ME 105 Thermodynamics

Second Midterm Exam – 50 MINUTES

Three questions, equal weight.

NOTE: Please write your name and the question number on each page of the exam and answer questions only in the allocated space.

This time pages without names on them or without question numbers WILL BE DISCARDED since pages without names give many opportunities of manipulating grades. We cannot do detective work on over 150 exams.

Question #1

Devices can be designed to serve as both heat pumps to deliver heat and air conditioning systems to remove heat.

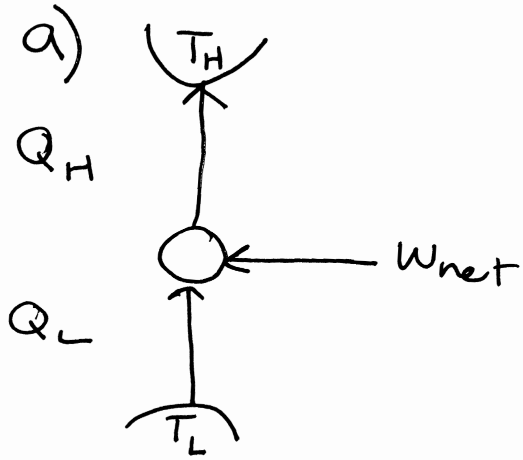
a) In the winter the device in a heat pump configuration supplies energy in the form of heat to a house at the rate of 140,000 kJ/h when the house is maintained at 25°C. Over a period of one month, the heat pump operates for 100 hours to transfer energy from a heat source outside the house to inside the house. Consider a heat pump receiving heat from two different outside energy sources. In one application, the heat pump receives heat from the outside air at 5°C. In a second application, the heat pump receives heat from a lake having a water temperature of 10°C. If electricity is used to run the heat pump determine the maximal difference in electrical energy consumption per month between using the lake water versus the outside air as the surroundings temperature reservoir.

b) In the summer, the same device acts as an air conditioning system to maintain the house at 25 C when the outside air temperature is 35 C and the lake temperature is 15 C. Assume that the energy removed from the house is also 140,000 kJ/h and the device operates for 100 hours per month. If electricity is used to run the device determine the maximal difference in electrical energy consumption per month between using the lake water versus the outside air as the surroundings temperature reservoir.

QUESTION #

ME 105 Name ANSWER KEY

a)



$T_H = 298K$ [0.5]

$T_{L1} = 278K$ $T_{L2} = 283K$

$Q_H = 1.4 \times 10^7 kJ$

$$COP_{HP} = \frac{Q_H}{W_{net}} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L} \quad [2]$$

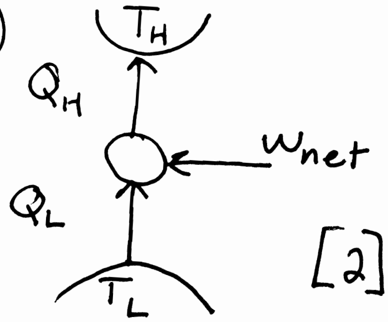
$COP_{HP1} = 14.9$ [0.5] $COP_{HP2} = 19.9$ [0.5]

$W_{net,1} = 939597.3 kJ$ [0.5]

$W_{net,2} = 703517.6 kJ$ [0.5]

$\boxed{\Delta W_{net} = 236079.7 kJ}$ [0.5]

b)



$W_{net} = 0$ for lake [1]

$Q_L = 1.4 \times 10^7 J$ $T_L = 298K$ $T_H = 308K$ [0.5]

[2] $$COP_R = \frac{Q_L}{W_{net}} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L} = 29.8 \quad [0.5]$$

$W_{net} = 469798.7 kJ$ $\boxed{\Delta W_{net} = 469798.7 kJ}$ [1]

ME 105 Name ANSWER KEY

Question # 2

An aircraft engine operates on a simple ideal Brayton cycle with a pressure ratio of 10. Heat is added to the cycle at a rate of 500 kW; air passes through the engine at a rate of 1kg/s; and the air at the beginning of the compression is at 70 kPa and 0°C. Determine the power produced by this engine and its thermal efficiency. Use constant specific heats at room temperature.

$$\eta_{th} = 1 - \frac{1}{r_p^{(k-1)/k}} = 1 - \frac{1}{10^{(0.4)/1.4}} = \boxed{0.482} \quad [5]$$

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_H} \Rightarrow \dot{W}_{net} = \eta_{th}\dot{Q}_H = (0.482)\,500\text{kW}$$

$$\boxed{\dot{W}_{net} = 241 \text{ kW}}$$

QUESTION # ME 105 Name ANSWER KEY

Question #3. (concepts – answer briefly in the space provided)

[2] a) Can there be a situation in which a system operates as a Carnot cycle between two reservoirs at two different temperatures and the heat interaction with the reservoirs is irreversible? Explain.

No. By definition a Carnot cycle is reversible.

[2] b) You need to increase the entropy of a system at 200 K by 10 kJ/K entropy. What would you do to increase the entropy of the systems in a) a reversible process b) in an irreversible process.

a) $S_{heat} = \frac{Q}{T} \Rightarrow Q = (S_{heat})T$

$Q = \frac{10 kJ}{K}(200K) = 2000 kJ$

[1] Add 2000 kJ of heat via an infinitesimal temperature difference. (makes process reversible.)

[1] b) Add heat with irreversibilities. These irreversibilities could be friction, mixing, chemical reactions, heat transfer through a finite temperature difference, ...

Since irreversibilies cause $S_{gen} > 0$, to raise entropy by 10 kJ/kg, $Q_{heat} < 2000$ kJ since $\Delta S = S_{heat} + S_{gen}$ when heat added with irreversibilities.

QUESTION # ME 105 Name ANSWER KEY

[2] c) An ideal gas with k=1.3 undergoes an isentropic process in which the temperature changes from 20 C to 40 C. What is the relative change in pressure.

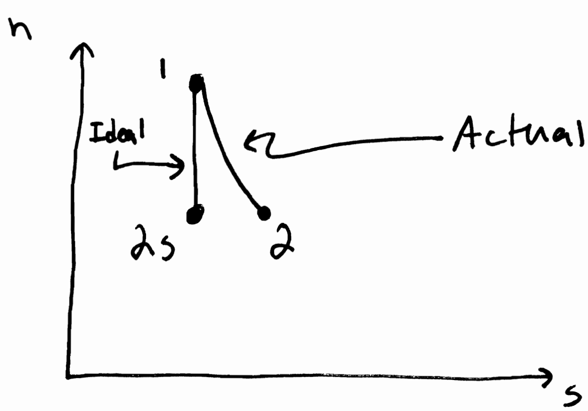
For an ideal gas:

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

$$\left(\frac{P_2}{P_1}\right) = \left(\frac{(40+273)K}{(20+273)K}\right)^{\frac{1.3}{0.3}}$$

$$\boxed{\left(\frac{P_2}{P_1}\right) = 1.331}$$

[2] d) Show on a Mollier diagram a schematic of an ideal and an actual process across a nozzle



ME 105 Name ANSWER KEY

[2] e) A compressed gas at a pressure P is in an enclosed container with a volume V. The container is placed in a vacuum chamber , zero pressure, of volume 2V. the compressed gas container wall breaks and the gas expands to occupy the 2V volume chamber. Is there any change in the exergy of the system? Explain in words.

Yes. Exergy is the maximum useful work that can be obtained from a system at a given state in a specified environment. When the volume of the compressed gas increases, the pressure of the compressed gas decreases. When compared to the environment, the system, since at a lower pressure, has less ability to do useful work. Thus, the exergy decreases.