INDIAN INSTITUTE OF TECHNOLOGY KANPUR

ESO 201A: Thermodynamics

(2023-24 I Semester)

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Tutorial -12

Question 1: A space is kept at -15°C by a vapor-compression refrigeration system in an ambient at 25°C. The space gains heat steadily at a rate of 3500 kJ/h and the rate of heat rejection in the condenser is 5500 kJ/h. Determine the power input, in kW, the COP of the cycle and the second-law efficiency of the system.

Solution:

11-27 A vapor-compression refrigeration system is used to keep a space at a low temperature. The power input, the COP and the second-law efficiency are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis The power input is

$$\dot{W}_{\text{in}} = \dot{Q}_H - \dot{Q}_L = 5500 - 3500 = 2000\ \text{kJ/h} = (2000\ \text{kJ/h})\left(\frac{1\ \text{kW}}{3600\ \text{kJ/h}}\right) = \mathbf{0.5556kW}$$

The COP is

$$\text{COP}_\text{R} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{(3500/3600)\ \text{kW}}{0.5556\ \text{kW}} = \mathbf{1.75}$$

The COP of the Carnot cycle operating between the space and the ambient is

$$\text{COP}_{\text{Carnot}} = \frac{T_L}{T_H - T_L} = \frac{258\ \text{K}}{(298-258)\ \text{K}} = 6.45$$

The second-law efficiency is then

$$\eta_{\text{II}} = \frac{\text{COP}_\text{R}}{\text{COP}_{\text{Carnot}}} = \frac{1.75}{6.45} = 0.271 = \mathbf{27.1\%}$$

Question 2: Bananas are to be cooled from 28°C to 12°C at a rate of 1140 kg/h by a refrigerator that operates on a vapor-compression refrigeration cycle. The power input to the refrigerator is 8.6 kW. Determine the rate of heat absorbed from the bananas, in kJ/h, and the COP. The specific heat of bananas above freezing is 3.35 kJ/kg·°C.

Solution:

11-28 A refrigerator is used to cool bananas at a specified rate. The rate of heat absorbed from the bananas, the COP, The minimum power input, the second-law efficiency and the exergy destruction are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (a) The rate of heat absorbed from the bananas is

$$\dot{Q}_L = \dot{m}c_p(T_1 - T_2) = (1140\text{ kg/h})(3.35\text{ kJ/kg}\cdot{}^\circ\text{C})(28-12)^\circ\text{C} = \mathbf{61{,}100 kJ/h}$$

The COP is

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{(61{,}100/3600)\text{ kW}}{8.6\text{ kW}} = \frac{16.97\text{ kW}}{8.6\text{ kW}} = \mathbf{1.97}$$

Question 3: A vapor-compression refrigeration system absorbs heat from a space at 0°C at a rate of 24,000 Btu/h and rejects heat to water in the condenser. The water experiences a temperature rise of 12°C in the condenser. The COP of the system is estimated to be 2.05. Determine (a) the power input to the system, in kW, (b) the mass flow rate of water through the condenser, and (c) the second-law efficiency. Take $T_0 = 20°\text{C}$ and $c_{p,\text{water}} = 4.18\text{ kJ/kg}\cdot°\text{C}$. (3412 Btu/h = 1 kW).

Solution:

11-29 A vapor-compression refrigeration cycle is used to keep a space at a low temperature. The power input, the mass flow rate of water in the condenser, the second-law efficiency, and the exergy destruction are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

Analysis (a) The power input is

$$\dot{W}_{\text{in}} = \frac{\dot{Q}_L}{\text{COP}} = \frac{(24{,}000\text{ Btu/h})\left(\dfrac{1\text{ kW}}{3412\text{ Btu/h}}\right)}{2.05} = \frac{7.034\text{ kW}}{2.05} = \mathbf{3.431 kW}$$

(b) From an energy balance on the cycle,

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{\text{in}} = 7.034 + 3.431 = 10.46\text{ kW}$$

The mass flow rate of the water is then determined from

$$\dot{Q}_H = \dot{m}c_{pw}\Delta T_w \longrightarrow \dot{m} = \frac{\dot{Q}_H}{c_{pw}\Delta T_w} = \frac{10.46\text{ kW}}{(4.18\text{ kJ/kg}\cdot{}^\circ\text{C})(12^\circ\text{C})} = \mathbf{0.2086 kg/s}$$

(c) Second-law efficiency can be calculated as:

$$\text{COP}_{\text{R,Carnot}} = \frac{T_L}{T_H - T_L} = \frac{0+273}{20-0} = 13.65$$

$$\eta_{\text{II}} = \frac{\text{COP}}{\text{COP}_{\text{R,Carnot}}} = \frac{2.05}{13.65} = 0.1502 = 15.0\%$$

Question 4: Heat is supplied to an absorption refrigeration system from a geothermal well at 110°C at a rate of 5×10^5 kJ/h. The environment is at 25°C, and the refrigerated space is maintained at -18°C. Determine the maximum rate at which this system can remove heat from the refrigerated space.

