11. HYDRODYNAMICS

Hydrodynamics is concerned with the flow of fluids through pipes, ducts and surfaces of various shapes. At low velocities fluid particles move in layers which do not intermingle with one another. Lines which are tangential to the direction of flow of the fluid particles are called ***streamlines***, and such an orderly fluid flow is called ***laminar*** or ***streamline*** flow. At high velocities fluid particles intermingle and well defined streamlines are no longer identifiable; the flow is then said to be ***turbulent***.

11.1 Equation of Continuity

The ***equation of continuity*** is essentially a mathematical statement of the law of conservation of matter during fluid flow. Consider the flow of an incompressible fluid through a pipe of cross–sectional area A. If the average velocity of the fluid is v, then the volume of fluid passing through the pipe per unit time, or the flow rate (Q), is given by

$$Q = Av \tag{11.1}$$

in unit of m^3/s. Consider the flow of fluid through a pipe of varying cross–section (Fig. 11.1). The cross–sectional areas are A_1 and A_2, and the fluid velocities are v_1 and v_2 at sections 1 and 2 respectively. Since the same volume of fluid passing through section 1 per unit time must also pass through section 2, $Q_1 = Q_2$, or from eq. (11.1)

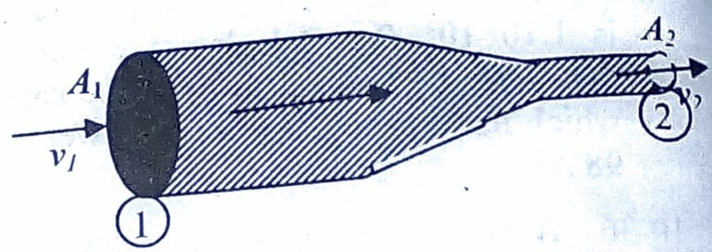
$$A_1 v_1 = A_2 v_2 \tag{11.2}$$

Eq. (11.2) is the equation of continuity. Thus an incompressible fluid flowing through a pipe will have its velocity increased if the pipe narrows down (such as occurs at a constriction), or decreased if the pipe widens.

11.2 Bernoulli's Principle

The ***Bernoulli's principle*** is basically that of energy conservation during fluid flow. Consider two sections 1 and 2 in a fluid flowing through a pipe of varying cross–section (Fig.11.2); Let v_1 and P_1 be the velocity and pressure of the fluid at

Fig. 11.1



section 1 which is at a height z_1 relative to some arbitrary reference level, while v_2 and P_2 are the velocity and pressure at section 2 which is at it height z_2 relative to the same reference level.

It can be shown that the work done in moving a small volume V of fluid from 1 to 2 is

$$W = (P_1 - P_2)V \tag{11.3}$$

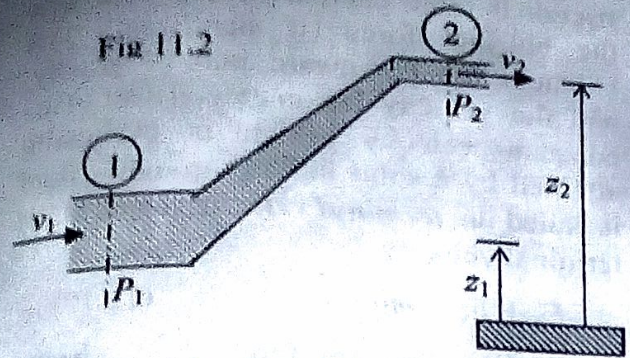
The change in kinetic energy (ΔE_k) of the small parcel of fluid is

$$\tfrac{1}{2} \times \text{mass} \times v_2^2 - \tfrac{1}{2} \times \text{mass} \times v_1^2 \text{, or}$$

$$\Delta E_k = \tfrac{1}{2}\rho V\left(v_2^2 - v_1^2\right) \tag{11.4}$$

where the mass of the fluid parcel is its density ρ multiplied by the volume V.

