15. A proposed landfill is to be 400 m by 200 m in plan area and 25 m deep. The average daily filling rate is expected to be 15 m by 10 m by 3 m deep, and the daily cover to be used is 0.2 m thick. Assume that the landfill will be operational every week from Monday through Friday.

The projected life of the landfill is most nearly

(A) 16 years
(B) 17 years
(C) 20 years
(D) 23 years

Solution:

The total volume of the proposed landfill is

$$V_{\text{total}} = (400\ \text{m})(200\ \text{m})(25\ \text{m}) = 2 \times 10^6\ \text{m}^3$$

The rate of trash input into the landfill is

$$\dot{V}_{\text{trash}} = \frac{(15\ \text{m})(10\ \text{m})(3\ \text{m})}{1\ \text{day}} = 450\ \text{m}^3/\text{day}$$

The rate of fill from use of the daily cover is

$$\dot{V}_{\text{cover}} = \frac{(15\ \text{m})(10\ \text{m})(0.2\ \text{m})}{1\ \text{day}} = 30\ \text{m}^3/\text{day}$$

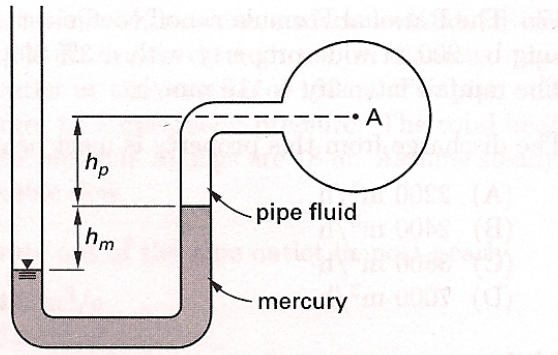
Since the landfill is to be operational for 5 days each week and there are 52 weeks in the year, the projected life of the landfill is

$$\begin{aligned} t_{\text{landfill}} &= \frac{V_{\text{total}}}{\dot{V}_{\text{trash}} + \dot{V}_{\text{cover}}} \\ &= \left(\frac{2 \times 10^6\ \text{m}^3}{450\ \dfrac{\text{m}^3}{\text{day}} + 30\ \dfrac{\text{m}^3}{\text{day}}} \right) \left(\frac{1\ \text{wk}}{5\ \text{days}} \right) \left(\frac{1\ \text{yr}}{52\ \text{wk}} \right) \\ &= 16.03\ \text{years} \quad (16\ \text{years}) \end{aligned}$$

Answer is A.

HYDRAULICS AND HYDROLOGIC SYSTEMS

16. A manometer is shown with $h_p = 25$ cm and $h_m = 63$ cm. The pipe fluid is oil with a specific gravity of 0.8. Mercury has a specific gravity of 13.6. Assume standard conditions.

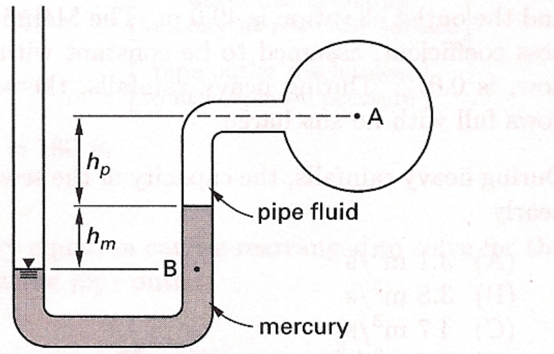


The gage pressure at point A is most nearly

(A) −80 kPa
(B) −86 kPa
(C) −88 kPa
(D) −90 kPa

Solution:

The gage pressure at point B is zero. The mass density of water is $\rho_w = 1000\ \text{kg/m}^3$ at standard conditions.



Therefore, from equilibrium,

$$\begin{aligned} p_{\text{B}} = 0 &= \gamma_{\text{oil}} h_p + \gamma_{\text{Hg}} h_m + p_{\text{A}} \\ &= (\text{SG})_{\text{oil}} \rho_w g h_p + (\text{SG})_{\text{Hg}} \rho_w g h_m + p_{\text{A}} \end{aligned}$$

This can be rearranged to solve for gage pressure at point A.

