V}{\sigma}$

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Viscous force = $\tau A = \mu \frac{du}{dy} A \propto \mu \frac{V L^2}{L} \propto \mu V L$

Froude no. $= \frac{V}{\sqrt{gL}}$

Weber no $= \frac{\text{Inertia force}}{\text{surface Tension force}}$

$(Fr\ No)^2 = \frac{\text{Inertia}}{\text{gravity}} = \frac{\rho v^2 L^2}{mg}$

$= \frac{\rho v^2 L^2}{\rho L^3 g} = \frac{v^2}{Lg}$

$= \frac{\rho v^2 L^2}{\sigma L} = \frac{\rho v^2 L}{\sigma}$

Complex Potential and Complex Velocity

Complex Potential

$$\boxed{F(z) = \phi(x,y) + i\psi(x,y)} \qquad i^2 = -1$$

$$\frac{dF(z)}{dz} = \underbrace{\frac{\partial\phi}{\partial x} + i\frac{\partial\psi}{\partial x}}_{} \quad \text{or} \quad \underbrace{\frac{\partial\psi}{\partial y} - i\frac{\partial\phi}{\partial y}}_{}$$

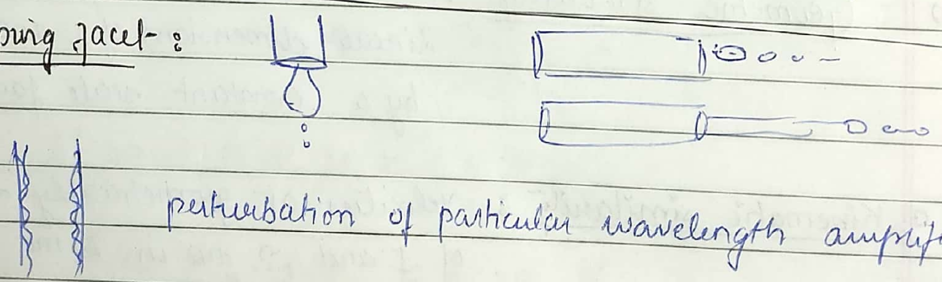
$x+iy_0$. $x+iy$

x_0+iy

$$\frac{df(z_0)}{dz} = \lim \frac{f(z)-f(z_0)}{z-z_0} = \frac{f(x+iy_0)-f(x_0+iy_0)}{x-x_0} \quad \frac{\partial f(z)}{\partial x}$$

$$\frac{f(x_0+iy)-f(x_0+iy_0)}{i(y-y_0)} \quad \frac{\partial f(z)}{\partial y}$$

Dripping jacet :



perturbation of particular wavelength amplified

Rayleigh instability

Complex velocity

$$W(z) = F'(z) = \frac{\partial\psi}{\partial y} - i\frac{\partial\phi}{\partial y} = u(x,y) - iv(x,y)$$

$$W\bar{W} = \underline{(u-iv)(u+iv)}$$

$$= u^2 + v^2$$

(i) $F(z) = Cz$

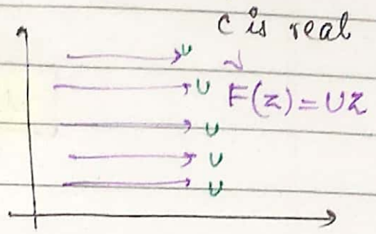
$w(z) = \frac{dF}{dz} = C$

$u(x,y) - iv(x,y) = C$

Assume, C is real $\Rightarrow$ $v = 0$

(ii) $F(z) = Vz$

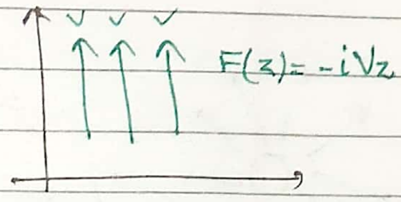
C is real



(iii) $F(z) = -iCz$

$w(z) = u - iv \Rightarrow v = C$

$u = 0$



- not applicable for boundary layer flow

$e^{i\theta} = \cos\theta + i\sin\theta$

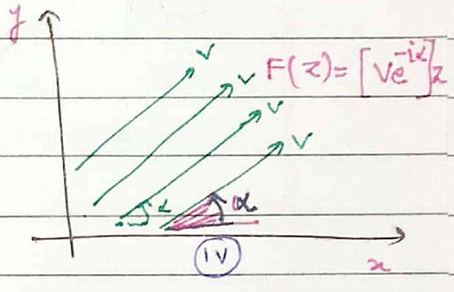
(iv) $F(z) = (Ce^{-i\alpha})z$

$= C(\cos\alpha - i\sin\alpha)z$

$w(z) = C(e^{-i\alpha}) = C(\cos\alpha - i\sin\alpha)$

$u = C\cos\alpha$

$v = C\sin\alpha$

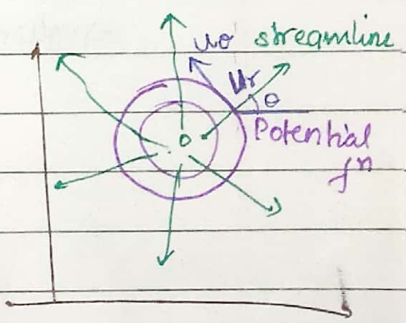


(v) $F(z) = C\ln z$

$w(z) = \frac{C}{z} = \frac{C}{x+iy}$

$\frac{u}{z} = \frac{C(x-iy)}{(x^2+y^2)} =$

$u - iv = \frac{Cx}{x^2+y^2} - i\frac{y}{x^2+y^2}$



Take $z = x+iy$

$= r\cos\theta + ir\sin\theta$

$= re^{i\theta}$

$\ln z = \ln r + i\theta$

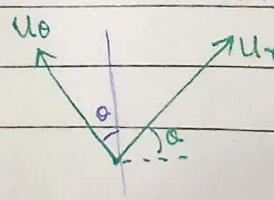
$\phi + i\psi = C\ln r + iC\theta$

$\phi = C\ln r$ ⟂ constant r

$\psi = C\theta$ ⟂ constant θ

$u = U_r\cos\theta - U_\theta\sin\theta$

$v = U_r\sin\theta + U_\theta\cos\theta$



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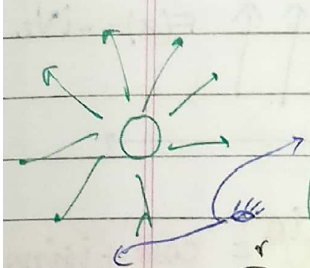
$$u - iv = (u_r\cos\theta - u_\theta\sin\theta) - i(u_r\sin\theta + u_\theta\cos\theta)$$

$$= u_r(\cos\theta - i\sin\theta) - iu_\theta(\cos\theta - i\sin\theta)$$

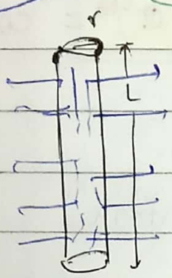
$$\boxed{u - iv = (u_r - iu_\theta)e^{-i\theta}} \quad \text{——— (I)}$$

$$W = \frac{c}{z} = u - iv$$

$$\Rightarrow u - iv = \frac{ce^{-i\theta}}{r} \quad \text{——— (II)}$$



Equating (I) & (II) $\quad u_r - iu_\theta = \frac{c}{r}$



$Q = m^3/s$

$A = 2\pi r L$

$V_r = \frac{Q}{A} = \frac{Q}{2\pi r L}$

$V_r = \frac{C}{r}$

$$\Rightarrow \boxed{U_r = \frac{C}{r}} \qquad U_\theta = 0$$

(strength of source)
m: volume flow rate from / to the source / sink per unit depth

Volume flow : $\int \hat{n}\cdot\vec{V}\, dA$ any surface around origin

$$= \int_0^{2\pi} u_r (r\,d\theta\, L)$$

- Volume flow rate per unit depth $\Rightarrow Q$

$$\Rightarrow \frac{\text{volume flow rate}}{\text{unit depth}} = \int_0^{2\pi} u_r\, r\, d\theta$$

$$= \int_0^{2\pi} \frac{C}{r}\, r\, d\theta$$

$$\boxed{m = \frac{Q}{L} = 2\pi C}$$

$$\boxed{C = \frac{m}{2\pi}}$$

$$\boxed{F(z) = \frac{m}{2\pi}\ln z}$$

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Source at $z=0$, $F(z) = \frac{m}{2\pi} \ln z$

