0-3-1 [UL] Air with a density (ρ) of 1 kg/m^3 flows through a pipe of diameter 20 cm at a velocity of 10 m/s. Determine (a) the volume flow rate in L/min and (b) mass flow rate in kg/min. Use the PG flow state daemon to verify your answer.

SOLUTION

(a) $\dot{V} = AV;$

$$\dot{V} = \frac{\pi(0.2^2)}{4}(10); \qquad \Rightarrow \dot{V} = 0.314\frac{\text{m}^3}{s}; \qquad \Rightarrow \dot{V} = 18.8\times10^3\,\frac{\text{L}}{\text{min}}$$

(b) $\dot{m} = \rho AV; \qquad \Rightarrow \dot{m} = \rho\dot{V};$

$$\Rightarrow \dot{m} = (1)(0.314); \qquad \Rightarrow \dot{m} = 0.314\frac{\text{kg}}{s}; \qquad \Rightarrow \dot{m} = 18.8\frac{\text{kg}}{\text{min}}$$

TEST Verification: The PG (or IG) flow state TESTcalc can be used to verify this solution.

0-3-2 [UG] Steam flows through a pipe of diameter 5 cm with a velocity of 50 m/s at 500 kPa. If the mass flow rate of steam is measured at 0.2 kg/s, determine (a) the specific volume (v) of steam in m^3/kg, and (b) the volume flow rate in m^3/s.

SOLUTION

(a) $\dot{m} = \rho AV; \quad \Rightarrow \dot{m} = \frac{AV}{v};$

$$\Rightarrow v = \frac{AV}{\dot{m}}; \quad \Rightarrow v = \frac{(1.963 \times 10^{-3})(50)}{0.2};$$

$$\Rightarrow v = 0.49 \frac{\text{m}^3}{\text{kg}}$$

(b) $\dot{\forall} = v\dot{m}; \quad \Rightarrow \dot{\forall} = (0.49)(0.2); \quad \Rightarrow \dot{\forall} = 0.098 \frac{\text{m}^3}{\text{s}}$

TEST Verification: The PC flow state TESTcalc can be used to verify this solution.

0-3-3 [UZ] Water flows through a variable-area pipe with a mass flow rate of 10,000 kg/min. Determine the minimum diameter of the pipe if the flow velocity is not to exceed 5 m/s. Assume density (ρ) of water to be 1000 kg/m^3. Use the SL flow state daemon to verify your answer.

SOLUTION

$$\dot{m} = \rho A V; \qquad \Rightarrow \dot{m} = \rho V \frac{\pi(d^2)}{4};$$

$$\Rightarrow d^2 = \frac{4\dot{m}}{\rho V \pi}; \qquad \Rightarrow d^2 = \frac{4\left(\frac{10000}{60}\right)}{(1000)(5)\pi}; \qquad \Rightarrow d^2 = 0.0424;$$

$$\Rightarrow d = \sqrt{0.0424}; \qquad \Rightarrow d = 0.206\text{m}$$

TEST Verification: The SL flow state TESTcalc can be used to verify this solution.

0-3-4 [BEA] A mixture of water (ρ = 1000 kg/m^3) and oil (ρ = 800 kg/m^3) is flowing through a tube of diameter 2 cm with a velocity of 4 m/s. The mass flow rate is measured to be 1.068 kg/s. Determine (a) the density (ρ) of the liquid mixture and (b) the percentage of oil in the mixture by mass. Assume liquids to be incompressible.

SOLUTION

(a) $\dot{m} = \rho AV; \qquad \Rightarrow \rho = \dfrac{\dot{m}}{AV};$

$$\rho = \frac{4\dot{m}}{\pi d^2 V}; \qquad \Rightarrow \rho = \frac{4(1.068)}{\pi(0.02)^2(4)};$$

$$\rho = 850\,\frac{\text{kg}}{\text{m}^3}$$

(b) $\rho = \dfrac{m}{\cancel{V}}; \qquad \Rightarrow \rho = \dfrac{m_o + m_w}{\cancel{V}}; \qquad \Rightarrow \rho = \dfrac{\rho_o \cancel{V}_o + \rho_w \cancel{V}_w}{\cancel{V}};$

