Total Pressure: It is defined as the force exerted by a static fluid on a surface (either plane or curved) when the fluid comes in contact with the surface. This force is always normal to the surface.

Center of Pressure: The center of pressure is defined as the point of application of the resultant pressure on the surface.

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Energy in fluid flow = KE + PE + Internal energy

A body of mass m when moving at a velocity V, $KE = \frac{1}{2}mV^2$

KE per unit weigth, $\frac{KE}{Weight} = \frac{\frac{1}{2}m}{\gamma(vol)} = \frac{V^2}{2g}$ expressed as $N.m/N = m$

True KE per unit weigth, $\frac{True\ KE}{Weight} = \alpha\frac{V^2}{2g}$, where α is KE coefficient

A fluid particle weight W situated a distance z above datum possesses a $PE = Wz$

Thus, PE per unit weight $= z\ N.m/N(i.e.m)$

Δin internal energy I **(change in temperature) per unit weight = heat generated by fluid friction (frictional loss of energy,** h_L + external heat added or taken out from fluid, Q_H).

Thus, $\Delta \boldsymbol{I} = I_2 - I_1 = \frac{c}{g}(T_2 - T_1) = h_L + Q_H$

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Energy Equation for Steady Flow of any Fluid

$$\Delta \boldsymbol{E} = E_{out} - E_{in} = E_{section2} - E_{section1}$$

$$= (KE + PE + IE)_{section2} - (KE + PE + IE)_{section1}$$

$$= \gamma_2 A_2 ds_2 \left(\boldsymbol{\alpha_2} \frac{\boldsymbol{V_2^2}}{\boldsymbol{2g}} + \boldsymbol{z_2} + \boldsymbol{I_2}\right) - \gamma_1 A_1 ds_1 \left(\boldsymbol{\alpha_1} \frac{\boldsymbol{V_1^2}}{\boldsymbol{2g}} + \boldsymbol{z_1} + \boldsymbol{I_1}\right)$$

According to the First law of thermodynamics, $\boldsymbol{Work\ done + Heat = \Delta E}$

$\therefore$Work done by pressure forces+shaftwork + Heat $= \Delta E$

$$(p_2 A_2 ds_2 - p_1 A_1 ds_1) + \gamma_1 A_1 ds_1 h_M + \gamma_1 A_1 ds_1 Q_H = \gamma_2 A_2 ds_2 \left(\alpha_2 \frac{V_2^2}{2g} + z_2 + I_2\right) - \gamma_1 A_1 ds_1 \left(\alpha_1 \frac{V_1^2}{2g} + z_1 + I_1\right)$$

Considering $\gamma_1 A_1 ds_1 = \gamma_2 A_2 ds_2$ and dividing by $\gamma_1 A_1 ds_1 and\ \gamma_2 A_2 ds_2$

$$\left(\frac{p_2}{\gamma_2} - \frac{p_1}{\gamma_1}\right) + h_M + Q_H = \left(\alpha_2 \frac{V_2^2}{2g} + z_2 + I_2\right) - \left(\alpha_1 \frac{V_1^2}{2g} + z_1 + I_1\right)$$

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Energy Equation for Steady Flow of Incompressible Fluids

$$\left(\frac{p_2}{\gamma_2}-\frac{p_1}{\gamma_1}\right)+h_M+Q_H=(\alpha_2\frac{V_2^2}{2g}+z_2+I_2)-(\alpha_1\frac{V_1^2}{2g}+z_1+I_1)$$ For any fluid

For incompressible any fluid $\gamma_1=\gamma_2=\gamma$. And assuming $\boldsymbol{\alpha=unity}$ (introducing little error)

$$\boldsymbol{z_1+\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+h_M+Q_H=z_2+\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+(I_2-I_1)}$$

$$\left(\frac{p_1}{\gamma_1}+z_1+\frac{V_1^2}{2g}\right)+h_M+Q_H=\left(\frac{p_2}{\gamma_2}+z_2+\frac{V_2^2}{2g}\right)+h_L+Q_H$$

$$\left(\frac{p_1}{\gamma_1}+z_1+\frac{V_1^2}{2g}\right)+h_M=\left(\frac{p_2}{\gamma_2}+z_2+\frac{V_2^2}{2g}\right)+h_L$$

