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Chapter 10. Thermodynamic Properties of Substances

Practice Problems

1.

The molar enthalpy of 250°F (120°C) steam with a quality of 92% is most nearly

(A)

16,000 Btu/lbmol (37 MJ/kmol)

(B)

18,000 Btu/lbmol (41 MJ/kmol)

(C)

20,000 Btu/lbmol (46 MJ/kmol)

(D)

22,000 Btu/lbmol (51 MJ/kmol)

2.

The ratio of specific heats for air at 600°F (300°C) is most nearly

(A)

1.33

(B)

1.38

(C)

1.41

(D)

1.67

3.

The density of helium at 600°F (300°C) and one standard atmosphere is most nearly

(A)

0.0052 $lbm/ft^3$ (0.085 $kg/m^3$)

(B)

0.0061 $lbm/ft^3$ (0.098 $kg/m^3$)

(C)

0.0076 lbm/ft$^3$ (0.12 kg/m$^3$)
(D)

0.0095 lbm/ft$^3$ (0.15 kg/m$^3$)
4.

What is the thermodynamic state of water at 600°F and 300 psia?

(A)

subcooled liquid

(B)

saturated vapor

(C)

superheated vapor

(D)

real or ideal gas

5.

106°F water flows in a closed feedwater heater. At the pressure in the feedwater heater, water has a saturation temperature of 293°F and a saturation enthalpy of 262 Btu/lbm. What is most nearly the enthalpy of the water?

(A)

75 Btu/lbm

(B)

110 Btu/lbm

(C)

120 Btu/lbm

(D)

130 Btu/lbm

6.

A 25% mixture (by volume) of ethylene glycol and water is used in a solar heating application. The mixture is intended to operate at standard atmospheric pressure and an average temperature of 150°F. At 150°F, ethylene glycol has a specific gravity of 1.11 (based on 60°F water) and a specific heat of 0.63 Btu/lbm-°F. What is most nearly the specific heat of the mixture at 150°F?

(A)

0.892 Btu/lbm-°F

(B)

0.899 Btu/lbm-°F

(C)

0.908 Btu/lbm-°F

(D)

0.913 Btu/lbm-°F

Solutions

1.

*Customary U.S. Solution*

From appendixMERM24A (also *NCEES Handbook:* Properties of Saturated Steam (U.S. Customary Units)), for 250°F steam, the enthalpy of saturated liquid, $h_f$, is 218.6 Btu/lbm. The heat of vaporization, $h_{fg}$, is 945.4 Btu/lbm. The enthalpy is given by equationMERM24040 (also *NCEES Handbook:* Properties for Two-Phase (Vapor-Liquid) Systems).

$$\begin{aligned} h &= h_f + xh_{fg} = 218.6\ \frac{\text{Btu}}{\text{lbm}} + (0.92)\left(945.4\ \frac{\text{Btu}}{\text{lbm}}\right) \\ &= 1088.4\ \text{Btu/lbm} \end{aligned}$$

As in *NCEES Handbook* table "Temperature-Independent Properties of Liquids and Gases (U.S. Units)," the molecular weight of water is 18 lbm/lbmol. The molar enthalpy is given by equationMERM24014.

$$\begin{aligned} H &= (\text{MW})h = \left(18\ \frac{\text{lbm}}{\text{lbmol}}\right)\left(1088.4\ \frac{\text{Btu}}{\text{lbm}}\right) \\ &= 19{,}591\ \text{Btu/lbmol} \quad (20{,}000\ \text{Btu/lbmol}) \end{aligned}$$

*The answer is (C).*

*SI Solution*

From appendixMERM24N (also *NCEES Handbook:* Saturated Steam (SI Units), for 120°C steam, the enthalpy of saturated liquid, $h_f$, is 503.81 kJ/kg. The heat of vaporization, $h_{fg}$, is 2202.1 kJ/kg. The enthalpy is given by equationMERM24040 (also *NCEES Handbook:* Properties for Two-Phase (Vapor-Liquid) Systems).

$$\begin{aligned} h &= h_f + xh_{fg} = 503.81\ \frac{\text{kJ}}{\text{kg}} + (0.92)\left(2202.1\ \frac{\text{kJ}}{\text{kg}}\right) \\ &= 2529.7\ \text{kJ/kg} \end{aligned}$$

As in *NCEES Handbook* table "Temperature-Independent Properties of Liquids and Gases (SI Units)," the molecular weight of water is 18 kg/kmol. Molar enthalpy is given by equationMERM24014.

$$\begin{aligned} H &= \text{MW} \times h = \left(18\ \frac{\text{kg}}{\text{kmol}}\right)\left(2529.7\ \frac{\text{kJ}}{\text{kg}}\right) \\ &= 45\,535\ \text{kJ/kmol} \quad (46\ \text{MJ/kmol}) \end{aligned}$$

*The answer is (C).*

2.

