Tutorial 5

Tutorial 5: (1) Carnot cycles for heat engines & heat pumps & (2) Entropy Basics

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Problem Solving Questions:

1. Complete the table below for the following property substances.

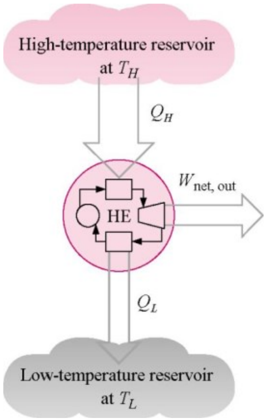
Substance	Pressure (kPa)	Temperature (C)	State	Specific entropy (kJ/kgK)
water	5000	120		
water		120	Saturated liquid	
water	10	50		
R-134a		-30		1.3
R-134a	100		Saturated Vapor	
Ammonia		-45	Sat. Mixture, x = 0.4	
Ammonia	150	80		

2. A heat engine receives 150MW of heat energy. The engine produces 50 MW of net work.

(a) Determine the cycle thermal efficiency

(b) Determine the heat rejected by the cycle to the lower temperature reservoir.

[ans: η_{th}=33.3%; Q_L=100MW]

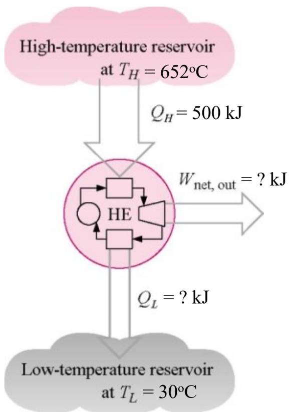


3. A Carnot heat engine receives 500 kJ of heat per cycle from a high-temperature heat reservoir at 652°C and rejects heat to a low-temperature heat reservoir at 30°C. Determine:

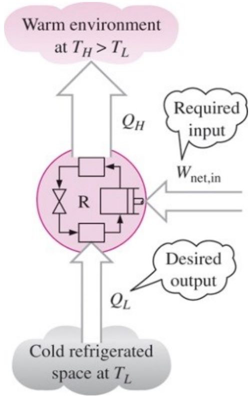
(a) The thermal efficiency of this Carnot engine.

(b) The amount of heat rejected to the low-temperature heat reservoir.

[(a) η_{th}=67.2%; (b) Q_L=164kJ]

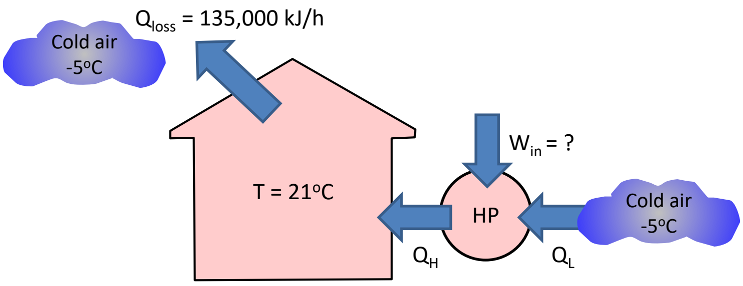


4. An inventor claims to have developed a refrigerator with a COP of 13.5 that maintains the refrigerated space at 2°C while operating in a room where the temperature is 25°C. Evaluate the maximum possible (Carnot) COP of a refrigerator operating in these conditions. Is the inventor's claim true?



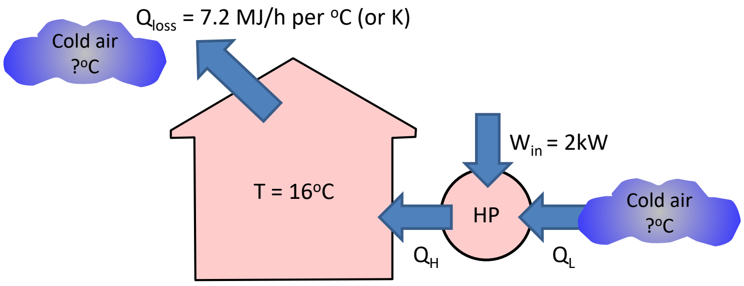
[ans: COP=11.96; No]

5. A heat pump is to be used to heat a building during the winter. The building is to be maintained at 21°C at all times. The building is estimated to be losing heat at a rate of 135,000 kJ/h when the outside temperature drops to -5°C. Determine the minimum power required to drive the heat pump unit for this outside temperature.