$$\Rightarrow \rho = \rho_o \frac{\cancel{V}_o}{\cancel{V}} + \rho_w \frac{\cancel{V}_w}{\cancel{V}}; \qquad \Rightarrow \rho = \rho_o \frac{\cancel{V}_o}{\cancel{V}} + \rho_w \frac{\cancel{V} - \cancel{V}_o}{\cancel{V}};$$

$$\Rightarrow \rho = \rho_o \frac{\cancel{V}_o}{\cancel{V}} + \rho_w \frac{\cancel{V}}{\cancel{V}} - \rho_w \frac{\cancel{V}_o}{\cancel{V}};$$

$$\Rightarrow \rho = (\rho_o - \rho_w)\frac{\cancel{V}_o}{\cancel{V}} + \rho_w;$$

$$\Rightarrow \frac{\cancel{V}_o}{\cancel{V}} = \frac{\rho - \rho_w}{\rho_o - \rho_w};$$

$$\Rightarrow \frac{\cancel{V}_o}{\cancel{V}} = \frac{850 - 1000}{800 - 1000};$$

$$\Rightarrow \frac{\cancel{V}_o}{\cancel{V}} = 0.75;$$

$$\frac{m_o}{m} = \frac{\rho_o \cancel{V}_o}{\rho \cancel{V}}; \qquad \Rightarrow \frac{m_o}{m} = \frac{800}{850}(0.75);$$

$$\Rightarrow \frac{m_o}{m} = 0.70588; \qquad \Rightarrow \frac{m_o}{m} = 70.7\ \%$$

0-3-5 [CK] Air flows through a pipe of diameter 10 cm with an average velocity of 20 m/s. If the mass flow rate is measured to be 1 kg/s, (a) determine the density (ρ) of air in kg/m^3. (b) **What-if Scenario:** What would be the answer if CO_2 were flowing instead (with all the readings unchanged)?

SOLUTION

(a) $\dot{m} = \rho A V; \qquad \Rightarrow \rho = \dfrac{\dot{m}}{AV};$

$$\Rightarrow \rho = \frac{1}{(7.85\times10^{-3})(20)}; \qquad \Rightarrow \rho = 6.37\ \frac{\text{kg}}{\text{m}^3}$$

(b) As velocity, diameter and mass flow rate remain the same, the density of the CO_2 is same as that of the air, that is, 6.37 kg/m^3.

TEST Verification: The PG (or IG) flow state TESTcalc can be used to verify this solution.

0-3-6 [CP] Air flows steadily through a constant-area duct. At the entrance the velocity is 5 m/s and temperature is 300 K. The duct is heated such that at the exit the temperature is 600 K. (a) If the specific volume (v) of air is proportional to the absolute temperature (in K) and the mass flow rate remains constant throughout the duct, determine the exit velocity. (b) How would heating affect the pressure (0: remain same; 1: increase; -1: decrease)

SOLUTION

(a) As $\dot{m}$ remains constant,

$$\dot{m}_1 = \dot{m}_2;$$

$$\Rightarrow \rho_1 \cancel{A_1} V_1 = \rho_2 \cancel{A_2} V_2;$$

v is proportional to T. Therefore, $v = cT$;

$$\Rightarrow \frac{V_1}{v_1} = \frac{V_2}{v_2}; \qquad \Rightarrow \frac{V_1}{cT_1} = \frac{V_2}{cT_2}; \qquad \Rightarrow V_2 = V_1 \frac{T_2}{T_1};$$

$$\Rightarrow V_2 = \frac{(5)(600)}{(300)}; \qquad \Rightarrow V_2 = 10 \ \frac{\text{m}}{\text{s}}$$

(b) As the velocity increases due to temperature rise, friction increases, thus decreasing the pressure slightly. It is a common misconception that heating a flow increases the pressure at the exit.

