In Session Practice Problems – Thermodynamics (EGN 3343)

March 2024

Hello everyone,

These are some problems that, in my experience, provide students with a wider understanding of the topics covered in the first third of the semester. I will go over these and other problems during my sessions. I highly recommend that you attend these sessions to solve any doubts.

Disclaimer: There is no guarantee that any of these problems will be included in any exam, so the best way to approach these problems is like practice problems that will help you familiarize yourself with important concepts learned during the semester. Finally, do not use this guide as your ONLY study resource for the exams.

Important Note: All problems and diagrams presented here were extracted from Cengel, Yunus, et al. Thermodynamics: An Engineering Approach. Available from: Yuzu Reader, (9th Edition). McGraw-Hill Higher Education (US), 2018.

6-58 Refrigerant-134a enters the evaporator coils placed at the back of the freezer section of a household refrigerator at 100 kPa with a quality of 20 percent and leaves at 100 kPa and -26°C. If the compressor consumes 600 W of power and the COP of the refrigerator is 1.2, determine (a) the mass flow rate of the refrigerant and (b) the rate of heat rejected to the kitchen air. Answers: (a) 0.00414 kg/s, (b) 1320 W

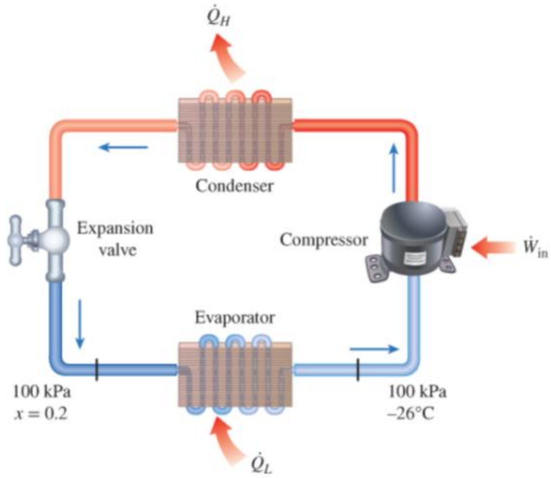

FIGURE P6–58

6.58

Refrigerant

$P_1 = 100\ kPa$ $\quad P_2 = 100\ kPa$ $\quad W_{in} = 600W$

$x = 0.2$ $\quad T_2 = -26\,^{\circ}C$ $\quad COP = 1.2$

(sat. mixture)

$\dot{m} = ?$ $\quad Q_H = ?$

$$COP_R = \frac{1}{\frac{Q_H}{Q_L} - 1} \qquad Q_H = Q_L + W_{in}$$

$$COP_R = \frac{1}{\cancel{\frac{Q_L}{Q_L}} + \frac{W_{in}}{Q_L} \cancel{- 1}} = \frac{1}{\frac{W_{in}}{Q_L}}$$

$$COP_R = \frac{Q_L}{W_{in}} \rightarrow Q_L = COP_R\,(W_{in})$$

$$Q_L = 1.2\,(600\,W) = 720\,W = 0.72\,kW$$

Energy Balance of evaporator

$$Q_L = \dot{m}\,(h_{out} - h_{in})$$

$$\dot{m} = \frac{Q_L}{h_{out} - h_{in}}$$

(Table A13)

Interpolating $h_{out} = 236.088\ \frac{kJ}{kg}$

$h_{in} = h_f + x\,h_{fg}$ (Table A11)

$$h_{in} = 17.25 + 0.2\,(216.95)$$

$$h_{in} = 60.64\ \frac{kJ}{kg}$$

$$\dot{m} = \frac{0.72}{236.088 - 60.64} = 0.0041037\ \frac{kg}{s}$$

$$\boxed{\dot{m} \approx 0.0041\,kg/s}$$

$$Q_H = Q_L + W$$

$$Q_H = 720 + 600$$

$$\boxed{Q_H = 1320\ W}$$

6-111 A Carnot heat pump is to be used to heat a house and maintain it at 25°C in winter. On a day when the average outdoor temperature remains at about 2°C, the house is estimated to lose heat at a rate of 55,000 kJ/h. If the heat pump consumes 4.8 kW of power while operating, determine (a) how long the heat pump ran on that day; (b) the total heating costs, assuming an average price of \$0.11/kWh for electricity; and (c) the heating cost for the same day if resistance heating is used instead of a heat pump. Answers: (a) 5.90 h. (b) \$3.11, (c) \$40.3