Source at $z = z_0$ $\boxed{F(z) = \frac{m}{2\pi} \ln(z-z_0)}$

(vi) $F(z) = -ic \ln z$

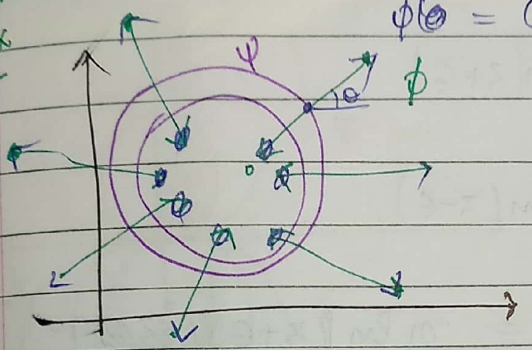
$$z = re^{i\theta}$$

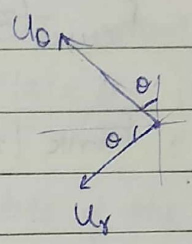
$$\ln z = \ln r + i\theta$$

$$F(z) = -ic\ln r + C\theta = C\theta - ic\ln r$$

$$\phi = C\theta \qquad \psi = -C\ln r$$

flow around vortex





$$u = -u_r\cos\theta - u_\theta\sin\theta$$

$$v = u_\theta\cos\theta - u_r\sin\theta$$

$$u - iv = -u_r\cos\theta - u_\theta\sin\theta - i(u_\theta\cos\theta - u_r\sin\theta)$$

$$= -u_r\cos\theta + iu_r\sin\theta - iu_\theta\cos\theta - u_\theta\sin\theta$$

$$= -u_r(\cos\theta - i\sin\theta) - iu_\theta(\cos\theta - i\sin\theta)$$

$$= -(u_r + iu_\theta)e^{-i\theta}$$

$$u - iv = F'(z) = \frac{-ic}{z} = \frac{-ice^{-i\theta}}{r} \qquad u_\theta$$

$$u_r + iu_\theta = \frac{ic}{r}$$

$$\boxed{u_\theta = \frac{c}{r}}$$

Circulation $\Gamma = \int_0^{2\pi} u_\theta \cdot r\,d\theta = \int_0^{2\pi} \frac{c}{r} \cdot r\,d\theta = 2\pi C$

$\oint \vec{v}\cdot\vec{ds} = \Gamma = \int_0^{2\pi} (u_r\hat{r} + u_\theta\hat{\theta})\cdot(dr\,\hat{r} + (r\,d\theta)\hat{\theta})$ — general form

$$\boxed{C = \frac{\Gamma}{2\pi}} \qquad \frac{m^2}{m\cdot s}$$

$\Gamma > 0$ CCW

$\Gamma < 0$ CW

$$\boxed{F(z) = -i\frac{\Gamma}{2\pi}\ln z}$$

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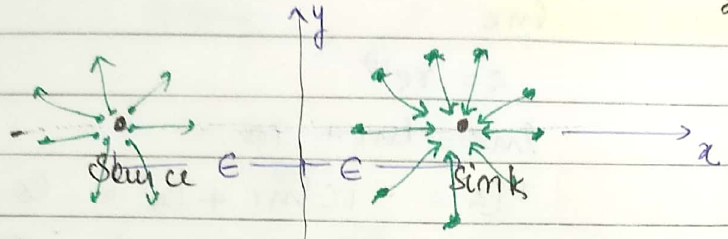
~~$F(z) = -i\theta$~~ Vortex at $z=0$, $F(z) = -i\frac{\Gamma}{2\pi}\ln z$

When Vortex of strength: Γ is located at $z = z_0$

Vortex at $z = z_0$, $F(z) = -i\frac{\Gamma}{2\pi}\ln(z-z_0)$

(VII)



Source: $F_{source}(z) = +\frac{m}{2\pi}\ln(z+\epsilon)$

Sink: $F_{sink}(z) = -\frac{m}{2\pi}\ln(z-\epsilon)$

$$F_{source}(z) + F_{sink}(z) = \frac{m}{2\pi}\ln\left[\left(\frac{z+\epsilon}{z-\epsilon}\right)\right]$$

$$F(z) = \frac{m}{2\pi}\ln\left(\frac{1+\epsilon/z}{1-\epsilon/z}\right)$$

$$= \frac{m}{2\pi}\ln\left[\left(1+\epsilon/z\right)\left(1-\epsilon/z\right)^{-1}\right]$$

$$= \frac{m}{2\pi}\ln\left(1+2\epsilon/z\right)$$

$\left(1+\frac{\epsilon}{z}\right)\left(1+\frac{\epsilon}{z}+\cdots\right)$

$\left(1+\frac{2\epsilon}{z}\right) + \frac{\epsilon^2}{z^2} \to 0$

$\boxed{\text{(considering } \epsilon \to 0)}$

$$\ln x = (x-1) - \frac{1}{2}(x-1)^2 + \frac{1}{3}(x-1)^3 - \cdots$$

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{1}{3}x^3 + \cdots$$

$$F(z) = \frac{m}{2\pi}\ln\left(1+\frac{2\epsilon}{z}\right) = \frac{m}{2\pi}\left[\frac{2\epsilon}{z} + \cancel{\cdots}^{\,0}\right]$$

$$F(z) = \frac{m\epsilon/\pi}{z} \to \mu = \frac{\mu}{z}$$

↳ of the form $\frac{c}{z} = F(z)$

$$F(z) = \frac{\mu}{re^{i\theta}} = \frac{\mu}{r}e^{-i\theta}$$

$$= \frac{\mu}{r}\left[\cos\theta - i\sin\theta\right]$$

$$\phi + i\psi = \frac{\mu}{r}\cos\theta + i\left(-\frac{\mu}{r}\sin\theta\right)$$

$$\psi = -\frac{\mu\sin\theta}{r} \qquad \phi = \frac{\mu}{r}\cos\theta$$

$$\psi = \frac{-\mu y}{(x^2+y^2)} \qquad \phi = \frac{\mu}{\sqrt{x^2+y^2}}\,\frac{x}{\sqrt{x^2+y^2}}$$

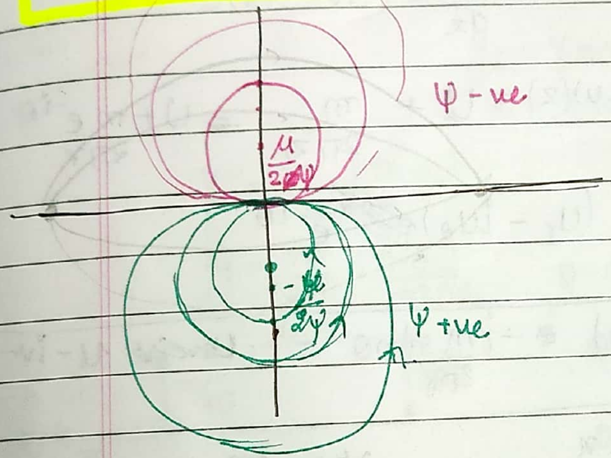
$$\phi = \frac{\mu x}{(x^2+y^2)}$$

$$\psi(x^2+y^2) = -\mu y \qquad \Rightarrow x^2+y^2 - \frac{\mu}{\phi}x = 0$$

$$\boxed{x^2+y^2 + \frac{\mu y}{\psi} = 0} \qquad \Rightarrow \boxed{x^2 + \left(y - \frac{\mu}{2\phi}\right)^2 = \frac{\mu^2}{4\phi^2}}$$

$$\boxed{x^2 + \left(y + \frac{\mu}{2\psi}\right)^2 = \frac{\mu^2}{4\psi^2}}$$

– streamline is that line along which ~~stree~~ ψ is constant.



DOUBLET when $\epsilon \to 0$

$$\boxed{F(z) = \frac{\mu}{z}}$$ – elemental flow

Centres of the circle of radius $\left(\frac{\mu}{2\psi}\right)$ are located at

$y = \pm\frac{\mu}{2\psi}$ when $\psi > 0 \Rightarrow$ lower half

$\psi < 0 \Rightarrow$ upper half

$$w(z) = \frac{dF}{dz} = \frac{-\mu}{z^2} = \frac{-\mu}{r^2}e^{-i2\theta}$$

$$(u_r - i u_\theta)\,\cancel{e^{-i\theta}} = \frac{-\mu}{r^2}e^{-i\theta}\cdot \cancel{e^{-i\theta}}$$

$$(u_r - i u_\theta) = \frac{-\mu}{r^2}(\cos\theta - i\sin\theta)$$

$$u_r = -\frac{\mu\cos\theta}{r^2} \qquad u_\theta = -\frac{\mu\sin\theta}{r^2}$$

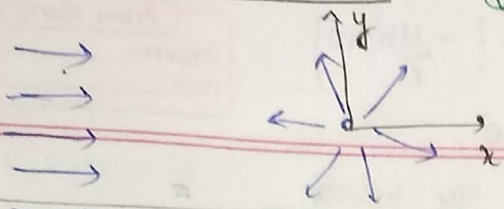
When centre is z_0

$$F(z) = \frac{\mu}{(z-z_0)}$$

o Cooling tower – some water evaporates to ~~make~~ cool remaining ~~co~~

RANKINE HALF BODY

Source + uniform flow



$$\boxed{F(z) = Uz + \frac{m}{2\pi}\ln z}$$
(uniform flow)

$$F(z) = (Ur\cos\theta + Ur\,i\sin\theta) + \frac{m}{2\pi}\ln(re^{i\theta})$$

$$\phi + i\psi = F(z)$$

$$= Ur\cos\theta + iUr\sin\theta + \frac{m}{2\pi}[\ln r + i\theta]$$

$$\phi : Ur\cos\theta + \frac{m}{2\pi}\ln r$$

$$\psi : Ur\sin\theta + \frac{m\theta}{2\pi}$$

$$= \left[Ur\cos\theta + \frac{m}{2\pi}\ln r\right] + i\left[Ur\sin\theta + \frac{m\theta}{2\pi}\right]$$

$$W(z) = \frac{dF}{dz} = (U_r - iU_\theta)e^{-i\theta}$$

$$W(z) = U + \frac{m}{2\pi z} = U + \frac{m}{2\pi r}e^{-i\theta}$$

$$U + \frac{m}{2\pi r}e^{-i\theta} = (U_r - iU_\theta)e^{-i\theta}$$

$$\left(Ue^{i\theta} + \frac{m}{2\pi r}\right)e^{-i\theta} = (U_r - iU_\theta)e^{-i\theta}$$

