Problems for FE Thermodynamics Review

1. A 300-m$^3$ rigid tank is filled with saturated liquid-vapor mixture of water at 200 kPa. If 75 percent of the mass is vapor, the total mass in the tank is:

   (a) 331 kg  
   (b) 556 kg  
   (c) 300 kg  
   (d) 451 kg  
   (e) 195 kg

\[ V_{\text{tank}} = 300 \text{ m}^3; \quad P = 200 \text{ kPa}; \quad x = 0.75; \quad v = v_f + x v_{fg} = 0.6646 \text{ m}^3/\text{kg} \]
\[ m = \frac{V_{\text{tank}}}{v} = 451 \text{ kg} \]

2. The pressure of an automobile tire is measured to be 190 kPa (gage) before a trip and 215 kPa (gage) after the trip, both at a location where the local atmospheric pressure is 95 kPa. If the air temperature in the tire is 25 °C before the trip, the air temperature after the trip is:

   (a) 27.2 °C  
   (b) 64.2 °C  
   (c) 51.1 °C  
   (d) 28.3 °C  
   (e) 25.0 °C

3. A fan is to accelerate quiescent air to a velocity of 12 m/s at a rate of 3 m$^3$/min. If the density of air is 1.156 kg/m$^3$, the minimum power that must be supplied to the fan is:

   (a) 4.14 W  
   (b) 1.2 W  
   (c) 9.2 W  
   (d) 4.04 W  
   (e) 2.3 W

\[ V_{\dot{}} = 3 \text{ m}^3/\text{min} = 0.05 \text{ m}^3/\text{sec}; \quad m_{\dot{}} = \rho \times V_{\dot{}} = 0.0575 \text{ kg/s} \]
\[ \text{Steady state energy balance:} \quad \frac{dE}{dt} = 0 = Q_{\dot{}} - W_{\dot{}} + m_{\dot{}} \left( h_i - h_e + \frac{1}{2} V_i^2 - \frac{1}{2} V_e^2 \right) \]
Assuming state of air (inlet vs. exit) does not change \( h_i - h_e = 0 \), energy balance is:
\[ W_{\dot{}} = m_{\dot{}} \left( \frac{1}{2} V_i^2 - \frac{1}{2} V_e^2 \right). \]
\( V_i \) is negligible.
\[ W_{\dot{}} = -\frac{1}{2} m_{\dot{}} V_e^2 = -4.14 \text{ W}. \] (Negative power means work is done on the system)

4. Water is boiling at 1 atm pressure in a stainless steel pan on an electric range. It is observed that 2 kg of the liquid water evaporates in 30 min. The rate of heat transfer to the water is:

   (a) 2.51 kW  
   (b) 2.32 kW  
   (c) 2.97 kW  
   (d) 0.47 kW  
   (e) 3.12 kW

Control mass is the 2kg that goes from sat. liquid to sat. vapor:
Energy balance: Combine $P \Delta v$ work with $\Delta u$ to get $\Delta h$. Change in enthalpy is $h_{fg}$:
\[ m_{\text{evap}} \times h_{fg} = Q_{\dot{}} \times t \]
\[ m_{\text{evap}} = 2 \text{ kg}; \quad P = 101.325 \text{ kPa}; \quad \text{time} = 1800 \text{ sec}; \]
\[ h_{fg} = 888.99 \text{ kJ/kg}; \quad Q_{\dot{}} = m_{\text{evap}} \times h_{fg} / \text{time} = 2.51 \text{ kg*(kJ/kg)/s} = 2.51 \text{ kW} \]
5. A 0.5-m³ cylinder contains nitrogen gas at 600 kPa and 300 K. Now the gas is compressed isothermally to a volume of 0.1 m³. The work done on the gas during this compression process is:

