Cavitation

With increasing velocity or potential head, pressure within flowing fluid drops.
If at any point the local velocity is so high that pressure in a liquid is reduced to its vapor pressure, the liquid will then vaporize (or boil) at that point and bubbles of vapor will form.
This vaporization or formation of vapor cavities is called cavitation.
To avoid cavitation, it is necessary that the absolute pressure at every point be above the vapor pressure.

Harmful effects

- vapor cavities formed, flow becomes discontinuous
- high dynamic pressure produced
- causes vibration, pitting and other deleterious effects upon hydraulic machines, ship propellers, spillways and other hydraulic structures.

Prevention

Design machines so that there are no local velocities high enough to produce pressures lower than vapor pressure (pv).

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Relation between Absolute and Relative Velocities

V = Absolute velocity of a body, is its velocity relative to the earth.

v = Relative velocity of a body, is the velocity relative to a second body, which may in turn be a motion relative to the earth.

The absolute velocity V of the first body is the vector sum of its velocity v relative to the second body and the absolute of the latter.

$$V = v + u$$

α and β are the angles made by the absolute and relative velocities of a fluid respectively with the positive direction of the linear velocity u of some point on a solid body.

$$V\sin\alpha = v\sin\beta$$

$$V_u = V\cos\alpha = u + v\cos\beta$$

V_u is the component of the absolute velocity V of the fluid in the direction of u.

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Force upon a Moving Vane or Blade

There are two principal differences between the action upon a stationary and a moving object.

- One is that for the case of a moving object, it is necessary to consider both absolute and relative velocities, which makes the determination of ΔV more difficult.
- The other is that the amount of fluid that strikes a single moving object in any time interval Δt is different from that which strikes a stationary object.

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Force upon a Moving Vane or Blade

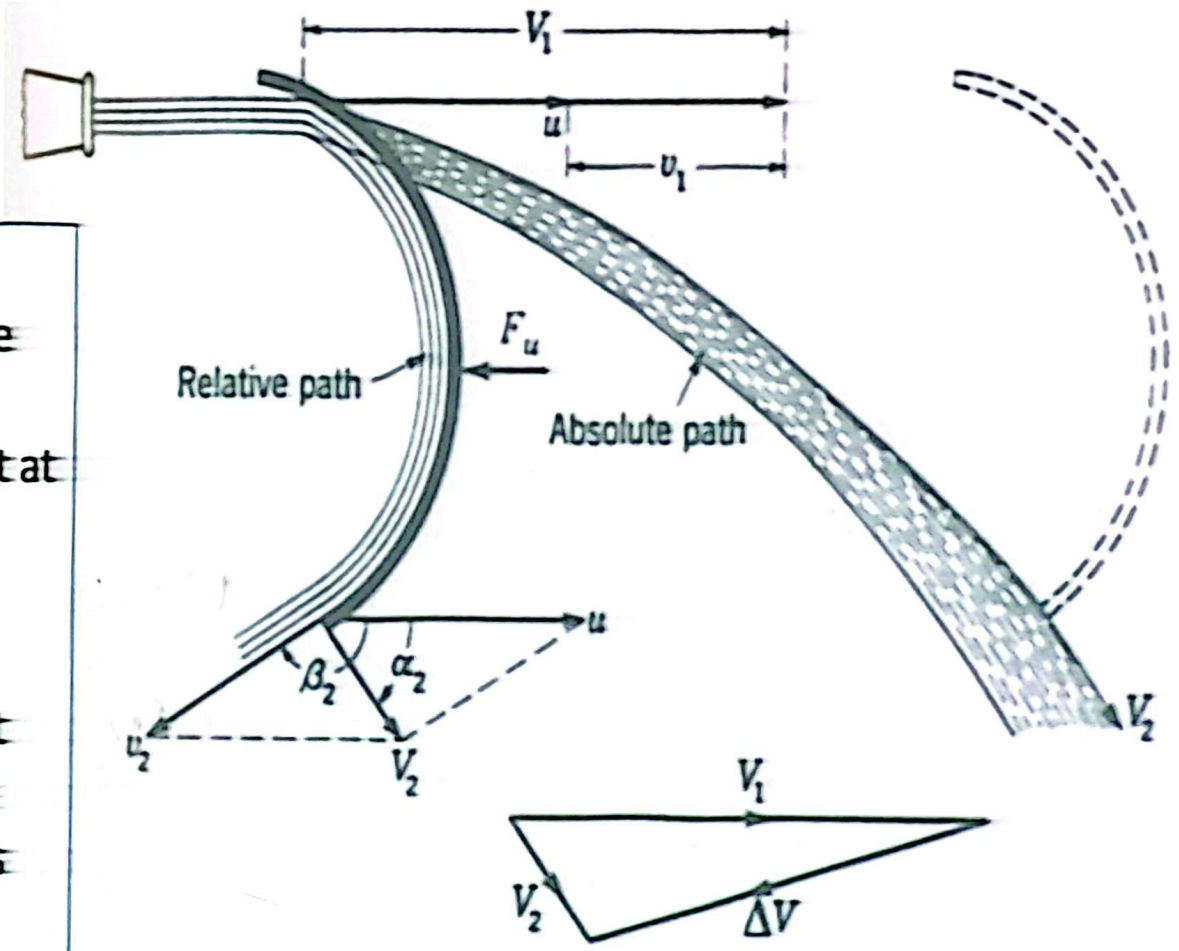
If the cross section aarea of a steam is A_1 and its velocity is V_1, then the rate at which fluid is emitted fron the nozzle, $G = \gamma Q = \gamma A_1 V_1$