~~$U_r = Ue^{i\theta}$~~

$U_\theta =$

$$\left\{\begin{aligned} U_r &= U\cos\theta + \frac{m}{2\pi r} \\ U_\theta &= -U\sin\theta \end{aligned}\right.$$

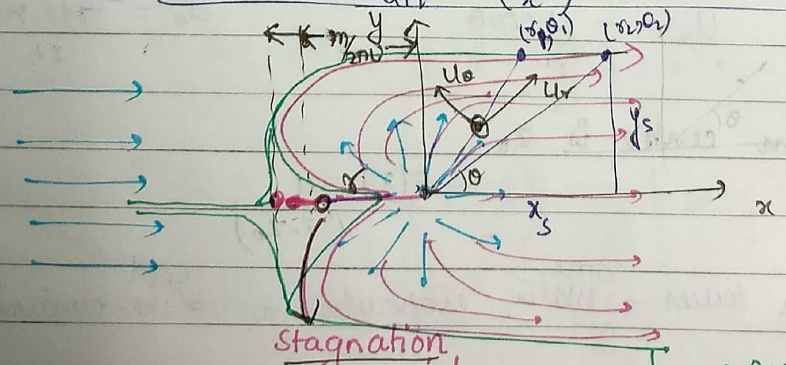
$$\left(U + \frac{m}{2\pi r}\cos\theta\right) - \frac{im}{2\pi r}\sin\theta = u - iv$$

$$u = U + \frac{m}{2\pi}\cdot\frac{x}{x^2+y^2} \qquad v = \frac{m}{2\pi}\frac{y}{x^2+y^2}$$

$$\frac{\partial\psi}{\partial y} = U + \frac{m}{2\pi}\frac{x}{x^2+y^2} \qquad \phi = Ux + \frac{m}{4\pi}\ln(x^2+y^2)$$

$$\psi = Uy + \frac{m}{2\pi}$$

$$\psi = U.y + \frac{m}{2\pi}\tan^{-1}\left(\frac{y}{x}\right)$$



$$\boxed{\psi = \frac{m}{2}}$$

Stagnatⁿ point : $U_r = U_\theta = 0$ (by defⁿ)

$$U\cos\theta + \frac{m}{2\pi r} = 0 \qquad U\sin\theta = 0$$

$\theta = \pi,\ \cancel{0}$ (r becomes −)

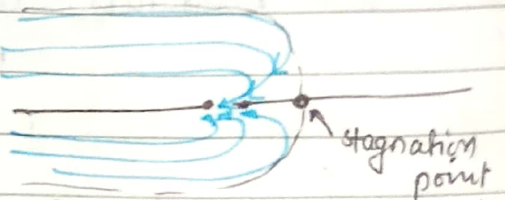
We want to know where is this point located?

$$-U + \frac{m}{2\pi r} = 0$$

$$\boxed{r = \frac{m}{2\pi U}}$$

$$\psi = Ur\sin\theta + \frac{m\theta}{2\pi}$$

eg. uniform flow + sink



$\theta = \pi$, $\boxed{\psi = \frac{m}{2}}$

$$\therefore \frac{m}{2} = Ur\sin\theta + \frac{m\theta}{2\pi}$$

If there is upper flow only, strength will be diff.

Body streamline

$$\boxed{r_s = \frac{m}{2\pi U}\left(\frac{\pi - \theta_s}{\sin\theta_s}\right)}$$

$$\frac{m}{2} - \frac{m\theta}{2\pi} = Ur\sin\theta$$

$$\frac{m}{2\pi}(\pi - \theta) = Ur\sin\theta$$

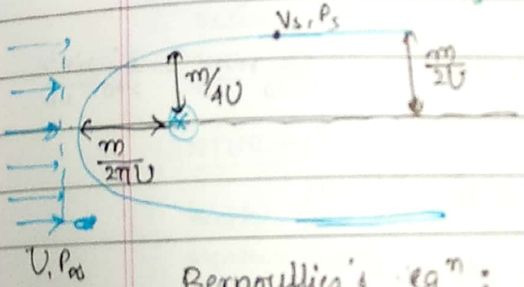
$$y_s = r_s\sin\theta_s = \frac{m}{2\pi U}\frac{(\pi - \theta_s)}{\sin\theta_s}\cdot\sin\theta_s$$

$$x_s = r_s\cos\theta_s = \frac{m}{2\pi U}\left(\frac{\pi - \theta_s}{\sin\theta_s}\right)\cos\theta_s$$

$$y_s = \frac{m}{2\pi U}(\pi - \theta_s)$$

$$x_s = \frac{m}{2\pi U}\frac{(\pi - \theta_s)}{\tan\theta_s}$$

Q. To get an idea of how this envelope looks?



$\theta = \pi/2$ $\left(y_s \text{ at origin} = \frac{m}{4U}\right)$

$\theta = 0$ $\left(y_s \text{ at } \infty = \frac{m}{2U}\right)$

Bernoullie's eq^n:

$$\frac{\rho V_s^2}{2} + P_s = \frac{\rho U^2}{2} + P_\infty$$

$$\overline{V_s} = \overline{W_s} = \left(U\cos\theta_s + \frac{m}{2\pi r}\right) - iU\sin\theta_s$$

$$V_s^2 = |V_s|^2 = W_s\overline{W}_s = \left(U\cos\theta_s + \frac{m}{2\pi r}\right)^2 + (U\sin\theta_s)^2 = U^2 + \left(\frac{m}{2\pi r}\right)^2 + \frac{mU\cos\theta_s}{\pi r}$$

Let $\nu = \pi - \theta_s$ $\quad r_s = \frac{m}{2\pi U}\frac{\nu}{\sin\nu}$

$$\therefore V_s^2 = U^2 + \left(\frac{m}{2\pi\cdot\frac{m}{2\pi U}\cdot\frac{\nu}{\sin\nu}}\right)^2 - \frac{mU\cos\nu}{\pi\cdot\frac{m}{2\pi U}\frac{\nu}{\sin\nu}}$$

$$V_s^2 = U^2 + \frac{U^2\sin^2\nu}{\nu^2} - \frac{2U^2\cos\nu\sin\nu}{\nu}$$

$$P_s - P_\infty = \frac{\rho}{2}\left[U^2 - V_s^2\right] = \frac{\rho}{2}\left[U^2\frac{\sin 2\nu}{\nu} - \frac{U^2\sin^2\nu}{\nu^2}\right]$$

$$= \frac{\rho U^2}{2}\left[\frac{\sin 2\nu}{\nu} - \frac{\sin^2\nu}{\nu^2}\right]$$

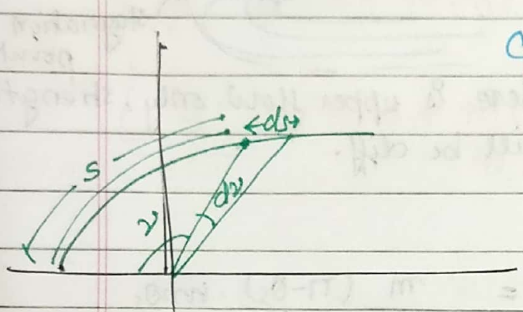
-ve

Introduce dimensionless pressure or pressure coefficient as

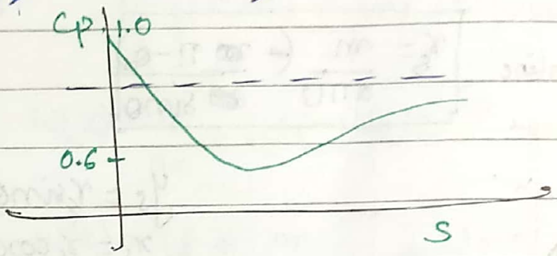
$$C_p = \frac{(P_s - P_\infty)}{\frac{1}{2}\rho U^2} = \frac{\sin 2\nu}{\nu} - \frac{\sin^2\nu}{\nu^2}$$

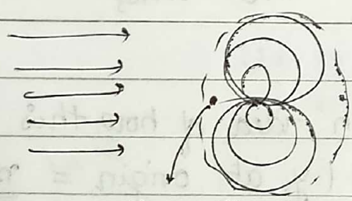
Change in pressure head as a f^n of overall kinetic head from Bernoullies' eq^n.

$$P_s - P_\infty = \left(1 - \frac{V_s^2}{U^2}\right) \cdot \frac{\rho U^2}{2}$$



$$C_p = \frac{2\sin\nu\cos\nu}{\nu} - \frac{1}{\nu^2}\sin^2\nu$$





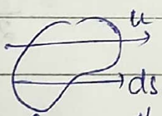
C_p is measured gradually and as $s \to \infty$,

~~Cp app~~ $P_s \to P_\infty$ because $V_s \to U$

$s = 0,\ \nu = 0$ $\quad 2\lim_{\nu\to 0}\frac{\sin\nu}{\nu} - \lim_{\nu\to 0}\frac{\sin^2\nu}{\nu^2}$

$= 1$

25.10.17



energy through ds per unit time

$\rho u\, ds = d\dot{m} \qquad \dot{m} = \rho\int u\, ds$

$$d\dot{E}_k = (\rho u\, ds)\frac{u^2}{2}$$

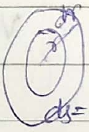
$$\dot{E}_k = \int d\dot{E}_k = \frac{\rho}{2}\int u^3 ds$$

Kinetic Head $\boxed{\frac{\dot{E}_k}{\dot{m}}} = \frac{\rho\int u^3 ds}{2\rho\int u\, ds}$

