Six-Minute Solutions

for Chemical PE Exam Problems

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Problems

MASS/ENERGY BALANCES AND THERMODYNAMICS

PROBLEM 1

A perfectly insulated covered tank maintained at atmospheric pressure is 10 ft high and 16.5 ft in diameter. The tank is half-filled with water at 80°F. The density of water at this temperature is 62.21 lbm/ft^3. The heat capacity of liquid water is 1.0 Btu/lbm-°F. The heat of vaporization of water at 212°F is 970.3 Btu/lbm. The heat capacity of the water vapor is 0.48 Btu/lbm-°F. The enthalpy change of the water as a result of a temperature change from 80°F to 350°F is most nearly

(A) 13×10^6 Btu
(B) 69×10^6 Btu
(C) 78×10^6 Btu
(D) 160×10^6 Btu

Hint: Calculate the enthalpy change as the temperature of the water increases from 80°F to 212°F. Then calculate the enthalpy change as the water evaporates completely and the enthalpy change as the temperature of the water vapor increases to 350°F.

PROBLEM 2

Dry air and vinyl chloride (C_2H_3Cl) are combined to produce a saturated mixture at 14.3 lbf/in^2 and 77°F. At this temperature, the vapor pressure of vinyl chloride is 5.77 lbf/in^2. The average molecular weight of vinyl chloride and dry air are 62.50 lbm/lbmol and 28.96 lbm/lbmol, respectively. Assume the ideal gas law applies. The mass ratio of vinyl chloride to dry air in the saturated mixture is most nearly

(A) 0.676
(B) 1.06
(C) 1.40
(D) 1.46

Hint: Calculate the mole fraction of vinyl chloride using the vapor pressure of vinyl chloride and the total pressure. Use the molecular weights of vinyl chloride and air to convert the mole fraction to the mass ratio.

PROBLEM 3

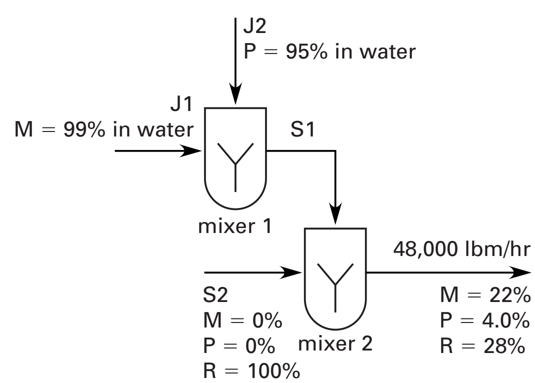
Dry air and vinyl chloride (C_2H_3Cl) are mixed to produce a saturated mixture at 3739 mm Hg and 20°C. At this temperature, the vapor pressure of vinyl chloride is 2580 mm Hg. The average molecular weights of vinyl chloride and dry air are 62.50 g/mol and 28.96 g/mol, respectively. Assume the ideal gas law applies. In 100 cm^3 of saturated mixture, the mass of vinyl chloride is most nearly

(A) 0.0088 g
(B) 0.41 g
(C) 0.88 g
(D) 13 g

Hint: Use the ideal gas law to calculate the density of vinyl chloride.

PROBLEM 4

A process stream consisting of 22% M (by weight), 4.0% P (by weight), and 28% R (by weight) in water at 48,000 lbm/hr is produced by mixing two streams, S1 and S2. Stream S1 is produced in mixer 1 by mixing two streams, J1 and J2. Stream J1 is 99% M (by weight) in water, and stream J2 is 95% P (by weight) in water. Stream S2 is 100% R. There is no M or P in stream S2.



