FE exam review
Fluid Mechanics/Dynamics

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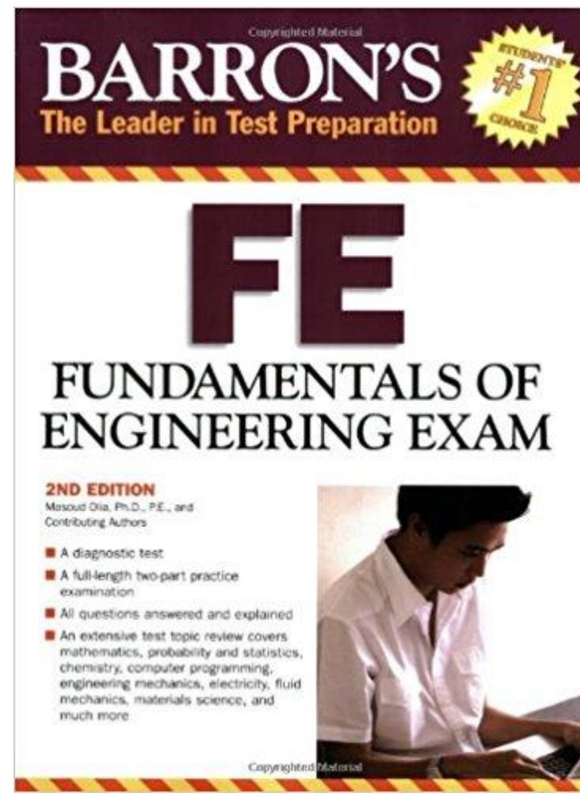
Chemical: 8-12 problems
Civil: 4-6 (+ 8-12) problems
Environmental: 9-14 problems
Mechanical: 9-14 problems
Other : 8-12 (+ 4-6) problems
out of 110 problems



Acknowledgement: This material was mainly based on Olia (2008).

Olia, M. (2008). *Barron's FE Fundamentals of Engineering Exam*. Barron's Educational Series.

1 What is the pressure at a point 18,000 ft below the surface of the ocean?

$$(\gamma = 64.0 \text{ lb/ft}^3)$$

(A) 1,150,000 psig
(B) 250 psig
(C) 8,000 psig
(D) 258,000 psig

The Pressure Field in a Static Liquid

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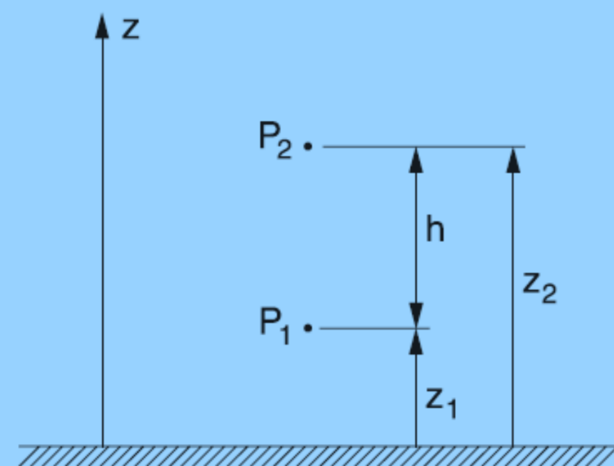


The difference in pressure between two different points is

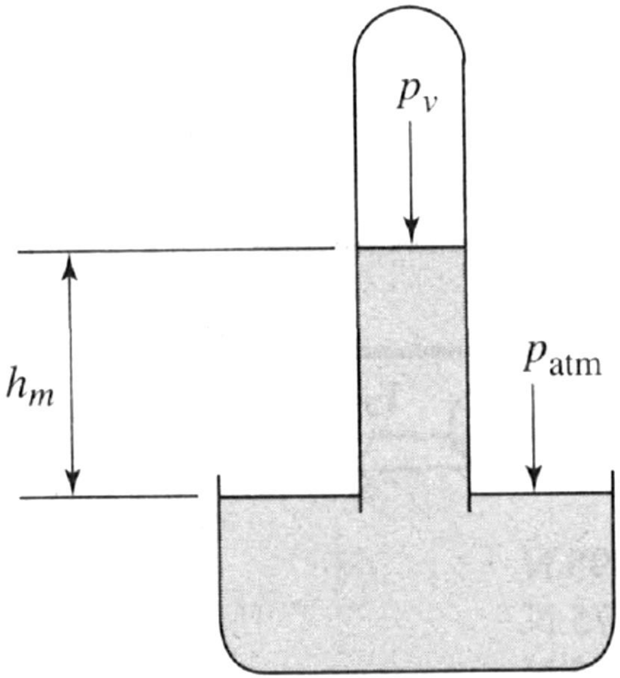
$$P_2 - P_1 = -\gamma (z_2 - z_1) = -\gamma h = -\rho g h$$

Absolute pressure = atmospheric pressure + gage pressure reading

Absolute pressure = atmospheric pressure – vacuum gage pressure reading

2

For the barometer shown in the figure, what is the atmospheric pressure if $h_m = 20$ cm, $\rho_m = 13{,}550\ \text{kg/m}^3$, and $p_v = 0$ kPa?