Circular pipe $\quad$ max^m velocity

$$u = 2\bar{u}\left[1 - \left(\frac{r}{R}\right)^2\right]$$

$$\bar{u} = \frac{\int_S u\, ds}{\int S} = \frac{\int_0^R u\, 2\pi r\, dr}{\pi R^2}$$



$ds = 2\pi r\, dr$

$$= \frac{4\bar{U}}{R^2}\int_0^R \left(r - \frac{r^3}{R^2}\right) dr = \frac{4\bar{U}}{R^2}\left[\frac{R^2}{2} - \frac{R^2}{4}\right]$$

$$\bar{U} = \frac{8\bar{U}}{8R}\ \bar{U}$$

$$\frac{\frac{1}{2}\int u^3 ds}{\bar{V}S} = \frac{(2\pi)(8\bar{U}^3)}{2\bar{V}(\pi R^2)}\int_0^R \left(r - \frac{r^3}{R^2}\right)^3 dr$$

$1 - \frac{r^6}{R^6} - \frac{3r^2}{R^2} + 3\ldots$

$8\bar{u}^3\ 2\pi r\, dr$

or $\left(1 - \frac{r^2}{R^2}\right)^3$

$$= \frac{8\bar{V}^2}{R^2}\left[\frac{r^4}{4} - \frac{r^{10}}{10R^6} - \frac{3r^6}{6R^2} + \frac{3r^8}{8R^4}\right]_0^R$$

$$r^3 - \frac{r^9}{R^6} - \frac{3r^5}{R^2} + \frac{3r^7}{R^4}$$

$$= \frac{8\bar{V}^2}{R^2}\left[\frac{1}{4} - \frac{1}{10} - \frac{1}{2} + \frac{3}{8}\right]R^4$$

$$= \frac{\bar{V}^2}{5}R^2$$

$$\frac{1}{4} - \frac{1}{10} + \frac{3}{8}$$

$$= \frac{8\bar{V}^2}{R^2}\int_0^R r - \frac{r^7}{R^6} - \frac{3r^3}{R^2} + \frac{3r^5}{R^4}\,dr$$

$$= \frac{8\bar{V}^2}{R^2}\left[\frac{R^2}{2} - \frac{R^8}{8R^6} - \frac{3R^4}{4R^2} + \frac{3}{6}\frac{R^6}{R^2}\right] = 8\bar{V}^2\left(\frac{1}{2} - \frac{1}{8} - \frac{3}{4} + \frac{1}{2}\right)$$

$$\frac{\alpha\bar{V}^2}{2} = \bar{V}^2$$

$\therefore \boxed{\alpha = 2}$ Parabolic

$\boxed{\alpha = 1}$ turbulent

α : correction factor

Flow Metering

Flow Bore meters

VENTURIMETER

Kinetic head converted to pressure head.

Energy Balance : $\alpha_b \bar{V}_b^2 - \alpha_a \bar{V}_a^2 = \frac{2(P_a - P_b)}{\rho}$

Continuity eq^n : $V_a \pi r_a^2 = V_b \pi r_b^2$

$$\bar{V}_b = \frac{1}{\sqrt{\alpha_b - \left(\frac{D_b}{D_a}\right)^4 \alpha_a}}\sqrt{\frac{2(P_a - P_b)}{\rho}}$$

Pa, Pb, INLET CONE, THROAT, V_b, V_a (average velocity)

$$\boxed{\bar{V}_b = \frac{C_v}{\sqrt{1-\beta^4}}\sqrt{\frac{2\Delta P}{\rho}}}$$

If $D_b < \frac{1}{4} D_a$

$D_b < 0.25\, D_a$

$\left(\frac{D_b}{D_a}\right)^4 < 0.000\ldots$

C_v : Venturi coefficient

$0.97 < C_v < 0.99$

[C_v is brought considering losses, all kinetic head not converted to pressure head)

If C_v is given, we can tell how much energy is lost]

- angle of discharge cone has to be small so that boundary layer doesn't separate from surface. (b/w 5° and 15°)
- upstream cone shorter than downstream cone

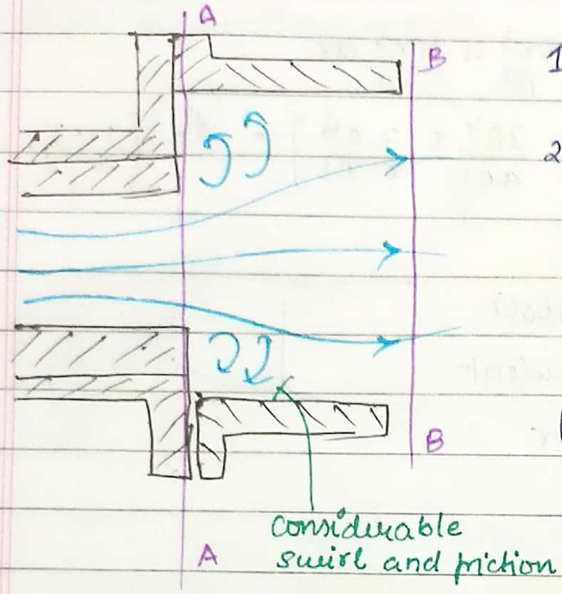
Flange used to join pipes

ORIFICEMETER

$C_v = 0.6$ (Huge energy loss)

26.10

SUDDEN EXPANSION OF CROSS-SECTION :



1. Fluid stream separates from the wall and continues as a jet
2. At further downstream, jet expands to fill the entire cross-section

For the control volume AABB M² eqn.

$$(P_a S_b - P_b S_b) = \dot{m}\left[\bar{V}_b - \bar{V}_a\right]$$

energy eqn:

$$\frac{P_a - P_b}{\rho} = \frac{\bar{V}_b^2 - \bar{V}_a^2}{2} + h_{fe}$$

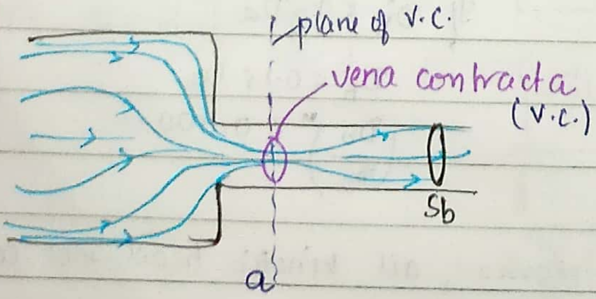
$$h_{fe} = \frac{(\bar{V}_a - \bar{V}_b)^2}{2} = \frac{\bar{V}_a^2}{2}\left[1 - \frac{S_a}{S_b}\right]^2 = \frac{\bar{V}_a^2}{2} K_e$$

frictional loss coeff.

K_e : Expansion loss coefficient

any loss = $\frac{(\text{velocity at upstream})^2}{2}$ (coefficient)

SUDDEN CONTRACTION :



Whatever loss occurs is after vena contracta.

The jet first ~~expands~~ contracts then expands.

Minm Area of C.S at V.C.

$$h_{fc} = K_c \frac{\bar{V}_b^2}{2}$$

Vena contracta area = $0.6\, S_b$

Velocity at vena contracta $= \frac{V_b}{0.6}$

Kinetic energy ratio $= \frac{V_{vc}^2}{V_b^2} = \left(\frac{1}{0.6}\right)^2 = 2.8$

$K_e \frac{V_a^2}{2} = K$

$h_{fe} = k_e \cdot \frac{V_a^2}{2} =$

Frictional energy loss as the stream expands beyond vena contracta

$$K_e = \left[1 - \frac{0.6\, S_b}{S_b}\right]^2 = 0.16$$

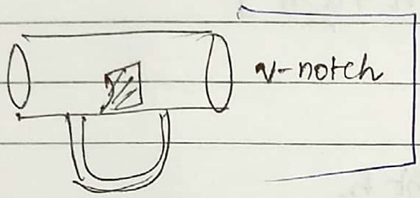
$$h_{fe} = K_e \cdot \frac{\bar{V}_b^2}{(0.6)^2} \cdot \frac{1}{2} = \frac{\bar{V}_b^2}{2} \times 0.16 \times 2.8 = 0.44\, \frac{\bar{V}_b^2}{2}$$

$$\boxed{K_c = 0.44}$$

For laminar flow, $K_c < 0.1$ and h_{fe} is neglected

For turbulent " $K_c = 0.4\left[1 - \frac{S_b}{S_a}\right]$

$\frac{S_b}{S_a} \to 0 \qquad k_c = 0.4$



- Ori

$$u_0 = \frac{C_0}{\sqrt{1-\beta^4}}\left(\sqrt{\frac{2(P_a - P_b)}{\rho}}\right)$$

u_0 - velocity through orifice

β - $\frac{d}{\text{Pipe dia}}$

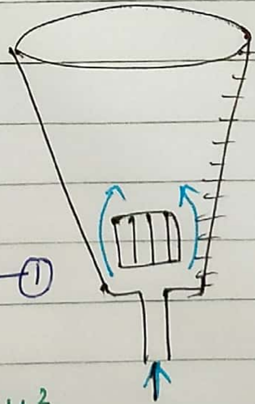
C_0 depends on $Re_0 = \frac{D_0 u_0 \rho}{\mu} = \frac{4\dot{m}}{\pi D_0 \mu}$

$Re_0 > 30{,}000 \Rightarrow C_0 = 0.61$

$\beta < 0.25$ - can be neglected

Availability of straight pipe both upstream or downstr is imp otherwise there will be swirls, B.L before entry of the fluid.