$$\begin{aligned} p_{\text{A}} &= -[(\text{SG})_{\text{oil}} \rho_w g h_p + (\text{SG})_{\text{Hg}} \rho_w g h_m] \\ &= - \left[\begin{array}{l} (0.8) \left(1000\ \dfrac{\text{kg}}{\text{m}^3} \right) \left(9.81\ \dfrac{\text{m}}{\text{s}^2} \right) \left(\dfrac{25\ \text{cm}}{100\ \dfrac{\text{cm}}{\text{m}}} \right) \\ + (13.6) \left(1000\ \dfrac{\text{kg}}{\text{m}^3} \right) \left(9.81\ \dfrac{\text{m}}{\text{s}^2} \right) \left(\dfrac{63\ \text{cm}}{100\ \dfrac{\text{cm}}{\text{m}}} \right) \end{array} \right] \\ &= -86\,014\ \text{Pa} \quad (86\ \text{kPa}) \end{aligned}$$

Answer is B.

17. The Rational Formula runoff coefficient of a 300 m long by 200 m wide property with a 3% slope is 0.35. The rainfall intensity is 116 mm/h.

The discharge from this property is most nearly

(A) 2200 m^3/h
(B) 2400 m^3/h
(C) 3800 m^3/h
(D) 7000 m^3/h

Solution:

The discharge from this property is

$$Q = ciA$$
$$= (0.35)\left(116\ \frac{\text{mm}}{\text{h}}\right)\left(\frac{1\ \text{m}}{1000\ \text{mm}}\right)(300\ \text{m})(200\ \text{m})$$
$$= 2436\ \text{m}^3/\text{h}\ \ (2400\ \text{m}^3/\text{h})$$

Answer is B.

18. A concrete sanitary sewer is 150 m long and has a pipe diameter of 1.25 m. The inlet elevation is 50.0 m, and the outlet elevation is 49.0 m. The Manning roughness coefficient, assumed to be constant with depth of flow, is 0.012. During heavy rainfalls, the sewer pipe flows full with no surcharge.

During heavy rainfalls, the capacity of the sewer is most nearly

(A) 3.1 m^3/s
(B) 3.8 m^3/s
(C) 4.7 m^3/s
(D) 5.7 m^3/s

Solution:

The slope is calculated to be

$$S = \frac{\text{inlet elev} - \text{outlet elev}}{\text{pipe length}} = \frac{50.0\ \text{m} - 49.0\ \text{m}}{150\ \text{m}}$$
$$= 0.00667$$

Since the pipe flows full during heavy rainfalls, the wetted perimeter is the entire perimeter of the pipe. The hydraulic radius is calculated to be

$$R = \frac{\text{area}}{\text{wetted perimeter}} = \frac{\frac{\pi(1.25\ \text{m})^2}{4}}{\pi(1.25\ \text{m})} = 0.3125\ \text{m}$$

From Manning's equation, the velocity of flow is

$$\text{v} = \left(\frac{1}{n}\right)R^{\frac{2}{3}}S^{\frac{1}{2}} = \left(\frac{1}{0.012}\right)(0.3125\ \text{m})^{\frac{2}{3}}(0.00667)^{\frac{1}{2}}$$
$$= 3.13\ \text{m/s}$$

The flow capacity is then

$$Q = \text{v}A = \left(3.13\ \frac{\text{m}}{\text{s}}\right)\left(\frac{\pi(1.25\ \text{m})^2}{4}\right)$$
$$= 3.84\ \text{m}^3/\text{s}\ \ (3.8\ \text{m}^3/\text{s})$$

Answer is B.

Problems 19 and 20 are based on the following information.

Water is pumped from a lake with a pipe inlet at an elevation of 200 m to a tank at an elevation of 205 m. The pipeline from the lake to the tank is 300 m long and is cast iron, with a 30 cm inside pipe diameter. The pump efficiency is 80%. Minor losses, entrances losses, and exit losses are negligible. The flow rate through the piping is 1.25 m^3/s. Assume steady, incompressible flow. The kinematic viscosity of water is $1 \times 10^{-6}\ m^2/s$. The roughness factor for cast iron is $e = 0.25$ mm.