(A) 128 kPa
(B) 26.6 kPa
(C) 4.36 kPa
(D) 82.4 kPa

$$P_{atm} = P_A = P_v + \gamma h = P_B + \gamma h = P_B + \rho g h$$

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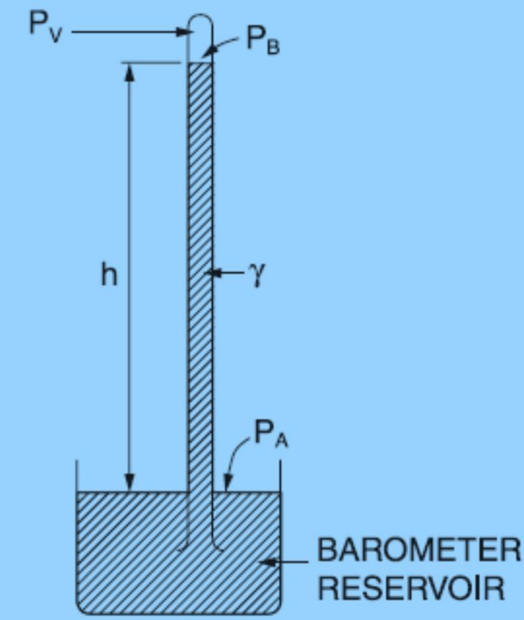
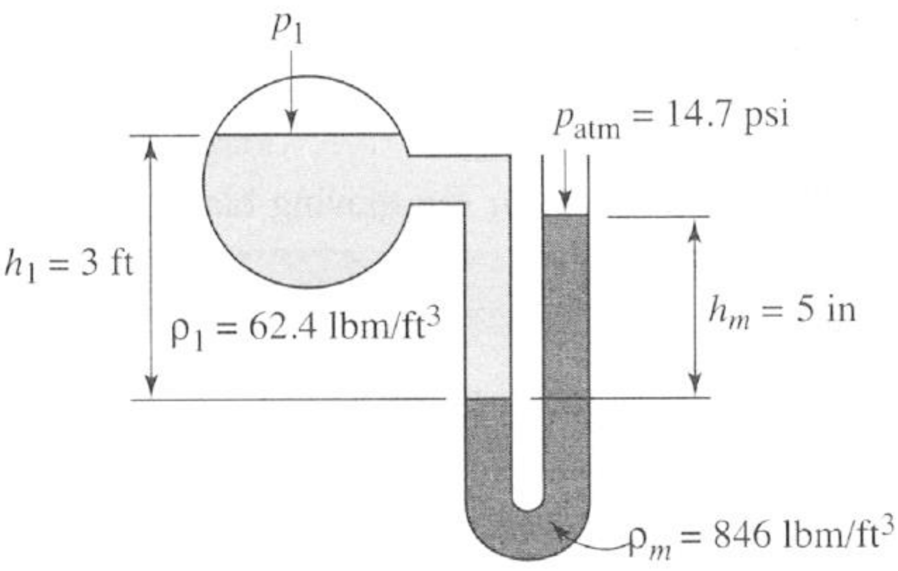


P_v = vapor pressure of the barometer fluid

3 In the figure, what is the absolute pressure (p_A) in vessel A?



(A) 15.8 psia
(B) 18.4 psia
(C) 13.6 psia
(D) 11.0 psia

Manometers

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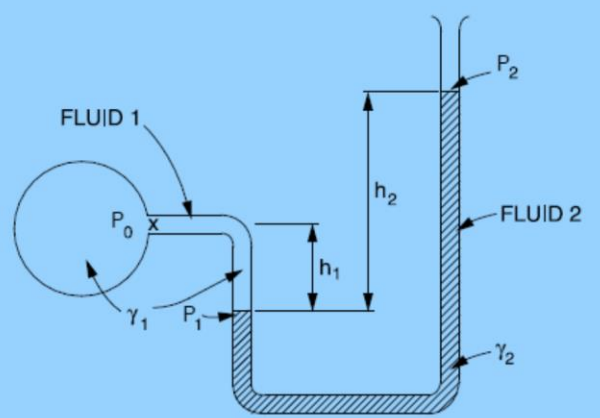


For a simple manometer,

$$P_0 = P_2 + \gamma_2 h_2 - \gamma_1 h_1 = P_2 + g\,(\rho_2\, h_2 - \rho_1\, h_1)$$

If $h_1 = h_2 = h$

$$P_0 = P_2 + (\gamma_2 - \gamma_1)h = P_2 + (\rho_2 - \rho_1)gh$$

Note that the difference between the two densities is used.