Solution:

11-85 The conditions at which an absorption refrigeration system operates are specified. The maximum rate at which this system can remove heat from the refrigerated space is to be determined.

Analysis The maximum COP that this refrigeration system can have is

$$\mathrm{COP}_{\mathrm{R,max}} = \left(1 - \frac{T_0}{T_s}\right)\left(\frac{T_L}{T_0 - T_L}\right) = \left(1 - \frac{298\ \mathrm{K}}{383\ \mathrm{K}}\right)\left(\frac{255}{298 - 255}\right) = 1.316$$

Thus,

$$\dot{Q}_{\mathrm{L,max}} = \mathrm{COP}_{\mathrm{R,max}}\, \dot{Q}_{\mathrm{gen}} = (1.316)(5 \times 10^5\ \mathrm{kJ/h}) = \mathbf{6.58 \times 10^5\ kJ/h}$$

Question 5: Propal alcohol (C_3H_7OH) is burned with 50 percent excess air. Write the balanced reaction equation for complete combustion and determine the air-to-fuel ratio.

Solution:

15-17 Propal alcohol C3H7OH is burned with 50 percent excess air. The balanced reaction equation for complete combustion is to be written and the air-to-fuel ratio is to be determined.

Assumptions **1** Combustion is complete. **2** The combustion products contain CO_2, H_2O, O_2, and N_2 only.

Properties The molar masses of C, H_2, O_2 and air are 12 kg/kmol, 2 kg/kmol, 32 kg/kmol, and 29 kg/kmol, respectively (Table A-1).

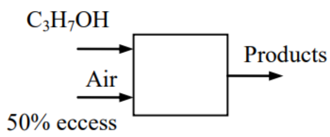
Analysis The combustion equation in this case can be written as

$$C_3H_7OH + 1.5a_{\mathrm{th}}[O_2 + 3.76N_2] \longrightarrow B\,CO_2 + D\,H_2O + E\,O_2 + F\,N_2$$

where a_{th} is the stoichiometric coefficient for air. We have automatically accounted for the 50% excess air by using the factor $1.5a_{\mathrm{th}}$ instead of a_{th} for air. The coefficient a_{th} and other coefficients are to be determined from the mass balances

Carbon balance: $B = 3$

Hydrogen balance: $2D = 8 \longrightarrow D = 4$



Oxygen balance: $1 + 2 \times 1.5a_{\mathrm{th}} = 2B + D + 2E$

$0.5a_{\mathrm{th}} = E$

Nitrogen balance: $1.5a_{\mathrm{th}} \times 3.76 = F$

Solving the above equations, we find the coefficients (E = 2.25, F = 25.38, and a_{th} = 4.5) and write the balanced reaction equation as

$$C_3H_7OH + 6.75[O_2 + 3.76N_2] \longrightarrow 3\,CO_2 + 4\,H_2O + 2.25\,O_2 + 25.38\,N_2$$

The air-fuel ratio is determined by taking the ratio of the mass of the air to the mass of the fuel,

$$\mathrm{AF} = \frac{m_{\mathrm{air}}}{m_{\mathrm{fuel}}} = \frac{(6.75 \times 4.75\ \mathrm{kmol})(29\ \mathrm{kg/kmol})}{(3 \times 12 + 8 \times 1 + 1 \times 16)\ \mathrm{kg}} = \mathbf{15.51 kg\ air/kg\ fuel}$$

Question 6: An absorption refrigeration system that receives heat from a source at 95°C and maintains the refrigerated space at 0°C is claimed to have a COP of 3.1. If the environmental temperature is 19°C, can this claim be valid? Justify your answer.

Solution:

11-83 The COP of an absorption refrigeration system that operates at specified conditions is given. It is to be determined whether the given COP value is possible.

Analysis The maximum COP that this refrigeration system can have is

$$\mathrm{COP}_{\mathrm{R,max}} = \left(1 - \frac{T_0}{T_s}\right)\left(\frac{T_L}{T_0 - T_L}\right) = \left(1 - \frac{292\ \mathrm{K}}{368\ \mathrm{K}}\right)\left(\frac{273}{292 - 273}\right) = 2.97$$

which is smaller than 3.1. Thus the claim is **not possible**.