For the case of a single object, the amount fluid which strike the body per unit time will be less than this if the body is moving away from the nozzle and more than this if the body is moving towards the nozzle.

If the body moves in the same direction of jet and in same or higher velocity, none of the fluid will act upon the body.

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Force upon a Moving Vane or Blade



$V_1 = u + v_1$

$V_2 = u + v_2$

$V_2 = V_1 + \Delta V$

$\Delta V = V_2 - V_1$

β = Vane angle

V_1 = absolute velocity of the jet at entrance

V_2 = absolute velocity of jet at exit

v_1 = relative velocity at entrance

v_2 = relative velocity at exit

u = absolute velocity of the vane in the same direction as the original jet

If the friction is neglected $v_1 = v_2$

Force upon a Moving Vane or Blade

If it moves with the velocity less than that of jet, the amount of fluid that will strike the body per unit time will be proportional to the difference between two velocities, i.e., to $v_1 = V_1 - u$. Where V_1 is the jet velocity and u body velocity in the same direction.

$$G' = \gamma Q' = \gamma A_1 (V_1 - u) = \gamma A_1 v_1$$

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Force upon a Moving Vane or Blade

$(F_{V/F})_x$ and $(F_{V/F})_y$ = Force exerted by vane on fluid in x and y direction.

In x-direction

$$\sum F_x = -(F_{V/F})_x = \rho Q'(V_{2x} - V_{1x})$$
$$= \rho Q'(V_2 cos\alpha_2 - V_1)$$
$$= \rho Q'(u + v_2 cos\beta_2 - V_1)$$
$$= \rho Q'(u + (V_1 - u)cos\beta_2 - V_1)$$
$$= \rho Q'(V_1 - u)(cos\beta_2 - 1)$$