P = pressure

γ = specific weight of fluid

h = height

g = acceleration of gravity

ρ = fluid density

4 Water flows through a 20-cm-diameter pipe. If the critical Reynolds number is 2,300, what is the maximum value of the average velocity for which laminar flow can be assumed?

(A) 0.047 m/s

(B) 1.2 m/s

(C) 0.0092 m/s

(D) 0.75 m/s

Reynolds Number

$$\text{Re} = \text{v}D\rho/\mu = \text{v}D/\upsilon$$

$$\text{Re}' = \frac{\text{v}^{(2-n)}D^n\rho}{K\left(\frac{3n+1}{4n}\right)^n 8^{(n-1)}}, \text{ where}$$

ρ = the mass density

D = the diameter of the pipe, dimension of the fluid streamline, or characteristic length

μ = the dynamic viscosity

υ = the kinematic viscosity

Re = the Reynolds number (Newtonian fluid)

Re′ = the Reynolds number (Power law fluid)

K and n are defined in the Stress, Pressure, and Viscosity section.

The critical Reynolds number $(\text{Re})_c$ is defined to be the minimum Reynolds number at which a flow will turn turbulent.

5 What is the coefficient of drag for a flow of air ($\rho = 1.225$ kg/m^3, $\mu = 1.8 \times 10^{-5}$ N · s/m^2) over a flat plate that is 93 cm long, if $V_\infty = 86$ m/s?

(A) 3.38×10^{-3}

(B) 5.70×10^{-3}

(C) 2.19×10^{-3}

(D) 8.27×10^{-3}

Drag Force

The *drag force* F_D on objects immersed in a large body of flowing fluid or objects moving through a stagnant fluid is

$$F_D = \frac{C_D \rho v^2 A}{2}, \text{ where}$$

C_D = the *drag coefficient*,

v = the velocity (m/s) of the flowing fluid or moving object, and

A = the *projected area* (m^2) of blunt objects such as spheres, ellipsoids, disks, and plates, cylinders, ellipses, and air foils with axes perpendicular to the flow.

ρ = fluid density

For flat plates placed parallel with the flow:

$C_D = 1.33/\text{Re}^{0.5}$ $(10^4 < \text{Re} < 5 \times 10^5)$

$C_D = 0.031/\text{Re}^{1/7}$ $(10^6 < \text{Re} < 10^9)$

6 Water flows through a 17-cm-diameter horizontal pipe ($f = 0.017$) at a rate of $0.34\ m^3/s$. What is the frictional head loss per meter of pipe length?

(A) 1.31 m
(B) 1.14 m
(C) 0.02 m
(D) 0.78 m

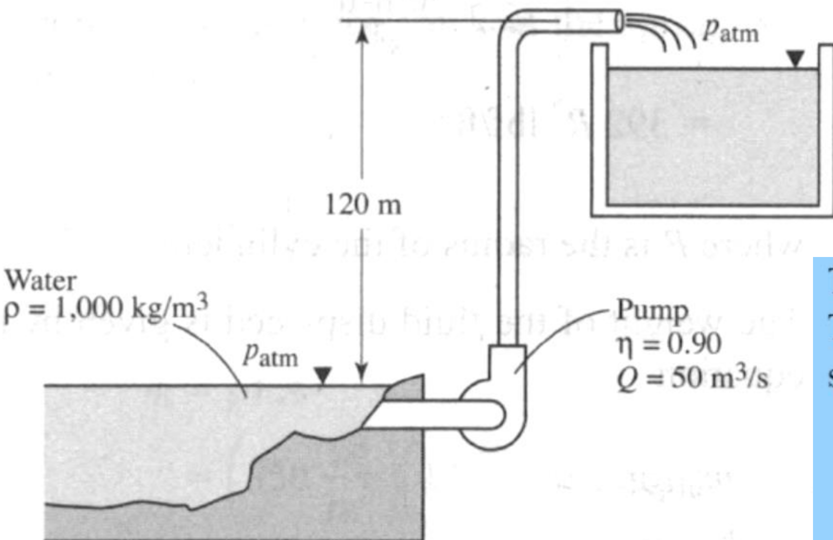
Head Loss Due to Flow

The *Darcy-Weisbach equation* is

$$h_f = f\frac{L}{D}\frac{v^2}{2g}, \text{ where}$$

f	=	$f(\text{Re}, \varepsilon/D)$, the Moody, Darcy, or Stanton friction factor
D	=	diameter of the pipe
L	=	length over which the pressure drop occurs
ε	=	roughness factor for the pipe, and other symbols are defined as before

7). What is the pumping power required for the system shown in the figure? (Neglect friction in the pipes.)