The percentage of component P in stream S1 is most nearly

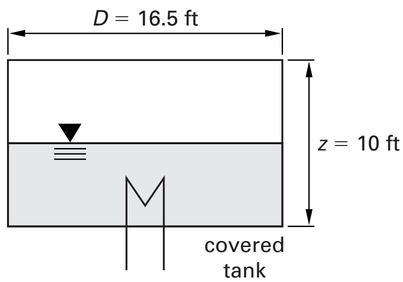
(A) 2.0%
(B) 15%
(C) 46%
(D) 83%

Hint: The mass flow rate of component P in stream S1 must equal the mass flow rate of P in the desired product because S1 is the sole source of P in the desired product. Performing a mass balance around mixer 1 yields the mass flow rate of S1.

Solutions

MASS/ENERGY BALANCES AND THERMODYNAMICS

SOLUTION 1



The volume of the tank is

$$V = \left(\frac{\pi D^2}{4}\right) z = \left(\frac{\pi\,(16.5\text{ ft})^2}{4}\right)(10\text{ ft})$$
$$= 2138\text{ ft}^3$$

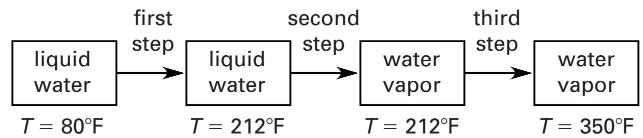
Because the tank is half-filled, the volume occupied by the water in the tank is

$$V_{\text{H}_2\text{O}} = \frac{V}{2} = \frac{2138\text{ ft}^3}{2}$$
$$= 1069\text{ ft}^3$$

The density of water, ρ, is given as 62.21 lbm/ft^3. The mass of water in the tank is

$$m = \rho V_{\text{H}_2\text{O}} = \left(62.21\ \frac{\text{lbm}}{\text{ft}^3}\right)\left(1069\text{ ft}^3\right)$$
$$= 66{,}500\text{ lbm}$$

Because enthalpy is a function of state, the entire process may be considered as if it happened in three steps. In the first step, the liquid water goes from a temperature of 80°F to 212°F and there are no phase transitions. The enthalpy change of the liquid water in the first step is calculated as the enthalpy change of liquid water going from 80°F to 212°F. The second step involves an isothermal change of phase from liquid at 212°F to vapor at 212°F. The enthalpy change in the second step is identical to the heat of vaporization. In the last step, the water vapor at 212°F goes to water vapor at 350°F.



For the first step, the enthalpy change per pound of the liquid water from 80°F to 212°F is

$$\Delta h_{80\to 212} = c_{p,l}\,(T_{212} - T_{80})$$
$$= \left(1\ \frac{\text{Btu}}{\text{lbm-°F}}\right)(212\text{°F} - 80\text{°F})$$
$$= 132\text{ Btu/lbm}$$

In the second step, the enthalpy change equals the heat of vaporization of the water at 212°F because this step involves a change of phase at constant temperature.

The heat of vaporization of water at 212°F, ΔH_{212}, is given as 970.3 Btu/lbm. In the third step, the enthalpy change per pound of the water vapor from 212°F to water vapor at 350°F is

$$\Delta h_{212\to 350} = c_{p,v}(T_{350} - T_{212})$$
$$= \left(0.48\ \frac{\text{Btu}}{\text{lbm-°F}}\right)(350\text{°F} - 212\text{°F})$$
$$= 66.24\text{ Btu/lbm}$$

The enthalpy changes for the individual steps sum to give the total enthalpy change. The total enthalpy change per pound of water from 80°F to 350°F is

$$\Delta h_{80\to 350} = \Delta h_{80\to 212} + \Delta h_{212} + \Delta h_{212\to 350}$$
$$= 132\ \frac{\text{Btu}}{\text{lbm}} + 970.3\ \frac{\text{Btu}}{\text{lbm}} + 66.24\ \frac{\text{Btu}}{\text{lbm}}$$
$$= 1168.54\text{ Btu/lbm}$$

The total enthalpy change is

$$(\Delta h_{80\to 350})\,m = \left(1168.54\ \frac{\text{Btu}}{\text{lbm}}\right)(66{,}500\text{ lbm})$$
$$= 78\times 10^6\text{ Btu}$$

The answer is (C).