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Sample: Molecular Physics Thermodynamics - Thermodynamics Final

1. The specific internal energy (u) of a system is 411.7 Joule/kg. Express this value in the following units:

a) Btu/lbm

b) kcal/kg

c) kW-hr/lbm

d) ft-lbf /lbm

Solution

a) $411.7\frac{\text{Joule}}{\text{kg}} = 411.7 \cdot \frac{0.00094783\, Btu}{2.2046\, lbm} = 0.177\frac{\text{Btu}}{\text{lbm}}.$

b) $411.7\frac{\text{Joule}}{\text{kg}} = 411.7 \cdot \frac{0.00023885\, kcal}{\text{kg}} = 0.098\frac{kcal}{kg}.$

c) $411.7\frac{\text{Joule}}{\text{kg}} = 411.7 \cdot \frac{\frac{1}{3600000}\text{kW-hr}}{2.2046\, lbm} = 0.00005187\frac{kW\text{-}hr}{lbm}.$

d) $411.7\frac{\text{Joule}}{\text{kg}} = 411.7 \cdot \frac{0.73756\text{ ft-lbf}}{2.2046\, lbm} = 137.74\frac{\text{ft-lbf}}{lbm}.$

2. Two cubic feet of a liquid-vapor mixture of motor oil at 70°F and 14.7 psia weighs 97.28 lbf. List the values of three intensive and two extensive properties of the oil.

Solution:

Intensive properties:

Temperature of a liquid-vapor mixture of motor oil

$$T = 70°\text{F} = \frac{5}{9}(70 - 32)°\text{C} = 21.1°\text{C}.$$

Density of a liquid-vapor mixture of motor oil

$$\rho = \frac{m}{V} = \frac{44.15\, kg}{0.056634\, m^3} = 780\frac{kg}{m^3}.$$

Pressure of a liquid-vapor mixture of motor oil

$$P = 14.7\, psia = 14.7 \cdot 6894.8\, Pa = 101353\, Pa.$$

Extensive properties:

Mass of a liquid-vapor mixture of motor oil

$$m = \frac{W}{g} = \frac{97.28\text{ lbf}}{9.8\frac{m}{s^2}} = \frac{97.28 \cdot 4.4482\, N}{9.8\frac{m}{s^2}} = 44.15\, kg.$$

Volume of a liquid-vapor mixture of motor oil:

$$V = 2\, ft^3 = 2 \cdot 0.028317\, m^3 = 0.056634\, m^3.$$

3. Define the following terms:

a) Specific heat at constant pressure

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$$c_p = \left(\frac{\partial h}{\partial T}\right)_p,$$

where h is the specific enthalpy of the system, $p = const$ is a pressure of the system, T is the temperature of the system.

b) Specific heat at constant volume

$$c_V = \left(\frac{\partial u}{\partial T}\right)_V,$$

where u is the specific internal energy of the system, $V = const$ is a volume of the system, T is the temperature of the system.

c) Critical point

The critical point or critical state is the point at which two phases of a substance initially become indistinguishable from one another.

d) Triple point

Triple Point is the temperature and pressure at which solid, liquid, and vapor phases of a particular substance coexist in equilibrium.

e) Saturation

The saturation is a condition in which mixture of vapor and liquid can exist together at a given temperature and pressure. The temperature at which vaporization starts to occur for a given pressure is called the saturation temperature or boiling point. The pressure at which vaporization starts to occur for a given temperature is called the saturation pressure. For pure substances there is a definite relationship between saturation pressure and saturation temperature. The graphical representation of this relationship between saturation pressure and saturation temperature is called the vapor pressure curve.

4. Helium gas is heated in a constant volume process from -200 to 500 oF. Using Table 3.7 to obtain specific heat values for helium and assuming ideal gas behavior, determine:

a) The ratio of the final to initial pressure

Initial temperature of helium gas is $T_i = \frac{5}{9}(-200 + 459.67)K = 144.26\ K.$

Final temperature of helium gas is $T_f = \frac{5}{9}(500 + 459.67)K = 533.15\ K.$

According to Gay-Lussac's law the pressure of an ideal gas of fixed volume is proportional to its temperature:

$$\frac{P_f}{T_f} = \frac{P_i}{T_i} \rightarrow \frac{P_f}{P_i} = \frac{T_f}{T_i} = \frac{533.15}{144.26} = 3.7.$$

b) The change in specific internal energy

$$\Delta u = c_V(T_f - T_i) = 3.123\frac{kJ}{kgK} \cdot (533.15 - 144.26)K = 1214.5\frac{kJ}{kg}.$$

c) The change in specific enthalpy

$$\Delta h = c_P(T_f - T_i) = 5.200\frac{kJ}{kgK}\cdot(533.15 - 144.26)K = 2022.2\frac{kJ}{kg}.$$

5. 200 Btu are transported into a system via a work mode and 75 Btu are removed via heat transfer mode. Determine the net energy gain for this system.

Solution:

Net energy gain is the difference between work transported into the system and heat removed from the system:

$$E_G = W - Q = 200\text{ Btu} - 75\text{ Btu} = 125\text{ Btu} = 125\cdot 1055.05\text{ J} = 131.88\text{ kJ}.$$

6. A sealed rigid tank contains 5.0 kg of water (liquid plus vapor) at 100 oC with a quality of 30.375%. Using the Thermodynamic Tables that accompany the textbook and the relationship between quality and other thermodynamic properties:

a) Calculate the specific volume of the water.