(A) 58,900 kW (B) 65,400 kW
(C) 82,300 kW (D) 53,000 kW

The Energy Equation

The energy equation for steady incompressible flow with no shaft device is

$$\frac{P_1}{\gamma}+z_1+\frac{v_1^2}{2g}=\frac{P_2}{\gamma}+z_2+\frac{v_2^2}{2g}+h_f \text{ or}$$

$$\frac{P_1}{\rho g}+z_1+\frac{v_1^2}{2g}=\frac{P_2}{\rho g}+z_2+\frac{v_2^2}{2g}+h_f$$

h_f = the head loss, considered a friction effect, and all remaining terms are defined above.

Pump Power Equation

$\dot{W} = Q\gamma h/\eta = Q\rho gh/\eta_t$, where

Q = volumetric flow (m³/s or cfs)

h = head (m or ft) the fluid has to be lifted

η_t = total efficiency $(\eta_{pump} \times \eta_{motor})$

$\dot{W}$ = power (kg•m²/sec³ or ft-lbf/sec)

8 What is the Mach number of a fluid stream flowing at a velocity of 370 ft/sec? (c = 1,080 ft/sec)

(A) 0.66 (B) 2.92

(C) 0.34 (D) 3.4

Mach Number

The local *speed of sound* in an ideal gas is given by:

$$c = \sqrt{kRT}\text{, where}$$

$c \equiv$ local speed of sound

$k \equiv$ ratio of specific heats $= \dfrac{c_p}{c_v}$

$R \equiv$ specific gas constant $= \overline{R}$/(molecular weight)

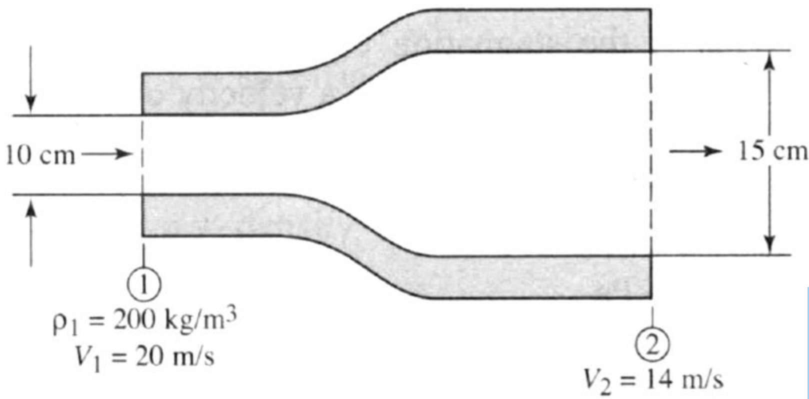
$T \equiv$ absolute temperature

This shows that the acoustic velocity in an ideal gas depends only on its temperature. The *Mach number* (Ma) is the ratio of the fluid velocity to the speed of sound.

$$\text{Ma} \equiv \frac{V}{c}$$

$V \equiv$ mean fluid velocity

9. For steady flow of a compressible fluid in the expander shown in the figure, what is the density at the exit section (ρ_2)?



(A) 190 kg/m^3
(B) 62 kg/m^3
(C) 642 kg/m^3
(D) 127 kg/m^3

The Continuity Equation

So long as the flow Q is continuous, the *continuity equation*, as applied to one-dimensional flows, states that the flow passing two points (1 and 2) in a stream is equal at each point, $A_1 v_1 = A_2 v_2$.

$$Q = Av$$

$$\dot{m} = \rho Q = \rho A v, \text{ where}$$

Q = volumetric flow rate

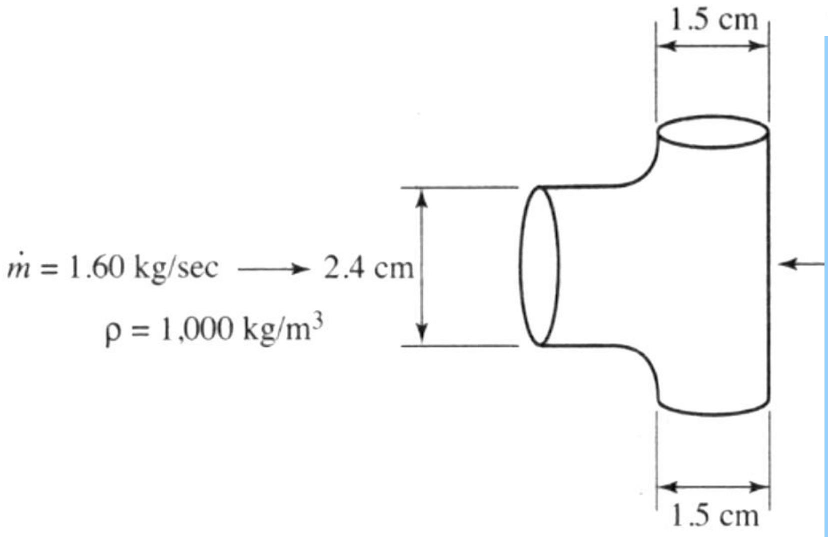
$\dot{m}$ = mass flow rate

A = cross-sectional area of flow

v = average flow velocity

ρ = the fluid density

For steady, one-dimensional flow, $\dot{m}$ is a constant. If, in addition, the density is constant, then Q is constant.



