1-1-1 [ZN] Compare the mole of atoms in the unit of kmol in a 1 in^3 block of copper with that in an identical block of aluminum.

SOLUTION

Use Table A-1 or the SL system state TESTcalc to obtain density of copper and aluminum.

$$m_{\text{copper}} = \rho \cancel{V}; \qquad \Rightarrow m_{\text{copper}} = (8900)(1)^3\left(\frac{0.0254}{1}\right)^3 \left[\frac{\text{kg}}{\text{m}^3}\times\text{in}^3\times\frac{\text{m}^3}{\text{in}^3}\right];$$

$$\Rightarrow m_{\text{copper}} = 0.145845 \text{ kg};$$

$$n_{\text{copper}} = \frac{m}{\bar{M}}; \qquad \Rightarrow n_{\text{copper}} = \frac{0.145845}{63.55}\left|\frac{\text{kg}}{\text{kg}/\text{kmol}}\right|;$$

$$\Rightarrow n_{\text{copper}} = 0.002295 \text{ kmol}$$

Similarly,

$$m_{\text{al}} = \rho \cancel{V}; \qquad \Rightarrow m_{\text{al}} = (2700)(1)^3\left(\frac{0.0254}{1}\right)^3 \left[\frac{\text{kg}}{\text{m}^3}\times\text{in}^3\times\frac{\text{m}^3}{\text{in}^3}\right];$$

$$\Rightarrow m_{\text{al}} = 0.044245 \text{ kg};$$

$$n_{\text{al}} = \frac{m}{\bar{M}}; \qquad \Rightarrow n_{\text{al}} = \frac{0.044254}{26.98}; \qquad \Rightarrow n_{\text{al}} = 0.00164 \text{ kmol}$$

TEST Solution:

Use the SL system state TESTcalc. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-2 [ZE] Determine the mass of one molecule of water (H_2O). Assume the density to be 1000 kg/m^3.

SOLUTION

Use Table C-1 or any PG TESTcalc to obtain molar mass of H2O.

$$\text{Molar mass} = 18.016\ \frac{\text{kg}}{\text{kmol}};$$

A kmol is 6.023×10^{26}

$$\text{Therefore, mass of one molecule} = \frac{18.016}{6.023\times10^{26}};$$

$$\Rightarrow \text{Mass of one molecule} = 2.99\times10^{-26}\ \text{kg}$$

`

1-1-3 [ZI] A chamber contains 14 kg of nitrogen (molar mass = 28 kg/kmol) at 100 kPa, and 300 K. (a) How many kmol of N_2 is in there? (b) If 1 kmol of hydrogen (molar mass 2 kg/kmol) is added to the chamber, what is the total mole (in kmol) in the system now? (c) What is the average molar mass of the mixture? Assume universal gas constant to be 8.314 kJ/kmol-K.

SOLUTION

Use Table C-1 or any PG TESTcalc to obtain molar mass of pure gases.

(a) $n_{N2} = \dfrac{m_{N2}}{\bar{M}_{N2}}; \quad \Rightarrow n_{N2} = \dfrac{14}{28}\left[\dfrac{\text{kg}}{\text{kg/kmol}}\right] = 0.5 \text{ kmol}$

(b) The new mole after hydrogen is added is 0.5 + 1 = 1.5 kmol

(c) The new mass of the system is 14 + 1*2 = 16 kg
Therefore, the apparent molar mass of the mixture is given by:

$$\bar{M} = \frac{m}{n}; \quad \Rightarrow \bar{M} = \frac{16}{1.5}; \quad \Rightarrow \bar{M} = 10.67 \ \frac{\text{kg}}{\text{kmol}}$$

TEST Solution:

Use the n-IG system state TESTcalc. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-4 [ZL] One kmol of nitrogen (N_2) is mixed with 2 kg of oxygen (O_2). Determine the total amount in (a) kg and (b) kmol.

SOLUTION

Use Table C-1 or any PG TESTcalc to obtain molar mass of pure gases.

(a) Total mass of the mixture:

$$m = m_{\mathrm{N2}} + m_{\mathrm{O2}}; \quad \Rightarrow m = n_{\mathrm{N2}}\bar{M}_{\mathrm{N2}} + m_{\mathrm{O2}}; \quad \Rightarrow m = 1(28) + 2; \quad [\mathrm{kg}]$$

$$\Rightarrow m = 30 \text{ kg}$$

(b) Total mole of the mixture:

$$n = n_{\mathrm{N2}} + n_{\mathrm{O2}}; \quad \Rightarrow n = n_{\mathrm{N2}} + \frac{m_{\mathrm{O2}}}{\bar{M}_{\mathrm{O2}}}; \quad \Rightarrow n = 1 + \frac{2}{32}; \quad [\mathrm{kmol}]$$

$$\Rightarrow n = 1.0625 \text{ kmol}$$

TEST Solution:

Use the n-IG system state TESTcalc. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-5 [BEU] 10 kmol of a gas with a molar mass of 25 kg/kmol is mixed with 20 kg of another gas with a molar mass of 2 kg/kmol. If the pressure and temperature of the mixture are measured as 100 kPa and 400 K respectively, determine the molar mass of the gas mixture.

SOLUTION

Total mass of the mixture:

$$m = m_A + m_B; \quad \Rightarrow m = n_A \bar{M}_A + m_B; \quad \Rightarrow m = 10(25) + 20; \quad [\text{kg}]$$

$$\Rightarrow m = 270 \text{ kg}$$

Total mole of the mixture:

$$n = n_A + n_B; \quad \Rightarrow n = n_A + \frac{m_B}{\bar{M}_B}; \quad \Rightarrow n = 10 + \frac{20}{2}; \quad [\text{kmol}]$$

$$\Rightarrow n = 20 \text{ kmol}$$

Molar mass of the mixture:

$$\bar{M} = \frac{m}{n}; \quad \Rightarrow \bar{M} = \frac{270}{20}; \quad \Rightarrow \bar{M} = 13.5 \ \frac{\text{kg}}{\text{kmol}}$$

`

1-1-6 [ZG] A chamber contains a mixture of 2 kg of oxygen (O_2) and 2 kmol of hydrogen (H_2). (a) Determine the average molar mass of the mixture in kg/kmol. (b) If the specific volume of the mixture is 2 m^3/kg, determine the volume of the chamber in m^3.

SOLUTION

Use Table C-1 or any PG TESTcalc to obtain molar mass of pure gases.

(a) Total mass of the mixture:

$$m = m_{\text{H2}} + m_{\text{O2}}; \quad \Rightarrow m = n_{\text{H2}}\bar{M}_{\text{H2}} + m_{\text{O2}}; \quad \Rightarrow m = 2(2) + 2; \quad [\text{kg}]$$

$$\Rightarrow m = 6 \text{ kg}$$

Total mole in the mixture:

$$n = n_{\text{H2}} + n_{\text{O2}}; \quad \Rightarrow n = n_{\text{H2}} + \frac{m_{\text{O2}}}{\bar{M}_{\text{O2}}}; \quad \Rightarrow n = 2 + \frac{2}{32}; \quad [\text{kmol}]$$

$$\Rightarrow n = 2.0625 \text{ kmol}$$

Molar mass of the mixture:

$$\bar{M} = \frac{m}{n}; \quad \Rightarrow \bar{M} = \frac{6}{2.0625}; \quad \Rightarrow \bar{M} = 2.91 \frac{\text{kg}}{\text{kmol}}$$

(b) $$\cancel{V} = mv; \quad \Rightarrow \cancel{V} = (6)(2); \quad \Rightarrow \cancel{V} = 12 \text{ m}^3$$

TEST Solution:

Use the n-IG system state TESTcalc. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

`

1-1-7 [ZZ] 2 kg of hydrogen (H_2) is mixed with 2 kg of oxygen (O_2). If the final mixture has a volume of 3 m^3: Determine (a) molar mass (b) specific volume and (c) the molar specific volume of the final mixture.

SOLUTION

Use Table C-1 or any PG TESTcalc to obtain molar mass of pure gases.