0-3-7 [CU] Hydrogen flows through a nozzle exit of diameter 10 cm with an average velocity of 200 m/s. If the mass flow rate of air is measured as 1 kg/s, determine (a) the density (ρ) of hydrogen at the exit in kg/m^3. (b) Determine the specific volume (v) of hydrogen at the exit in m^3/kg, (c) If hydrogen is supplied from a tank, determine the loss of mass of this tank (in kg) in one hour.

SOLUTION

(a) $\dot{m} = \rho AV; \quad \Rightarrow \rho = \frac{\dot{m}}{AV}; \quad \Rightarrow \rho = \frac{1}{\left(\pi/4\right)\left(0.1^2\right)\left(200\right)};$

$$\rho = 0.6366\ \frac{\text{kg}}{\text{m}^3}$$

(b) $v = \rho^{-1}; \quad \Rightarrow v = \left(0.6366\right)^{-1};$

$$v = 1.57\ \frac{\text{m}^3}{\text{kg}}$$

(c) $\dot{m} = 1\ \frac{\text{kg}}{\text{s}}; \quad \Rightarrow m = \left(1\right)\left(3600\right);$

$$m = 3600\ \text{kg}$$

TEST Verification: The PG (or IG) flow state TESTcalc can be used to verify this solution.

0-3-8 [CX] A horizontal-axis wind turbine has a diameter of 50 m and faces air coming at it at 20 miles per hour. If the density (ρ) of air is estimated as 1.1 kg/m^3, determine the mass flow rate of air through the turbine in kg/s. Assume the flow of air is not disturbed by the rotation of the turbine. How would your answer change if the turbine is slightly angled with an yaw angle of 10 degrees (yaw angle is the angle between the turbine axis and the wind direction)? [0: remain same; 1: increase; -1: decrease]

SOLUTION

(a) $\dot{V} = AV; \;\Rightarrow \dot{V} = \frac{\pi d^2}{4}V;$

$$\Rightarrow \dot{V} = \frac{\pi(50)^2}{(4)}(20 \text{ mph})\left(1{,}609\frac{\text{m}}{\text{mile}}\right)(3{,}600);$$

$$\Rightarrow \dot{V} = 17{,}551.5 \;\frac{\text{m}^3}{\text{s}};$$

$$\dot{m} = \rho\dot{V}; \qquad \Rightarrow \dot{m} = (17{,}551.5)(1.1);$$

$$\Rightarrow \dot{m} = 19{,}300 \;\frac{\text{kg}}{\text{s}}$$

(b) The effective area of the flow is reduced to the projected area when the turbine is not normal to the flow.

$$\dot{m}_{\text{new}} = \rho A_{\text{new}} V; \qquad \Rightarrow \dot{m}_{\text{new}} = \rho A(\cos\theta)V; \qquad \Rightarrow \dot{m}_{\text{new}} = \dot{m}\cos\theta;$$

$$\Rightarrow \dot{m}_{\text{new}} = 19{,}300\cos 10°;$$

$$\Rightarrow \dot{m}_{new} = 19{,}000 \;\frac{\text{kg}}{\text{s}}$$

TEST Verification: The PG (or IG) flow state TESTcalc can be used to verify this solution.

0-3-9 [CC] Steam at 400°C enters a nozzle with an average velocity of 20 m/s. If the specific volume (v) and the flow area at the inlet are measured as 0.1 m^3/kg and 0.01 m^2 respectively, determine (a) the volume flow rate in m^3/s, and (b) the mass flow rate in kg/s. Use the PC flow state daemon to verify your answers.

SOLUTION

(a) $\dot{V\!\!\!/} = AV; \quad \Rightarrow \dot{V\!\!\!/} = (0.01)(20); \quad \Rightarrow \dot{V\!\!\!/} = 0.2 \dfrac{\text{m}^2}{\text{s}}$

(b) $\dot{m} = \rho \dot{V\!\!\!/}; \quad \Rightarrow \dot{m} = \dfrac{1}{v}\dot{V\!\!\!/}; \quad \Rightarrow \dot{m} = \dfrac{1}{0.1}(0.2); \quad \Rightarrow \dot{m} = 2 \dfrac{\text{kg}}{\text{s}}$

TEST Verification: The PC flow state TESTcalc can be used to verify this solution.