THE IMPULSE-MOMENTUM PRINCIPLE

The resultant force in a given direction acting on the fluid equals the rate of change of momentum of the fluid.

$$\Sigma F = \Sigma Q_2 \rho_2 v_2 - \Sigma Q_1 \rho_1 v_1, \text{ where}$$

ΣF = the resultant of all external forces acting on the control volume

$\Sigma Q_1 \rho_1 v_1$ = the rate of momentum of the fluid flow entering the control volume in the same direction of the force

$\Sigma Q_2 \rho_2 v_2$ = the rate of momentum of the fluid flow leaving the control volume in the same direction of the force

Water flows into the tee shown.

10 What is the average velocity of the water entering the tee?

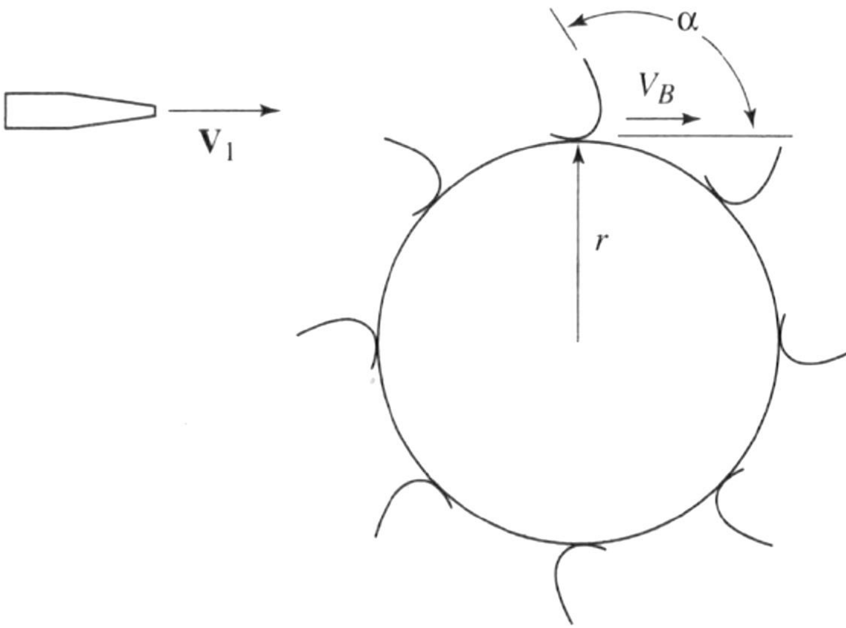
(A) 4.63 m/s
(B) 3.95 m/s
(C) 3.54 m/s
(D) 0.35 m/s

11 What is the magnitude of the force (F) required to keep the tee stationary?

(A) 5.66 N
(B) 2.21 N
(C) 6.32 N
(D) 7.41 N

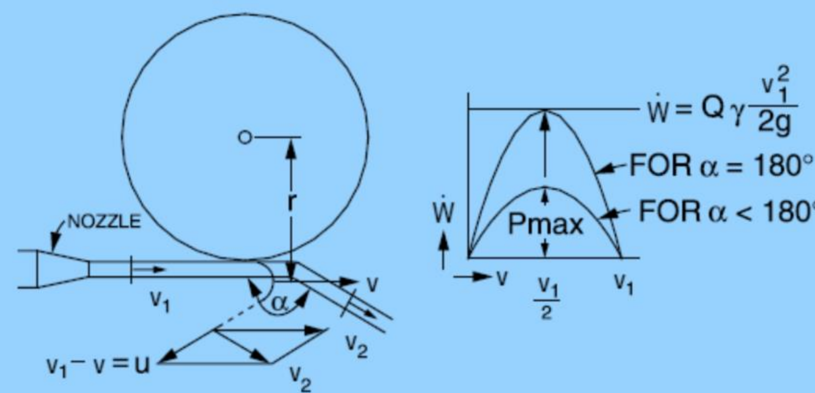
12

If 16 kg/s of water, traveling at 67 m/s, enters the impulse turbine shown in the figure, which has a 26-cm diameter and a blade angle α of 120°, what is the maximum power that can be generated?