ROTAMETER :



Balance of 3 forces
- → Weight of float ↓
- → Buoyancy force on float ↑
- → Drag force on float ↑

ρ_f : density of float
V_f : volume of float

At eq^m =

$$V_f \rho_f g - V_f \rho g = F_{Drag} \quad \text{—(1)}$$

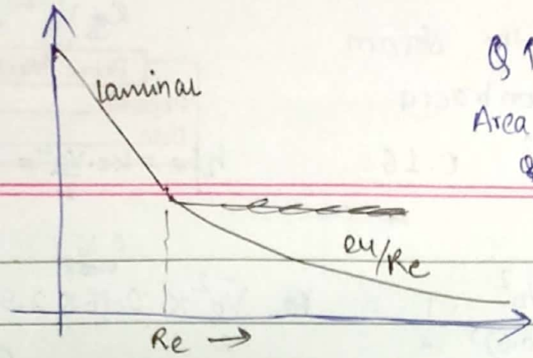
$$F_D = A_f C_D \rho \frac{u^2}{2}$$

$$F_{Drag} = 6\pi r \mu u = C_D \pi r^2 \rho \frac{u^2}{2}$$

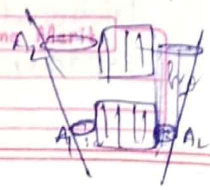
C_D : drag coeff. A_f : Projected area
u : velocity of fluid around float

$$C_D = \frac{12\mu}{r u \rho} = \frac{24}{Re}$$

(for non-laminar)



Q ↑
Area same
so, v ↑
moves up



At A_2, it settles A ↑ v ↓
F_D ↓

only F_D changes in eqⁿ (1)

$D_t = D_f + ah$ ↑

$$q = \frac{u\pi}{4}\left(D_t^2 - D_f^2\right) = \frac{u\pi}{4}\left[(D_f + ah)^2 - D_f^2\right]$$

$$= \frac{u\pi}{4}\left[2aDh + \cancel{a^2h^2}^{\,0}\right]$$

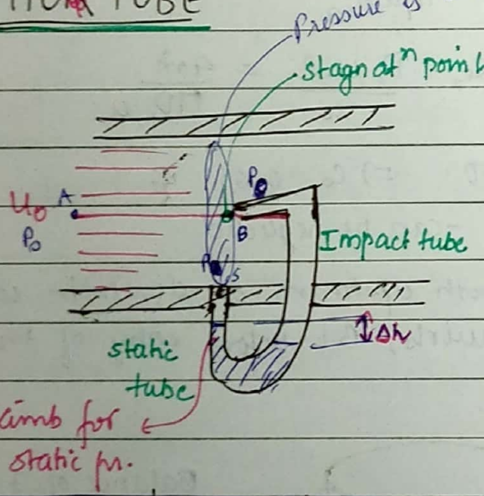
$$Q \propto (h)^1$$

∴ Flow is a linear f^n of height h.

In orifice meter, flow rate $\propto \sqrt{(\Delta P)}$ reading

PITOT TUBE

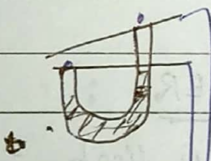
Pressure is same across this c.s as no vertical velocity



$$\frac{u_0^2}{2} + \frac{P_0}{\rho} = 0 + \frac{P_S}{\rho}$$

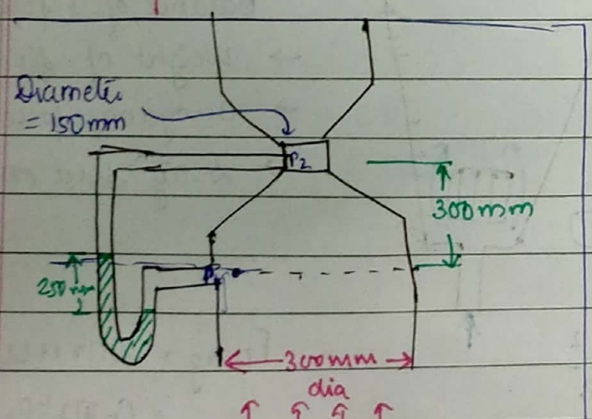
$$u_0 = \sqrt{\frac{2(P_S - P_0)}{\rho}}$$

$\Delta P = \Delta h \rho g$



same pressure drop in this configuration.

Q

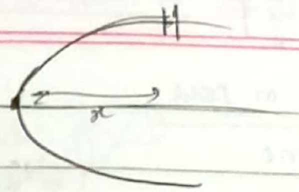


All kinetic head converted to pressure head → measured by manometer.

Particle image velocimetry
- measures local velocity
Cross-correlation f^n

1. Calculate $(P_1 - P_2)$
2. Calculate flow rate (also refered as discharge rate) of oil

Scanned by CamScanner



x such that we recover 98% of pressure

$P_1 + \rho_o g(0.250) - \rho_m g(0.250) - \rho_o g(0.3) = P_2$

Q $C_v = 0.98$

$\Delta P = \cancel{250} h \rho_m g = 250 \times 10^{-3} \times 13.6 \times 10^3 \times 9.81 = 33.354 \text{ kPa}$

$V_2 = \dfrac{C_v}{\sqrt{1-\beta^4}} \sqrt{\dfrac{2\Delta P}{\rho}}$ $\beta = \dfrac{150}{300} = \dfrac{1}{2}$

$= \dfrac{0.98}{\sqrt{1-\frac{1}{16}}} \sqrt{\dfrac{2 \times 33.794 \times 10^3}{0.9 \times 10^3}}$

$P_2 + \dfrac{300}{1000} \times 900 \times 9.81 + \dfrac{250}{1000} \times 13600 \times 9.81 = P_1 + \dfrac{250}{1000} \times 900 \times 10$

$P_2 - P_1 = -33795.45 \text{ Pa}$

$\Delta P = 33795.45 \text{ Pa}$

Assuming $C_v = 1$

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

$A_1 V_1 = A_2 V_2$

$\pi \dfrac{(300)^2}{4} V_1 = \pi \dfrac{(150)^2}{4} V_2$

$V_2 = 4V_1$

$\dfrac{34 \times 10^3}{0.9 \times 10^3} = \dfrac{16V_1^2 - V_1^2}{2} + g(0.3)$

$V_1^2 = 4.644$

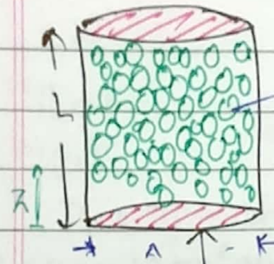
$V_1 = 2.155 \text{ m/s}$ $V_2 = 8.62 \text{ m/s}$

$Q = 0.152 \text{ m}^3/\text{s}$

Considering C_v, $V_2 = 8.798 \text{ m/s}$, $Q = 0.155 \text{ m}^3/\text{s}$ — can't be used because there is hydrostatic head.

FLOW THROUGH POROUS MEDIA

ϵ = void fraction = $\boxed{\text{Porosity}}$



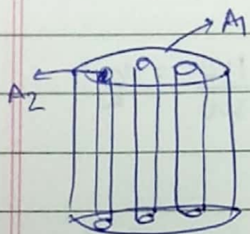
$= \frac{\text{Volume of void or pore}}{\text{Total volume}}$

$\epsilon V_i = V_s$

$1-\epsilon = \frac{\text{volume of solid}}{\text{total volume}}$

$\frac{Q}{A}$ = Darcy velocity = Superficial velocity V_s

$= -\frac{k}{\mu}\frac{\partial P}{\partial z}$



$\frac{Q}{\epsilon A}$ = Interstitial velocity V_i $= \frac{k}{\mu}\frac{\Delta P}{L}$

Total volume $= A_1 L$

Void " $= A_2 L$

$\frac{A_2 L}{A_1 L} = \epsilon$

so, $\boxed{A_2 = A_1 \epsilon}$

property of medium

[k: permeability] (m^2) (Darcy)

[μ: viscosity of the fluid

property of fluid

- Darcy velocity need not be in only one direction
  We can have ~~have~~ velocity in x, y "

$$\bar{v}_D = -\frac{k}{\mu}\frac{\partial p}{\partial x}\hat{i} - \frac{k}{\mu}\frac{\partial p}{\partial y}\hat{j}$$

- 'k' ~~can be~~ tensor $\begin{bmatrix} k_{xx} & \cdot & \cdot \\ \cdot & k_{yy} & \cdot \\ \cdot & \cdot & k_{zz} \end{bmatrix}$ generally, we take diagonal elements

For isotropic medium, $k_{xx} = k_{yy} = k_{zz}$

- When 2 fluids flow simultaneously, k becomes relative permeab

$$V_{oil} = -\frac{k\, k_{r\,oil}}{\mu_{oil}}\frac{\partial p}{\partial z}$$

$$V_{water} = -\frac{k\, k_{r\,water}}{\mu_{water}}\frac{\partial p}{\partial z}$$

$$D_h = 4\frac{A_i}{W_p} = 4\frac{A_i L}{W_p L} = 4\,\frac{\text{Flow volume}}{\text{Wetted surface area}}$$

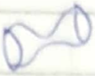
$$= 4\,\frac{\epsilon\{\text{Bed volume}\}}{\{\text{no. of particles}\}\{\frac{\text{surface area}}{\text{particle}}\}}$$

total vol of porous medium

No. of particles $= \dfrac{(\text{Bed volume})(\text{Fract}^n \text{ of solid in bed})}{(\text{volume per particle})}$