Fig 11.2



The change in potential energy (ΔE_p) of the fluid parcel is *mass* × height difference × g, or

$$\Delta E_p = \rho V g(z_2 - z_1) \qquad (11.5)$$

The work done must be equal to the total change in energy (energy conservation), i.e.

$$W = \Delta E_k + \Delta E_p$$

or in view of eqs (11.3) to (11.5)

$$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right) + \rho g\left(z_2 - z_1\right)$$

or

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g z_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g z_2 \qquad (11.6)$$

Equation (11.6) is the ***Bernoulli's equation*** for fluid flow and it is more generally written as

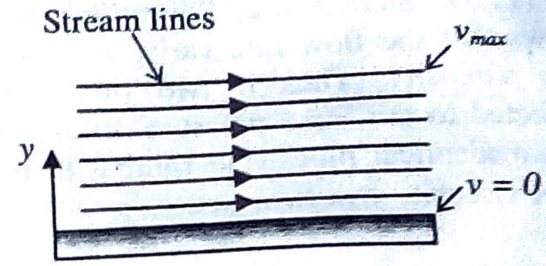
$$P + \tfrac{1}{2}\rho v^2 + \rho g z = \text{constant} \qquad (11.6a)$$

11.3 Friction in Fluids; Viscosity

A fluid, unlike a solid, does not move all in one piece. Instead, different layers of the fluid move with different velocities. The laminar flow of a fluid over a flat plate is depicted in Fig. 11.3. The layer of fluid in contact with the plate clings to it, i.e. its velocity is zero, while the topmost layer of fluid has the maximum velocity. Whenever two adjacent layers of fluid move with different velocities, friction is set up between them, in much the same way as friction develops between a solid surface which slides over another. The term ***viscosity*** is used to describe friction in fluids.

Fluid friction is due to the attractive intermolecular forces between the fluid particles in one layer and those of the adjacent layer. In Fig. 11.3 the fluid velocity increases gradually in the *y*-direction, that is, perpendicular to the plate.

Fig. 11.3



The friction (or ***viscous***) force *F* between two adjacent fluid layers is directly proportional to the velocity gradient (*dv/dy*) and the area of contact (*A*) between the two layers, i.e.

$$F = \eta A \frac{dv}{dy} \qquad (11.7)$$

where η, the constant of proportionality, is the viscosity of the fluid. The unit of η is $N.s/m^2$ or $kg/m.s$. For convenience another unit, the ***poise***, is defined such that 1 *poise* = 1 $dyne.s/cm^2$ = 0.1 $N.s/m^2$. The viscosity of a fluid is strongly temperature dependent; for liquids, it decreases with increasing temperature.

A common type of fluid flow is that through pipes (Fig. 11.4). The fluid layer next to the wall of the pipe is at rest (v = 0) and the fluid velocity increases away from the wall, attaining a maximum value at the centre. The relationship between the velocity (v) and the distance (y) from the centre of the pipe is parabolic:

$$v = -\frac{1}{4\eta}\left(R^2 - y^2\right)\frac{\Delta P}{\Delta L} \qquad (11.8)$$

where R is the pipe radius and $\Delta P/\Delta L$ is the pressure gradient along the pipe. It can be shown that the rate of fluid flow (Q) is related to the pressure gradient and the viscosity according to the equation

$$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L} \qquad (11.9)$$

Eq. (11.9), referred to as ***Poiseuille's law***, shows that the flow rate varies inversely with viscosity. Thus if two fluids are subjected to the same pressure difference in two identical pipes, the fluid with the lower viscosity will flow faster.

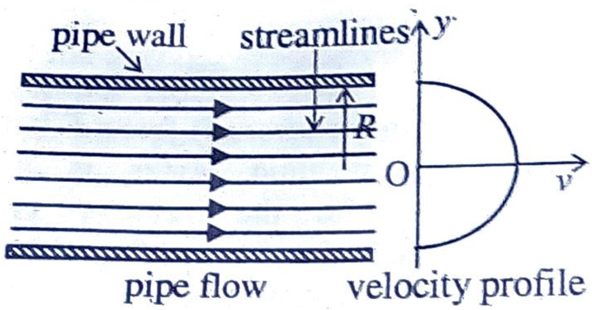


Fig. 11.4

11.4 Motion of Solids through Fluids

A solid moving through a fluid experiences a resistance which depends on the viscosity of the fluid and on the shape, size and speed of the solid. This resistance (also called the ***viscous drag***) increases with increasing velocity. A solid body falling through a fluid, for instance, gathers speed as it falls due to gravitational pull. However, the resistance offered by the fluid also increases, thus tending to reduce its velocity. Eventually a point is reached at which the (upward) frictional force exerted by the fluid plus the buoyant force (if significant), just balances the downward pull of gravity, and the velocity becomes constant. This constant velocity which is eventually attained by a solid falling through a fluid is called the ***terminal velocity***. Thus, at the terminal velocity,

$$F_b + F_v = mg \qquad (11.10)$$

where F_b = buoyant force, F_v = viscous drag and mg = weight of the body.