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Energy Equation for Steady Flow of Incompressible Fluids

If there is no machine beween sec 1 and 2 and if no het is gained or lost then the energy equation for incompressible fluid becomes

$$\left(\frac{p_1}{\gamma_1} + z_1 + \frac{V_1^2}{2g}\right) = \left(\frac{p_2}{\gamma_2} + z_2 + \frac{V_2^2}{2g}\right) + h_L$$

If head loss is neglected $\left(\frac{p_1}{\gamma_1} + z_1 + \frac{V_1^2}{2g}\right) = \left(\frac{p_2}{\gamma_2} + z_2 + \frac{V_2^2}{2g}\right)$

$$\left(\frac{\boldsymbol{p}}{\boldsymbol{\gamma}} + \boldsymbol{z} + \frac{\boldsymbol{V^2}}{\boldsymbol{2g}}\right) = \boldsymbol{constant.}$$

Both these forms are Bernoulli's theorem.

For channel flow, $z_1 + h_1 + \alpha_1 \frac{V_1^2}{2g} = z_2 + h_2 + \alpha_2 \frac{V_2^2}{2g} + h_L$

Here, α_1 and α_1 are the KE coefficient and h_1 and h_2 are the depths of flow in section 1 and section 2 respectively.

Each term represent energy in m-N/N or m-kg/kg or simply in m.

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Energy Equation for 1D steady flow

Toal energy at the upstream section is equal to the total energy at the downstream section plus the frictional loss of energy h_f between the two sections.

$$\boldsymbol{H_1 = H_2 + h_f}$$

For pipe flow, $\boldsymbol{z_1 + \frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + h_f}$

For channel flow, $\boldsymbol{z_1 + h_1 + \alpha_1 \frac{V_1^2}{2g} = z_2 + h_2 + \alpha_2 \frac{V_2^2}{2g} + h_f}$

Here, α_1 and α_1 are the KE coefficient and h_1 and h_2 are the depths of flow in section 1 and section 2 respectively.

Each term represent energy in m-N/N or m-kg/kg or simply in m.

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Hydraulic Grade line and Energy Grade line

The **pressure head**, $\frac{p}{\gamma}$ can be determined by **piezometer tubes** or pressure gauges.

Elevation head plus pressure head, $z + \frac{p}{\gamma}$, is known as **piezometric head**.

The line joining piezometric heads is called **Hydraulic grade line (H.G.L)**.

Total head is equal to the sum of three heads, $z + \frac{p}{\gamma} + \frac{V^2}{2g}$

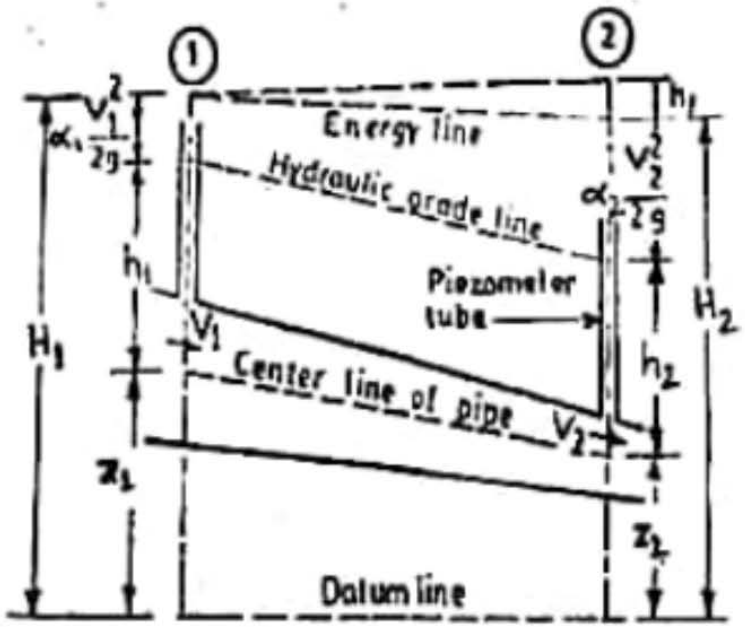
The line joining total energy or head is known as the total energy line (T.E.L) or the energy grade line (E.G.L).