Fraction of solids in bed $= (1-\epsilon)$

$$D_h = \left(\frac{4\epsilon}{1-\epsilon}\right) \frac{(\text{Bed volume})}{(\text{Bed volume})\left(\dfrac{\text{surface area per particle}}{\text{volume per particle}}\right)}$$

Berl saddle 

Rasching Ring

~~Coulson & Richardson, McCabe & Smith~~

$$D_h = 4\frac{\epsilon}{1-\epsilon}\left(\frac{\text{volume}}{\text{surface area}}\right)_{\text{particle}} \qquad \frac{\frac{4}{3}\pi R^3}{4\pi R^2}$$

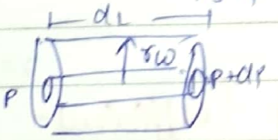
$$= 4\left(\frac{\epsilon}{1-\epsilon}\right)\left(\frac{D}{6}\right) - \text{If spherical}$$

- If not spherical, we ~~call~~ use sphericity factor multiplied by D

ϕ_s : Sphericity : $\dfrac{\text{surface volume ratio for a sphere of diameter } D_p}{\text{surface volume ratio for the particle whose nominal size is } D_p}$ — $6/D_p$

$$x = \frac{6}{\phi_s D_p} \Rightarrow \frac{1}{x} = \frac{\phi_s D_p}{6}$$

Frictional loss $= \dfrac{\Delta P}{\rho} = \dfrac{2}{\rho}\dfrac{\tau_w}{r_w}\cdot L$



$$\frac{\tau}{r} = \frac{\tau_w}{r_w}$$

$$\pi r^2 P - \pi(r^2)(P+dP) = \tau(2\pi r\, dL)$$

$$\frac{2\tau}{r} + \frac{dP}{dL} = 0$$

Interstitial

$$Re = \frac{D_h V_i \rho}{\mu} = \frac{2}{3}\frac{D V_i \rho}{\mu}\left(\frac{\epsilon}{1-\epsilon}\right)$$

$$= \frac{2 D V_s \rho}{3\mu(1-\epsilon)}$$

$$\boxed{(N_{Re})_{PM} = \frac{d V_s \rho}{(1-\epsilon)\mu}}$$

Porous medium

$f = \dfrac{16}{Re}$ → McCabe Smith

Fanning ~~Fahling~~, Moody, Darcy friction factor

f_{PM}

Ergun equation

Laminar

$$f_{PM} = 1.75 + \frac{150}{(N_{Re})_{PM}}$$

V_o : superficial velocity

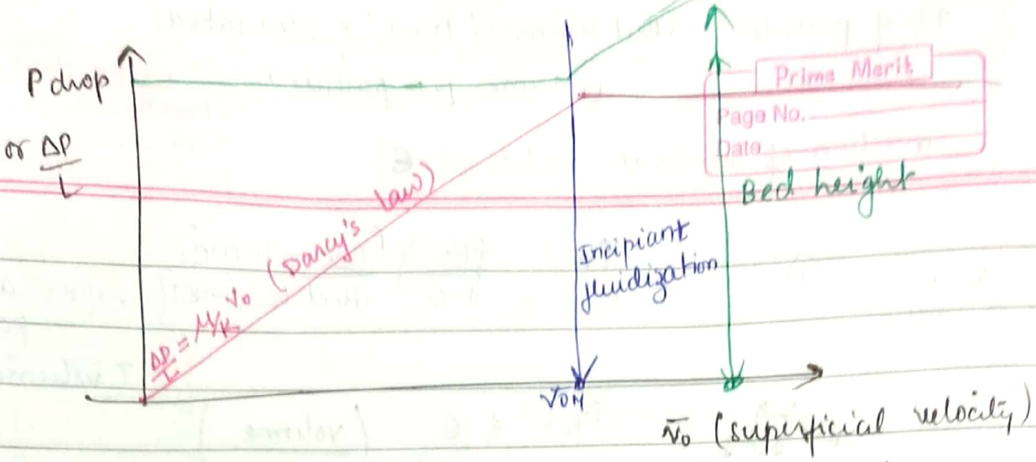
$$\frac{\Delta P}{L} = \underbrace{\frac{150 \bar{V}_o \mu}{\phi_s^2 D_p^2}\frac{(1-\epsilon)^2}{\epsilon^3}}_{Re_p < 1} + \underbrace{\frac{1.75 \rho \bar{V}_o^2}{\phi_s D_p}\frac{(1-\epsilon)}{\epsilon^3}}$$

11

D_p : nominal size of particle

$$y = k_1 x + k_2 x^2$$

D^2



Fluidized catalytic cracking unit

FCC unit catalyst

When we go on increasing v, pores' eq^m disturbed.

- BUBBLING occurs.

Churning

$\bar{V}_{OM}$ - velocity beyond which ~~no mor~~ fluidization occurs

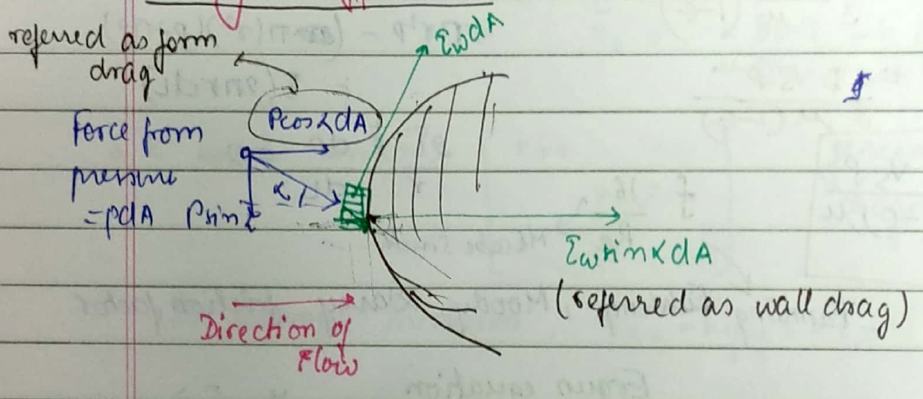
F_D, F_B, W

{Pressure drop across the bed} A = wt. of bed per unit area of cross section (allowing for buoyancy force)

$= (1-\epsilon)(\rho_p - \rho) Lg$ — (1) ~~Weight of solid~~

09.11.17

Drag Coefficient-



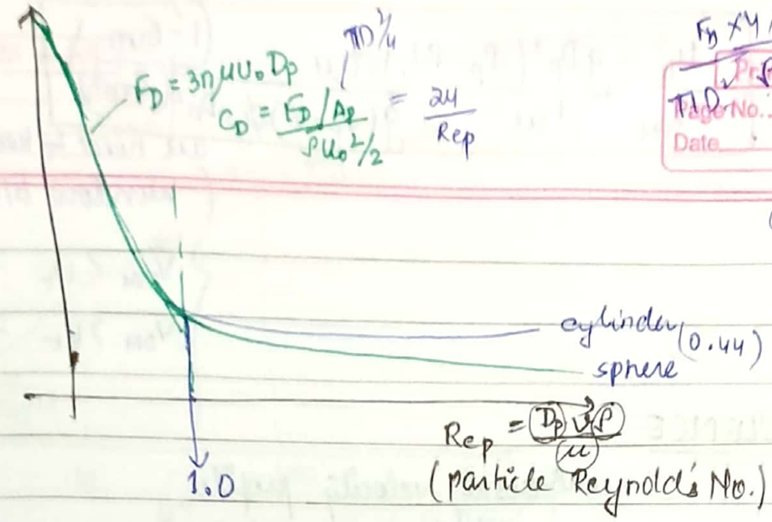
For flow past immersed object, the force in the directⁿ of flow exerted by the fluid on the solid is called "drag"

Drag coefficient (C_D) = $\dfrac{\text{Total drag/Projected area}}{\frac{\rho U_o^2}{2}}$ U_o: velocity of particle $\left[f = \dfrac{\tau_w}{\frac{\rho V_o^2}{2}} \right]$

Projected area is the area obtained by projecting the object on a plane ⊥r to the directⁿ of flow.

sphere — circle

C_D



$Re_p = \frac{D_p v \rho}{\mu}$ (particle Reynold's No.)

$\frac{F_D \times 4 \times 2}{\pi D^2 \rho U_0^2}$ $y =$

$\frac{3\pi\mu U_0 D_p \times 8}{\pi D^2 \rho U_0^2}$

U_0/v : generally terminal velocity

D_p : particle dia

$Re > 1$, $C_D \neq \frac{24}{Re_p}$

$\frac{C_D}{Re_p}$

other particles do not interfere

Free settling :

$$\frac{m\,du}{dt} = F_e - F_b - F_D$$

$F_e = mg$, $F_b = \frac{m\rho g}{\rho_p}$, $F_D = \frac{C_D \rho u^2 A_p}{2}$

$$\frac{du}{dt} = g\frac{(\rho_p-\rho)}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m}$$

If centrifuge is used ?

