THERMODYNAMICS PRACTICE PROBLEMS

1. A Carnot refrigerator has a coefficient of performance of 10. If the refrigerator's interior is to be kept at –45°C, the temperature of the refrigerator's high temperature reservoir is most nearly

(A) 250K
(B) 270K
(C) 300K
(D) 350K

Solution

For a refrigerator,

$$\mathrm{COP} = \frac{T_{\mathrm{low}}}{T_{\mathrm{high}} - T_{\mathrm{low}}}$$

Solve for the hot side temperature.

$$\begin{aligned} T_{\mathrm{high}} &= \frac{T_{\mathrm{low}}}{\mathrm{COP}} + T_{\mathrm{low}} = \frac{-45^\circ\mathrm{C} + 273}{10} + (-45^\circ\mathrm{C} + 273) \\ &= 250.8\mathrm{K} \end{aligned}$$

Answer is (A).

2. Helium is compressed isentropically from 1 atmosphere and 5°C to a pressure of 8 atmospheres. The ratio of specific heats for helium is 5/3. What is the final temperature of the helium?

(A) 290°C
(B) 340°C
(C) 370°C
(D) 650°C

Solution

$$\frac{T_2}{T_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1-k}{k}}$$

$$\frac{1-k}{k} = \frac{1-\frac{5}{3}}{\frac{5}{3}} = \frac{3-5}{5} = -0.4$$

$$T_2 = T_1\left(\frac{P_1}{P_2}\right)^{\frac{1-k}{k}} = (5^\circ\text{C}+273)\left(\frac{1\text{ atm}}{8\text{ atm}}\right)^{-0.4}$$
$$= 638.7\text{K} \ \ (366^\circ\text{C})$$

Answer is (C).

3. The thermal efficiency of a Carnot cycle operating between 170°C and 620°C is closest to

(A) 44%
(B) 50%
(C) 63%
(D) 73%

Solution

$$T_{\text{high}} = 620^\circ\text{C} + 273 = 893\text{K}$$

$$T_{\text{low}} = 170^\circ\text{C} + 273 = 443\text{K}$$

$$\eta_{\text{Carnot}} = \frac{T_{\text{high}} - T_{\text{low}}}{T_{\text{high}}} = \frac{893\text{K} - 443\text{K}}{893\text{K}} = 0.504 \quad (50.4\%)$$

Answer is (B).

4. Superheated steam at 4.0 MPa and 275°C expands isentropically to 1.4 MPa. What is the quality factor of the resulting vapor? The data for the steam are as follows.

For 4.0 MPa, 275°C:	$h = 2886.2\,\text{kJ/kg}$; $s = 6.2285\,\text{kJ/kg}\cdot\text{K}$
For 1.4 MPa, dry saturated vapor:	$h_g = 2790.0\,\text{kJ/kg}$; $s_g = 6.4693\,\text{kJ/kg}\cdot\text{K}$
For 1.4 MPa, saturated liquid:	$h_f = 830.3\,\text{kJ/kg}$; $s_f = 2.2842\,\text{kJ/kg}\cdot\text{K}$

(A) 91%
(B) 92%
(C) 93%
(D) 94%

Solution

The entropy is unchanged in an isentropic process.

$$s = xs_g + (1-x)s_f$$

$$6.2285\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}} = x\left(6.4693\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right) + (1-x)\left(2.2842\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)$$

$$4.1851x = 3.9443$$

$$x = 0.9425$$

Answer is (D).

5. A compressor takes atmospheric air (molecular weight of 29 kg/kmol) at 103.4 kPa and 20°C and delivers it at 1.034 MPa and 175°C. The compression process is polytropic. The work required to compress one unit mass of air is most nearly

(A) 50 kJ/kg
(B) 100 kJ/kg
(C) 150 kJ/kg
(D) 200 kJ/kg

Solution

For a process with polytropic exponent n,

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}}$$

$$\frac{20°\text{C} + 273}{175°\text{C} + 273} = \left(\frac{103.4\ \text{kPa}}{1034\ \text{kPa}}\right)^{\frac{n-1}{n}}$$

$$0.6540 = (0.10)^{\frac{n-1}{n}}$$

Take the base-10 logarithm of both sides.

$$\log(0.6540) = \left(\frac{n-1}{n}\right)\log(0.10)$$

$$\frac{n-1}{n} = 0.1844$$

$n = 1.23$

If air's specific gas constant is not known, it can be calculated.

$$R = \frac{\overline{R}}{\text{molecular weight}} = \frac{8.314 \ \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}}{29 \ \frac{\text{kg}}{\text{kmol}}} = 0.2867 \ \text{kJ/kg}\cdot\text{K}$$

$$w = \frac{P_2 v_2 - P_1 v_1}{1-n} = \frac{R(T_2 - T_1)}{1-n}$$

$$= \frac{\left(0.2867 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)(175°\text{C} - 20°\text{C})}{1 - 1.23} = -193.2 \ \text{kJ/kg}$$

Answer is (D).