19. Using the Darcy equation, the head loss in the piping is most nearly

(A) 300 m
(B) 310 m
(C) 320 m
(D) 330 m

Solution:

The roughness factor for cast iron is $e = 0.25$ mm. The relative roughness is

$$\text{relative roughness} = \frac{e}{D} = \frac{0.25\ \text{mm}}{(30\ \text{cm})\left(\frac{10\ \text{mm}}{1\ \text{cm}}\right)}$$
$$= 0.000833$$

The area of flow is

$$A = \frac{\pi D^2}{4} = \frac{\pi\left((30\ \text{cm})\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)\right)^2}{4} = 0.07069\ \text{m}^2$$

The Reynolds number is

$$\text{Re} = \frac{\text{v}D}{\nu} = \frac{\left(\frac{Q}{A}\right)D}{\nu}$$
$$= \frac{\left(\frac{1.25\ \frac{\text{m}^3}{\text{s}}}{0.07069\ \text{m}^2}\right)(30\ \text{cm})\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)}{1 \times 10^{-6}\ \frac{\text{m}^2}{\text{s}}}$$
$$= 5.305 \times 10^6$$

From the Moody diagram for the calculated e/D and Re, the friction factor is $f \approx 0.0195$.

Therefore, from the Darcy equation, the head loss in the piping is

$$h_f = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right) = f\left(\frac{L}{D}\right)\left[\frac{\left(\frac{Q}{A}\right)^2}{2g}\right]$$

$$= (0.0195)\left[\frac{300\ \text{m}}{(30\ \text{cm})\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)}\right] \times \left[\frac{\left(\frac{1.25\ \frac{\text{m}^3}{\text{s}}}{0.07069\ \text{m}^2}\right)^2}{(2)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}\right]$$

$$= 310.8\ \text{m} \quad (310\ \text{m})$$

Answer is B.

20. The power provided by the pump to raise water from the lake to the tank at the flow rate indicated is most nearly

(A) 3.0 MW
(B) 3.8 MW
(C) 4.8 MW
(D) 5.4 MW

Solution:

The total head required to lift the fluid is

$$\begin{aligned} h &= (\text{tank elev} - \text{lake elev}) + \text{pipe head loss} \\ &= (205\ \text{m} - 200\ \text{m}) + 311\ \text{m} \\ &= 316\ \text{m} \end{aligned}$$

The input power required by the pump to provide the required head is

$$\dot{W} = \frac{Q\gamma_w h}{\eta} = \frac{Q\rho_w g h}{\eta}$$

$$= \frac{\left(1.25\ \frac{\text{m}^3}{\text{s}}\right)\left(1000\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(310.8\ \text{m})}{0.80}$$

$$= 4.764 \times 10^6\ \text{W} \quad (4.8\ \text{MW})$$

Answer is C.

21. A reservoir with a water surface level at an elevation of 200 m drains through a 1 m diameter pipe with the outlet at an elevation of 180 m. The pipe outlet discharges to atmospheric pressure. The total head losses in the pipe and fittings are 18 m. Assume steady, incompressible flow.

The flow rate out of the pipe outlet is most nearly

(A) 4.9 m^3/s
(B) 6.3 m^3/s
(C) 31 m^3/s
(D) 39 m^3/s

Solution:

Using the pipe outlet as the datum, the variables in the energy equation are as follows.

$$p_1 = 0 \quad \left[\begin{array}{c}\text{reservoir free surface is} \\ \text{at atmospheric pressure}\end{array}\right]$$

$$z_1 = 200\ \text{m}$$

$$v_1 \approx 0 \quad \left[\begin{array}{c}\text{water has negligible} \\ \text{velocity at reservoir surface}\end{array}\right]$$

$$p_2 = 0 \quad \left[\begin{array}{c}\text{pipe outlet discharges} \\ \text{to atmospheric pressure}\end{array}\right]$$

$$z_2 = 180\ \text{m}$$

The energy equation can be rearranged to solve for the velocity at the pipe outlet.

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} + h_{f\text{total}}$$

$$\begin{aligned} v_2 &= \sqrt{2g\left(\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - \frac{p_2}{\gamma} - z_2 - h_{f\text{total}}\right)} \\ &= \sqrt{2g\left(\frac{p_1}{\rho g} + z_1 + \frac{v_1^2}{2g} - \frac{p_2}{\rho g} - z_2 - h_{f\text{total}}\right)} \\ &= \sqrt{(2)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)\left[\begin{array}{r}0 + 200\ \text{m} + 0 \\ -\,0 - 180\ \text{m} - 18\ \text{m}\end{array}\right]} \\ &= 6.26\ \text{m/s} \end{aligned}$$

The flow rate out of the pipe outlet is

$$Q = vA = \left(6.26\ \frac{\text{m}}{\text{s}}\right)\left(\frac{\pi(1\ \text{m})^2}{4}\right) = 4.92\ \text{m}^3/\text{s} \quad (4.9\ \text{m}^3/\text{s})$$

Answer is A.