Problem Solving Tips

1. For a pipe of varying cross-section, equation of continuity holds:

   $A_1v_1 = A_2v_2$.

2. Bernoulli's equation:

   $$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right) + \rho g\left(z_2 - z_1\right)$$

   For a horizontal pipe, $z_2 = z_1$ and Bernoulli's equation reduces to

   $$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right).$$

3. Poiseuille's law:

   $$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L}$$

   where $\Delta P/\Delta L$ is always negative (fluid always flows down a pressure gradient, i.e. from a high pressure zone to a low pressure zone).

4. The ***poise***, which is a common unit of viscosity, should always be converted to SI units before plugging into the equation (1 *poise* = 0.1 $N.s/m^2$; 1 *centipoise* = 10^{-2} *poise* = 10^{-3} $N.s/m^2$).

5. To determine the terminal velocity of a solid body falling through a fluid medium, buoyant force + viscous drag = weight of the body.

SOLVED PROBLEMS

11-1 *The average velocity of water flowing through a 10 cm diameter mains pipe is 3 cm/s. (a) What is the flow rate? (b) What is the velocity of water flowing out of a 1 cm diameter faucet in the building?*

Solution

(a) $Q = Av = \dfrac{\pi}{4}(0.10)^2(3 \times 10^{-2})$

$= 2.36 \times 10^{-4}\ m^3/s$

(b) For a 1 cm diameter faucet,

$A = \dfrac{\pi}{4}(0.01)^2 = 7.85 \times 10^{-5}\ m^2$

$v = Q/A = (2.36 \times 10^{-4})/(7.85 \times 10^{-5})$

$= 3\ m/s$

11-2 *At a certain point in a pipeline where the diameter is 30 cm, the speed of water flow is 1.5 m/s. What is the speed of flow at a point where the diameter is 1 cm?*

(OAU)

Solution

$v_1 = 1.5\ m/s$,

$A_1 = \dfrac{\pi}{4}(0.30)^2 = 7.07 \times 10^{-2}\ m^2$

$A_2 = \dfrac{\pi}{4}(0.01)^2 = 7.854 \times 10^{-5}\ m^2$

$A_1v_1 = A_2v_2 \Rightarrow v_2 = A_1v_1/A_2$ or

$v_2 = (7.07 \times 10^{-2})(1.5)/(7.854 \times 10^{-5})$

$= 1.35 \times 10^3\ m/s.$

11-3 *A 2,000 litre water tank is being filled with water which flows in through a 2.5 cm diameter pipe with velocity 4 m/s. How long will it take to fill the tank?*

Solution

For the pipe,

$A = \dfrac{\pi}{4}(0.025)^2 = 4.909 \times 10^{-4}\ m^2$

$Q = Av = (4.909 \times 10^{-4})(4)$

$= 1.963 \times 10^{-3}\ m^3/s$

Since 1 litre $= 10^{-3}\ m^3$,

capacity of tank $= 2.0\ m^3$

Time to fill tank $= 2/(1.963 \times 10^{-3})$

$= 1019\ s$ (or 17 *minutes*).

11-4 *A horizontal pipe 15 cm in diameter has a constriction of diameter 6 cm. The velocity of water flowing through the 15 cm portion is 2 m/s. Determine (a) the flow rate, and (b) the velocity at the constriction.*

Solution

$A_1 = \dfrac{\pi}{4}(0.15)^2 = 1.767 \times 10^{-2}\ m^2$,

$v_1 = 2\ m/s$

$A_2 = \dfrac{\pi}{4}(0.06)^2 = 2.827 \times 10^{-3}\ m^2$

(a) $Q = A_1v_1 = (1.767 \times 10^{-2})(2)$

$= 3.534 \times 10^{-2}\ m^3/s$

(b) $A_1v_1 = A_2v_2$; $v_2 = A_1v_1/A_2$

$= (3.534 \times 10^{-2})/(2.827 \times 10^{-3})$

$v_2 = 12.5$ m/s

11-5 *How much work is done in pumping 1.4 m³ of water through a 13 mm internal diameter pipe if the difference in pressure at the two ends of the pipe is 1 × 10⁵ N/m²?*