*Customary U.S. Solution*

As in *NCEES Handbook:* Temperature, the absolute temperature is

$$600^\circ\text{F} + 460^\circ = 1060^\circ\text{R}$$

From tableCERM24001 (also *NCEES Handbook:* Temperature-Dependent Properties of Air (U.S. Customary Units)), the specific heat at constant pressure for air at 1060°R is

$$c_p = 0.250\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{R}}$$

From equationMERM24095(b) (also *NCEES Handbook:* Ideal Gas Law),

$$\begin{aligned} c_v &= c_p - \frac{R}{J} \\ &= 0.250\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{R}} - \frac{1545.35\ \frac{\text{ft-lbf}}{\text{lbmol-}^\circ\text{R}}}{\left(778\ \frac{\text{ft-lbf}}{\text{Btu}}\right)\left(28.967\ \frac{\text{lbm}}{\text{lbmol}}\right)} \\ &= 0.1814\ \text{Btu/lbm-}^\circ\text{R} \end{aligned}$$

The ratio of specific heats is given by equationMERM24028.

$$\begin{aligned} k = \frac{c_p}{c_v} &= \frac{0.250\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{R}}}{0.1814\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{R}}} \\ &= 1.378 \quad (1.38) \end{aligned}$$

*The answer is (B).*

*SI Solution*

From tableCERM24001 (also *NCEES Handbook:* Temperature-Dependent Properties of Air (SI Units)), the specific heat at constant pressure for air is

$$c_p = 1.047\ \text{kJ/kg·K}$$

From equationMERM24095(a) (also *NCEES Handbook:* Ideal Gas Law),

$$\begin{aligned} c_v &= c_p - \frac{R}{J} \\ &= \left(1.047\ \frac{\text{kJ}}{\text{kg·K}}\right)\left(1000\ \frac{\text{J}}{\text{kJ}}\right) - \frac{8.3145\ \frac{\text{J}}{\text{mol·K}}}{0.0289\ \frac{\text{kg}}{\text{mol}}} \\ &= 760\ \text{J/kg·K} \end{aligned}$$

The ratio of specific heats is given by equationMERM24028.

$$\begin{aligned} k = \frac{c_p}{c_v} &= \frac{\left(1.047\ \frac{\text{kJ}}{\text{kg·K}}\right)\left(1000\ \frac{\text{J}}{\text{kJ}}\right)}{760\ \frac{\text{J}}{\text{kg·K}}} \\ &= 1.377 \quad (1.38) \end{aligned}$$

*The answer is (B).*
3.

*Customary U.S. Solution*

As in *NCEES Handbook:* Temperature, the absolute temperature is

$$600^\circ\text{F} + 460^\circ = 1060^\circ\text{R}$$

From equationMERM24050 (also *NCEES Handbook:* Ideal Gas Law), the density of helium is

$$\begin{aligned} \rho &= \frac{p}{RT} = \frac{\left(14.7\ \frac{\text{lbf}}{\text{in}^2}\right)\left(12\ \frac{\text{in}}{\text{ft}}\right)^2\left(4\ \frac{\text{lbm}}{\text{lbmol}}\right)}{\left(1545.35\ \frac{\text{ft-lbf}}{\text{lbmol-}^\circ\text{R}}\right)(1060^\circ\text{R})} \\ &= 0.00517\ \text{lbm/ft}^3 \quad \left(0.0052\ \text{lbm/ft}^3\right) \end{aligned}$$

*The answer is (A).*

*SI Solution*

As in *NCEES Handbook:* Temperature, the absolute temperature is

$$300^\circ\text{C} + 273^\circ = 573\text{K}$$

From equationMERM24050 (also *NCEES Handbook:* Ideal Gas Law), the density of helium is

$$\begin{aligned}\rho &= \frac{p}{RT} = \frac{(101\,300\ \text{Pa})\left(4\ \frac{\text{g}}{\text{mol}}\right)}{\left(8314.5\ \frac{\text{J}}{\text{kmol·K}}\right)(573\text{K})} \\ &= 0.085\ \text{kg/m}^3\end{aligned}$$

*The answer is (A).*
4.