The total head is indicated by Pitot tube, the line joining the liquid levels in Pitot tubre is the total energy line or energy grade line.

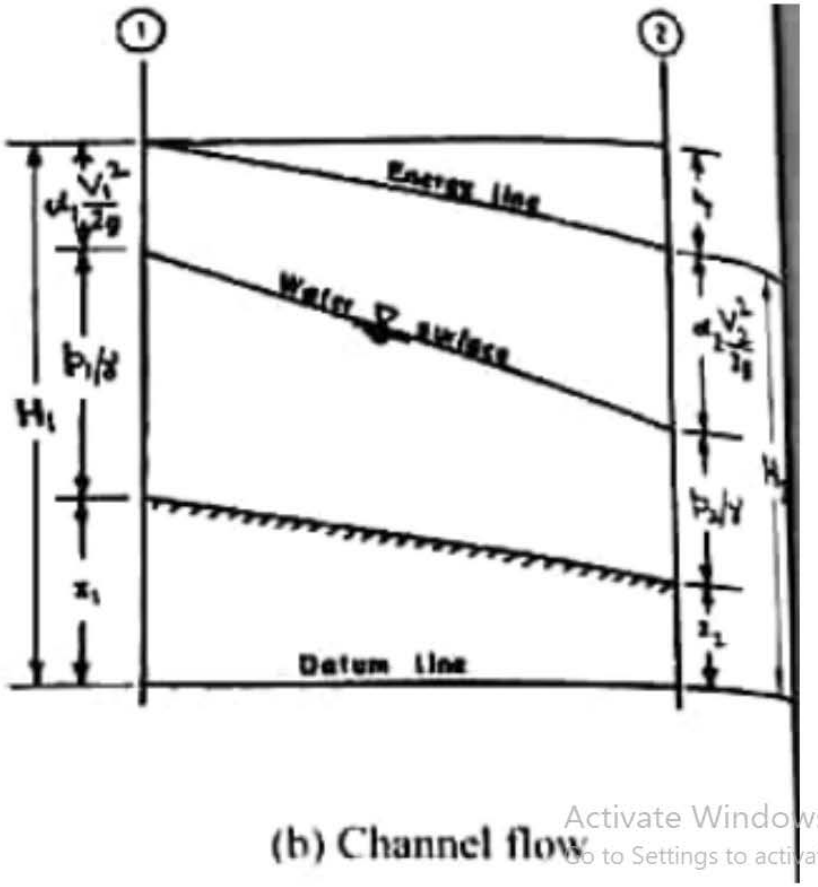
T.E.L lies above H.G.L and the distance between these twoline is the velocity head, $\frac{V^2}{2g}$.

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one-dimensional steady flow.



(a) Pipe flow



(b) Channel flow

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Power consideration in Fluid Flow

Power $\boldsymbol{P}$, is the rate of doing work, $\mathbf{P} = \frac{\boldsymbol{W}}{\boldsymbol{t}} = \frac{\boldsymbol{Energy}}{\boldsymbol{time}} = \frac{\boldsymbol{Energy}}{\boldsymbol{weight}} \times \frac{\boldsymbol{weight}}{\boldsymbol{time}}$

$\boldsymbol{P} = \boldsymbol{H} \times \boldsymbol{G} = \boldsymbol{H\gamma Q}$ in N-m/s, or Joule/s, or Waat

$$\text{Kilowatts} = \frac{\boldsymbol{\gamma QH}}{\mathbf{1000}}$$

Where, $\boldsymbol{\gamma}$ = unit weight of fluid, in N/m3

$\boldsymbol{Q}$ =the rate of flow in m3/s

$\boldsymbol{H}$ = the energy head in m

In this eqn H may be any head for which the corresponding power is desired.

To find th epower extrcated from the flow by a turbine, substitute H by h_t.

