Homework 7

Monday, April 12, 2021 3:49 PM

"I pledge my honor I have abided by the Stevens Honor system."

- Alex [signature]

1. An inventor claims to have developed a heat pump that produces 200 kW of heating for a 293 K heated zone whilst only using 75 kW of power and a heat source at 273 K. Using the maximum theoretical COP of this device, justify the validity of this claim. [5]

$$COP_{actual} = \frac{\dot{Q}_H}{\dot{W}_{net}} = \frac{200}{75} = 2.67$$

$$COP_{rev} = \frac{T_H}{T_H - T_L} = \frac{293}{293-273} = 14.65$$

$$COP_{actual} < COP_{rev}$$

$$\boxed{\therefore \text{ Claim is valid}}$$

2. A heat engine operating on a Carnot cycle has a thermal efficiency of 55%. The waste heat is rejected to a lake at 60°F at a rate of 800 Btu/min. What is the power output from the engine? What is the temperature of the high temperature source? [5]

$$\eta_{th} = 1 - \frac{\dot{Q}_L}{\dot{Q}_H} \; ; \; .55 = 1 - \frac{800}{\dot{Q}_H} = 1777.78 \text{ Btu/min}$$

$$\dot{W}_{out} = \eta_{th}(\dot{Q}_H) = .55(1777.78)(.02358) = 23.056 \text{ hp}$$

$$\frac{\dot{Q}_H}{\dot{Q}_L} = \frac{T_H}{T_L} \qquad T_L = 520 \text{ R}$$

$$T_H = T_L \left(\frac{\dot{Q}_H}{\dot{Q}_L} \right) = 520 \left(\frac{1777.78}{800} \right) = 1156 R$$

3. The entropy change for a process is given by the equation below:

$$\Delta S = S_2 - S_2 = \int_1^2 \left(\frac{\delta Q}{T}\right) + S_{gen}$$

$S_{gen} = 0$ for reversible process

$S_{gen} > 0$ for irreversible process

Find the change in entropy for the following processes and explain your result [15]

Process	ΔS (positive/ negative/ equal to zero/ anything is possible)	Explanation (show equation if necessary)
Adiabatic irreversible	0	No internal entropy in a reversible process
Adiabatic reversible	+ne → increasing	$S_d = \frac{dQ}{T} + \frac{dW}{T}$ → lost work; $dS = \frac{dW}{T}$ ∴ entropy always increases
Reversible heat addition	0	Temperature difference is small $T_1 \approx T_2$
Reversible heat rejection	0	Temperature difference is small $T_1 \approx T_2$
Irreversible heat rejection	+ne	$T_1 > T_2$ → heat transfer from hot to cold body results in net increase in entropy
Irreversible heat addition	−ne	$T_1 < T_2$ → Heat transfer from cold to hot

4. During the isothermal heat addition process of a Carnot cycle (reversible), 900 kJ of heat is added to the working fluid from a source at 400°C. What is the entropy change of the working fluid? What is the entropy change of the source? What is the total entropy change for the process? [15]

$$\Delta S_{fluid} = \frac{Q_{in}}{T_{in}} = \frac{900}{400+273} = 1.337 \, kJ/K$$

$$\Delta S_{source} = \frac{Q_{out}}{T_{source}} = \frac{-900}{400+273} = -1.337 \, kJ/K$$

$$\Delta S_{total} = \Delta S_{fluid} + \Delta S_{source} = 1.337 - 1.337 = 0$$

5. Refrigerant-134a enters the coils of the evaporator of a refrigeration system as a saturated liquid–vapor mixture at a pressure of 140 kPa. The refrigerant absorbs 180 kJ of heat from the cooled space, which is maintained at -10°C, and leaves as saturated vapor at the same pressure. Assuming the refrigerant and cooled space are internally reversible. Determine (a) the entropy change of the refrigerant, (b) the entropy change of the cooled space, and (c) the total entropy change for this process – where does this entropy generation occur? [15]

$$\Delta S_{fridge} = \frac{Q_{in}}{T} = \frac{180}{(273 - 18.77)} = .708 \text{ kJ/K}$$

$$\Delta S_{space} = \frac{-Q_{out}}{T} = \frac{-180}{(273 - 10.273)} = -.684 \text{ kJ/K}$$

$$\Delta S_{total} = \Delta S_{fridge} + \Delta S_{space} = .708 - .684 = .024 \text{ kJ/K}$$

6. An ideal gas at 20°C is contained in a piston-cylinder device. The system now expands isothermally from state 1 to 2. [15]
   a. If the expansion process is reversible and 100 kJ of heat is transferred to the gas from the surroundings, calculate the change in entropy.
   b. If the expansion process between these same states is irreversible, would the entropy change be greater/less than/same as that from part (a)? Briefly explain.
   c. For an irreversible process between the same two states, will the heat transfer by greater/less than/ same as the 100 kJ transferred in the reversible process (part a). Briefly explain.

A.) $\Delta Q = 100$ kJ $\quad T = 293$ K

$$\Delta S = \frac{\Delta Q}{T} = \frac{100}{293} = .341 \text{ kJ/K}$$

B.) It would be greater because of residual energy generation. Net entropy change would be positive based on the second law of thermodynamics.

C.) More heat is required for a real process than for a reversible process, which is why reversible processes are ideal.

7. A rigid tank contains 5 kg of refrigerant R-134a initially at 30°C and 140 kPa. The refrigerant is now cooled while being stirred until its pressure drops to 90 kPa. Determine the entropy change of the refrigerant during the process. Show the process on a T-s diagram. [15]

$v_1 = .17172 \ m^3/kg \quad s_1 = 1.0912 \ kJ/kg\,K$

Constant volume

$$x_2 = \frac{(v_2 = v_1) - v_f}{v_g - v_f} = \frac{.17172 - .0007223}{.21263 - .0007223} = .8069$$

$$s_2 = .06008 + (.8069(.8942)) = .7816 \ kJ/kg\,K$$

$$\Delta S_{R\text{-}134a} = m(s_2 - s_1) = 5(.7816 - 1.0912) = -1.548 \ kJ/K$$

8. Write a short essay (a paragraph or two is fine) relating a subject in your discipline to the material we have studied so far in thermodynamics. [15]

In the field of computer engineering, heat transfer and heat resistance is a very important topic. This relates to many topics discussed in Thermodynamics, namely ones dealing with heat resistance or heat required for specific metals or substances in general to overheat or even melt. Notable topics include utilizing the specific heat of a substance to determine its ability to resist large amounts of heat exposure. As we continue to delve into the topic of entropy, it highlights how processes involving multiple counterparts transferring energy and heat can become very complex and require an in-depth analysis to ensure the system doesn't fail. For example, with resistors in even a simple circuit, a lot of heat can be generated as a result of the amount of electrical energy being supplied to it. This is an example of energy conservation that we discussed in this class, with energy being supplied, and resulting energy and heat being generated. This also corresponds with cooling processes that are necessary as a result of this heat being generated. This is especially notable for the processor in a computer, which can get very hot and requires a high-precision cooling system to ensure it doesn't overheat. Using properties of heat transfer and the specific heat of a substance, a heat flow can be incorporated in order to help evacuate heat generated. In other words, thanks to Thermodynamics, fans and other cooling systems have been proven to allow very powerful computers and circuits to run without overheating. Thus, showing just how vital Thermodynamics really is to this field, for without this information, computers would basically be worthless (and so would my major).