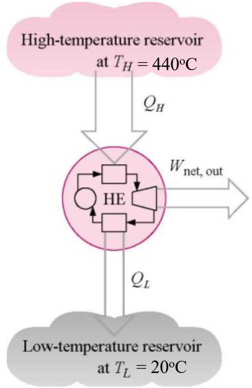
[ans: 3.3kW]

6. A house loses heat at a rate of 7.2 MJ/h per °C difference between the inside and outside of the house. Calculate the lowest outside temperature for which a heat pump requiring a power input of 2 kW can maintain the house at 16°C.



[ans: T_{air} = -1°C]

7. 3150 kJ of heat is transferred into a cycle at 440°C. 1294.8 kJ of heat are rejected from the same cycle at 20°C. Heat transfer occurs at constant temperature.

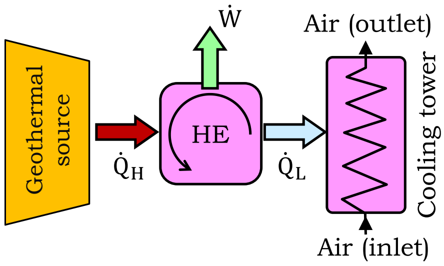


(a) Is the Clausius inequality satisfied and is the cycle reversible or irreversible?

(b) Calculate the net-work and cycle efficiency for this cycle.

[(a) Yes – reversible; (b) W_{net}=1855.4 kJ, η_{th}=58.9%]

8. A power plant generates 150 MW of electrical power. It uses a supply of 1000 MW from a geothermal source and rejects energy to air in a cooling tower.

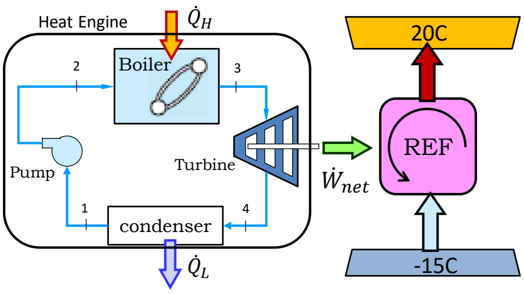


(a) Find the heat given to the air.

(b) How much air should be flowing to the cooling tower (kg/s) if the air temperature cannot be increased by more than 10°C? Assume air as an ideal gas with constant specific heats

[(a) 850 MW, (b) 84,661 kg/s]

9. Consider a Carnot heat engine using water as the working fluid. As heat is added to the boiler, the water changes from a saturated liquid to a saturated vapor under a constant temperature of 200°C. Heat is rejected in the condenser, where the water remains a saturated mixture ($x_4 > x_1$) at a constant pressure of 20 kPa. The heat engine powers a Carnot cycle refrigerator that operates between -15°C and 20°C.



(a) Find the heat added to the water (q_H) in kJ/kg.

(b) How much heat (i.e Q_H (in kW)) should be added to the heat engine so that the heat pump (refrigerator) can remove 1 kJ from the cold space at -15°C?

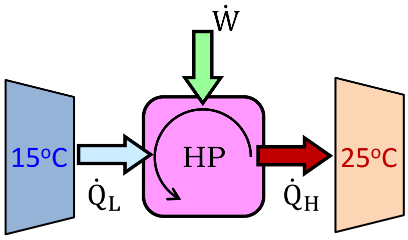
(c) What is the mass flow rate of water so that the heat pump (refrigerator) can remove 1 kW from the cold space at -15C?

[(a) 1940.75 kJ/kg, (b) 0.46 kW, (d) 0.000237 kg/s]

10. A reversible heat pump uses 1 kW of power to heat a 25ºC room. The heat pump draws in energy from the outside at 15ºC.

(a) Determine the heat delivered to the room and the heat removed from the cold temperature reservoir.

(b) Assuming every process is reversible, what are the total rates of entropy into the heat pump from the outside and from the heat pump to the room?



$$\left[(a)\dot{Q}_H = 29.8kW, \dot{Q}_L = 28.8kW \ (b)\frac{\dot{Q}_L}{T_L} = 0.1\frac{kW}{K}; \frac{\dot{Q}_H}{T_H} = 0.1\frac{kW}{K}\right]$$