(OAU)

Solution

$P_1 - P_2 = 1 \times 10^5\ N/m^2$, $V = 1.4\ m^3$

$W = (P_1 - P_2)V = 1 \times 10^5 \times 1.4$

$= 1.4 \times 10^5$ J

(Note that W is independent of the pipe's diameter).

11-6 *What is the minimum power rating of a pump which is required to deliver 10 m³ per minute of water into a water main at a pressure of 2 × 10⁵ Pa?*

Solution

Work done (W) = pressure diff. × volume

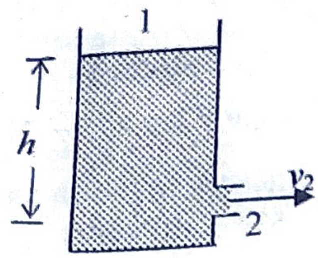
$= (2 \times 10^5)(10) = 2 \times 10^6$ J per min.

Work done per sec. $= 2 \times 10^6/60$
$= 3.33 \times 10^4$ J

i.e. Power delivered $= 3.33 \times 10^4$ Watt
$= 3.33 \times 10^4/746$ hp $= 4.46$ hp

11-7 *Water flows out of a tank through a hole of diameter 2 cm. Determine (a) the velocity of outflow, and (b) the rate of outflow when the level of the water in the tank is 2 m above the hole.*

Solution



(a) Apply Bernoulli's eq. to points (1) and (2) (see figure):

$$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right) - \rho g h$$

(since $z_2 - z_1 = -h$).

Since $P_1 = P_2 =$ atmospheric pressure,

$$\rho g h = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right), \text{ or}$$

$$v_2^2 = v_1^2 + 2gh$$

Noting that $v_1 = 0$ gives

$$v_2^2 = 2gh = 2(9.8)(2) = 39.2, \text{ or}$$

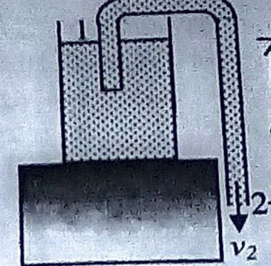
$$v_2 = 6.26 \ m/s$$

(b) $A_2 = \dfrac{\pi}{4}(0.02)^2 = 3.14 \times 10^{-4} \ m^2$

$$Q = A_2 v_2 = (3.14 \times 10^{-4})(6.26)$$
$$= 1.97 \times 10^{-3} \ m^3$$

11-8 *Water is drawn out of a large reservoir with a syphon whose lower end is 3 m below the water level in the reservoir. Calculate the rate at which the water is syphoned out if the tube has a diameter of 4 cm.*

Solution



Apply Bernoulli's eq. to (1) and (2) in figure:

$$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right) - \rho g h$$

Noting that $P_1 = P_2$ and $v_1 = 0$ gives

$$v_2^2 = 2gh = (2)(9.8)(3) = 58.8, \text{ or}$$

$$v_2 = 7.67 \ m/s$$

$$A_2 = \tfrac{1}{4}\pi(0.04)^2 = 1.257 \times 10^{-3} \ m^2$$

$$Q = A_2 v_2 = (1.257 \times 10^{-3})(7.67)$$
$$= 9.64 \times 10^{-3} \ m^3/s$$

11-9 *At a certain point A in a water pipeline the velocity of water is 3 m/s and the gauge pressure is 5×10^5 Pa. At another point B in the same pipeline the diameter of the pipe is twice that at point A, and B is 10 m higher than A. Determine the gauge pressure at B.*