(a) $n_{H_2} = \frac{m}{\bar{M}}; \quad \Rightarrow n_{H_2} = \frac{2}{(2)}; \quad \Rightarrow n_{H_2} = 1\ \text{kmol}$

$n_{O_2} = \frac{m}{\bar{M}}; \quad \Rightarrow n_{O_2} = \frac{2}{(32)}; \quad \Rightarrow n_{O_2} = 0.0625\ \text{kmol}$

$\bar{M}_{\text{mixture}} = \frac{m}{n}; \quad \Rightarrow \bar{M}_{\text{mixture}} = \frac{4}{(1+0.0625)}; \quad \Rightarrow \bar{M}_{\text{mixture}} = 3.76\ \frac{\text{kg}}{\text{kmol}}$

(b) $v = \frac{V\!\!\!-}{m}; \quad \Rightarrow v = \frac{3}{4}; \quad \Rightarrow v = 0.75\ \frac{\text{m}^3}{\text{kg}}$

(c) $\bar{v} = \frac{V\!\!\!-}{n}; \quad \Rightarrow \bar{v} = \frac{3}{1.0625}; \quad \Rightarrow \bar{v} = 2.82\ \frac{\text{m}^3}{\text{kmol}}$

TEST Solution:

Use the n-IG system state TESTcalc. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-8 [ZK] A 4 m x 5 m x 6 m room contains 120 kg of air. Determine (a) density, (b) specific volume, (c) mole, and (d) specific molar volume of air. Assume molar mass of air to be 29 kg/kmol.

SOLUTION

(a) $\mathcal{V} = (4)(5)(6); \quad \Rightarrow \mathcal{V} = 120 \text{ m}^3;$

$$\rho = \frac{120}{120}; \quad \Rightarrow \rho = 1 \ \frac{\text{kg}}{\text{m}^3}$$

(b) $v = \dfrac{\mathcal{V}}{m}; \quad \Rightarrow v = \dfrac{120}{120}; \quad \Rightarrow v = 1 \ \dfrac{\text{m}^3}{\text{kg}}$

(c) $\bar{M} = \dfrac{m}{n}; \quad \Rightarrow n = \dfrac{m}{\bar{M}}; \quad \Rightarrow n = \dfrac{120}{29}; \quad \Rightarrow n = 4.138 \text{ kmol}$

(d) $\bar{v} = \dfrac{\mathcal{V}}{n}; \quad \Rightarrow \bar{v} = \dfrac{120}{4.138}; \quad \Rightarrow \bar{v} = 29 \ \dfrac{\text{m}^3}{\text{kmol}}$

`

1-1-9 [ZP] A 5 cm diameter upside-down piston-cylinder device contains 0.04 kg of an ideal gas at equilibrium at 100 kPa, 300 K, occupying a volume of 0.5 m^3. Determine (a) the gas density in kg/m^3, and (b) the specific volume in m^3/kg.

(c) A mass is now hung from the piston so that the piston moves down and the pressure decreases. Determine the mass in kg necessary to reduce the pressure inside to 50 kPa after the piston comes to a new equilibrium. Assume the piston to be weightless.

(data supplied: g = 9.81 m/s^2; Outside pressure: 100 kPa; Univ Gas Constant = 8.314 kJ/(kmol-K).

SOLUTION

(a) $\rho = \frac{m}{\cancel{V}}; \quad \Rightarrow \rho = \frac{0.04}{0.5}; \quad \Rightarrow \rho = 0.08 \ \frac{\text{kg}}{\text{m}^3}$

(b) $v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{1}{\rho}; \quad \Rightarrow v = \frac{1}{0.08}; \quad \Rightarrow v = 12.5 \frac{\text{m}^3}{\text{kg}}$

(c) $p_i A_{\text{piston}} + \frac{m_w g}{1000} = p_0 A_{\text{piston}}; \quad \left[\text{kPa} \cdot \text{m}^2 = \text{kg} \frac{\text{m}}{\text{s}^2} \frac{\text{kN}}{\text{N}} = \text{kN} \right]$

$$\Rightarrow m_w = \frac{(p_0 - p_i) A_{\text{piston}} (1000)}{g}; \quad [\text{kg}]$$

$$\Rightarrow m_w = \frac{(100-50)(1000)}{9.81} \pi \left(\frac{.05}{2} \right)^2;$$

$$\Rightarrow m = 10 \text{ kg}$$

`

1-1-10 [ZU] 10 kg of water ($\rho = 1000$ kg/m^3) and 5 kg of ice ($\rho = 916$ kg/m^3) are at equilibrium at 0^{o}C. Determine the specific volume of the mixture.

SOLUTION

Total volume of the mixture:

$$\cancel{V} = \frac{10}{1000} + \frac{5}{916}; \qquad \Rightarrow \cancel{V} = 0.015 \text{ m}^3;$$

$$v = \frac{\cancel{V}}{m} = \frac{0.015}{(10+5)}; \qquad \Rightarrow v = 0.001 \ \frac{\text{m}^3}{\text{kg}}$$

`

1-1-11 [ZX] If equal volumes of iron and copper (look up Table A-1 for densities) are melted together, determine (a) the specific volume and (b) density of the alloy. Assume no change in the final volume. (c) **What-if Scenario:** What would the answers (specific volume and density) be if equal masses of iron and copper were melted together?

SOLUTION

Assume 1 $\mathrm{m^3}$ is the volume of both metals.

$$m_{\text{iron}} = \rho \cancel{V}; \quad \Rightarrow m_{\text{iron}} = (7480)(1); \quad \Rightarrow m_{\text{iron}} = 7480 \text{ kg};$$

$$m_{\text{copper}} = \rho \cancel{V}; \quad \Rightarrow m_{\text{copper}} = (8900)(1); \quad \Rightarrow m_{\text{copper}} = 8900 \text{ kg};$$

(a) $$v_{\text{mix}} = \frac{\left(\cancel{V}_{\text{iron}} + \cancel{V}_{\text{copper}}\right)}{\left(m_{\text{iron}} + m_{\text{copper}}\right)}; \quad \Rightarrow v_{\text{mix}} = \frac{(1+1)}{(7480+8900)}; \quad \Rightarrow v_{\text{mix}} = 0.000122 \ \frac{\mathrm{m^3}}{\mathrm{kg}}$$

(b) $$\rho_{\text{mix}} = \frac{1}{v_{\text{mix}}}; \quad \Rightarrow \rho_{\text{mix}} = \frac{1}{0.000122}; \quad \Rightarrow \rho_{\text{mix}} = 8190 \ \frac{\mathrm{kg}}{\mathrm{m^3}}$$

(c) Assume 1000 kg is the mass of each metals

$$\cancel{V}_{iron} = \frac{m_{iron}}{\rho_{iron}}; \quad \Rightarrow \cancel{V}_{iron} = \frac{1000 \text{ kg}}{7480 \ \mathrm{kg/m^3}}; \quad \Rightarrow \cancel{V}_{iron} = 0.13369 \ \mathrm{m^3};$$

$$\Rightarrow \cancel{V}_{iron} = \frac{m_{copper}}{\rho_{copper}}; \quad \Rightarrow \cancel{V}_{iron} = \frac{1000 \text{ kg}}{8900 \ \mathrm{kg/m^3}}; \quad \Rightarrow \cancel{V}_{iron} = 0.11236 \ \mathrm{m^3};$$

$$v_{\text{mix}} = \frac{\left(\cancel{V}_{\text{iron}} + \cancel{V}_{\text{copper}}\right)}{\left(m_{\text{iron}} + m_{\text{copper}}\right)}; \quad \Rightarrow v_{\text{mix}} = \frac{0.13369 \ \mathrm{m^3} + 0.11236 \ \mathrm{m^3}}{1000 \text{ kg} + 1000 \text{ kg}};$$

$$\Rightarrow v_{\text{mix}} = 0.000123 \ \frac{\mathrm{m^3}}{\mathrm{kg}}$$

$$\rho_{\text{mix}} = \frac{1}{v_{\text{mix}}}; \quad \Rightarrow \rho_{\text{mix}} = \frac{1}{0.000123 \ \mathrm{m^3/kg}}; \quad \Rightarrow \rho_{\text{mix}} = 8128.45 \ \frac{\mathrm{kg}}{\mathrm{m^3}}$$

1-1-12 [ZC] What is the atmospheric pressure in kPa if a mercury barometer reads 750 mm? Assume ρ = 13,600 kg/m^3.

SOLUTION

$$p_0 = \frac{\rho_{\mathrm{Hg}} g L}{1000}; \qquad \Rightarrow p_0 = \frac{(13600)(9.81)(0.75)}{1000}; \qquad \Rightarrow p_0 = 100.062 \text{ kPa}$$

`

1-1-13 [ZV] Determine the height of a mountain if the absolute pressure measured at the bottom and top are 760 mm and 720 mm of mercury, respectively. Assume ρ_{Hg} = 13,600 kg/m^3 and ρ_{air} = 1.1 kg/m^3.

SOLUTION

Let State-1 and State-2 represent states at the bottom and top of the mountain.