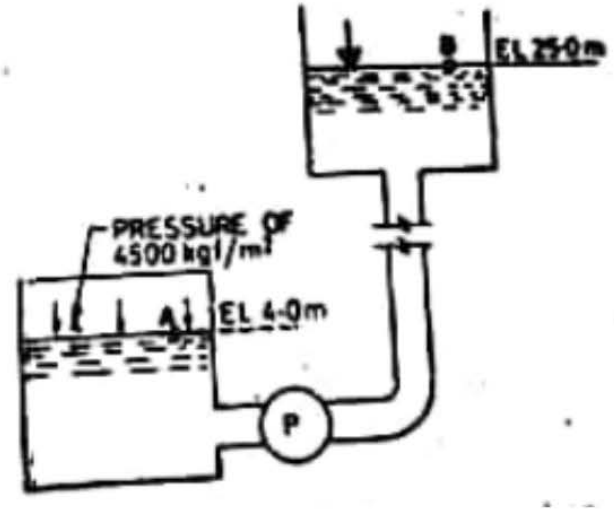
To find power loss because of fluid friction, substitute h_l for H.

To find power of a jet substitute $\frac{\boldsymbol{V_j^2}}{\boldsymbol{2g}}$ for H where V_j is the jet velocity.

Horse power is a measure of power in MKS units and is equal to m-kg/s, HP $= \frac{\boldsymbol{\gamma QH}}{\mathbf{75}}$

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A 15 HP pump working with 80% efficiency is discharging crude oil (sp gr. = 0.90) to the over head tank as shown in the Figure. If the losses in the whole system is 1.5 m of flowing fluid, find the discharge.



$$z_A + \frac{p_A}{\gamma} + \frac{V_A^2}{2g} + H_{pump} = z_B + \frac{p_B}{\gamma} + \frac{V_B^2}{2g} + h_{f,A-B}$$

$$\therefore 4 + \frac{4500}{900} + 0 + H_{pump} = 25 + 0 + 0 + 1.5$$

$$\therefore H_{pump} = 17.5$$

Now, $HP = \frac{\gamma Q H_{pump}}{75}$ or, $15 \times 0.8 = \frac{900 \times Q \times 17.5}{75}$

$$\therefore \text{Q} = 0.0571 \frac{m^3}{s}$$

Here, $z_A = 4\ m$, $z_B = 25\ m$

$p_A = 4500\ \frac{kg}{m^2}$,

$p_B = 0$ (atmp pressure)

$\frac{V_A^2}{2g}$ and $\frac{V_B^2}{2g}$ are negligible.

$h_{f,A-B} = 1.5\ m$

$\gamma_{oil} = 0.09 \times 1000 = 900\ \frac{kg}{m^3}$

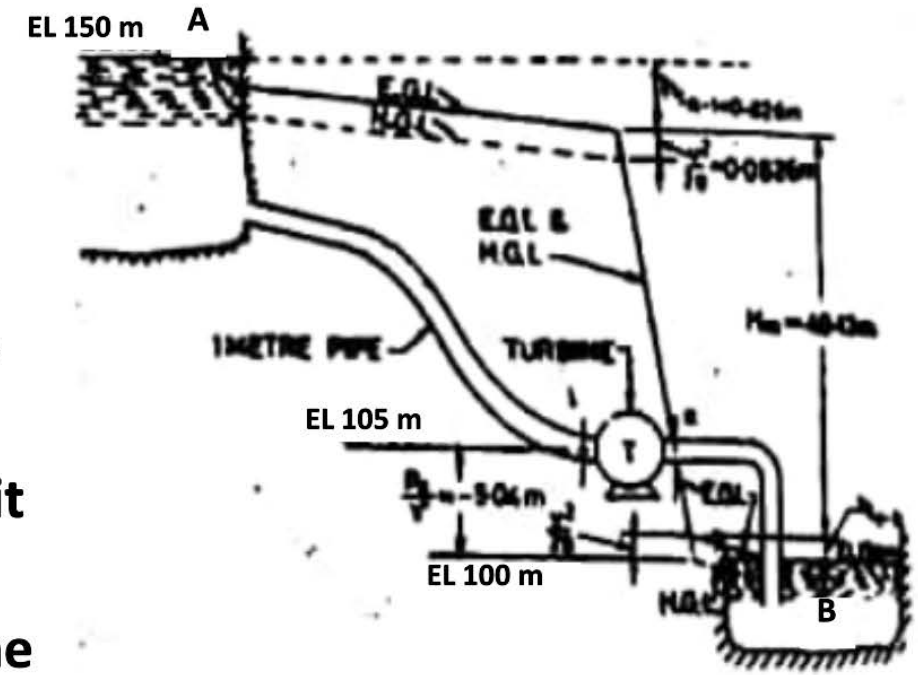
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A turbine T draws water from a reservoir through a 1 m dia pipe and discharges through another pipe of same dia into tailrace B. The head loss from headrace A to the turbine is found to be 10 times the velocity head in the pipe and that from the turbine to the tailrace B is only 0.5 time. The discharge is 1 cumec.