Assume, at terminal velocity, $\frac{du}{dt} = 0$

$$U_t = \sqrt{\frac{2g(\rho_p-\rho)m}{A_p \rho_p C_D \rho}}$$

D_p, ρ_p

If we write $m = \frac{1}{6}\pi D_p^3 \rho_p$

$A_p = \frac{\pi D_p^2}{4}$, $Re_p \leq 1 \Rightarrow C_D = \frac{24}{Re_p}$

$Re_p >> 1 \Rightarrow C_D = const = 0.44$

$$U_t = \frac{g D_p^2(\rho_p-\rho)}{18\mu}$$

$$U_t = 1.75\sqrt{\frac{g D_p(\rho_p-\rho)}{\rho}}$$

$\cancel{\frac{2g(\rho_p-\rho)\frac{\pi D_p^3}{6}\rho_p}{\frac{\pi D_p^2}{4}\rho_p\frac{24}{Re_p}\rho}}$

$\frac{g(\rho_p-\rho)D_p \rho v D_p}{18\rho\,\mu}$

Hindered settling

$$U_s = U_t(\epsilon)^n$$

ϵ : vol. fn of solid

$(4.6 < \epsilon < 2.5)$

Stoke's region $\quad Re_p \uparrow$

- In Ergun eqn, when the size of particles is very small, then the

$$\boxed{Re_p < 1 \quad V_{OM} \approx \frac{g(\rho_p-\rho)\epsilon_m^3}{150\mu\,(1-\epsilon_m)} \phi_s^2 D_p^2}$$

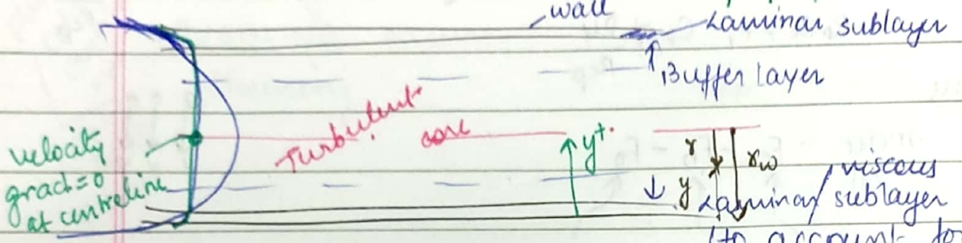
$$\boxed{\frac{U_t}{V_{OM}} = \frac{g D_p^2(\rho_p-\rho)}{18\mu} \cdot \frac{150\mu}{g(\rho_p-\rho)\phi_s D_p^2} \frac{(1-\epsilon_m)}{(\epsilon_m^3)}}$$

we need to keep it as high as poss.
window b/w U_t & V_{OM}

$V_{OM} < U_t$ - no fluidization
$V_{OM} > U_t$ - particles will flow with fluid

TURBULENCE

universal velocity profile



(to account for velo. at wall = 0)

Dimensionless variables:

shear velocity (u_f)

• Friction velocity = $v^* = \bar{V}\sqrt{\frac{f}{2}} = \sqrt{\frac{\tau_w}{\rho}}$ → has dimension

$u^+ = \frac{u}{u^*}$ - dimensionless velocity

$y^+ = \frac{y u^* \rho}{\mu}$ - " distance

y: distance from wall of tube $(r_w - r)$

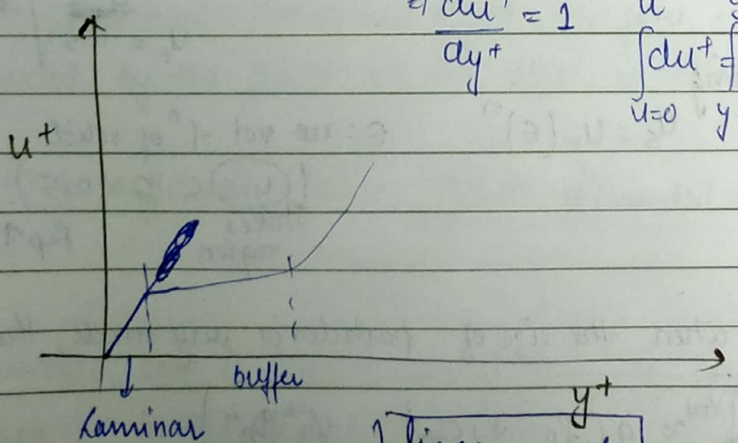
$r_w = r + y \Rightarrow dr = -dy$

For viscous sublayer, $-\frac{du}{dr} = \frac{\tau_w}{\mu}$

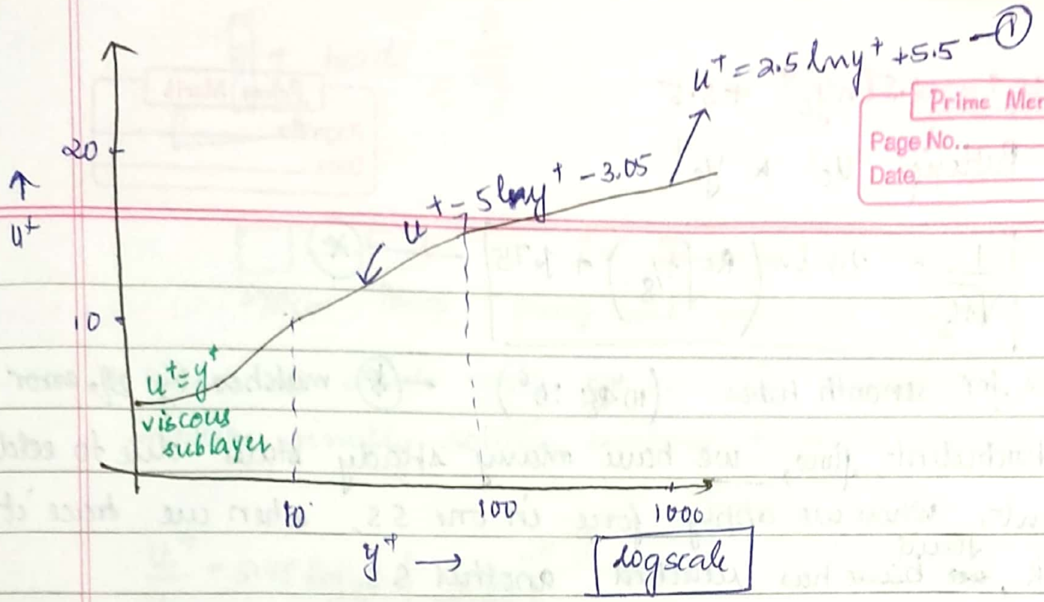
$y^+ = \frac{y \cdot u \rho}{u^+ \mu}$

$\frac{du}{dy} = \frac{\tau_w}{\mu}$

$\Rightarrow \frac{du^+}{dy^+} = 1$ $\int_{u=0}^{u^+} du^+ = \int_{y=0}^{y^+} dy^+$ $u^+ = y^+$



linear scale



y^+		
	$0 \rightarrow 5$	viscous subdayer
	$5 \rightarrow 30$	buffer layer
	$30 \rightarrow$ centre of pipe	turbulent core

At the centre of the pipe $\quad u_c^+ = 2.5 \ln y_c^+ + 5.5$ — (II) $\left[u_c^+ = \dfrac{u_{max}}{u^*} \quad y_c^+ = \dfrac{r_w u^*}{\mu/\rho} \right.$

To find u^+ at any y^+

subtracting (I) from (II)

$$u^+ - u_c^+ = 2.5 \ln \frac{y^+}{y_c^+}$$

$$\bar{v} = \frac{1}{\pi r_w^2} \int_0^r u(2\pi r)\,dr$$

$$= \frac{2}{r_w^2} \int_0^{r_w} u(r_w - y)\,dy$$

$r = r_w - y$
$dr = -dy$
$r = 0 \Rightarrow y = r_w$
$r = r_w \Rightarrow y = 0$

[u is taken as the turbulent part dominating

$$= \frac{5\left(\frac{\mu}{\rho}\right)^2}{r_w^2 u^*} \int_0^{y_c^+} \left(0.4 u_c^+ + \ln \frac{y^+}{y_c^+}\right)\left(y_c^+ - y^+\right) dy^+$$

$$\frac{\bar{V}}{u^*} = u_c^+ - 3.75$$

[laminar $\bar{V} = \frac{1}{2} U_{max}$]

$$\frac{\bar{V}}{U_{max}} = \frac{1}{1 + 3.75\sqrt{f/2}}$$

$$y_c^+ = \frac{r_w \bar{V}}{(\mu/\rho)} \sqrt{f/2} = \frac{D\bar{V}}{2\left(\frac{\mu}{\rho}\right)} \sqrt{f/2} = \frac{Re}{2}\sqrt{f/2}$$

$$u_c^+ = \frac{1}{\sqrt{f/2}} + 3.75$$

Scanned by CamScanner

$u_c^+ = 2.5 \ln y_c^+ + 5.5$

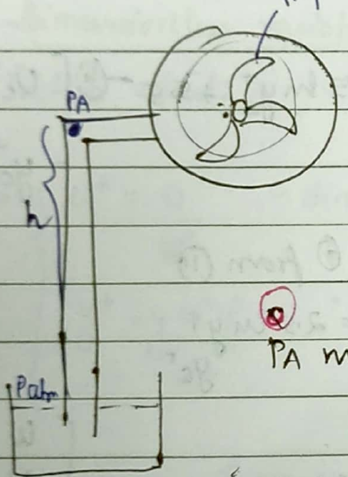
Putting u_c^+ & y_c^+

$$\boxed{\frac{1}{\sqrt{f/2}} = 2.5 \ln\left(Re\sqrt{f/8}\right) + 1.75} \longrightarrow (*)$$

- Re for smooth tubes $(10^4 < Re < 10^6)$ — (*) matches by 2% error

For turbulent flow, we have many steady states due to eddies present. When we apply force in one s.s, when we trace it back, fluid have has reached another s.s.