In y-direction

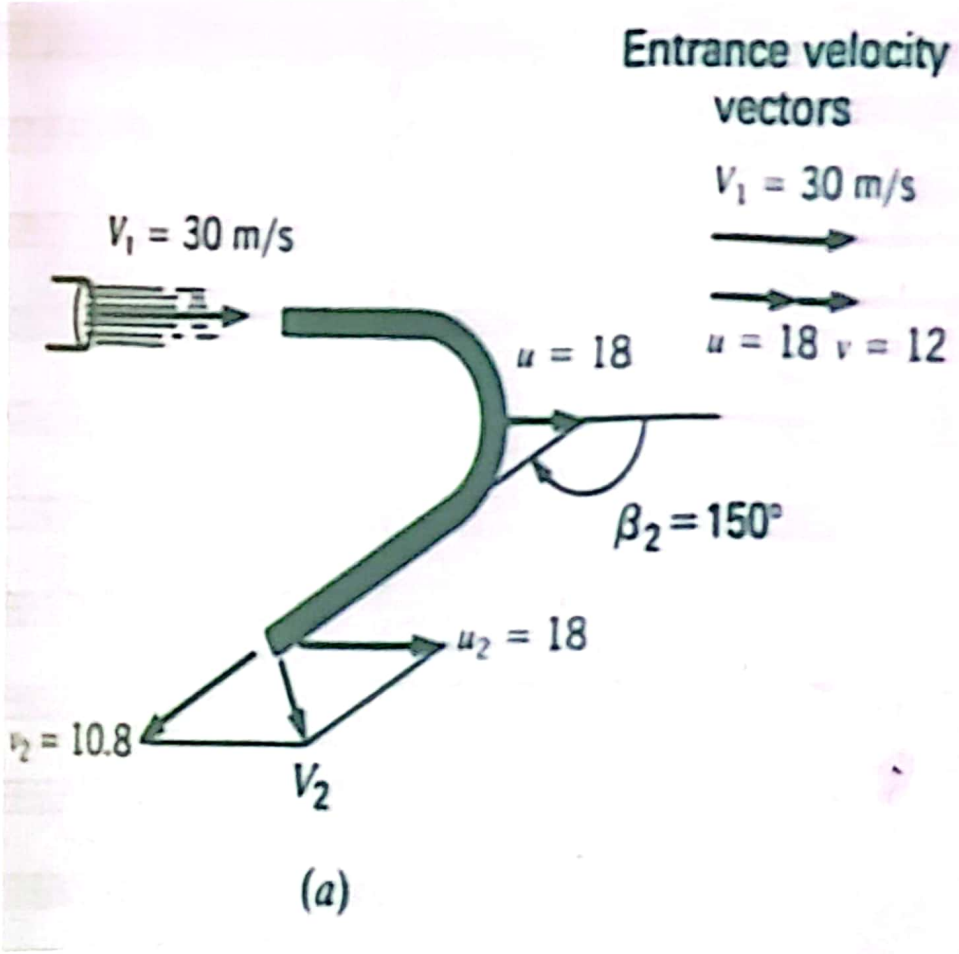
$$\sum F_y = -(F_{V/F})_y = \rho Q'(V_{2y} - V_{1y})$$
$$= \rho Q'(v_2 sin\beta_2 - 0)$$
$$= \rho Q'(V_1 - u)sin\beta_2$$

In case of series of moving vanes only the amount of water striking the vanes per second changes and $Q = A_1 V_1$

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Force upon a Moving Vane or Blade

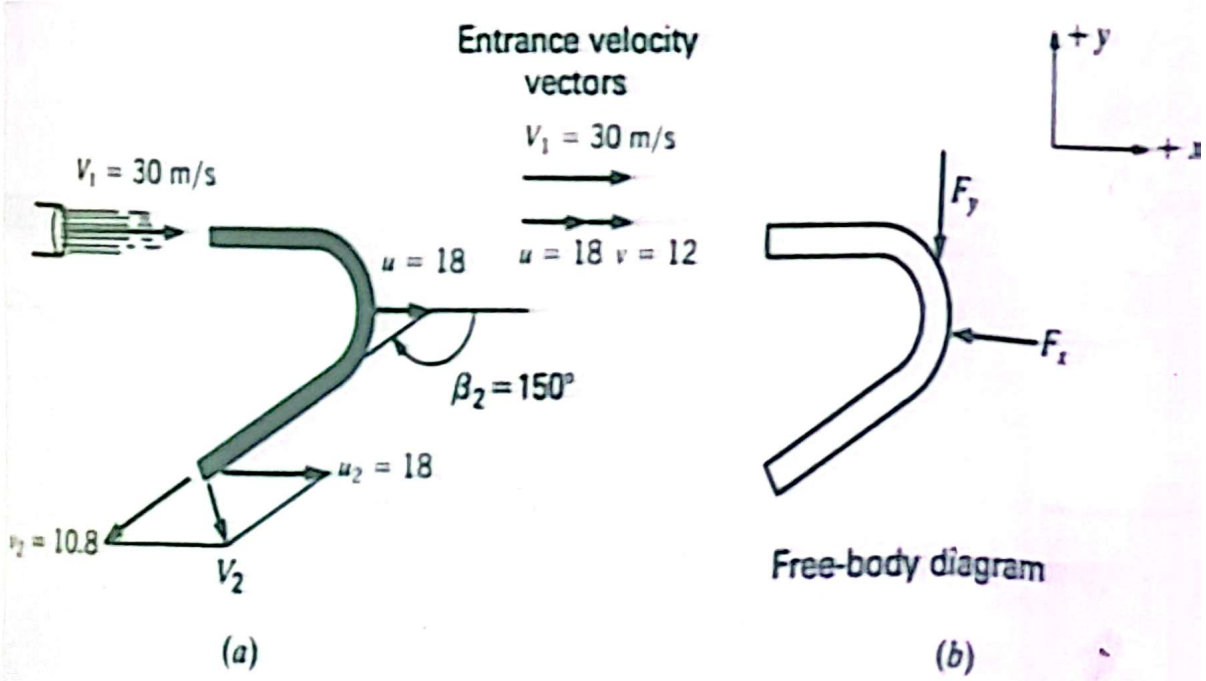
Example: A 5 cm diameter water jet with a velocity of 30 m/s impinges on a single vane moving in the same direction (thus $F_x = F_u$) at a velocity of 18 m/s. If $\beta_2 = 150°$ and friction losses over the vane are such that $v_2 = 0.9\, v_1$, compute the force exerted by the water on the vane. The velocity diagram at the entrance and exit to the vane are shown in the accompanying figure.