(a) Calculate the pressure heads at inlet and exit of the turbine

(b) Compute thepower given by the water to the turbine in HP and KW

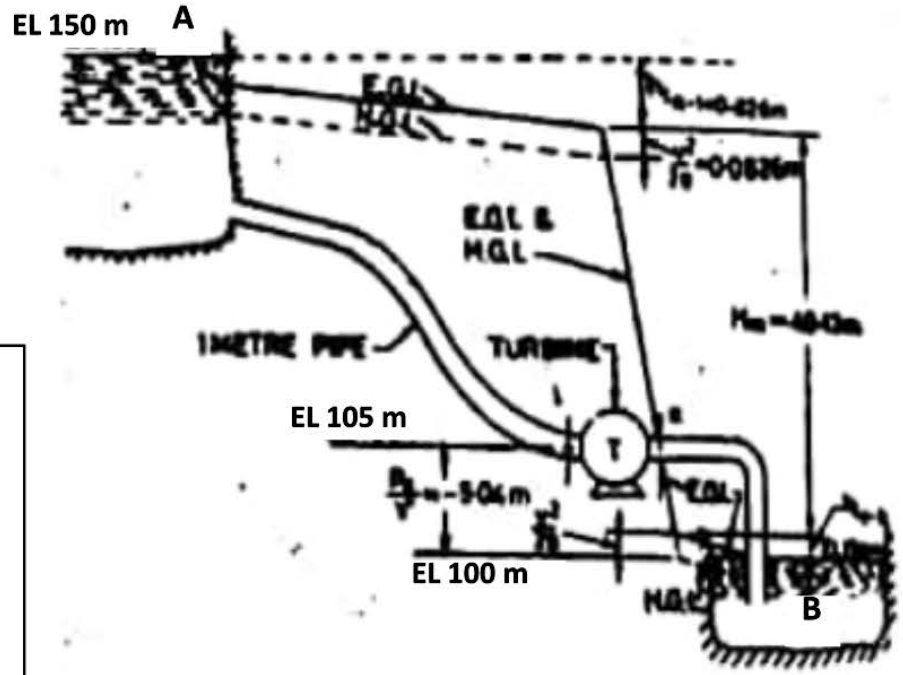
© draw the DGL and EGL



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(a) Calculate $\frac{p_i}{\gamma}$ and $\frac{p_e}{\gamma}$ of the turbine