From barometric measurements, the difference in pressure is:

$$\Delta p_0 = p_{0,2} - p_{0,1}; \qquad \Rightarrow \Delta p_0 = \frac{\rho_{\text{liq,Hg}} g L_2}{1000} - \frac{\rho_{\text{liq,Hg}} g L_1}{1000}; \qquad \Rightarrow \Delta p_0 = \frac{(13600)(9.81)(0.72 - 0.76)}{1000};$$

$$\Rightarrow \Delta p_0 = -5.337 \text{ kPa};$$

Using hydrostatic pressure variation with constant air density (z is the altitude):

$$p_{0,1} - p_{0,2} = \frac{\rho_{\text{air}} g \left(z_2 - z_1\right)}{1000};$$

$$\Rightarrow \left(z_2 - z_1\right) = -\frac{1000 \Delta p_0}{\rho_{\text{air}} g}; \qquad \Rightarrow \left(z_2 - z_1\right) = -\frac{(1000)(-5.337)}{(1.1)(9.81)}; \Rightarrow \left(z_2 - z_1\right) = 495 \text{ m}$$

`

1-1-14 [ZQ] A Bourdon gage measures the pressure of water vapor at the top of a cylindrical tank with a height of 6 m to be 300 kPa. Determine (a) the absolute pressure at the bottom of the tank if 50% of the tank is filled with water vapor. (b) What is the change in absolute pressure if the variation of pressure in the vapor phase were neglected? Assume ρ_{vap} = 2.16 kg/m^3.

SOLUTION

(a) Assuming atmospheric pressure to be 101 kPa

$$p_{\text{top}} = p_0 + p_{\text{gage}}; \quad \Rightarrow p_{\text{top}} = 101\text{ kPa} + 300\text{ kPa}; \quad \Rightarrow p_{\text{top}} = 401\text{ kPa};$$

$$p_{\text{bottom}} = p_{\text{top}} + \frac{\rho_{vapor}\,g}{(1000)}\frac{h}{2} + \frac{\rho_{water}\,g}{(1000)}\frac{h}{2};$$

$$\Rightarrow p_{\text{bottom}} = 401\text{ kPa} + \frac{(2.16)(9.81)(3)}{1000} + \frac{(1000)(9.81)(3)}{1000}; \quad \Rightarrow p_{\text{bottom}} = 430.49\text{ kPa}$$

(b) When the variation of pressure in the vapor is neglected:

$$\Rightarrow p_{\text{bottom}} = 401 + \cancelto{0}{\frac{(2.16)(9.81)(3)}{1000}} + \frac{(1000)(9.81)(3)}{1000}; \Rightarrow p_{\text{bottom}} = 430.43\text{ kPa};$$

$$\text{error} = \left(\frac{430.43 - 430.49}{430.49}\right)100; \quad \Rightarrow \text{error} = -0.015\%$$

`

1-1-15 [ZT] An unknown mass is placed on the piston of a vertical piston-cylinder device containing nitrogen. The piston is weightless and has an area of 1 m^2. The outside pressure is 100 kPa and the pressure inside is measured at 101 kPa. Determine (a) the unknown mass. (b) Due to a leak, the piston gradually moves down until the leak is fixed, at which point half the gas (by mass) has escaped. What is the pressure inside in this new position of the piston? (c) **What-if Scenario:** By what percent will the pressure inside change if the mass placed on the piston is doubled?

SOLUTION

(a) $p_i A_{\text{piston}} = p_0 A_{\text{piston}} + \dfrac{m_w g}{1000}; \quad \left[\text{kPa} \cdot \text{m}^2 = \text{kg} \dfrac{\text{m}}{\text{s}^2} \dfrac{\text{kN}}{\text{N}} = \text{kN} \right]$

$$\Rightarrow p_i = p_0 + \frac{m_w g}{(1000) A_{\text{piston}}}; \quad [\text{kPa}]$$

$$\Rightarrow m_w = \frac{(p_i - p_0) A_{\text{piston}} (1000)}{g}; \quad [\text{kg}]$$

$$\Rightarrow m_w = \frac{(101-100)(1)(1000)}{9.81}; \quad \Rightarrow m_w = 101.94 \text{ kg}$$

(b) The force balance on the piston in the new position is unchanged. Therefore, the pressure inside does not change.

$p_i = 101$ kPa

`

1-1-16 [ZY] Determine the readings of the two Bourdon gages (outer first) if the inner tank (see figure) has a pressure of 500 kPa, the outer tank a pressure of 50 kPa and the atmosphere a pressure of 100 kPa.

SOLUTION

$p_{abs} = p_0 + p_{gage}$

(a.1) Therefore, the outer gage will read 50-100 = -50 kPag or 50 kPav

(a.2) The inner gage will read 500-50 = 450 kPag

`

1-1-17 [ZF] (a) Determine the absolute pressure in kPa of the gas trapped in the piston cylinder device if the piston is weightless and the depth of the piston from the free surface is 20 m. Assume the outside pressure to be 100 kPa. (b) **What-if Scenario:** How would the answer change if the piston has a diameter of 1 m and the mass of the piston is 100 kg.

SOLUTION

(a) $p_i = p_0 + \dfrac{\rho_w g L}{1000}$; $\quad \Rightarrow p_i = 100 + \dfrac{(1000)(9.81)(20)}{(1000)}$; $\quad \Rightarrow p_i = 196.2 \text{ kPa}$

(b) A vertical force balance on the piston must include the buoyancy force upward (which is equal to the weight of the displaced fluid)

$$p_i A_p = p_w A_p + \frac{m_p g}{1000} - \frac{m_w g}{1000}; \qquad \left[\text{kPa}\cdot\text{m}^2 = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}} = \text{kN} \right]$$

$$\Rightarrow p_i = p_w + \frac{(m_p - m_w)g}{(1000)A_p}; \qquad \Rightarrow p_i = p_w + \frac{(\rho_p - \rho_w)\cancel{V}_p g}{(1000)A_p}; \quad \Rightarrow p_i = p_w + \frac{(\rho_p - \rho_w)t_p g}{(1000)}; \qquad [\text{kPa}]$$

$$\Rightarrow p_i = 196.2 + \frac{(9000-1000)(0.1)(9.81)}{(1000)}; \quad \Rightarrow p_i = 274.68 \text{ kPa}$$

`

1-1-18 [ZD] A piston separates two chambers in a horizontal cylinder as shown in the accompanying figure. Each chamber has a volume of 1 m^3 and the pressure of the gas is 50 kPa. The piston has a diameter of 50 cm and has a mass of 200 kg. If the cylinder is now set vertically, determine the pressure in each chamber. Assume pressure times volume to remain constant in each chamber.

SOLUTION

Let State-1 and State-2 represent the top and bottom chambers respectively.

$p\mathcal{V}$ being constant:

$$p_1\mathcal{V}_1 = p_0\mathcal{V}_0; \qquad \Rightarrow p_1\mathcal{V}_1 = (5)(1); \qquad \Rightarrow p_1\mathcal{V}_1 = 5;$$

$$p_2\mathcal{V}_2 = p_0\mathcal{V}_0; \qquad \Rightarrow p_2\mathcal{V}_2 = (5)(1); \qquad \Rightarrow p_2\mathcal{V} = 5;$$

Total volume:

$$\mathcal{V}_1 + \mathcal{V}_2 = 2; \quad \Rightarrow \frac{50}{p_1} + \frac{50}{p_2} = 2;$$

$$\Rightarrow \frac{1}{p_1} + \frac{1}{p_2} = 0.4; \qquad (1)$$

A vertical force balance on the piston yields:

$$p_2A_p = p_1A_p + \frac{m_pg}{1000}; \quad [\text{kPa}]$$

$$\Rightarrow p_2 = p_1 + \frac{m_pg}{(1000)A_p}; \qquad \Rightarrow p_2 = p_1 + \frac{(200)(9.81)}{(1000)\pi(0.5^2/4)}; \qquad \Rightarrow p_2 = p_1 + 10; \quad [\text{kPa}]$$

$$\Rightarrow p_2 = p_1 + 10; \qquad (2)$$

Solving Eqs (1) and (2) yields:

$p_1 = 3.09$ kPa

$p_2 = 13.09$ kPa

1-1-19 [ZM] Two closed chambers A and B are connected by a water manometer. If the gage pressure of chamber A is 10 mm of mercury vacuum and the height difference of the water columns is 10 cm: Determine the pressure in tank B if ρ_{water} = 923 kg/m^3 , ρ_{vap} = 2.16 kg/m^3.

SOLUTION

$$p_A = p_0 - \frac{\rho_{\text{Hg}} g h_{\text{Hg}}}{1000}; \qquad \Rightarrow p_A = p_0 - \frac{(13590)(9.81)(0.01)}{1000}; \qquad \Rightarrow p_A = p_0 - 1.333 \text{ kPa};$$

Equating the pressures at the horizontal level (at the top of the left water column)

$$p_A = p_B + \frac{\rho_{\text{water}} g h_{\text{water}}}{1000};$$

$$\Rightarrow p_B = p_0 - 1.333 - \frac{(923)(9.81)(0.1)}{1000}; \qquad \Rightarrow p_B = p_0 - 2.238;$$

$$\Rightarrow p_{B,gage} = -2.238 \text{ kPa}$$

`

1-1-20 [ZJ] Air flows through a Venturi meter as shown in the accompanying figure. Determine the difference in pressure between point A and B if the height difference of the water columns is 3 cm. Assume ρ_{air} = 1.2 kg/m^3 and ρ_{water} = 1000 kg/m^3.