(a) 720 kJ  (b) 483 kJ  (c) 240 kJ  (d) 175 kJ  (e) 143 kJ

6. A well-sealed room contains 60 kg of air at 200 kPa and 25 °C. Now solar energy enters the room at an average rate of 0.8 kJ/s while a 120-W fan is turned on to circulate air in the room. If heat transfer through the walls is negligible, the air temperature in the room in 30 min. will be:

(a) 25.6 °C  (b) 49.8 °C  (c) 53.4 °C  (d) 52.5 °C  (e) 63.4 °C

Energy balance: \( \Delta U = Q_{\text{dot,solar}} - W_{\text{dot,fan}} \Delta t \)

\[ Q_{\text{dot,solar}} = 0.8 \text{ kJ/s} \]
\[ W_{\text{dot,fan}} = -0.120 \text{ kJ/s} \]
\[ C_v = 0.717 \text{ kJ/kg-K} \]
\[ \Delta t = 1800 \text{ s} \]

\[ T_2 = T_1 + \left( Q_{\text{dot,solar}} - W_{\text{dot,fan}} \right) \Delta t / m/C_v \]

\[ = 25 \degree C + \left( 0.8 + 0.120 \text{ kJ/s} \right) \times 1800 \text{s} / 60 \text{ kg} / 0.717 \text{ kJ/kg-K} = 63.4 \degree C \]

7. A 2-kW electric resistance heater submerged in 5-kg water is turned on and kept on for 10 min. During the process, 300 kJ heat is lost from the water. The temperature rise of the water is:

(a) 0.4 °C  (b) 43.1 °C  (c) 57.4 °C  (d) 71.8 °C  (e) 180 °C

\[ \Delta U = Q_{\text{loss}} - W_{\text{heater}} = -300 \text{ kJ} - W_{\text{dot,heater}} \Delta t = -300 \text{ kJ} - \left( -2 \text{ kW} \times 600 \text{s} \right) = 900 \text{ kJ} \]

\[ \Delta U = mC \Delta T = 5 \text{ kg} \times 4.18 \text{ kJ/kg-K} \times \Delta T \]

\[ \Delta T = 900 \text{ kJ} / 5 \text{ kg} / 4.18 \text{ kJ/kg-K} = 43.1 \degree C \]

8. In a heating system, cold outdoor air at 7°C flowing at a rate of 4 kg/min is mixed adiabatically with heated air at 70°C flowing at a rate of 3 kg/min. The exit temperature of the mixture is:

(a) 34 °C  (b) 39 °C  (c) 45 °C  (d) 63 °C  (e) 77 °C
9. Steam is compressed by an adiabatic compressor from 0.2 MPa and 150 °C to 0.8 MPa and 350 °C at a rate of 1.30 kg/s. The power input to the compressor is:

(a) 511 kW  (b) 393 kW  (c) 302 kW  (d) 717 kW  (e) 901 kW

Steady state energy balance for control volume:
\[ \frac{dE}{dt} = 0 = Q_{dot} - W_{dot} + m_{dot}(h_i - h_e) \]

adiabatic: \( Q_{dot} = 0; \quad W_{dot} = m_{dot}(h_i - h_e) = 1.30 \text{ kg/s}\cdot(2769 \text{ kJ/kg} - 3162.2) \)

\[ W_{dot} = -511 \text{ kW} \]

10. Refrigerant R-134a at 1.4 MPa and 90 °C is throttled to a pressure of 0.6 MPa. The temperature of the refrigerant after throttling is:

(a) 22°C  (b) 56°C  (c) 82°C  (d) 80°C  (e) 90°C

11. Steam is condensed at a constant temperature of 30°C as it flows through the condenser of a power plant by rejecting heat at a rate of 55 MW. The rate of entropy change of steam as it flows through the condenser is:

(a) -1.83 MW/K  (b) -0.18 MW/K  (c) 0 MW/K  (d) 0.56 MW/K  (e) 1.22 MW/K

\[ \frac{dS}{dt} = \frac{Q}{T} + m_{dot}(s_e - s_i) + S_{gen}; \quad \text{Steady state: } \frac{dS}{dt} = 0 \]