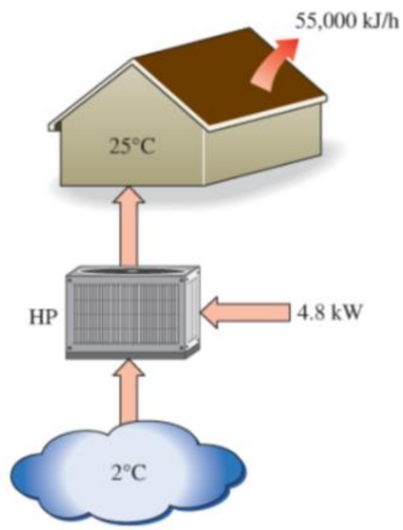

FIGURE P6–111

6.111.

$T_{in} = 25°C \qquad T_{out} = 2°C$

$\dot{Q}_{loss} = 55000 \ \frac{kJ}{h}$

$W = 4.8 \ kW$

a. How long should the pump run?

$$COP_{HP} = \frac{1}{1 - \frac{T_L}{T_H}}$$

$$COP_{HP} = \frac{1}{1 - \frac{2+273}{25+273}} = 12.9565$$

$$COP_{HP} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

$$Q_H = Q_L + W$$

$$Q_L = Q_H - W$$

$$COP_{HP} = \frac{1}{\cancel{1} - \cancel{\frac{Q_H}{Q_H}} - \frac{W}{Q_H}} = \frac{Q_H}{W}$$

$$Q_H = W \, COP_{HP}$$

$$Q_H = 4.8\,kW\,(12.9565)$$

$$Q_H = 62.1913\,kW$$

↳ This corresponds to the rate of heat provided by the heat pump

We must provide the same energy the house losses in a day

$$Q_{loss} = 55000 \frac{\cancel{kJ}}{\cancel{h}} (24 \cancel{h})$$

$$= 1320000 \text{ kJ}$$

$$\text{time} = \frac{Q_{loss}}{\dot{Q}_A} = \frac{1320000 \cancel{kJ}}{62.1913 \cancel{kJ}/s}$$

$$\text{time} = 21224.83 s \left(\frac{1 min}{60 s}\right)\left(\frac{1 h}{60 min}\right)$$

$$\boxed{\text{time} = 5.8957 h \approx 5.90 h}$$

6. Total heating cost?

$0.11 kWh

We first need to know

what is a kWh

$$\frac{1 kJ}{1 s} = 1 kW \cdot 1h = 1 kWh$$

$$\frac{1 kJ}{1 s} = 1 \frac{kJ}{s} \left[1 \cancel{h} \left(\frac{60 \cancel{min}}{1 \cancel{h}}\right)\left(\frac{60 s}{1 \cancel{min}}\right)\right]$$

$$= 1 \frac{kJ}{\cancel{s}} (3600 \cancel{s}) = 3600 kJ$$

1 kwh = 3600 kJ

Now we need to know
How many kJ are spent in
the 5.9 h of operation

$\dot{W}_m = 4.8\ kW \qquad t = 5.8957\ h$

$W_m = \dot{W}_n \cdot t$

$W_m = 4.8\ kW \left(5.8957\ h \left(\frac{60\ min}{1\ h}\right)\left(\frac{60\ s}{1\ min}\right)\right)$

$W_m = 101879.20\ kJ$

Now we convert it to kwh
and find the cost.

cost = 0.11 \$ per kwh

$1\ kW \cdot h = 1\ kw\ (60\ min) = 1\ kw\ (3600)\ s = 3600\ kw \cdot s$

$\rightarrow 3600\ \frac{kJ}{s} \cdot s = 3600\ kJ \xrightarrow{so} 1\ kwh = 3600\ kJ$

$101879.20\ kJ \left(\frac{1\ kwh}{3600\ kJ}\right) = 28.2997\ kwh$

$$cost = 28.2997\ kWh \left(\frac{0.11\ \$}{1\ kWh}\right) = \boxed{3.11\ \$}$$

c. If a resistor was used instead, our Q_H would correspond to the work our resistor should make.