(a)

Force upon a Moving Vane or Blade

5 cm diameter water jet with a velocity of 30 m/s, vane moving in the same direction at a velocity of 18 m/s. If $\beta_2 = 150°$ and $v_2 = 0.9v_1$



v_2 relative velocity at exit $= 0.9v_1$ (relative velocity at entrance) $= 0.9(V_1 - u) = 0.9(30 - 18) = 10.8\ m/s$

$$V_2 \sin\alpha_2 = v_2 \sin\beta_2$$
$$= 10.8 \times 0.5 = 5.4\ m/s$$

$$V_2 \cos\alpha_2 = u + v_2 \cos\beta_2$$
$$= 18 + 10.8 \times (-0.866)$$
$$= 8.65\ m/s$$

$V_2 = 10.2\ m/s$ and $\alpha_2 = 32.12°$

$$\sum F_x = \rho Q'(V_2 \cos\alpha_2 - V_1)$$
$$= 1000 \times 0.001963(30 - 18)(8.65 - 30)$$
$$= 503\ N \text{ (rightward)}$$

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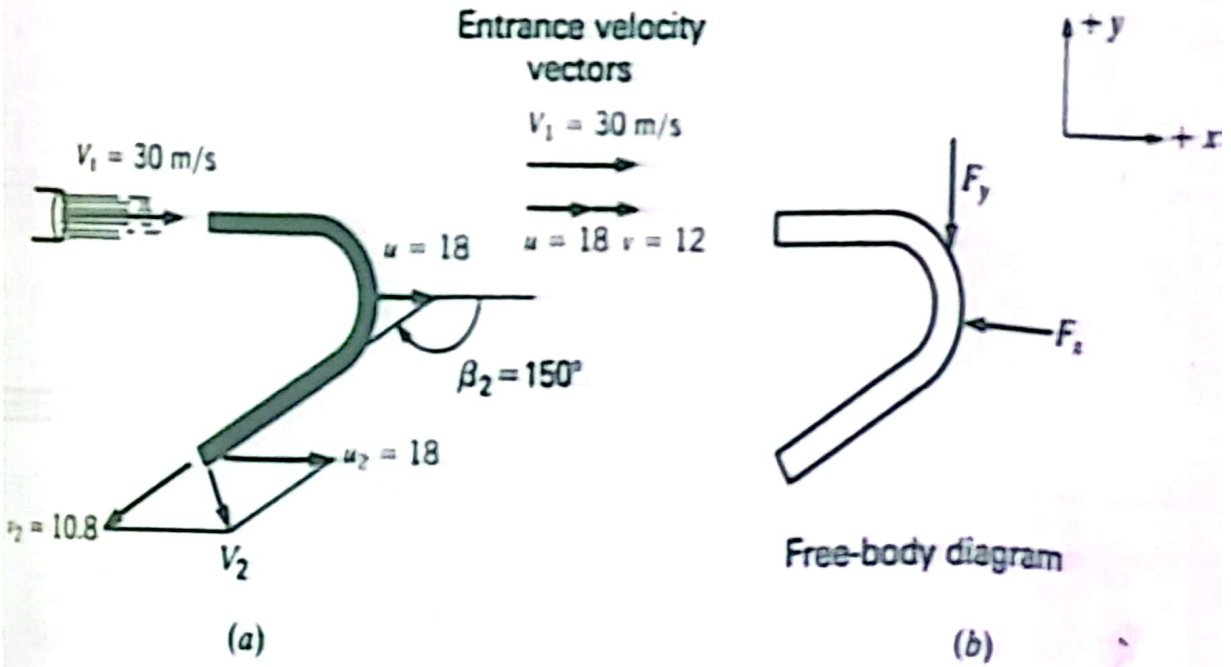
Force upon a Moving Vane or Blade