SOLUTION

Let h_1 be the distance of the centerline from the top of the right water column while h represent the displacement.

Equating the pressures at the horizontal level (at the top of the left water column)

$$p_A + \frac{\rho_{\text{air}} g h_1}{1000} + \frac{\rho_{\text{air}} g h}{1000} = p_B + \frac{\rho_{\text{air}} g h_1}{1000} + \frac{\rho_{\text{liquid}} g h}{1000};$$

$$\Rightarrow p_A - p_B = \frac{\left(\rho_{\text{liquid}} - \rho_{\text{air}}\right) g h}{1000}; \qquad \Rightarrow p_A - p_B = 0.294 \text{ kPa}$$

`

1-1-21 [KR] The maximum blood pressure of a patient requiring blood transfer is found to be 110 mmHg. What should be the minimum height of the ivy to prevent a back flow? Assume □$_{\text{blood}}$ = 1050 kg/m3.

SOLUTION

$$p_{\text{blood}} = p_0 + \frac{\rho_{\text{Hg}} g h_{\text{Hg}}}{1000}; \qquad \Rightarrow p_{\text{blood}} = p_0 + \frac{(13590)(9.81)(0.11)}{1000}; \qquad \Rightarrow p_{\text{blood}} = p_0 + 14.665 \text{ kPa};$$

$$p_{\text{IV}} = p_0 + \frac{\rho_{\text{blood}} g h_{\text{IV}}}{1000};$$

$$p_{\text{blood}} = p_{\text{IV}};$$

$$\Rightarrow \frac{\rho_{\text{Hg}} g h_{\text{Hg}}}{1000} = \frac{\rho_{\text{blood}} g h_{\text{IV}}}{1000};$$

$$\Rightarrow h_{\text{IV}} = \frac{\rho_{\text{Hg}}}{\rho_{\text{blood}}} h_{\text{Hg}}; \qquad \Rightarrow h_{\text{IV}} = \frac{13590}{1050}(0.11); \qquad \Rightarrow h_{\text{IV}} = 1.4237 \text{ m}$$

`

1-1-22 [KO] The temperature assigned for the ice and steam points are 0 and 100 on the Celsius scale and 32 and 212 on the Fahrenheit scale. Both scales use a linear division. (a) Show that the two scales are related by $C/5 = (F - 32)/9$. (b) At what temperature do they show the same reading?

SOLUTION

(a) Let the linear Fahrenheit scale be represented by the equation $\mathrm{F} = a\mathrm{C} + b$

For ice point:

$$32 = a(0) + b;$$

$$\Rightarrow b = 32;$$

For steam point:

$$212 = a(100) + b; \qquad \Rightarrow 212 = a(100) + 32;$$

$$\Rightarrow a = \frac{180}{100} = \frac{9}{5}$$

Therefore, $F = \frac{9}{5}C + 32$, or

$$\Rightarrow \frac{C}{5} = \frac{F - 32}{9}$$

(b) Substituting $C = F$

$$C = \frac{9}{5}C + 32;$$

$$\Rightarrow C = -40$$

So they both will have the same reading at -40 ^{o}C or ^{o}F.

`

1-1-23 [KB] The temperature T on a thermometric scale is defined in terms of property x by the function $T = a.\ln(xb)$, where a and b are constants. The values of x are found to be 1.8 and 6.8 at the ice point and the steam point, the temperatures of which are assigned numbers 0 and 100 respectively. Determine the temperature corresponding to a reading of $x = 2.4$ on this thermometer.

SOLUTION

$T = a\ln x + \ln b$

ice point:

$0 = a\ln(1.8) + b;$

steam point:

$100 = a\ln(6.8) + b;$

Solving,

$a = \dfrac{100}{1.329}; \quad \Rightarrow a = 75.24;$

$b = -44.23;$

For $x = 2.4$

$T = (75.24)(\ln 2.4) + (-44.22); \quad \Rightarrow T = 21.6$

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1-1-24 [KS] Two liquid-in-glass thermometers are made of identical materials and are accurately calibrated at 0^oC and 100^oC. While the first tube is cylindrical, the second tube has a conical bore, 15% greater in diameter at 0^oC than at 100^oC. Both tubes are subdivided uniformly between the two calibration points into 100 parts. If the conical bore thermometer reads 50^oC. What will the cylindrical thermometer read? Assume the change in volume of the liquid is proportional to the change in temperature.

SOLUTION

Let us represent the radius and height of the cone above a temperature mark by the linearly marked temperature.

Given: $r_0 = 1.15 r_{100}$, $r_0 = 1.075 r_{50}$

Taking advantage of the linear relation between r and h (height of the cone above a temperature mark)

$$\frac{V_{50}}{V_{100}} = \frac{r_{50}^2 h_{50} - r_{100}^2 h_{100}}{r_0^2 h_0 - r_{100}^2 h_{100}}; \quad \Rightarrow \frac{V_{50}}{V_{100}} = \frac{r_{50}^3 - r_{100}^3}{r_0^3 - r_{100}^3}; \quad \Rightarrow \frac{V_{50}}{V_{100}} = \frac{(r_{50}/r_0)^3 - (r_{100}/r_0)^3}{(r_0/r_0)^3 - (r_{100}/r_0)^3};$$

$$\Rightarrow \frac{V_{50}}{V_{100}} = \frac{(1/1.075)^3 - (1/1.15)^3}{1-(1/1.15)^3}; \quad \Rightarrow \frac{V_{50}}{V_{100}} = 0.43;$$

In the cylindrical thermometer, the volume being proportional the height, the temperature reading would be $43\ ^oC$

1-1-25 [KA] The signal (e.m.f.) produced by a thermocouple with its test junction at T °C is given by $\varepsilon = aT + bT^2$ [mV], where a = 0.2 mV/°C and b = 5.1 x 10^{-4} mV/°C^2. (a) Draw a graph of ε against T within the range of -200°C to 500°C. Suppose you define a new scale after your name. The temperature in your scale is assumed to be linearly related to the signal through $T' = a' + b'\varepsilon$ with T' = 25 at ice point and T' = 150 at the steam point. (b) Find the values of a' and b', and plot T' against T.

SOLUTION

Non-linear scale:

$$\varepsilon = a + bT^2;$$

$$\Rightarrow \varepsilon_0 = a = 0.2 \text{ mV};$$

$$\Rightarrow \varepsilon_{100} = a + b\left(100^2\right); \qquad \Rightarrow \varepsilon_{100} = 0.2 + (5.1e-4)\left(100^2\right); \qquad \Rightarrow \varepsilon_{100} = 5.3 \text{ mV};$$

Linear scale:

$$T' = a' + b'\varepsilon;$$

$$\Rightarrow 25 = a' + b'\varepsilon_0; \qquad \Rightarrow 25 = a' + b'(0.2);$$

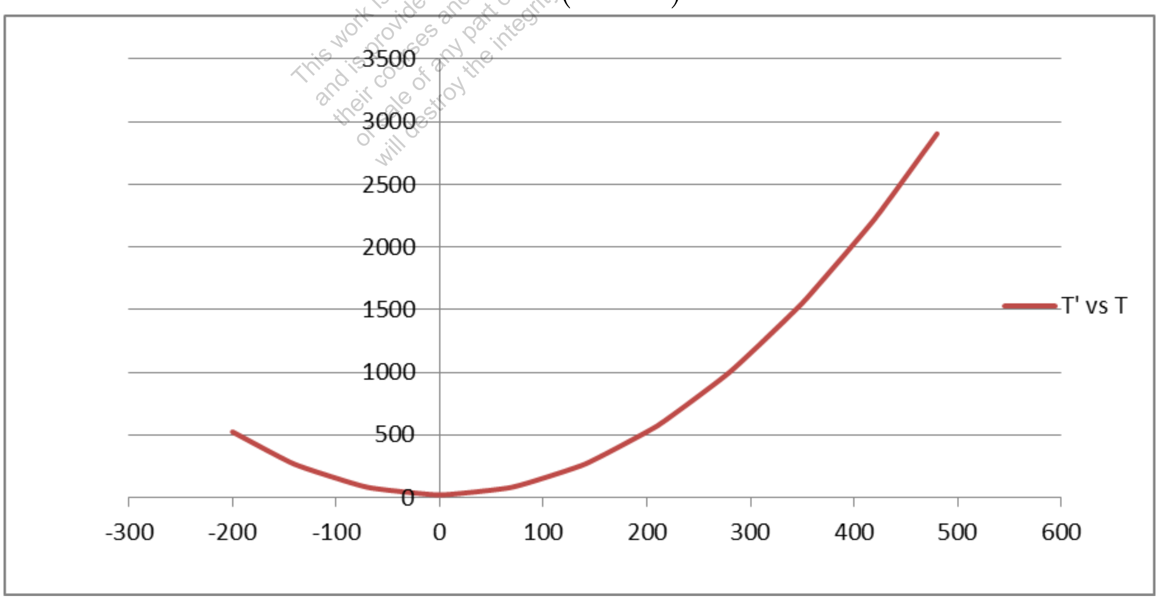
$$\Rightarrow 150 = a' + b'\varepsilon_{100}; \qquad \Rightarrow 150 = a' + b'(5.3);$$