$$Q_H = 62.1913\ kW$$

$$Q_H = 62.1913\ kW (5.90\ h)\left(\frac{60\ min}{1\ h}\right)\left(\frac{60\ s}{1\ min}\right)$$

$$Q_H = 1320943.21\ kJ \left(\frac{1\ kWh}{3600\ kJ}\right)$$

$$Q_H = 366.92\ kWh$$

$$cost = 366.92\ kWh \left(\frac{0.11\ \$}{1\ kW}\right) = \boxed{40.36\ \$}$$

6-152 A heat pump with refrigerant-134a as the working fluid is used to keep a space at 25°C by absorbing heat from geothermal water that enters the evaporator at 60°C at a rate of 0.065 kg/s and leaves at 40°C. Refrigerant enters the evaporator at 12°C with a quality of 15 percent and leaves at the same pressure as saturated vapor. If the compressor consumes 1.6 kW of power, determine (a) the mass flow rate of the refrigerant, (b) the rate of heat supply, (c) the COP, and (d) the minimum power input to the compressor for the same rate of heat supply. Answers: (a) 0.0338 kg/s, (b) 7.04 kW, (c) 4,40

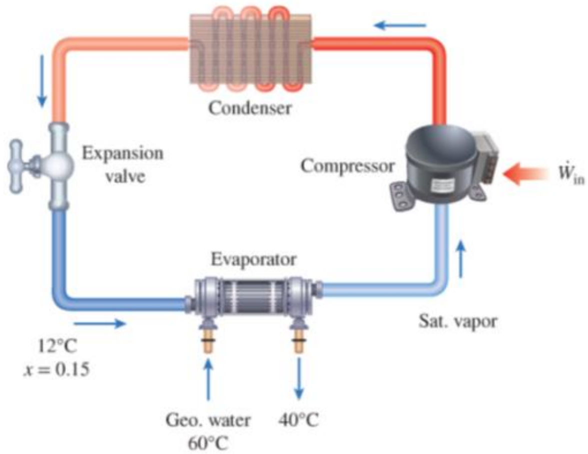

FIGURE P6–152

6 - 152.

This problem consist of a heat pump and a heat exchanger (The evaporator) at the same time.

a.

To find the mass flow rate of the refrigerant we are going to need the energy balance equation for the heat exchanger (evaporator)

$$m_{in}(\ldots) + \cancel{Q_{in}} + \cancel{W_{in}} - m_{out}(\ldots) - \cancel{Q_{out}} - \cancel{W_{out}}$$
$$= \cancel{m_2(\ldots)} - \cancel{m_1(\ldots)}$$

$$\dot{m}_{in}\left(u + Pv + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{2000}}\right) = \dot{m}_{out}\left(u + Pv + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{2000}}\right)$$

$$\dot{m}_{in,w}(h_{in,w}) + \dot{m}_{in}(h_{in,R}) = \dot{m}_{out,w}(h_{out,w}) + \dot{m}_{out,R}(h_{out,R})$$

$$\dot{m}_R(h_{out,R} - h_{in,R}) = \dot{m}_w(h_{in,w} - h_{out,R})$$

$$h_{in\,R} = h_f + x h_{fg}$$

Table A-11

$$h_{in\,R} = 68.17 + 0.15\,(189.16) = 96.544\ \frac{kJ}{kg}$$

$$h_{out\,R} = 257.33\ \frac{kJ}{kg}$$

$$h_{in,w} - h_{out,w} = \Delta h_w = c_p(T_{in} - T_{out})$$

$$\Delta h = c_p(T_2 - T_1)$$

$$c_{p,w} = 4.18\ \frac{kJ}{kg \cdot K}$$ (Table A-3)

$$m_R(h_{out,R} - h_{in,R}) = m_w(h_{in,w} - h_{out,w})$$

$$m_R(h_{out,R} - h_{in,R}) = m_w c_{p,w}(T_{in} - T_{out})$$

$$m_R = \frac{m_w c_{p,w}(T_{in} - T_{out})}{h_{out,R} - h_{in\,R}}$$

$$m_R = \frac{0.065\ kg/s\left(4.18\ \frac{kJ}{kg \cdot K}\right)\left(60+273-(40+273)\right)K}{257.33\ \frac{kJ}{kg} - 96.544\ \frac{kJ}{kg}}$$

$$m_R = 0.033796 \approx 0.0338\ kg/s$$

b.