5 cm diameter water jet with a velocity of 30 m/s, vane moving in the same direction at a velocity of 18 m/s. If $\beta_2 = 150°$ and $v_2 = 0.9v_1$

$$\sum F_y = -\rho Q'(V_2 sin\alpha_2 - 0)$$
$$= -1.963(30 - 18)(5.4) =$$
$$-127.2\ N \text{ (upward)}$$

If the vane were one of a series of moving vanes, $Q = A_1 V_1$

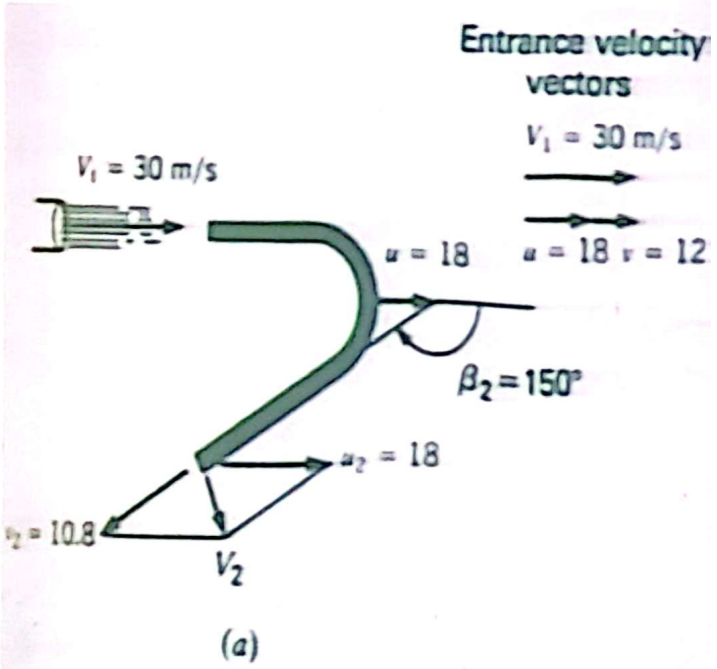
$$\sum F_x = \rho Q(V_2 cos\alpha_2 - V_1)$$
$$= 1000 \times 0.001963 \times 30(8.65 - 30)$$
$$= 1257.3\ N \text{ (rightward)}$$



Force upon a Moving Vane or Blade

The power of the original jet, $P_{in} = \frac{\gamma Q\left(\frac{V_1^2}{2g}\right)}{1000}$

$$= \frac{9810 \times 0.001963 \times 30\left(\frac{30^2}{2 \times 9.81}\right)}{1000} = 26.5 \text{ kW}$$



(a)

The power of water as it leaves the system,

$$P_{out} = \frac{\gamma Q\left(\frac{V_2^2}{2g}\right)}{1000} = \frac{9810 \times 0.001963 \times 30\left(\frac{10.2^2}{2 \times 9.81}\right)}{1000} = 3.06 \text{ kW}$$

The power transferred to the blades,

$$P_{transfer} = \frac{Fu}{1000} = \frac{1257.3 \times 18}{1000} = 22.63 \text{ kW}$$