Using Table A–4: at 100°C $v_f = 0.001043\frac{m^3}{kg}$, $v_g = 1.6720\frac{m^3}{kg}$. The specific volume of the water is

$$v = v_f + xv_{fg} = v_f + x(v_g - v_f) = 0.001043\frac{m^3}{kg} + 0.30375\left(1.6720\frac{m^3}{kg} - 0.001043\frac{m^3}{kg}\right)$$
$$= 0.50860\frac{m^3}{kg}.$$

b) Determine the mass of water in the vapor phase.

$$m_g = x\cdot m = 0.30375\cdot 5.0\text{ kg} = 1.5\text{ kg}.$$

c) Determine the saturation pressure and temperature of this water if it had the specific volume calculated in part (a) and a quality of 100%.

A quality of 100% means that the mixture is pure vapor

$$v = v_g.$$

Using Table A–4: the saturation pressure is $P_{sat} = 361.53\ kPa$ and the saturation temperature $T_{sat} = 140°\text{C}$.

d) Determine the amount of heat transfer required to completely condense the saturated vapor determined in part (c) into a saturated liquid.

The amount of work required to completely condense the saturated vapor into a saturated liquid

$$W_{in} = -W_{out} = -P_{sat}(v_f - v_g)m = P_{sat}(v_g - v_f)m$$
$$= 361.53\ kPa\cdot\left(0.50860\frac{m^3}{kg} - 0.001080\frac{m^3}{kg}\right)\cdot 5.0\text{ kg} = 917.42\text{ kJ}.$$

7. The pressure in an isochoric automobile tire increases from 28.0 psia at 70.0 oF to 35.0 psia on a trip during hot weather. Assume the air behaves as an ideal gas with cv = 0.171 Btu/lbm-R.

a) Determine the air temperature inside the tire at the end of the trip.

Initial temperature of the air is $T_i = \frac{5}{9}(70 + 459.67)K = 294.26\,K$.

According to Gay-Lussac's law the pressure of an ideal gas of fixed volume is proportional to its temperature:

$$\frac{P_f}{T_f} = \frac{P_i}{T_i} \to T_f = T_i \frac{P_f}{P_i} = 294.26\,K \cdot \frac{35.0 \text{ psia}}{28.0 \text{ psia}} = 367.83K.$$

b) <u>Determine how much heat was absorbed per unit mass of air in the tire during the trip.</u>

$$c_V = 0.171 \frac{Btu}{lbm°R} = 0.171 \cdot 4186.8 \frac{J}{kg \cdot K} = 716 \frac{J}{kgK}.$$

Heat that was absorbed per unit mass of air in the tire during the trip (the change in specific internal energy) is

$$u = c_V(T_f - T_i) = 716 \frac{J}{kgK} \cdot (367.83K - 294.26\,K) = 52.68 \frac{kJ}{kg}.$$

8. A heat engine operates as a reversible Carnot cycle transfers 6.0 kW of heat from a reservoir at 1000 K and then rejects it to the atmosphere at 300 K.

a) <u>Calculate the thermal efficiency of this engine.</u>

The thermal efficiency of engine which operates as a reversible Carnot cycle is

$$\eta = 1 - \frac{T_C}{T_H},$$

where $T_H = 1000$ K is the temperature of reservoir, $T_C = 300\,K$ is the temperature of the atmosphere. So

$$\eta = 1 - \frac{300\,K}{1000 \text{ K}} = 0.7.$$

b) <u>Calculate the power output of this engine.</u>

The power output of this engine is

$$P_{\text{out}} = \eta \frac{dQ_H}{dt} = 0.7 \cdot 6.0 \text{ kW} = 4.2 \text{ kW}$$

where Q_H - is the heat put into the system from a reservoir.

9. Write the energy rate balance (ERB) equation for the following components in a Carnot (reversible Rankin) power cycle. Neglect kinetic and potential energy terms (since their contribution is negligible) and assume steady state and steady flow conditions:

Solution

All four components associated with Carnot power cycle (boiler feed pump, boiler, turbine and condenser) are steady-flow devices, and thus all four processes that make up the reversible Carnot cycle can be analyzed as steady – flow process.

The steady flow equation per unit mass of steam reduces to

$$(\dot{Q}_{in} - \dot{Q}_{out}) + (\dot{W}_{in} - \dot{W}_{out}) = \dot{H}_e - \dot{H}_i.$$

Boiler feed pump.

Pump power $\dot{W}_{p,in}$ becomes

$$\dot{W}_{p,in} = 1.00\ kW = \dot{m}(h_1 - h_4) = \dot{m}v_4(P_1 - P_4)$$

where v_4 is the specific volume at state 4 that is saturated liquid water, P_i is the pressure at the state i.

Enthalpy rate at state 1,

$$\dot{H}_1 = \dot{H}_4 + \dot{W}_{p,in}.$$

Boiler.

The heat rate input to the pressurized water in the boiler is

$$\dot{Q}_{in} = \dot{m}(h_2 - h_1) = \dot{H}_2 - \dot{H}_1.$$

Turbine.

Power producing in turbine is

$$\dot{W}_{t,out} = 5\ MW = \dot{m}(h_3 - h_4) = \dot{H}_3 - \dot{H}_4.$$

Condenser

The discharged heat rate at the condenser is

$$\dot{Q}_{out} = 8\ MW = \dot{m}(h_4 - h_3) = \dot{H}_4 - \dot{H}_3.$$