The heat supplied to the heat pump (Q_L) is going to correspond to the heat supplied to the refrigerant by the geothermal water

$$\dot{Q}_L = m_w c_{pw} (T_{in} - T_{out})$$

$$\dot{Q}_L = 0.065 \frac{kg}{s} (4.18 \frac{kJ}{kg\,K} (60+273-[40+273]) K$$

$$\dot{Q}_L = 5.434 \text{ kW}$$

Now the heat supplied by our heat-pump (Q_H) is going to be given by

$$\dot{Q}_H = \dot{W} + \dot{Q}_L$$

$$\underbrace{\dot{Q}_H = \dot{W} + \dot{Q}_L = 1.6 + 5.434 = 7.034 \text{ kW}}$$

c.

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{7.034}{7.034 - 5.434}$$

$$\underbrace{COP_{HP} = 4.39625 \approx 4.40}$$

7-153 Steam expands in a turbine steadily at a rate of 40,000 kg/h, entering at 8 MPa and 500°C and leaving at 40 kPa as saturated vapor. If the power generated by the turbine is 8.2 MW, determine the rate of entropy generation for this process. Assume the surrounding medium is at 25°C. Answer: 11.4 kW/K

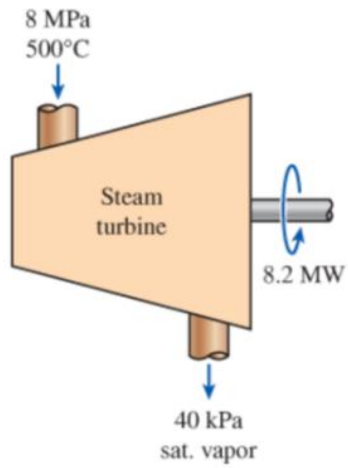

FIGURE P7–153

$$\frac{Q_{in}}{T} + m_{in} s_{in} - \frac{Q_{out}}{T} - m_{out} s_{out} + S_{gen} = \cancel{\Delta S_{sys}}$$

$$S_{gen} = m_{out} s_{out} - m_{in} s_{in} - \frac{Q_{net}}{T}$$

We know the mass flow rate, and we can find s_{in} and s_{out} from the tables. There is no way to find Q_{net}, so we need the energy equation

$$Q_{in} + \cancel{W_{in}} + m_{in}(\ldots) - Q_{out} - W_{out} - m_{out}(\ldots) = \cancel{\Delta E_{sys}}$$

$$Q_{net} = m_{out}\left(h + \cancel{\frac{gz}{1000}} + \cancel{\frac{V^2}{2000}}\right) - m_{in}\left(h + \cancel{\frac{gz}{1000}} + \cancel{\frac{V^2}{2000}}\right) + W_{out}$$

Before moving forward let's find h_{in}, h_{out}, s_{in}, and s_{out}

$h_{in} = 3399.5 \frac{kJ}{kg}$

$s_{in} = 6.7266 \frac{kJ}{kg \cdot K}$

$h_{out} = 2636.1 \, kJ/kg$

$s_{out} = 7.6691 \frac{kJ}{kg \cdot K}$

Now let's go back to the energy balance equation

$$\dot{m} = 40000 \frac{kg}{h} \left(\frac{1h}{60 \text{ min}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 11.1111 \, kg/s$$

$$\dot{Q}_{net} = 11.1111 \frac{kg}{s} \left(2636.1 - 3399.5\right) \frac{kJ}{kg} + 8200 \, kJ = -282.222 \, kJ$$

going back to the entropy balance equation

$$\dot{S}_{gen} = \dot{m}(s_{out} - s_{in}) - \frac{\dot{Q}_{net}}{T}$$

$$\dot{S}_{gen} = 11.1111(7.6691 - 6.7266) + \frac{282.222}{25 + 273}$$

$$\dot{S}_{gen} = 11.4192 \rightarrow \dot{S}_{gen} = 11.4 \, kW/K$$

7-190 Air enters a two-stage compressor at 100 kPa and 27°C and is compressed to 625 kPa. The pressure ratio across each stage is the same, and the air is cooled to the initial temperature between the two stages. Assuming the compression process to be isentropic, determine the power input to the compressor for a mass flow rate of 0.15 kg/s. What would your answer be if only one stage of compression were used? Answers: 27.1 kW, 31.1 kW