(A) 134 W
(B) 402 W
(C) 26.93 kW
(D) 8.98 kW

Impulse Turbine

- 

$$\dot{W} = Q\rho(v_1 - v)(1 - \cos\alpha)v, \text{ where}$$

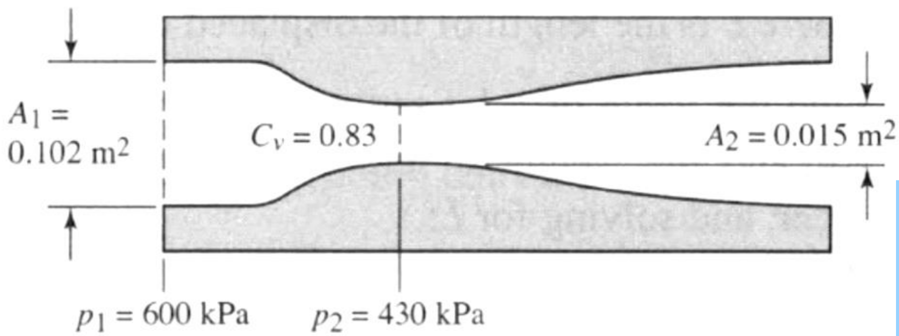
$\dot{W}$ = power of the turbine.

$$\dot{W}_{max} = Q\rho\left(v_1^2/4\right)(1 - \cos\alpha)$$

When $\alpha = 180°$,

$$\dot{W}_{max} = \left(Q\rho v_1^2\right)/2 = \left(Q\gamma v_1^2\right)/2g$$

13 What is the volumetric flow rate (Q) of water ($\gamma = 9{,}810\ \text{N/m}^3$) for the venturi flow meter shown in the figure?



(A) $0.232\ \text{m}^3/\text{s}$ **(B)** $0.248\ \text{m}^3/\text{s}$
(C) $0.733\ \text{m}^3/\text{s}$ **(D)** $0.467\ \text{m}^3/\text{s}$

Venturi Meters

$$Q = \frac{C_v A_2}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2g\left(\frac{P_1}{\gamma} + z_1 - \frac{P_2}{\gamma} - z_2\right)}, \text{ where}$$

Q = volumetric flow rate
C_v = the coefficient of velocity
A = cross-sectional area of flow
P = pressure
$\gamma = \rho g$
z_1 = elevation of venturi entrance
z_2 = elevation of venturi throat

The above equation is for *incompressible fluids*.

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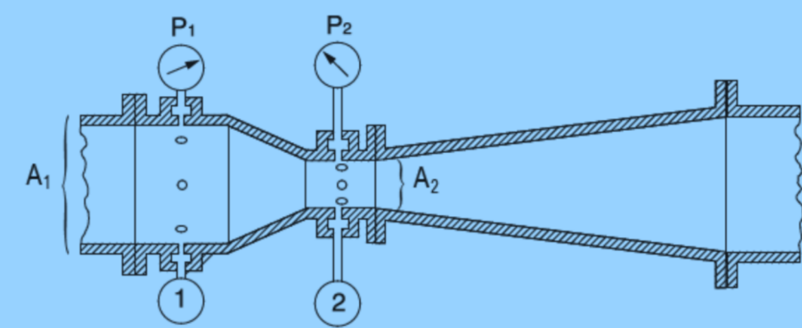

Solutions

1 **C** From equation 11.15: $p_g = \gamma h$

$$= \left(64.0\ \frac{\text{lbf}}{\text{ft}^3}\right)(18{,}000\ \text{ft})\left(\frac{\text{ft}^2}{144\ \text{in}^2}\right)$$
$$= 8{,}000\ \text{lbf/in}^2 \text{ or psig}$$

2 **B** From equation 11.25:

$$p_{atm} - p_v = \rho_m g h_m$$

Then

$$p_{atm} = \rho_m g h_m$$
$$= \left(13{,}550\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(0.20\ \text{m})$$
$$\times \left(\frac{\text{N}}{\frac{\text{kg}\cdot\text{m}}{\text{s}^2}}\right)\left(\frac{\text{kPa}}{1{,}000\frac{\text{N}}{\text{m}^2}}\right)$$
$$= 26.6\ \text{kPa}$$

3 **A** From equation 11.23:

$$p_1 = p_{atm} + \rho_m g h_m - \rho_1 g h_1$$

Then

$$\rho_m g h_m = \left(846\ \frac{\text{lbm}}{\text{ft}^3}\right)\left(32.2\ \frac{\text{ft}}{\text{s}^2}\right)(5\ \text{in})$$
$$\times \left(\frac{\text{lbf}}{32.2\ \frac{\text{lbm-ft}}{\text{s}^2}}\right)\left(\frac{\text{ft}^3}{1{,}728\ \text{in}^3}\right)$$
$$= 2.45\ \text{lbf/in}^2$$