Solving:

(a) $a' =$ 20.1°C

(b) $b' =$ 24.5°C/mV

(c) $T' = 20.10 + 24.5\varepsilon; \qquad \Rightarrow T' = 20.10 + 24.5\left(a + bT^2\right); \qquad \Rightarrow T' = 25 + 0.0125T^2$



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1-1-26 [KH] A projectile of mass 0.1 kg is fired upward with a velocity of 300 m/s. (a) Determine the specific kinetic energy (ke). If the sum of KE and PE is to remain constant, (b) determine the maximum vertical distance the projectile will travel.

SOLUTION

(a) Specific kinetic energy:

$$\text{ke} = \frac{1}{2(1000)}V^2; \quad \Rightarrow \text{ke} = \frac{1}{2000}(300)^2; \quad \Rightarrow \text{ke} = 45 \ \frac{\text{kJ}}{\text{kg}}$$

(b) Since initial PE and final PE are zero,

$$(\text{KE+PE})_0 = (\text{KE+PE})_z;$$

$$\Rightarrow \text{KE}_0 = \text{PE}_z;$$

$$\Rightarrow \frac{mV^2}{2000} = \frac{mgz}{1000};$$

$$\Rightarrow z = \frac{45000}{9.81}; \quad \Rightarrow z = 4587 \text{ m}$$

TEST Solution:

Use the SL system-state TESTcalc to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-27 [UQ] A truck of mass 10 tonnes (metric) is traveling at a velocity of 65 miles per hour. Determine (a) kinetic energy (KE) and (b) how high a ramp is necessary to bring it to a stop if the mechanical energy remains constant?

SOLUTION

(a) $\text{KE} = \dfrac{m}{2(1000)}V^2;\quad \Rightarrow \text{KE} = \dfrac{10000}{2000}(29.055)^2;\quad \Rightarrow \text{KE} = 4220\ \text{kJ}$

(b) Since initial PE and final PE are zero,

$$(\text{KE+PE})_0 = (\text{KE+PE})_z;$$

$$\Rightarrow \text{KE}_0 = \text{PE}_z;$$

$$\Rightarrow \frac{m}{2000}V^2 = \frac{mgz}{1000};$$

$$\Rightarrow z = \frac{V^2}{g};\quad \Rightarrow z = \frac{45000}{9.8};\quad \Rightarrow z = 43.03\ \text{m}$$

TEST Solution:

The SL system-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-28 [KN] A projectile of mass 0.1 kg is moving with a velocity of 250 m/s. If the stored energy (*E*) in the solid is 1.5625 kJ, (a) determine the specific internal energy (*u*). Neglect potential energy and assume the solid to be uniform. (b) How do you explain a negative value for internal energy?

SOLUTION

(a) $E = U + \text{KE} + \cancel{\text{PE}}^{\,0};$

$$\Rightarrow U = E - \text{KE};$$

$$\Rightarrow u = e - \text{ke}; \qquad \Rightarrow u = \frac{1.5625}{(0.1)} - \frac{(250)^2}{2000}; \qquad \Rightarrow u = -15.625 \text{ kJ}$$

(b) Value of internal energy depends on how the zero reference energy is defined. Just as elevation can be negative, so can u.

TEST Solution:

The SL system-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-29 [TB] A rigid chamber contains 100 kg of water at 500 kPa, 100^{o}C. A paddle wheel stirs the water at 1000 rpm with a torque of 100 N-m while an internal electrical resistance heater heats the water, consuming 10 amps of current at 110 Volts. Because of thin insulation, the chamber loses heat to the surroundings at 27^{o}C at a rate of 1.0 kW. Determine (a) the rate of shaft work transfer (W_{sh}) in kW, (b) the electrical work transfer (W_{el}) in kJ in 10 s, (c) the rate of heat transfer (Q) in kW. Include the sign in all your answers. (d) Determine the change (E_2 - E_1) in stored energy E of the system in 10 s in kJ. Neglect KE and PE.

SOLUTION

Work is transferred by the shaft and electricity into the system. Using the WinHip sign convention:

(a) $\dot{W}_{\text{sh}} = -2\pi NT; \quad \Rightarrow \dot{W}_{\text{sh}} = -2\pi \frac{1000}{60}\frac{100}{1000}; \quad [\text{kW}]$

$\Rightarrow \dot{W}_{\text{sh}} = -10.47 \text{ kW}$

(b) $W_{\text{el}} = -\frac{VI}{1000}\Delta t; \quad \Rightarrow W_{\text{el}} = -2\pi \frac{(110)(10)}{1000}(10); \quad [\text{kJ}]$

$\Rightarrow W_{\text{el}} = -117 \text{ kJ}$

(c) $\dot{Q} = -1 \text{ kW}$; (heat is lost; hence negative)

(d) Net energy gained:

$W_{\text{in}} - Q_{\text{out}} = \dot{W}_{\text{in,sh}}\Delta t + W_{\text{in,el}} - \dot{Q}_{\text{out}}\Delta t; \quad \Rightarrow W_{\text{in}} - Q_{\text{out}} = (10.47)(10) + 117 - 1(10);$

$\Rightarrow W_{\text{in}} - Q_{\text{out}} = 211.7 \text{ kJ};$

Therefore,

$E_2 - E_1 = \text{net energy gained} = 211.7 \text{ kJ}$

TEST Solution:

The SL state-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-30 [QM] A truck with a mass of 20000 kg is traveling at 70 miles per hour.

(a) Determine its kinetic energy (KE) in MJ.

(b) The truck uses an electrical brake, which can convert the kinetic energy into electricity and charge a battery. If the efficiency of the system is 50%, what is the amount of energy in kWh that will be stored in the battery as the truck comes to a halt?

SOLUTION

(a) Use the converter TESTcalc to convert mph to m/s and MJ to kWh

$$\mathrm{KE} = \frac{mV^2}{2000}; \quad [\mathrm{kJ}]$$

$$\Rightarrow \mathrm{KE} = \frac{(20000)(31.29^2)}{2000}; \qquad \Rightarrow \mathrm{KE} = 9790 \text{ kJ}; \qquad \Rightarrow \mathrm{KE} = 9.79 \text{ MJ}$$

(b) $$\text{Stored energy} = (0.5)(9790); \qquad \Rightarrow \text{Stored energy} = 4895 \text{ kJ}; \quad \Rightarrow \text{Stored energy} = \frac{4895}{3600} \text{ kWh};$$

$$\Rightarrow \text{Stored energy} = 1.359 \text{ kWh}$$

TEST Solution:

The SL state-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-31 [KI] Air flows through a pipe of diameter 50 cm with a velocity of 40 m/s. If the specific volume of air is 0.4 m^3/kg, determine (a) the specific kinetic energy (ke) of the flow, (b) the mass flow rate, and (c) the rate of transport of kinetic energy by the flow.

SOLUTION

(a) $\mathrm{ke} = \dfrac{\mathrm{KE}}{m}; \quad \Rightarrow \mathrm{ke} = \dfrac{1}{2000}V^2; \quad \Rightarrow \mathrm{ke} = \dfrac{1}{2000}(40)^2; \quad \Rightarrow \mathrm{ke} = 0.8\ \dfrac{\mathrm{kJ}}{\mathrm{kg}}$

(b) $\dot{m} = \rho AV; \quad \Rightarrow \dot{m} = \dfrac{AV}{v}; \quad \Rightarrow \dot{m} = \dfrac{\pi\left(0.5^2\right)}{4}\dfrac{40}{0.4}; \quad \Rightarrow \dot{m} = \dfrac{(0.19625)(40)}{0.4}; \quad \Rightarrow \dot{m} = 19.625\ \dfrac{\mathrm{kg}}{\mathrm{s}}$

(c) $\dot{\mathrm{KE}} = \dot{m}\left(\mathrm{ke}\right); \quad \Rightarrow \dot{\mathrm{KE}} = (19.625)(0.8); \quad \Rightarrow \dot{\mathrm{KE}} = 15.7\ \mathrm{kW}$

TEST Solution:
The PG flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-32 [KL] Steam flows through a pipe at 200 kPa, 379°C, with a velocity of 20 m/s and specific volume of 1.5 m^3/kg. If the diameter of the pipe is 1 m, determine (a) the mass flow rate in kg/s, (b) the molar flow rate in kmol/s, (c) KE (in kW), and (d) rate of flow work (W_F) in kW.