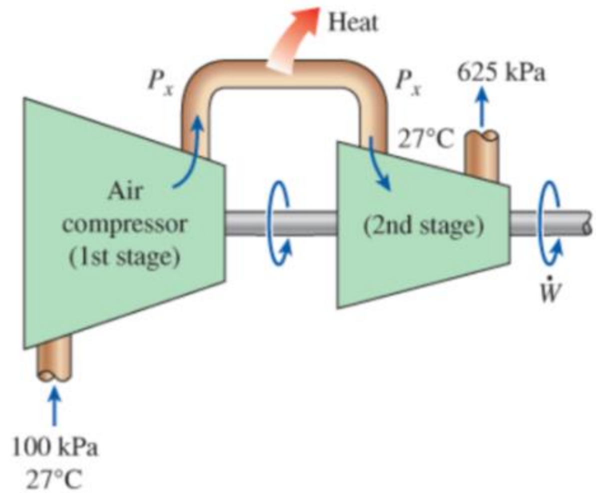

FIGURE P7–190

$\dot m = 0.15$ kg/s

$T_1 = 27°C$

$P_1 = 100$ kPa

$P_3 = 625$ kPa

Let's start calculating P_2 based on the pressure ratios

$$\frac{P_2}{P_1} = \frac{P_3}{P_2} \rightarrow P_2 = \sqrt{625(100)}$$

$$P_2 = 250 \text{ kPa}$$

a.

Let's continue with an energy balance equation for each of the stages

Stage 1:

$$\cancel{Q_{in}} + W_{in} + \dot m_{in}(\ldots) - \cancel{Q_{out}} - \cancel{W_{out}} - \dot m_{out}(\ldots) = \cancel{\Delta E_{sys}}$$

$$W_{in} = \dot m_{out}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right) - \dot m_{in}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right)$$

$$W_{in} = \dot{m}(h_{out} - h_{in}) = \dot{m} c_p (T_{out} - T_{in})$$

Stage 2:

$$\cancel{Q_{in}} + W_{in} + \dot{m}_{in}(\ldots) - \cancel{Q_{out}} - \cancel{W_{out}} - \dot{m}_{out}(\ldots) = \cancel{\Delta E_{sys}}$$

$$W_{in} = \dot{m}_{out}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right) - \dot{m}_{in}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right)$$

$$W_{in} = \dot{m}(h_{out} - h_{in}) = \dot{m} c_p (T_{out} - T_{in})$$

We can combine both equations to find the total work needed since Tin and Tout are equal for both stages.

$$W_{TOT} = 2\dot{m} c_p (T_{out} - T_{in})$$

$m = 0.15\ kg/s$

$T_{in} = 300\ K$

$c_p = 1.005\ \frac{kJ}{kg \cdot K}$ (Table A2)

$T_{out} =$

$k = 1.4$ (Table A2)

We can find Tout using isentropic relationship $\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_2 = 300 \left(\frac{250}{100}\right)^{\frac{1.4-1}{1.4}} = 389.7789\ K$$

$$W_{TOT} = 2(0.15)(1.005)(389.7789 - 300)$$

$$W_{TOT} = 27.0683\ W$$

$$\underbrace{W_{TOT} = 27.1\ W}$$

6. If we only have 1 stage, we only have energy balance equation, and we will need to recalculate the Tout

$$\cancel{Q_{in}} + W_{in} + \dot{m}_{in}(\ldots) - \cancel{Q_{out}} - \cancel{W_{out}} - \dot{m}_{out}(\ldots) = \cancel{\Delta E_{sys}}$$

$$W_{in} = \dot{m}_{out}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right) - \dot{m}_{in}\left(h + \cancel{\frac{V^2}{2000}} + \cancel{\frac{gz}{1000}}\right)$$

$$W_{in} = \dot{m}(h_{out} - h_{in}) = \dot{m}\, c_p (T_{out} - T_{in})$$

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_2 = 300 \left(\frac{625}{100}\right)^{\frac{1.4-1}{1.4}} = 506.4254$$

$$W_{in} = 0.15\,(1.005)(506.4254 - 300)$$

$$W_{in} = 31.1186\ kW$$

$$\boxed{W_{in} = 31.1\ kW}$$

as you can see the work increase significally that the importance of intercoolers.