Solution

$$v_A = 3 \ m/s, \ d_B/d_A = 2$$
$$\Rightarrow A_B/A_A = (d_B/d_A)^2 = 4$$

Continuity: $A_A v_A = A_B v_B$

$$v_B = A_A v_A/A_B = (3)(1/4) = 0.75 \ m/s$$

Bernoulli:

$$P_A - P_B = \tfrac{1}{2}\rho\left(v_B^2 - v_A^2\right) + \rho g h$$
$$= \tfrac{1}{2}(10^3)(0.75^2 - 3^2) + (10^3)(9.8)(10)$$
$$= 9.38 \times 10^4 \ Pa$$

$$P_B = P_A - 9.38 \times 10^4$$
$$= 5 \times 10^5 - 9.38 \times 10^4$$
$$= 4.06 \times 10^5 \ Pa$$

11-10 *A horizontal pipe of varying cross–section delivers water into a* *reservoir. At a point in the pipe the pressure is 2 x10^5 Pa and water flows past this point at 1 m/s. Calculate the pressure at another point in the pipe where the velocity of water is 10 m/s.*

Solution

$P_1 = 2 \times 10^5$ *Pa*, $v_1 = 1$ *m/s*,
$v_2 = 10$ *m/s*

Bernoulli:

$$P_1 - P_2 = \tfrac{1}{2}\rho\left(v_2^2 - v_1^2\right) + \rho g(z_2 - z_1)$$

Since the pipe is horizontal, $z_2 - z_1 = 0$

$$\Rightarrow P_1 - P_2 = \tfrac{1}{2}(10^3)(10^2 - 1^2)$$
$$= 4.95 \times 10^4 \ Pa$$
$$P_2 = P_1 - 4.95 \times 10^4$$
$$= 2 \times 10^5 - 4.95 \times 10^4$$
$$= 1.51 \times 10^5 \text{ Pa}$$

11-11 *Calculate the pressure drop per centimeter length of the aorta when the blood flow rate is 25 litre/min. The radius of the aorta is 1 cm and the coefficient of viscosity of blood is 4 × 10^{-2} poise.*

(OAU)

Solution

Poiseuille's law:

$$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L} \Rightarrow \Delta P = -\frac{8Q\eta\Delta L}{\pi R^4}$$

$\eta = 4 \times 10^{-2}$ *poise* $= 4 \times 10^{-3}$ *N.s/m*^{2};
$\Delta L = 0.01$ *m*; $R = 0.01$ *m*,
$Q = 25 \times 10^{-3}/60 = 4.167 \times 10^{-4}$ *m*^{3}/s

$$\Delta P = \frac{-8(4.167 \times 10^{-4})(4 \times 10^{-3})(0.01)}{\pi(0.01)^4}$$

$$= -4.24 \ Pa.$$

11-12 *Find the pressure drop along a 10 m section of a pipe of radius 2 cm through which water flows at an average velocity of 10 cm/s. Take the viscosity of water as 1 centipoise.*

Solution

$R = 2 \times 10^{-2}$ *m*, $\Delta L = 10$ *m*,
$v = 0.1$ *m/s*

$A = \pi(2 \times 10^{-2})^2 = 1.257 \times 10^{-3}$ *m*^{2},
$\eta = 0.1$ *cp* $= 10^{-3}$ *N.s/m*^{2}
$Q = Av = (1.257 \times 10^{-3})(0.1)$
$= 1.257 \times 10^{-4}$ *m*^{3}/s

$$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L} \Rightarrow \Delta P = -\frac{8Q\eta\Delta L}{\pi R^4}$$

or

$$\Delta P = \frac{-8(1.257 \times 10^{-4})(10^{-3})(10)}{\pi(2 \times 10^{-2})^4}$$

$$= 20.0 \ Pa.$$

11-13 *Water flows into a tank through a 2.5 cm diameter pipe. How long will it take for 1 m^3 of water to flow through a 10 m long section of the pipe if the pressure differential across the section is 5×10^4 N/m^2? Take the viscosity of water as 0.80 centipoise.*

Solution

$R = 1.25 \times 10^{-2}$ *m*, $\Delta L = 10$ *m*,
$\Delta P = 5 \times 10^4$ *N/m*^{2},
$\eta = 0.8 \times 10^{-2}$ *poise* $= 8 \times 10^{-4}$ *N.s/m*^{2}

$$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L}$$

$$= -\frac{\pi\left(1.25 \times 10^{-2}\right)\left(-5 \times 10^4\right)}{8\left(8 \times 10^{-4}\right)(10)}$$

$$= 5.99 \times 10^{-2} \ m^3/s$$

$\Rightarrow$ 1 *m*^{3} of water will flow through the pipe in $1/(5.99 \times 10^{-2})$ s, or 16.7 *s*