(b) Compute $P_{turbine}$ in HP and KW



$z_A = 150\,m, z_B = 100\,m, z_i = z_e = 105\,m$

$p_A = 0$, $p_B = 0$ (atmp pressure), $V_A = 0, V_B = 0$

$V_{pipe} = \frac{Q}{A} = \frac{1}{\pi\frac{(1)^2}{4}} = 1.273\,\frac{m}{s}$,

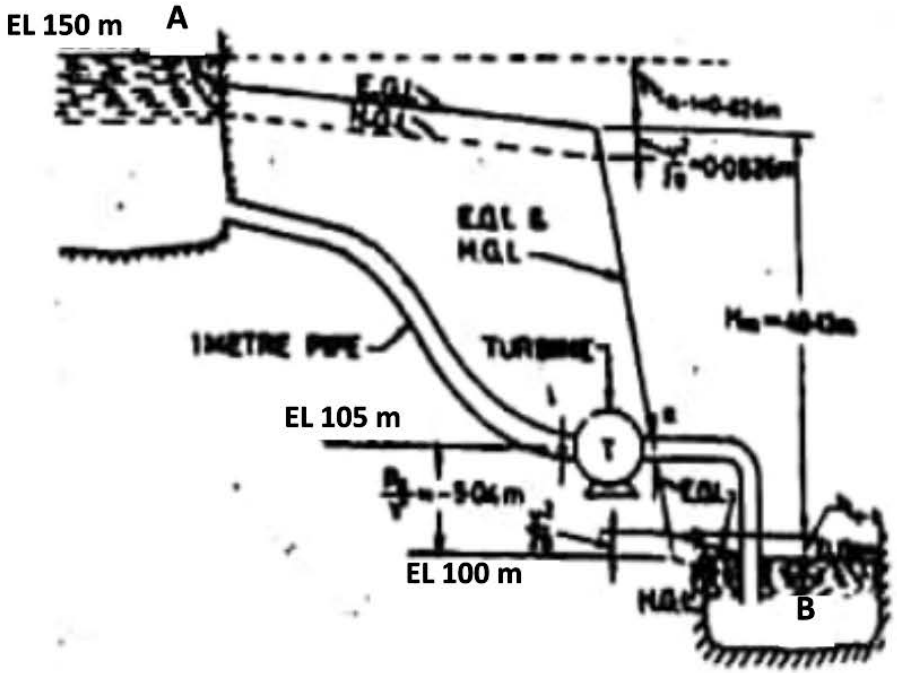
∴Velocity head, $\frac{V^2}{2g} = \frac{(1.273)^2}{2\times 9.81} = 0.0826\,m$

So, $h_{f,A-i} = 10 \times \frac{V^2}{2g} = 10 \times 0.0826 = 0.826\,m$

$h_{f,e-B} = 0.5 \times \frac{V^2}{2g} = 0.5 \times 0.0826 = 0.413\,m$

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(a) Calculate $\frac{p_i}{\gamma}$ and $\frac{p_e}{\gamma}$ of the turbine



$$z_A + \frac{p_A}{\gamma} + \frac{V_A^2}{2g} = z_i + \frac{p_i}{\gamma} + \frac{V_i^2}{2g} + h_{f,A-i}$$

$$150 + 0 + 0 = 105 + \frac{p_i}{\gamma} + 0.0826 + 0.826$$

$$\therefore \frac{p_i}{\gamma} = 44.0914m \text{ of water}$$

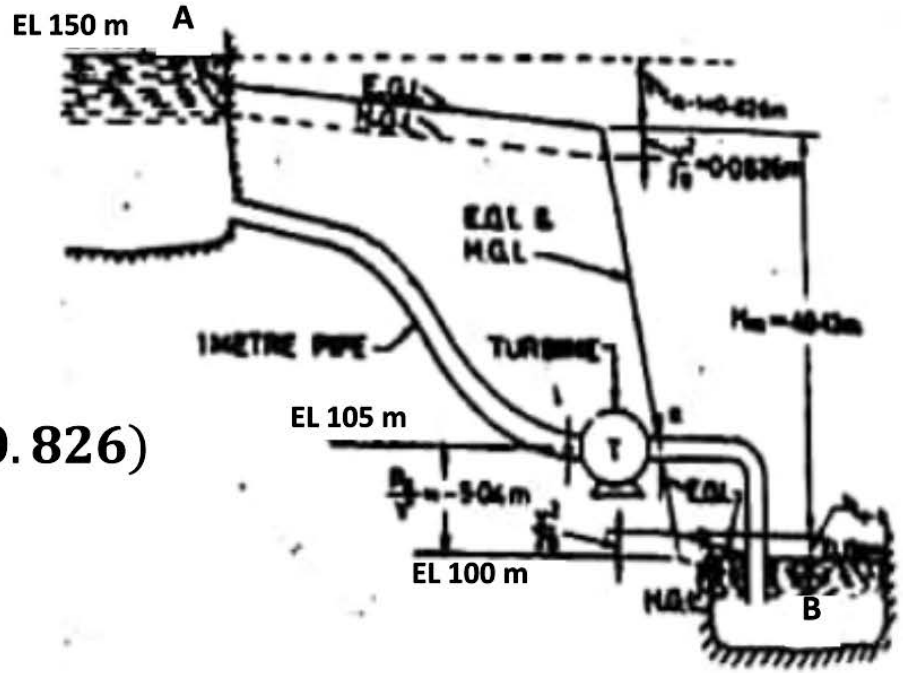
$$z_e + \frac{p_e}{\gamma} + \frac{V_e^2}{2g} = z_B + \frac{p_B}{\gamma} + \frac{V_B^2}{2g} + h_{f,e-B}$$