Also,

$$\rho_1 g h_1 = \left(62.4\ \frac{\text{lbm}}{\text{ft}^3}\right)\left(32.2\ \frac{\text{ft}}{\text{s}^2}\right)(3\ \text{ft})$$
$$\times \left(\frac{\text{lbf}}{32.2\ \frac{\text{lbm-ft}}{\text{s}^2}}\right)\left(\frac{\text{ft}^2}{144\ \text{in}^2}\right)$$
$$= 1.30\ \text{lbf/in}^2$$

so

$$p_1 = 14.7\ \frac{\text{lbf}}{\text{in}^2} + 2.45\ \frac{\text{lbf}}{\text{in}^2} - 1.30\ \frac{\text{lbf}}{\text{in}^2}$$
$$= 15.85\ \text{lbf/in}^2 \text{ or psia}$$

4 **C** From equation 11.56:

$$\text{Re} = \frac{\rho \bar{V} D}{\mu}$$

or

$$\bar{V} = \frac{\mu \text{Re}}{\rho D}$$
$$= \frac{\left(8 \times 10^{-4}\ \frac{\text{N}\cdot\text{s}}{\text{m}^2}\right)(2{,}300)}{\left(1{,}000\ \frac{\text{kg}}{\text{m}^3}\right)(0.20\ \text{m})}\left(\frac{\frac{\text{kg}\cdot\text{m}}{\text{s}^2}}{\text{N}}\right)$$
$$= 0.0092\ \text{m/s}$$

5 **A** From equation 11.82:

$$C_D = \frac{1.33}{\text{Re}_L^{0.5}} \; (10^4 < \text{Re}_L < 5 \times 10^5)$$

or

$$C_D = \frac{0.031}{\text{Re}_L^{1/7}} \; (10^6 < \text{Re}_L < 10^9)$$

The Reynolds number for this flow is given by equation 11.81:

$$\text{Re}_L = \frac{\rho V_\infty L}{\mu}$$

$$= \frac{\left(1.225\ \frac{\text{kg}}{\text{m}^3}\right)\left(86\ \frac{\text{m}}{\text{s}}\right)(0.93\ \text{m})}{\left(1.8 \times 10^{-5}\ \frac{\text{N·s}}{\text{m}^2}\right)}$$

$$= 5.443 \times 10^6$$

Therefore the second equation for the coefficient of drag is used:

$$C_D = \frac{0.031}{\text{Re}_L^{1/7}}$$

$$= \frac{0.031}{(5.443 \times 10^6)^{1/7}}$$

$$= 3.381 \times 10^{-3}$$

6 **B** From equation 11.66: $h_f = f\left(\frac{L}{D}\right)\left(\frac{\overline{V}^2}{2g}\right)$

Find the average velocity through the pipe as follows:

$$\overline{V} = \frac{Q}{A}$$

$$= \frac{0.34\ \frac{\text{m}^3}{\text{s}}}{\pi \frac{(0.17\ \text{m})^2}{4}}$$

$$= 14.98\ \text{m/s}$$

Then,

$$h_f = (0.017)\left[\frac{1\ \text{m}}{0.17\ \text{m}}\right]\left[\frac{\left(14.98\ \frac{\text{m}}{\text{s}}\right)^2}{2\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}\right]$$

$$= 1.14\ \text{m}$$

7 **B** Use the Bernoulli equation:

$$\frac{p_1}{\gamma} + \frac{\overline{V}_1^{\,2}}{2g} + z_1 + h_m = \frac{p_2}{\gamma} + \frac{\overline{V}_2^{\,2}}{2g} + z_2$$

In this case, $p_1 = p_2$ and $\overline{V}_1 = \overline{V}_2$, so

$$h_m = z_2 - z_1$$

$$= 120\ \text{m}$$

The pumping power is then given by the equation

$$\dot{W} = \rho g h Q$$

$$= \left(1{,}000\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(120\ \text{m})\left(50\ \frac{\text{m}^3}{\text{s}}\right)$$

$$\times \left(\frac{\text{N}}{\frac{\text{kg·m}}{\text{s}^2}}\right)\left(\frac{\text{kW}}{1{,}000\ \frac{\text{N·m}}{\text{s}}}\right)$$

$$= 58{,}860\ \text{kW}$$

But this is the power required to pump the water. The pump will need somewhat more power to account for its irreversibilities:

$$\eta = \frac{\dot{W}}{\dot{W}_{\text{supplied}}}$$

$$\dot{W}_{\text{supplied}} = \frac{\dot{W}}{\eta}$$

$$= \frac{58{,}860\ \text{kW}}{0.90}$$

$$= 65{,}400\ \text{kW}$$

8 **C** From equation 11.2:

$$M = \frac{\overline{V}}{c} = \frac{370\ \frac{\text{ft}}{\text{s}}}{1{,}080\ \frac{\text{ft}}{\text{s}}} = 0.343$$