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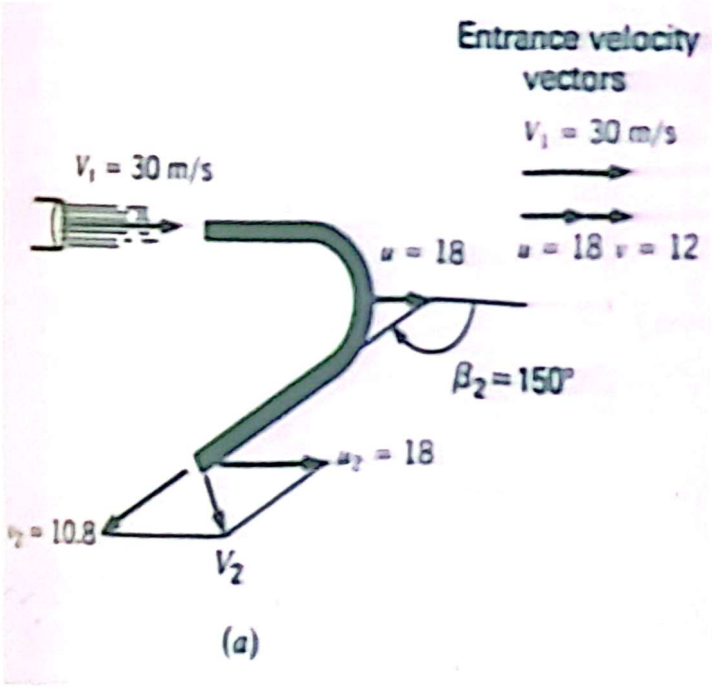
Force upon a Moving Vane or Blade

For the conservation of energy,

$$P_{in} - P_{out} - P_{transfer} - P_{friction\ loss} = 0$$

or, $26.5 - 3.06 - 22.63 - P_{friction\ loss} = 0$

or, $P_{friction\ loss} = 0.8$ kW



(a)

This can be verified by computing

$$= \frac{\gamma Q\left(\frac{v_1^2}{2g}\right)}{1000} - \frac{\gamma Q\left(\frac{v_2^2}{2g}\right)}{1000} =$$

$$\frac{9810 \times 0.001963 \times 30\left(\frac{12^2 - 10.8^2}{2 \times 9.81}\right)}{1000} = 0.8 \text{ kW}$$

The power loss is very small, so an assumption $v_1 = v_2$ will give reasonably good result.

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9.17 If 140 L/s of water flows through the system shown in Fig. 9-6, calculate the total head loss between 2 and 3.

$$p_2/\gamma + v_2^2/2g + z_2 = p_3/\gamma + v_3^2/2g + z_3 + h_L$$

$v_2 = Q/A_2 = (140 \times 10^{-3})/[(\pi)(0.300)^2/4] = 1.981$ m/s $\quad v_3 = Q/A_3 = (140 \times 10^{-3})/[(\pi)(0.150)^2/4] = 7.922$ m/s

$p_2/9.79 + 1.981^2/[(2)(9.807)] + 0 = 0 + 7.922^2/[(2)(9.807)] + 15 + h_L \quad h_L = p_2/9.79 - 18.00$

$p_1/\gamma + v_1^2/2g + z_1 = p_2/\gamma + v_2^2/2g + z_2 + h_L \quad 0 + 0 + 30 = p_2/9.79 + 1.981^2/[(2)(9.807)] + 0 + 0$

$p_2/9.79 = 29.80$ m $\quad h_L = 29.80 - 18.00 = 11.80$ m

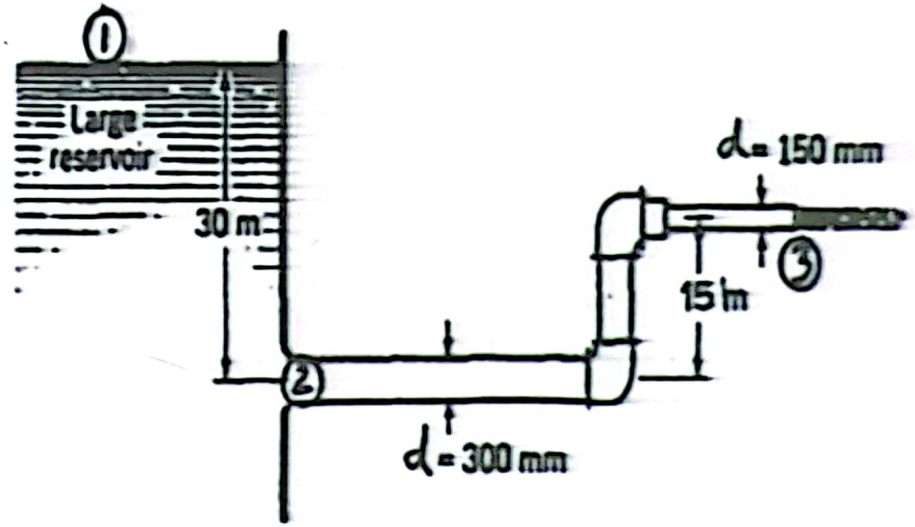


Fig. 9-6

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