11-14 *A viscous liquid flows through a 2 mm diameter tube of length 10 cm at the rate of 20 cm^3 per min. under a pressure difference of 20 cm of mercury. Determine the viscosity of the liquid if the density of mercury is 1.36 × 10^4 kg/m^3.*

Solution

$R = 10^{-3}$ *m*, $\Delta L = 0.10$ *m*
$Q = 20 \times 10^{-6}/60 = 3.33 \times 10^{-7}$ *m*^{3}/s
$\Delta P = \rho g h = -(1.36 \times 10^4)(9.8)(0.20)$
$= -2.67 \times 10^4$ *Pa*

$$Q = -\frac{\pi R^4}{8\eta}\frac{\Delta P}{\Delta L}$$

$$\eta = -\frac{\pi R^4}{8Q}\frac{\Delta P}{\Delta L}$$

$$= \frac{-\pi(10^{-3})^4(-2.67\times10^4)}{8(3.33\times10^{-7})(0.10)}$$

$$= 0.314 N.s/m^2$$

or 3.14 *poise*

11-15 *Determine the terminal velocity of a 2 mm diameter steel ball which falls through oil of viscosity 10 poise if the specific gravities of the oil and steel are 0.8 and 8.5 respectively. (Assume that the viscous drag on a ball of radius r is given by $F_v = 6\pi\eta rv$).*

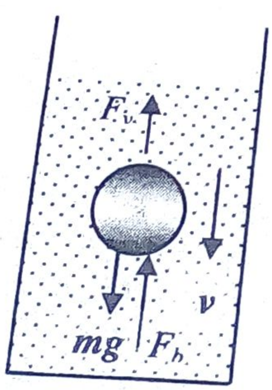
Solution

The two upward forces on the ball are the buoyant force (F_b) and the viscous drag F_v (see Figure).

F_b = weight of oil displaced (Archimedes' principle)

$$= \tfrac{4}{3}\pi r^3 \rho_O g = \tfrac{4}{3}\pi(10^{-3})^3(0.8\times10^3)(9.8)$$

$$= 3.28\times10^{-5} N$$



$$F_v = 6\pi\eta rv = 6\pi(1)(10^{-3})v$$

$$= 1.88\times10^{-2}v$$

(Note that η = 10 *poise* = 1 *N.s./m*^{2})

The downward force on the ball = *mg*

$$= \tfrac{4}{3}\pi r^3 \rho_S g. = \tfrac{4}{3}\pi(10^{-3})^3(8.5\times10^3)(9.8)$$

$$= 3.49\times10^{-4} N$$

At the terminal velocity, $F_b + F_v = mg$

i.e. $3.28\times10^{-5} + 1.88\times10^{-2}v$

$= 3.49\times10^{-4}$

$\Rightarrow v = 1.68\times10^{-2}$ *m/s* (or 1.68 *cm/s*).

SUPPLEMENTARY PROBLEMS

11-16 A 2.54 *cm* pipe *A*, is welded to another pipe *B* of diameter 0.6 *cm*. A liquid flows in the pipes laid horizontally. If the velocity of the liquid in pipe *A* is 0.16 *m/s*, calculate the velocity in pipe *B*. [Answer = 2.87 *m/s*]

11-17 A liquid dispenser consists of a 0.5 *cm* inner diameter tube *A*, connected to 4 pipette tips each of diameter 1.0 *mm*. If the velocity of liquid in *A* is 0.85 *m/s*, calculate the velocity in the pipette tips. [Answer = 5.31 *m/s*]

11-18 At a confluence, rivers *A* and *B* join to form river *C*. River *A* is 4.2 *m* wide, 2.2 *m* deep and the water flows at 1.8 *m/s*. River *B* is 3.8 *m* wide, 1.7 *m* deep and speed of the water is 2.1 *m/s*. If river *C* is 6.2 *m* wide and the current flows at 2.5 *m/s*, calculate how deep *C* is. [Answer = 1.95 *m*]

11-19 Fine dust moves through pipes just like a fluid. A sandblasting machine moves fine sand through a pipe of inner diameter 2.8 *cm* at 75 *L*/min. The sand comes out from two identical jets at a speed 45 *m/s*. Calculate the diameter of the holes through which the jets come out. [Answer = 4.21 *mm*]