If heat transfer takes place at 30°C, it is internally reversible: \( S_{gen} = 0 \)

Rate of entropy change is

\[ m_{dot}(s_e - s_i) = -55 \text{ MW}/303.15 \text{ K} = -0.181 \text{ MW/K} \]

12. Helium gas is compressed from 1 atm and 25 °C to a pressure of 10 atm adiabatically. The lowest temperature of helium after compression is:

(a) 25 °C  (b) 63 °C  (c) 250 °C  (d) 384 °C  (e) 476 °C

13. Liquid water enters an adiabatic piping system at 15°C at a rate of 8 kg/s. If the water temperature rises by 0.2°C during flow due to friction, the rate of entropy generation in the pipe is:

(a) 23 W/K  (b) 55 W/K  (c) 68 W/K  (d) 220 W/K  (e) 443 W/K
14. Air in an ideal Diesel cycle is compressed from 2 to 0.13 L, and then it expands during the constant pressure heat addition process to 0.30 L. Under cold air standard conditions, the thermal efficiency of this cycle is:

(a) 41%  (b) 59%  (c) 66%  (d) 70%  (e) 78%

\[ V_1 = 2 \text{ L}; \quad V_2 = 0.13 \text{ L}; \quad V_3 = 0.30 \text{ L}; \]

\[ r = V_1/V_2 = 15.385; \quad r_c = V_3/V_2 = 2.308; \quad k = 1.4 \]

\[ \eta_{\text{Diesel}} = 1 - r^{(1-k)} \left[ \left( r_c^k - 1 \right) / \left( k(r_c - 1) \right) \right] = 0.59 \]

15. An ideal Brayton cycle has a net work output of 150 kJ/kg and a back-work ratio of 0.4. If both the turbine and the compressor had an isentropic efficiency of 85 percent, the net work output of the cycle would be:

(a) 74 kJ/kg  (b) 95 kJ/kg  (c) 109 kJ/kg  (d) 128 kJ/kg  (e) 177 kJ/kg

\[ W_{\text{comp}}/W_{\text{turb}} = 0.4 \]

\[ W_{\text{net,ideal}} = W_{\text{turb}} - W_{\text{comp}} = 150 \text{ kJ/kg} \]

2 equations, 2 unknowns: \[ W_{\text{turb}} = 250 \text{ kJ/kg}, \quad W_{\text{comp}} = 100 \text{ kJ/kg} \]

\[ \eta = 0.85 \]

\[ W_{\text{net,actual}} = \eta W_{\text{turb}} - W_{\text{comp}}/ \eta = 95 \text{ kJ/kg} \]

16. A simple ideal Rankine cycle operates between the pressure limits of 10 kPa and 5 MPa, with a turbine inlet temperature of 600 °C. The mass fraction of steam that condenses at the turbine exit is:

(a) 6%  (b) 9%  (c) 12%  (d) 15%  (e) 18%

Turbine inlet: \[ P = 5 \text{ MPa}, \quad T = 600 \text{ °C} \rightarrow s = 7.2605 \text{ kJ/kg-K} \]

Turbine exit: \[ P = 10 \text{ kPa}. \quad \text{For ideal, } s_{\text{out}} = s_{\text{in}}. \quad x = (s - s_i)/s_{fg} = 0.88 \]

Condensed fraction = 1 - x = 0.12

17. Consider a refrigerator that operates on the vapor compression refrigeration cycle with R-134a as the working fluid. The refrigerant enters the compressor as saturated vapor at 160 kPa, and exits at 800 kPa and 50°C, and leaves the condenser as saturated liquid at 800 kPa. The coefficient of performance of the refrigerator is:

(a) 2.6  (b) 1.0  (c) 4.2  (d) 3.2  (e) 4.4