6. When 1.5 kg of an ideal gas (specific heat at constant volume $= 0.8216 \ \text{kJ/kg}\times\text{K}$) is heated at constant volume to a final temperature of 425°C, the total entropy increase is 0.4386 kJ/K. The initial temperature of the gas is most nearly

(A) 200°C
(B) 210°C
(C) 220°C
(D) 240°C

Solution

The total entropy increase for an ideal gas is

$$\Delta S = m\left(c_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{v_2}{v_1}\right)\right)$$

$$v_2 = v_1$$

$$0.4386 \ \frac{\text{kJ}}{\text{K}} = (1.5 \ \text{kg})\left(\left(0.8216 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)\ln\left(\frac{425°\text{C} + 273}{T_1}\right)\right)$$

$$\ln\left(\frac{698 \ \text{K}}{T_1}\right) = 0.3559$$

Take the antilogarithm of both sides and solve for T_1.

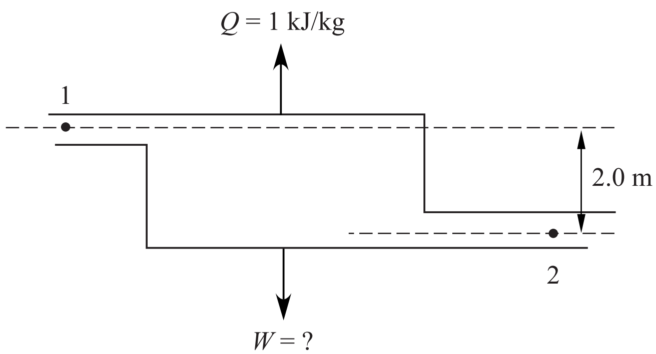
$$T_1 = 489\text{K} \quad (489\text{K} - 273 = 216°\text{C})$$

Answer is (C).

7. Steam enters a turbine with a velocity of 40 m/s and an enthalpy of 3433.8 kJ/kg. At the outlet, 2 meters lower than the inlet, the velocity is 162 m/s, and the enthalpy is 2675.5 kJ/kg. A heat loss of 1 kJ/kg is experienced from the turbine casing. The work output per unit mass is closest to

(A) 650 kJ/kg
(B) 700 kJ/kg
(C) 720 kJ/kg
(D) 750 kJ/kg

Solution



The steady flow energy equation is

$$\dot{W}_{\text{out}} = \dot{m}\left[\left(h_{\text{in}} + \frac{V_{\text{in}}^2}{2} + Z_{\text{in}}g\right) - \left(h_{\text{exit}} + \frac{V_{\text{exit}}^2}{2} + Z_{\text{exit}}g\right)\right] + \dot{Q}_{\text{in}}$$

$$\frac{\dot{W}_{\text{out}}}{\dot{m}} = \left(3433.8\,\frac{\text{kJ}}{\text{kg}} + \frac{\left(40\,\frac{\text{m}}{\text{s}}\right)^2}{(2)\left(1000\,\frac{\text{J}}{\text{kJ}}\right)} + \frac{(2\text{ m})\left(9.81\,\frac{\text{m}}{\text{s}^2}\right)}{1000\,\frac{\text{J}}{\text{kJ}}}\right) - \left(2675.5\,\frac{\text{kJ}}{\text{kg}} + \frac{\left(162\,\frac{\text{m}}{\text{s}}\right)^2}{(2)\left(1000\,\frac{\text{J}}{\text{kJ}}\right)} + 0\right) - 1\,\frac{\text{kJ}}{\text{kg}}$$

$$= 744.9\,\text{kJ/kg}$$

Answer is (D).

8. Compressed carbon dioxide (molecular weight = 44) is kept in a full 0.5 m^3 tank at 100°C and 500 kPa. The mass of the carbon dioxide in the tank is most nearly

(A) 3.0 kg
(B) 3.3 kg
(C) 3.5 kg
(D) 4.1 kg

Solution

The specific gas constant is

$$R = \frac{\bar{R}}{\text{molecular weight}} = \frac{8.314 \ \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}}{44 \ \frac{\text{kg}}{\text{kmol}}} = 0.1890 \ \text{kJ/kg}\cdot\text{K}$$

Use the ideal gas law.

$$PV = mRT$$

$$m = \frac{pV}{RT} = \frac{(500 \ \text{kPa})(0.5 \ \text{m}^3)}{\left(0.1890 \ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)(100°\text{C} + 273)}$$

Answer is (C).

9. A Carnot refrigeration cycle is used to keep a freezer at –5°C. Heat is rejected at 20°C. If the heat removal rate is 30 kW, the COP of the refrigeration cycle is most nearly

(A) 9
(B) 10
(C) 11
(D) 12

Solution

$$T_{\text{high}} = 20°\text{C} + 273 = 293\text{K}$$

$$T_{\text{low}} = -5°\text{C} + 273 = 268\text{K}$$

$$\text{COP} = \frac{T_{\text{low}}}{T_{\text{high}} - T_{\text{low}}} = \frac{268\text{K}}{293\text{K} - 268\text{K}} = 10.7$$

Answer is (C).

10. 0.2 kg of air is heated in a constant volume process from 20°C to 100°C. The specific heat at constant volume is $0.7186\ \text{kJ/kg}\cdot\text{K}$. The change in entropy for the heating process is most nearly

(A) 0.028 kJ/K
(B) 0.033 kJ/K
(C) 0.035 kJ/K
(D) 0.039 kJ/K

Solution

$$\Delta S = m\left(c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right)\right)$$

$$v_2 = v_1$$

$$\begin{aligned}\Delta S &= 0.2\ \text{kg}\left(0.7186\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)\ln\left(\frac{100°\text{C} + 273}{20°\text{C} + 273}\right) \\ &= 0.0347\end{aligned}$$

Answer is (C).