Centrifugal Pump



Process of putting in water into the pump – priming

$P_A = \{P_{atm} - \rho g h\} - \Delta P_f$ < Vapor pressure of liquid

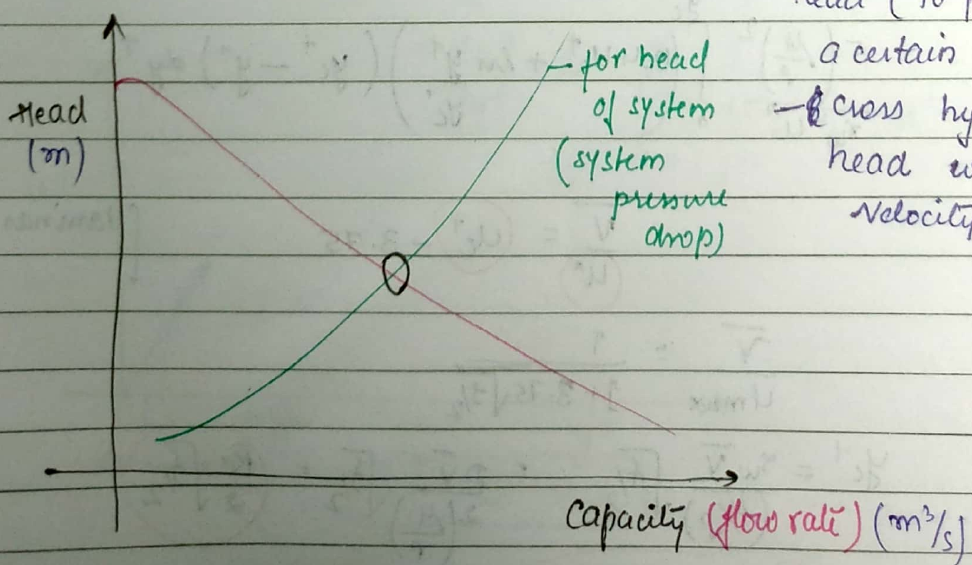
then, liquid will vapourise (boiling)

P_A must be greater than vapour pressure

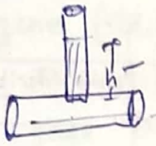
Net Positive Suction Head (NPSH) is the difference b/w absolute stagnation pressure and vapour pressure

Limitation on height
$h = 34\,ft$, $P_A = 0$ (vaccum)

Before that condition ①



Head (to pump to a certain height – cross hydrostatic head with some velocity)

 head $\frac{P}{\rho g}$

System — Pump They converge at one point, pump will work at this Q.

- when we want more pressure in downstream, ~~pus~~ impeller simply rotates without throwing liquid.

$$\frac{u^+}{u_f} = 5.75 \log_{10}\left[\frac{u_f y}{\mu/\rho}\right]^{\leftarrow y^+} + 5.5 \qquad u^+$$

$$\bar{u} = \frac{Q}{\pi R^2} = \frac{1}{\pi R^2}\int_0^R u\, 2\pi r\, dr$$

$r_w - y = r$

$-dy = dr$

$$= \frac{2}{R^2}\int_0^R u_f\left[5.75 \log_{10}\left(\frac{u_f y}{\mu/\rho}\right) + 5.5\right] r\, dr$$

$$= \frac{2u_f}{R^2}\int_0^R \left[5.75 \log_{10}\left(\frac{u_f(r - r_w)}{\mu/\rho}\right) + 5.5\right] r\, dr$$

$$= \frac{2u_f}{R^2} \qquad \log_{10}\frac{\rho u_f}{\mu/\rho}(r - r_w) = t$$

$$(r - r_w) = \frac{\mu}{\rho u_f} 10^t$$

$$\frac{2u_f}{R^2}\int_0^R [5.75\, t + 5.5]\left[\frac{\mu}{\rho u_f}10^t + R\right] \frac{10^t}{\ln 10} dt \qquad dr = \frac{\mu}{\rho u_f} 10^t\, dt \ln 10$$

$$= \frac{2u_f}{R^2}\left[\int_0^R \frac{5.75\mu\, t 10^t}{\rho u_f} + \right.$$

$$= \frac{2}{R^2}\int_0^R u_f\left[5.75 \log_{10}\left(\frac{u_f y}{\mu/\rho}\right) + 5.5\right][R - y]\, dy \qquad (R - r)$$

$\int \ln x\, dx$

$x \ln x - x$

$$= \frac{2}{R^2}\left[u_f\left[5.75 \log \frac{\mu}{\rho u_f}\right.\right.$$

$$= \frac{2}{R^2}\int_0^R [2.5 \ln y + 5.5][R - y]\, dy$$

$\int x \ln x\, dx$

$$= \frac{2}{R^2}\left[R\{2.5\, y[\ln y - 1]\}_0^R + 5.5\left[Ry - \frac{y^2}{2}\right]_0^R\right]$$

$$= \frac{x^2}{2}\ln x - \int \frac{1}{x}\cdot\frac{x^2}{2} dx$$

$$-\frac{2}{R^2}\left[\int_0^R 2.5\, y \ln y\, dy\right]$$

$$= \frac{x^2}{2}\ln x - \frac{x^2}{4}$$

$$\frac{2}{R^2}\left[R\left(2.5\, y(\ln y-1)\right)_0^R + 5.5\left(Ry-\frac{y^2}{2}\right)_0^R\right]$$

$$-\frac{2}{R^2}\left[2.5\left[\frac{y^2}{2}\ln y-\frac{y^2}{4}\right]_0^R\right]$$

R^2 —

$R\ln R - R$ —

$$=\frac{2}{R^2}\left[R\left(2.5\, R(\ln R-1)\right)+5.5\frac{R^2}{2}\right]$$

$\lim_{y\to 0} y\ln y$

$\lim_{y\to 0}\frac{\ln y}{1/y}$

$\frac{1/y}{-1/y^2}$

$-\frac{y}{1/\ln y}$

$\frac{01}{-\frac{1}{(\ln y)^2}\frac{1}{y}}$

$$-\frac{5}{4R^2}\left[2R^2\ln R - R^2\right]$$

$$= 5(\ln R-1)+5.5-2.5\ln R+1.25$$

$$2.5\ln R+1.75$$

$$\bar{u}=\left[5.75\log_{10}\left(\frac{R\,u_f}{\mu/\rho}\right)+1.75\right]u_f$$

$$\frac{u}{u_f}=5.75\log_{10}\left[\frac{u_f(R-r)}{\mu/\rho}\right]+5.5$$

y

$$\boxed{\frac{u-\bar{u}}{u_f}=5.75\log_{10}\left(\frac{y}{R}\right)+3.75} \longrightarrow (1)$$

Karman Prandtl equation for velocity distribution near hydrodynamically rough boundaries

$$\frac{u}{u_f}=5.75\log_{10}\left(\frac{y}{k}\right)+\cancel{3.75}\ 8.5$$

k: height of roughness element.

$$u^+-u^+_{ref}=5.75\log_{10}\left[\frac{y^+}{y^+_{ref}}\right]$$

$\hookrightarrow k/30$

Find $\boxed{\frac{u-\bar{u}}{u_f}=}$ same as (1)

The universal velocity profile ~~uti~~ ~~sam~~ gives same result irrespective of smooth / rough pipe.

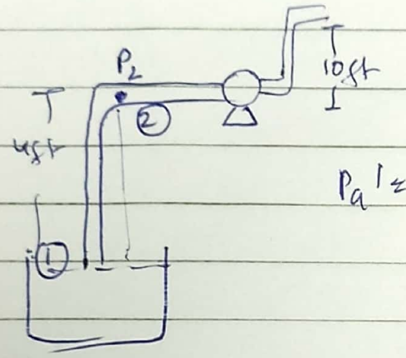
Q Benzene (37.8°C) is pumped through a system at 9.09 m^3/hr
The reservoir is at atmospheric pressure
The gage pressure at the end of discharge line is 345 KN/m². The discharge is 10ft and the suction is 4ft above the level of reservoir. The friction in suction line is 3.45 KPa, and discharge line is 37.9 KPa

$\rho_{benzene} = 865\ kg/m^3$ $P_{vap\ at\ 37.8°C} = 26.2\ KPa$

$\bar{V}_{avg} = 1.9\ m/s$ Calculate developed head of pump

NPSH

If $\eta = 60\%$, calculate total input power.



losses = 3.45 KPa + ~~37.9 KPa~~

= ~~4.215 m~~ 4.873 m

P_a' = absolute pressure at reservoir surface

$$\frac{\left(\frac{P_a' - P_v}{\rho} - \frac{h_f}{\rho}\right) - Z_a g}{g}$$

$m\ \frac{kg.m}{m s^2}$ $\frac{kg}{m s^2}$

$\dot{W}_{pump} =$

$$0 + \cancel{\frac{\bar{V}^2}{2g}} + \dot{w} + g(0) - (10)g - \frac{345}{\rho g} - \frac{\bar{V}^2}{2g} = h_L$$

$\dot{w} = \cancel{49.97\ W} \rightarrow 48.76$

. $(49.507 - 4.873) -$

$Re =$

$8.85 - 0.4066 -$ 43.414 m

7.22 m. 2.75 m

$W_{in} = \cancel{82.99\ W}\ \cancel{83.29\ W}\ 81.27\ m =$

Power to be supplied = $\dot{m}\ W_{in}$

= ~~839.038 kW~~

$\dot{m} = 2.18\ kg/s$

Power = 1.738 KW