As in *NCEES Handbook* table "Superheated Steam (U.S. Units)" the saturation temperature for 300 psia steam is 417°F, so since the water's temperature is higher than this, the water is either a superheated vapor or a gas. The critical temperature for water is 705°F, so the water can't be considered a gas. Therefore, it is a superheated vapor.

The answer is (C).

5.

Since the pressure of the water in the feedwater heater is not given, a subcooled liquid table can't be used directly. (The saturation temperature could be used to find the pressure, however, if this approach was taken.) As in *NCEES Handbook* table "Physical Properties of Liquid Water (U.S. Units)" the specific heat of liquid water is approximately 1 Btu/lbm-°F, which is the reason that saturated liquid enthalpy and saturation temperature have essentially the same numerical values. Calculate the subcooled enthalpy by subtracting the sensible heat from 106°F to 293°F.

$$\begin{aligned}h_{106^\circ\text{F}} &= h_{\text{saturation}} - c_p\left(T_{\text{saturation}} - T\right) \\ &= 262\ \frac{\text{Btu}}{\text{lbm}} - \left(1\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right)(293^\circ\text{F} - 106^\circ\text{F}) \\ &= 75\ \text{Btu/lbm}\end{aligned}$$

The answer is (A).

6.

Use a saturated steam table, such as appendixMERM24A (also *NCEES Handbook* table "Properties of Saturated Steam (U.S. Units)—Temperature Table") to get the properties of 150°F water. The specific volume is the reciprocal of the density. Since $\Delta h = c_p \Delta T$, the specific heat can be found from the change in enthalpy over a known temperature range. Use the saturation enthalpies at 140°F and 160°F.

$$\begin{aligned}\rho &= \frac{1}{v_f} \\ &= \frac{1}{0.01634\ \frac{\text{ft}^3}{\text{lbm}}} \\ &= 61.20\ \text{lbm/ft}^3\end{aligned}$$

$$\begin{aligned}c_{p,\text{water}} &= \frac{h_{\text{sat},T_2} - h_{\text{sat},T_1}}{T_2 - T_1} \\ &= \frac{128.00\ \frac{\text{Btu}}{\text{lbm}} - 107.99\ \frac{\text{Btu}}{\text{lbm}}}{160^\circ\text{F} - 140^\circ\text{F}} \\ &= 1.00\ \text{Btu/lbm-}^\circ\text{F}\end{aligned}$$

Specific heats of liquid mixtures are gravimetrically weighted.

Consider 1 $ft^3$ of mixture, containing 0.25 $ft^3$ of ethylene glycol and 1 – 0.25 $ft^3$ = 0.75 $ft^3$ water. The gravimetric fraction of ethylene glycol, $G_{\text{glycol}}$, in the mixture is

$$\begin{aligned} G_{\text{glycol}} &= \frac{m_{\text{glycol}}}{m_{\text{glycol}} + m_{\text{water}}} \\ &= \frac{\text{SG}_{\text{glycol}}\rho_{\text{water},60^\circ\text{F}}V_{\text{glycol}}}{\text{SG}_{\text{glycol}}\rho_{\text{water},60^\circ\text{F}}V_{\text{glycol}} + \rho_{\text{water},150^\circ\text{F}}V_{\text{water}}} \\ &= \frac{(1.11)\left(62.4\ \frac{\text{lbm}}{\text{ft}^3}\right)(0.25\ \text{ft}^3)}{\begin{array}{l}(1.11)\left(62.4\ \frac{\text{lbm}}{\text{ft}^3}\right)(0.25\ \text{ft}^3) \\ \quad + \left(61.2\ \frac{\text{lbm}}{\text{ft}^3}\right)(0.75\ \text{ft}^3)\end{array}} \\ &= 0.274 \end{aligned}$$

The gravimetric fraction of water in the mixture is

$$G_{\text{water}} = 1 - G_{\text{glycol}} = 1 - 0.274 = 0.726$$

The specific heat of the mixture is

$$\begin{aligned} c_{p,\text{mixture}} &= G_{\text{glycol}}c_{p,\text{ glycol}} + G_{\text{water}}c_{p,\text{water}} \\ &= (0.274)\left(0.63\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right) \\ &\quad + (0.726)\left(1.00\ \frac{\text{Btu}}{\text{lbm-}^\circ\text{F}}\right) \\ &= 0.899\ \text{Btu/lbm-}^\circ\text{F} \end{aligned}$$

The answer is (B).