SOLUTION

(a) $\dot{m} = \rho AV; \quad \Rightarrow \dot{m} = \frac{(0.785)(20)}{1.5}; \quad \Rightarrow \dot{m} = 10.47 \ \frac{\text{kg}}{\text{s}}$

(b) $\dot{n} = \frac{\dot{m}}{\bar{M}}; \quad \Rightarrow \dot{n} = \frac{10.47}{18}; \quad \Rightarrow \dot{n} = 0.582 \ \frac{\text{kmol}}{\text{s}}$

(c) $\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = \dot{m}\left(\frac{V^2}{2000}\right); \quad \Rightarrow \dot{\text{KE}} = (10.47)\left(\frac{20^2}{2000}\right); \quad \Rightarrow \dot{\text{KE}} = 2.09 \text{ kW}$

(d) $\dot{W}_F = pAV; \quad \Rightarrow \dot{W}_F = pv(\rho AV); \quad \Rightarrow \dot{W}_F = (200)(1.5)(10.47); \quad \Rightarrow \dot{W}_F = 3141 \text{ kW}$

TEST Solution:

The PC flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-33 [KG] Water flows down a 50 m long vertical constant-diameter pipe with a velocity of 10 m/s. If the mass flow rate is 200 kg/s, determine (a) the area of a cross-section of the pipe. Assuming the internal energy of water remains constant, determine the difference of rate of transport between the top and bottom for (b) kinetic energy, (c) potential energy, and (d) stored energy.

SOLUTION

(a) $\dot{m} = \rho AV; \quad \Rightarrow A = \frac{\dot{m}}{\rho V}; \quad \Rightarrow A = \frac{(200)}{(1000)(10)}; \quad \Rightarrow A = 0.02 \text{ m}^2$

(b) Assuming the density of water to remain constant,

$$(\rho AV)_1 = (\rho AV)_1;$$
$$\Rightarrow V_1 = V_2;$$

Difference between the rate of transport of KE between top (state-1) and bottom (state-2):

$$\dot{m}(\text{ke}_1 - \text{ke}_2) = 0$$

(c) Difference between the rate of transport of PE between top (state-1) and bottom (state-2):

$$\dot{m}(\text{pe}_1 - \text{pe}_2) = \frac{\dot{m}\rho g}{1000}(z_1 - z_2); \quad \Rightarrow \dot{m}(\text{pe}_1 - \text{pe}_2) = \frac{(200)(1000)(9.81)}{1000}(50 - 0);$$
$$\Rightarrow \dot{m}(\text{pe}_1 - \text{pe}_2) = 98100 \text{ kJ}$$

(d) Difference between the rate of transport of E between top (state-1) and bottom (state-2):

$$\dot{m}(e_1 - e_2) = \dot{m}\cancel{(u_1 - u_2)}^{0} + \dot{m}\cancel{(\text{ke}_1 - \text{ke}_2)}^{0} + \dot{m}(\text{pe}_1 - \text{pe}_2); \quad \Rightarrow \dot{m}(e_1 - e_2) = 98100 \text{ kJ}$$

TEST Solution:

The SL flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-34 [KZ] Water enters a system, operating at steady state, at 100 kPa, 25°C, 10 m/s at a mass flow rate ($\dot{m}$) of 200 kg/s. It leaves the system at 15 m/s, 1 MPa, 25°C. If the density of water is 1000 kg/m^3, determine:

(a) the rate of flow work at the inlet (magnitude only)

(b) the rate of transport of kinetic energy at the inlet, and

(c) the diameter of the pipe at the inlet.

SOLUTION

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

$$\dot{W}_F = pAV; \quad \Rightarrow \dot{W}_F = p\frac{\dot{m}}{\rho}; \quad \Rightarrow \dot{W}_F = (100)\left(\frac{200}{1000}\right); \quad \Rightarrow \dot{W}_F = 20\text{ kW}$$

(b) $\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = \dot{m}\dfrac{V^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = (200)\dfrac{(10)^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = 10\text{ kW}$

(c) $A = \dfrac{\dot{m}}{\rho V}; \quad \Rightarrow A = \dfrac{200}{(1000)(10)}; \quad \Rightarrow A = 0.02\text{ m}^2;$

$$\frac{\pi}{4}d^2 = 0.02;$$

$$\Rightarrow d = 0.1596\text{ m}; \quad \Rightarrow d = 15.96\text{ cm}$$

TEST Solution:
The SL flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-35 [BEX] Water (ρ = 997 kg/m^3) enters a system through an inlet port of diameter 10 cm with a velocity of 10 m/s. If the pressure at the inlet is measured as 500 kPa, determine (a) the mass flow rate ($\dot{m}$), (b) the rate of transport of kinetic energy ($\dot{KE}$) at the inlet, and (c) the rate of transport of flow energy ($\dot{J}$) assuming zero contribution from the potential and internal energy.

SOLUTION

(a) $\dot{m} = \rho AV; \quad \Rightarrow \dot{m} = \frac{\pi}{4} d^2 \rho V; \quad \Rightarrow \dot{m} = \frac{\pi}{4}\left(0.1^2\right)(997)(10); \quad \Rightarrow \dot{m} = 78.34 \ \frac{\text{kg}}{\text{s}}$

(b) $\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = \dot{m}\frac{V^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = (78.34)\frac{(10)^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = 3.917 \text{ kW}$

(c) $\dot{J} = \dot{m}j; \quad \Rightarrow \dot{J} = \dot{W}_F + \dot{E}; \quad \Rightarrow \dot{J} = pAV + \dot{m}e; \quad \Rightarrow \dot{J} = pAV + \dot{m}\left(\cancel{u}^{\,0} + \text{ke} + \cancel{\text{pe}}^{\,0}\right);$

$\Rightarrow \dot{J} = pAV + \dot{\text{KE}}; \quad \Rightarrow \dot{J} = (500)\frac{\pi}{4}\left(0.1^2\right)(10) + 3.917; \quad \Rightarrow \dot{J} = \frac{(10)^2}{2000};$

$\Rightarrow \dot{J} = 43.187 \text{ kW}$

TEST Solution:

The SL flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-36 [KK] At the exit of a device, the following properties were measured - mass transport rate : 51 kg/s; volume flow rate: 2 m^3/s; specific flow energy (j) : 230.8 kJ/kg; specific stored energy (e) : 211.2 kJ/kg; flow area: 0.01 m^2. Determine (a) the specific volume (v) in m^3/kg, (b) flow velocity in m/s, (c) the rate of flow work in kW, and (d) the pressure in kPa.

SOLUTION

(a) $\mathrm{v} = \frac{\dot{V}}{\dot{m}}; \quad \Rightarrow \mathrm{v} = \frac{2}{51}; \quad \Rightarrow \mathrm{v} = 0.039 \ \frac{\mathrm{m}^3}{\mathrm{kg}}$

(b) $\dot{m} = \rho AV; \quad \Rightarrow V = \frac{\dot{m}}{\rho \mathrm{A}}; \quad \Rightarrow V = \frac{(51)(0.039)}{0.01}; \quad \Rightarrow V = 198.9 \ \frac{\mathrm{m}}{\mathrm{s}}$

(c) $\dot{J} = \dot{m}j; \quad \Rightarrow \dot{J} = (51)(230.8); \quad \Rightarrow \dot{J} = 11{,}770.8 \text{ kW}$

(d) $j = h + \mathrm{ke} + \mathrm{pe}; \quad \Rightarrow j = u + pv + \mathrm{ke} + \mathrm{pe}; \quad \Rightarrow j = e + pv;$

$\Rightarrow pv = j - e; \quad \Rightarrow pv = 230.8 - 211.2; \quad \Rightarrow pv = 19.6 \text{ kJ};$

$\Rightarrow p = \frac{19.6}{0.039}; \quad \Rightarrow p = 502.56 \text{ kPa}$

TEST Solution:

The SL flow-state TESTcalc (with Custom working fluid) can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-37 [KP] Betz's law states that only 53% of the kinetic energy transported by wind can be converted to shaft work by a perfect wind turbine. For a 50 m diameter turbine in a 20 mph wind, what is the maximum possible shaft power ($\dot{W}_{sh}$)? Assume density of air to be 1.1 kg/m^3. (1 mph = 0.447 m/s).