11-20 Pipe *A* of inner diameter 2.54 *cm* carries water from the public water mains into a house, the water flowing at 0.65 *m/s* and a gauge pressure 1.5 × 10^5 *Pa*. Water flows to the second floor of the house, 7.8 *m* above pipe *A* through a narrower pipe of inner diameter 0.95 *cm*. Calculate (a) the speed of water coming out of the narrow pipe on the second floor, and (b) the pressure of the water at this height. Answer = 6.30×10^4 *Pa*]

11-21 Water flows from a pipe *A* of inner diameter 20 *cm* at a speed 2.3 *m/s* and at a pressure 1.5×10^5 *Pa*, into another pipe *B* of inner diameter 75 *cm*. Pipe *B* is 5 *m* below pipe *A* and the pressure is 8.0×10^4 *Pa*. Calculate the speed of water in pipe *B*. [Answer = 16.0 *m/s*]

11-22 Water fills an open tank to a height 1.8 *m* above its base. A puncture of diameter 4.0 *mm* occurs at a point 5 *cm* from the base. Calculate (a) the speed at which water gushes out, and (b) the rate at which water begins to flow out of the tank when the puncture occurs. [Answer = 5.86 *m/s*, 7.36×10^{-5} m^3/s]

11-23 Air flows past the lower surface of an airplane wing at 103 *m/s* and past the upper surface at 115 *m/s*. Calculate (a) the difference in the pressure between the lower and upper surfaces of the wing, and (b) the upward lift on the wing if the area of the wing is 15 m^2. Density of air is 1.29 kg/m^3. [Answer = 1687.3 *Pa*, 2.53×10^4 *N*]

11-24 Water flows steadily through a pipe of diameter 16.4 *mm* and length 12 *m*. Calculate the rate at which the water flows if the pressure difference between the two ends of the pipe is 600 *Pa*. The viscosity of water is taken to be 8×10^{-4} $N.s/m^2$. [Answer = 1.78 *L/s*]

11-25 In an experiment to determine the viscosity of a particular oil, an open reservoir of the oil is kept filled to a constant height 25 *cm* above a horizontal pipe plugged into the side of the reservoir. The pipe has an inner diameter 2.5 *mm* and length 0.8 *m*. The oil has a specific gravity 1.36.

Calculate the coefficient of viscosity of the oil if 19.00 *mL* of the oil flows out into a collecting beaker in 1 *min*. [Answer = 1.26×10^{-2} $N.s/m^2$]

11-26 Castor oil has coefficient of viscosity 2.42 $N.s/m^2$ at room temperature and a specific gravity 0.94. A 1.25 *m* tall drum is filled to the brim with castor oil. A horizontal pipe, 0.5 *m* in length and 1.5 *cm* inner diameter is connected at the base of the drum. Calculate the volume of oil that will flow out of the pipe when the tap at its end is opened. [Answer = 11.8 *mL/s*]

11-27 A horizontal capillary tube is 0.50 *m* long and has an inner diameter 0.50 *mm*. It is inserted into the lower end of a tall cylinder having diameter 3.91 *cm*. The cylinder is filled with water, which is allowed to flow out through the capillary tube. Calculate the time required for the water to fall from a height 1.20 *m* to height 0.60 *m* above the axis of the capillary tube. Coefficient of viscosity of water is 8×10^{-4} $N.s/m^2$. [Answer = 5.91 *hrs*]

11-28 Spherical balls of aluminum of 2.5 *mm* diameter are dropped into a very tall cylinder containing oil whose specific gravity is 0.94, and coefficient of viscosity is 2.42. Aluminum has specific gravity of 2.70. Calculate the terminal velocity of the balls as they fall through the oil. [Answer = 2.47×10^{-3} *m/s*]

11-29 Very fine insoluble dust is thoroughly mixed with water in a cylinder filled with water to a height 10 *cm*. If it takes the dust 7.5 *hrs* to completely settle in the cylinder, calculate the diameter of the finest dust. Specific gravity of dust is taken as 2.9 and the coefficient of viscosity of water as 8.0×10^{-4} $N.s/m^2$. [Answer = 8.46×10^{-6} *m*]