$$105 + \frac{p_e}{\gamma} + 0.0826 = 100 + 0 + 0 + 0.0413$$

$$\therefore \frac{p_e}{\gamma} = -5.0413\,m \text{ of water}$$

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(b) Compute $P_{turbine}$ in HP and KW



$$z_A + \frac{p_A}{\gamma} + \frac{V_A^2}{2g} - H_t = z_B + \frac{p_B}{\gamma} + \frac{V_B^2}{2g} + h_{f,A-B}$$

$$150 + 0 + 0 - H_t = 100 + 0 + 0 + (0.0413 + 0.826)$$

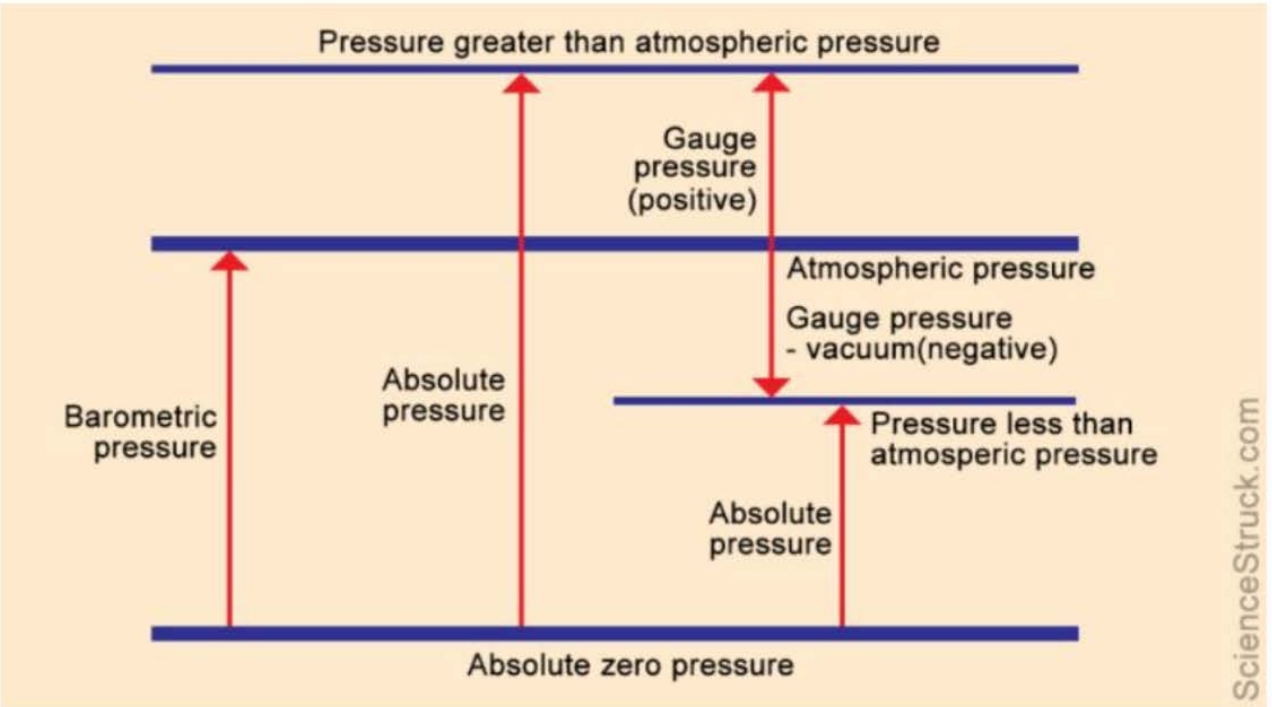
$$\therefore H_t = 49.1327\ m \text{ of water}$$

Now, $P_{turbine}(\text{HP}) = \frac{\gamma Q H_t}{75} = \frac{1000 \times 1 \times 49.1327}{75} = 655\ HP$

Now, $P_{turbine}(\text{kW}) = \frac{\gamma Q H_t}{1000} = \frac{1000 \times 9.81 \times 1 \times 49.1327}{1000} = 482\ kW$

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Cavitation



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