SOLUTION

$$\dot{KE} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{KE} = \dot{m}\frac{V^2}{2000}; \quad \Rightarrow \dot{KE} = \frac{1}{2000}\rho A V^3;$$

$$\Rightarrow \dot{KE} = \frac{1}{2000}(1.1)\frac{\pi}{4}(50^2)(8.94^3); \quad \Rightarrow \dot{KE} = 771.23\text{ kW};$$

$$W_{sh} = (0.53)(771.23); \quad \Rightarrow W_{sh} = 408.8\text{ kW}$$

TEST Solution:

The PG flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-38 [KU] For a 50 m diameter turbine in a 30 mph wind, determine (a) the mass flow rate of air (in kg/s) intercepted by the turbine, (b) the specific kinetic energy (ke) of the flow (in kJ/kg), (c) the rate of transport of kinetic energy kW, and (d) the maximum possible shaft power. Assume density of air as 1.1 kg/m^3 and use Betz's law (see problem 1-1-37 [KP]). (e) **What-if Scenario:** What will be the maximum shaft power if the wind velocity drops to 15 m/s?

SOLUTION

(a) $V = 30\text{ mph}; \quad \Rightarrow V = (30)(0.447); \quad \Rightarrow V = 13.41\ \frac{\text{m}}{\text{s}};$

$$A = \frac{\pi}{4}\left(50^2\right); \quad \Rightarrow A = 1963.5\text{ m}^2;$$

$$\dot{m} = \rho AV; \quad \Rightarrow \dot{m} = (1.1)(1963.5)(13.41); \quad \Rightarrow \dot{m} = 28{,}963.52\ \frac{\text{kg}}{\text{s}}$$

(b) $\text{ke} = \frac{V^2}{2000}; \quad \Rightarrow \text{ke} = \frac{13.41^2}{2000}; \quad \Rightarrow \text{ke} = 0.089914\ \frac{\text{kJ}}{\text{kg}}$

(c) $\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = (28963.52)(0.089914); \quad \Rightarrow \dot{\text{KE}} = 2604.2\text{ kW}$

(d) $W_{sh} = (0.53)(2604.2); \quad \Rightarrow W_{sh} = 1380.2\text{ kW}$

TEST Solution:

The PG flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-39 [KX] A pipe of diameter 0.1 m carries a gas with the following properties at a certain cross-section: p = 200 kPa; T = 30°C; v = 2 m^3/kg; V = 15 m/s. Determine (a) the mass flow rate in kg/s, (b) the volume flow rate (in m^3/s), (c) the specific kinetic energy (ke) in kJ/kg, (d) the flow rate of kinetic energy in W.

SOLUTION

(a) $A = \frac{\pi}{4}\left(0.1^2\right); \qquad \Rightarrow A = 0.00785 \text{ m}^2;$

$$\dot{m} = \rho A V; \qquad \Rightarrow \dot{m} = \frac{AV}{v}; \qquad \Rightarrow \dot{m} = \frac{(0.00785)(15)}{2}; \qquad \Rightarrow \dot{m} = 0.0589 \ \frac{\text{kg}}{\text{s}}$$

(b) $\dot{\mathcal{V}} = AV; \qquad \Rightarrow \dot{\mathcal{V}} = (0.00785)(15); \qquad \Rightarrow \dot{\mathcal{V}} = 0.1178 \ \frac{\text{m}^3}{\text{s}}$

(c) $\text{ke} = \frac{V^2}{2000}; \qquad \Rightarrow \text{ke} = \frac{15^2}{2000}; \qquad \Rightarrow \text{ke} = 0.1125 \ \frac{\text{kJ}}{\text{kg}}$

(d) $\dot{\text{KE}} = \dot{m}(\text{ke}); \qquad \Rightarrow \dot{\text{KE}} = (0.0589)(0.1125); \qquad \Rightarrow \dot{\text{KE}} = 6.626 \text{ W}$

TEST Solution:

The PG flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-40 [KC] At the inlet of a steam turbine the flow state is as follows: p_1 = 1 MPa, V_1 = 30 m/s, m_1 = 9 kg/s and A_1 = 0.1 m^2. Determine (a) the rate of energy transfer due to flow work and (b) the rate of transport of kinetic energy at the inlet port.

SOLUTION

(a) $\dot{W}_{F,i} = p_i A_i V_i$; $\Rightarrow \dot{W}_{F,i} = (1000)(0.1)(30)$; $\Rightarrow \dot{W}_{F,i} = 3000\,\text{kW}$; $\Rightarrow \dot{W}_{F,i} = 3\text{ MW}$

(b) $\dot{\text{KE}} = \dot{m}(\text{ke})$; $\Rightarrow \dot{\text{KE}} = \dot{m}\dfrac{V^2}{2000}$; $\Rightarrow \dot{\text{KE}} = \left(\dfrac{1}{2000}\right)(9)\left(30^2\right)$; $\Rightarrow \dot{\text{KE}} = 4.05\,\text{kW}$

TEST Solution:

The PC flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-41 [KV] Steam flows into a steady adiabatic turbine at 10 MPa, 600°C and leaves at 58 kPa and 90% quality. The mass flow rate is 9 kg/s. Additional properties at the exit that are known are: $A = 1.143$ m^2, $v = 2.54$ m^3/kg, $u = 2275.2$ kJ/kg, $e = 2275.4$ kJ/kg, and $h = 2422.4$ kJ/kg. If the turbine produces 1203 kW of shaft power, determine at the exit (a) the velocity in m/s. Also calculate the rate of transport of (b) kinetic energy, (c) stored energy, and (d) flow energy. Neglect potential energy.

SOLUTION

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

$$\Rightarrow V = \frac{\dot{m}v}{A}; \quad \Rightarrow V = \frac{(9)(2.54)}{1.143}; \quad \Rightarrow V = 20\ \frac{\text{m}}{\text{s}}$$

(b) $\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = \dot{m}\dfrac{V^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = \left(\dfrac{1}{2000}\right)(9)\left(20^2\right); \quad \Rightarrow \dot{\text{KE}} = 1.8\ \text{kW}$

(c) $\dot{E} = \dot{m}e; \quad \Rightarrow \dot{E} = \dot{m}\dfrac{V^2}{2000}; \quad \Rightarrow \dot{E} = (9)(2275.4); \quad \Rightarrow \dot{E} = 20,478.6\ \text{kW}$

(d) $\dot{J} = \dot{m}j; \quad \Rightarrow \dot{J} = \dot{m}(h + \text{ke} + \text{pe}); \quad \Rightarrow \dot{J} = \dot{m}(u + pv + \text{ke} + \text{pe}); \quad \Rightarrow \dot{J} = \dot{m}(e + pv);$

$$\Rightarrow \dot{J} = (9)\left[2275.4 + (58)(2.54)\right]; \quad \Rightarrow \dot{J} = 21,804.5\ \text{kW}$$

TEST Solution:

The PC flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-42 [KQ] In an adiabatic nozzle the specific flow energy *j* remains constant along the flow. The mass flow rate through the nozzle is 0.075 kg/s and the following properties are known at the inlet and exit ports. Inlet: p = 200 kPa, u = 2820 kJ/kg, A = 100 cm^2, V = 10 m/s; Exit: h = 3013 kJ/kg, v = 1.67 m^3/kg. Determine (a) the exit velocity and (b) the exit area.

SOLUTION

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

$$\Rightarrow v_1 = \frac{AV}{\dot{m}}; \quad \Rightarrow v_1 = \frac{(100\times10^{-4})(10)}{0.075}; \quad \Rightarrow v_1 = 1.333\ \frac{\text{m}^3}{\text{kg}};$$

$j_i = j_2;$

$$\Rightarrow (h + \text{ke} + \text{pe})_1 = (h + \text{ke} + \text{pe})_2;$$

$$\Rightarrow \text{ke}_2 = h_1 - h_2 + \text{ke}_1; \quad \text{(change in pe is neglected)}$$

$$\Rightarrow \frac{V_2^2}{2000} = u_1 + p_1 v_1 - h_2 + \frac{V_1^2}{2000}; \quad \Rightarrow \frac{V_2^2}{2000} = 2820 + (200)(1.33) - 3013 + \frac{10^2}{2000}; \quad \Rightarrow \frac{V_2^2}{2000} = 73.05;$$

$$\Rightarrow V_2 = 382.23\ \frac{\text{m}}{\text{s}}$$

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

$$\Rightarrow A_2 = \frac{\dot{m} v_2}{V_2}; \quad \Rightarrow A_2 = \frac{(0.075)(1.67)}{531.13}; \quad \Rightarrow A_2 = 2.358\times10^{-4}\ \text{m}^2$$

TEST Solution:

The SL flow-state TESTcalc (with Custom fluid) can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-43 [KT] A superheated vapor enters a device with a mass flow rate of 5 kg/s with the following properties: V = 30 m/s, p = 500 kPa, v = 0.711 m^3/kg, and u = 3128 kJ/kg. Neglecting potential energy, determine (a) the inlet area in m^2, (b) the rate of transport of K.E. in kW, (c) E in kW, (d) J in kW, and (e) the rate of flow work transfer in kW.