9 **D** From the principle of mass conservation, equation 11.43 gives:

$$\rho_1 A_1 \overline{V}_1 = \rho_2 A_2 \overline{V}_2$$

or

$$\rho_2 = \frac{\rho_1 A_1 \overline{V}_1}{A_2 \overline{V}_2} = \left(200\ \frac{\text{kg}}{\text{m}^3}\right)\left(\frac{\frac{\pi(0.10\ \text{m})^2}{4}}{\frac{\pi(0.15\ \text{m})^2}{4}}\right)\left(\frac{20\ \frac{\text{m}}{\text{s}}}{14\ \frac{\text{m}}{\text{s}}}\right) = 127\ \text{kg/m}^3$$

10 **C**

$$\overline{V} = \frac{Q}{A}$$

$$Q = \frac{\dot{m}}{\rho} = \frac{1.60\ \frac{\text{kg}}{\text{s}}}{1{,}000\ \frac{\text{kg}}{\text{m}^3}} = 1.60 \times 10^{-3}\ \frac{\text{m}^3}{\text{s}} \qquad A = \frac{\pi D^2}{4} = \frac{\pi(0.024\ \text{m})^2}{4} = 4.52 \times 10^{-4}\ \text{m}^2$$

$$\overline{V} = \frac{1.60 \times 10^{-3}\ \frac{\text{m}^3}{\text{s}}}{4.52 \times 10^{-4}\ \text{m}^2} = 3.54\ \frac{\text{m}}{\text{s}}$$

11 **A** $\sum \mathbf{F} = (\dot{m}\mathbf{V})_{\text{in}} - (\dot{m}\mathbf{V})_{\text{out}}$

This equation can be separated into its horizontal and vertical components:

$$\sum \mathbf{F}_x = (\dot{m}\mathbf{V}_x)_{\text{in}} - (\dot{m}\mathbf{V}_x)_{\text{out}}$$

and

$$\sum \mathbf{F}_y = (\dot{m}\mathbf{V}_y)_{\text{in}} - (\dot{m}\mathbf{V}_y)_{\text{out}}$$

Both the horizontal component of the outlet velocity, $(\mathbf{V}_x)_{\text{out}}$ and the vertical component of the inlet velocity, $(\mathbf{V}_y)_{\text{in}}$, are zero. Also, because the tee is symmetrical and both outlet ports have the same diameter, the momentum leaving each port will be of equal magnitude and opposite direction. Therefore:

$$\sum \mathbf{F}_y = 0$$

and

$$\sum \mathbf{F}_x = (\dot{m}\mathbf{V}_x)_{\text{in}} = \mathbf{F}$$

$$\mathbf{F} = \left(1.60\ \frac{\text{kg}}{\text{s}}\right)\left(3.54\ \frac{\text{m}}{\text{s}}\right)\left(\frac{\text{N}}{\frac{\text{kg m}}{\text{s}^2}}\right) = 5.66\ \text{N}$$

12 **C** The maximum power that can be generated by the impulse turbine shown in the figure is given by equation 11.91:

$$\dot{W}_{\max} = Q\rho\left(\frac{|V_1{}^2|}{4}\right)(1 - \cos\alpha) = \dot{m}\left(\frac{|V_1{}^2|}{4}\right)(1 - \cos\alpha)$$

$$= \left(16\ \frac{\text{kg}}{\text{s}}\right)\left[\frac{\left(67\ \frac{\text{m}}{\text{s}}\right)^2}{4}\right][1 - \cos(120°)] \times \left(\frac{\text{N}}{\frac{\text{kg·m}}{\text{s}^2}}\right)\left(\frac{\text{kW}}{1{,}000\ \frac{\text{N}\cdot\text{m}}{\text{s}}}\right)$$

$$= 26.93\ \text{kW}$$

13 **A** The volumetric flow rate through a venturi flow meter is given by equation 11.108:

$$Q = \frac{C_v A_2}{\sqrt{1 - (A_2/A_1)^2}}\sqrt{2g\left[\left(\frac{p_1}{\gamma} + z_1\right) - \left(\frac{p_2}{\gamma} + z_2\right)\right]}$$

$$= \frac{(0.83)(0.015\ \text{m}^2)}{\sqrt{1 - \left(\frac{0.015\ \text{m}^2}{0.102\ \text{m}^2}\right)^2}} \times \sqrt{2\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)\left[\left(\frac{(600\ \text{kPa})}{9{,}810\ \frac{\text{N}}{\text{m}^3}}\right)\left(\frac{1{,}000\ \frac{\text{N}}{\text{m}^2}}{\text{kPa}}\right) - \left(\frac{(430\ \text{kPa})}{9{,}810\ \frac{\text{N}}{\text{m}^3}}\right)\left(\frac{1{,}000\ \frac{\text{N}}{\text{m}^2}}{\text{kPa}}\right)\right]}$$

$$= 0.232\ \text{m}^3/\text{s}$$