SOLUTION

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

$$\Rightarrow A = \frac{\dot{m}}{\rho V}; \quad \Rightarrow A = \frac{\dot{m}v}{V}; \quad \Rightarrow A = \frac{(5)(0.711)}{30}; \quad \Rightarrow A = 0.1185 \text{ m}^2$$

(b) $$\dot{\text{KE}} = \dot{m}(\text{ke}); \quad \Rightarrow \dot{\text{KE}} = \dot{m}\frac{V^2}{2000}; \quad \Rightarrow \dot{\text{KE}} = \left(\frac{1}{2000}\right)(5)(30)^2; \quad \Rightarrow \dot{\text{KE}} = 2.25 \text{ kW}$$

(c) $$\dot{\text{E}} = \dot{\text{KE}} + \dot{U}; \quad \Rightarrow \dot{\text{E}} = 2.25 + (3128)(5); \quad \Rightarrow \dot{\text{E}} = 15642.5 \text{ kW}$$

(d) $$\dot{J} = \dot{E} + \dot{W}_F; \quad \Rightarrow \dot{J} = \dot{E} + pAV; \quad \Rightarrow \dot{J} = \dot{E} + pv\frac{AV}{v}; \quad \Rightarrow \dot{J} = \dot{E} + \dot{m}(pv);$$

$$\Rightarrow \dot{J} = 15642.5 + (5)(500)(0.711); \quad \Rightarrow \dot{J} = 17420 \text{ kW}$$

(e) $$\dot{W}_F = pAV; \quad \Rightarrow \dot{W}_F = pv\frac{AV}{v}; \quad \Rightarrow \dot{W}_F = \dot{m}(pv); \quad \Rightarrow \dot{W}_F = (5)(500)(0.711);$$

$$\Rightarrow \dot{W}_F = 1777.5 \text{ kW}$$

TEST Solution:

The PC flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-44 [KY] A mug contains 0.5 kg of coffee with specific stored energy (e) of 104.5 kJ/kg. If 0.1 kg of milk with specific stored energy (e) of 20.8 kJ/kg is mixed with the coffee, determine (a) the initial stored energy (E_i) of the system, (b) the final stored energy (E_f) of the system, and (c) the final specific energy (e_f) of the system.

SOLUTION

(a) $E_c = m_c e_c; \quad \Rightarrow E_c = (0.5)(104.5); \quad \Rightarrow E_c = 52.25 \text{ kJ}$

(b) $E_f = m_c e_c + m_m e_m; \quad \Rightarrow E_f = (0.5)(104.5) + (0.1)(20.8); \quad \Rightarrow E_f = 54.33 \text{ kJ}$

I $e_f = \dfrac{E_f}{m_f}; \quad \Rightarrow e_f = \dfrac{54.33}{0.5+0.1}; \quad \Rightarrow e_f = 90.55 \ \dfrac{\text{kJ}}{\text{kg}}$

`

1-1-45 [KF] What labels – extensive (0) or intensive (1) can be attached to the following properties: (a) *m*, (b) *v*, (c) *p*, (d) *T*, I ρ, (f) KE, (g) ke, (h) *m*, and (i) *V*?

SOLUTION

(a) m: Extensive
(b) v: Intensive
(c) p: Intensive
(d) T: Intensive
(e) ρ: Intensive
(f) KE: Extensive
(g) ke: Intensive
(h) $\dot{m}$: Extensive
(i) V: Intensive

TEST Solution:

Point the mouse over a property in any state TESTcalc to display more information about the symbol (including property classification) in the message panel located right below the TESTcalc.

`

1-1-46 [KD] What labels - intensive, extensive, total, and flow - can be attached to the following properties: (a) m, (b) $\dot{m}$, (c) S, (d) $\dot{S}$, (e) h, (f) KE, (g) ke, and (h) $\dot{\mathrm{KE}}$?

SOLUTION

(a) m: Extensive, total

(b) $\dot{m}$: Extensive, flow

(c) S: Extensive, total

(d) $\dot{S}$: Extensive, flow

(e) h: Intensive

(f) KE: Extensive, total

(g) ke: Intensive

(h) $\dot{\mathrm{KE}}$: Extensive, flow

TEST Solution:

Point the mouse over a property in any state TESTcalc to display more information about the symbol (including property classification) in the message panel located right below the TESTcalc.

`

1-1-47 [KM] What labels - extrinsic (0) or intrinsic (1) - can be attached to the following properties: (a) u, (b) e, (c) j, (d) KE, (e) ke, (f)s, and (g) S?

SOLUTION

(a) u: Intrinsic
(b) e: Extrinsic (contains V and/or z)
(c) j: Extrinsic (contains V and/or z)
(d) KE: Extrinsic (contains V)
(e) ke: Extrinsic (contains V)
(f) s: Intrinsic
(g) S: Intrinsic

TEST Solution:

Point the mouse over a property in any state TESTcalc to display more information about the symbol (including property classification) in the message panel located right below the TESTcalc.

`

1-1-48 [KJ] What labels - material, thermodynamic, intrinsic, and extrinsic - can be attached to the following properties: (a) *m*, (b) *v*, (c)*p*, (d) *T*, (e) *ρ*, (f) KE, (g) ke, (h) *m*·, and (i) *V*?

SOLUTION

(a) m: Intrinsic

(b) v: Intrinsic, thermodynamic

(c) p: Intrinsic, thermodynamic

(d) T: Intrinsic, thermodynamic

(e) ρ: Intrinsic, thermodynamic

(f) KE: Extrinsic (contains V)

(g) ke: Extrinsic (contains V)

(h) $\dot{m}$: Extrinsic (contains V)

(i) V: Extrinsic

TEST Solution:

Point the mouse over a property in any state TESTcalc to display more information about the symbol (including property classification) in the message panel located right below the TESTcalc.

`

1-1-49 [KW] A rigid tank of volume 10 L contains 0.01 kg of a working substance (the system) in equilibrium at a gauge pressure of 100 kPa. If the outside conditions are 25°C, 101 kPa, (a) how many independent *thermodynamic* properties of the system are supplied? (b) how many *extensive* properties of the system are supplied?

SOLUTION

(a) Independent thermodynamic properties: $2 \ (v \text{ and } p)$

(b) Extensive: $2 \ (\cancel{V} \text{ and } m)$

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1-1-50 [PR] A rigid tank of volume 10 L contains 0.01 kg of a working substance in equilibrium at a gauge pressure of 100 kPa. If the outside pressure is 101 kPa, determine two thermodynamic properties.

SOLUTION

Two independent thermodynamic properties:

$$v = \frac{\cancel{V}}{m}; \quad \Rightarrow v = \frac{10\left(10^{-3}\right)}{0.01}; \quad \Rightarrow v = 1\ \frac{\mathrm{m}^3}{\mathrm{s}}$$

$$p = p_g + p_0; \quad \Rightarrow p = 100 + 101; \quad \Rightarrow p = 201\ \mathrm{kPa}$$

TEST Solution:

The SL (or any other) flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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1-1-51 [PO] A vapor flows through a pipe with a mass flow rate ($\dot{m}$) of 30 kg/min. The following properties are given at a particular cross section, Area: 10 cm^2, Velocity: 60 m/s, Specific flow energy (j): 281.89 kJ/kg. If potential energy is negligible, determine two thermodynamic properties (v and h) for the flow state at the given cross section.

SOLUTION

(a) $\dot{m} = \rho AV = \frac{AV}{v}; \quad \Rightarrow v = \frac{AV}{\dot{m}}; \quad \Rightarrow v = 0.12 \ \frac{\mathrm{m}^3}{\mathrm{kg}}$

(b) $j = h + \mathrm{ke} + \cancel{\mathrm{pe}}^{\,0}; \quad \Rightarrow j = h + \mathrm{ke}; \quad \Rightarrow h = j - \mathrm{ke}; \quad \Rightarrow h = 280.09 \ \frac{\mathrm{kJ}}{\mathrm{kg}}$

TEST Solution:

The PC (or any other) flow-state TESTcalc can be used to verify this solution. Instructions and/or TEST-code can be found (linked under the problem statement) in the Problems module of the professional TEST site at www.thermofluids.net.

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