AREN 2110: Thermodynamics Name Solution
In-Class Practice Problems
Credit: ~~1~~ 2 point each to be added to homework score

1. A heat engine cycle is carried out with steam. The state of the steam throughout the cycle is within the saturated liquid-vapor region. The pressure of the steam is 1 MPa during heat addition and 0.4 MPA during heat rejection. The highest possible efficiency is:

[✓ a. 8.0%]
b. 15.6%
c. 20.2%
d. 79.8%
e. 100%

$$\eta = 1 - \frac{T_L}{T_H} = 1 - \frac{T_{sat\ 400kPa}}{T_{sat\ 1MPa}} = 1 - \frac{273+143.6}{273+179.9} = 0.08$$

T_H and T_L = T_{sat} @ respective high and low pressures

2. An air conditioning system operates using a reversed Carnot cycle to remove heat from the house at a rate of 32 kJ/s to maintain its temperature at a constant 20 °C. The temperature of the outdoor air is 35 °C. The power required to operate the air conditioner is

a. 0.58 kw
b. 3.20 kw
c. 1.56 kw
d. 2.26 kw
[✓ e. 1.64 kw]

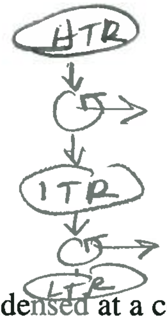
$$COP_{RC} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{1}{\frac{308}{293} - 1} = 19.53 = \frac{\dot{Q}_L}{\dot{W}} = \frac{32\ kW}{\dot{W}}$$

$$\dot{W} = \frac{32\ kW}{19.53} = 1.64\ kW$$

Air conditioner is refrigerator - desired output is cooling room (heat in)

3. Two Carnot heat engines are operating in series such that the heat sink for the first engine serves as the heat source for the second. The source temperature of the first heat engine is 1300 K and the sink temperature of the second heat engine is 300 K. The efficiency of both heat engines is the same. The temperature of the intermediate reservoir is

[✓ a. 625 K]
b. 800 K
c. 860 K
d. 453 K
e. 758 K



$$\eta_1 = \eta_2$$

$$1 - \frac{T_I}{1300k} = 1 - \frac{300k}{T_I}$$

$$T_I^2 = 300(1300) = 390000, \quad T_I = 625k$$

4. Steam is condensed at a constant temperature of 30 °C as it flows through the condenser of a power plant by rejecting heat at a rate of 55 MW. The rate of entropy change of the steam through the condenser is

a. -1.83 MW/K
[✓ b. - 0.18 MW/K]
c. 0.56 MW/K
d. 0 MW/K
e. 1.22 MW/K

$$\Delta S_{isoth} = \frac{Q}{T} = \frac{-55MW}{303k} = -0.18\frac{MW}{K}$$

↳ for isothermal heat transfer to/from "reservoir" reversible $\int ds = \int \frac{\delta Q}{T} = \frac{1}{T}\int \delta Q$

$$\Delta S = Q/T$$

5. Helium gas is compressed adiabatically from 1 atm and 25 °C to 10 atm. The lowest possible temperature of the helium after compression is

lowest possible = reversible, $\Delta s = \cancel{\frac{Q}{T}} + S_{gen} = 0$ ↙0 ↙0

$\therefore \; s_2 - s_1 = 0 = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$

$0 = 5.1926 \ln\left(\frac{T_2}{298}\right) - 2.0769 \ln 10$

$T_2 = 748.5\,K$

$T_2 = 475.5\,°C$

- a. 25 °C
- b. 63 °C
- c. 250 °C
- d. 384 °C
- [✓ e. 476 °C]

6. A unit mass of an ideal gas at temperature T undergoes a reversible isothermal process from pressure P_1 to pressure P_2 while losing heat to the surroundings at temperature T, in the amount of q. If the gas constant for the gas is R, the entropy change of the gas during the process is (note $-\ln(2) = \ln(0.5)$)

property

$\Delta s = s_2 - s_1 = C_p \ln \cancel{\frac{T_2}{T_1}} - R \ln \frac{P_2}{P_1}$ ↙0

$-\ln\frac{P_2}{P_1} = \ln P_1/P_2$

- a. $\Delta s = R \ln(P_2/P_1)$
- [✓ b. $\Delta s = R \ln(P_1/P_2)$]
- c. $\Delta s = 0$
- d. $\Delta s = R \ln(P_2/P_1) - q/T$
- e. $\Delta s = R \ln(P_1/P_2) - q/T$ this is S_{gen}, not ΔS

7. Liquid water flows into an adiabatic pipe section at a temperature of 15 °C and flow rate of 8 kg/s. The temperature of the water increases by 0.2 °C due to friction. The rate of entropy generation is

$\Delta S = \cancel{\frac{Q}{T}} + S_{gen}$ ↙0

$S_{gen} = C_p \ln\left(\frac{T_2}{T_1}\right)\dot{m} = 8\frac{kg}{s}\; 4.184\frac{kJ}{kgK} \ln\left(\frac{288.2}{288}\right)$

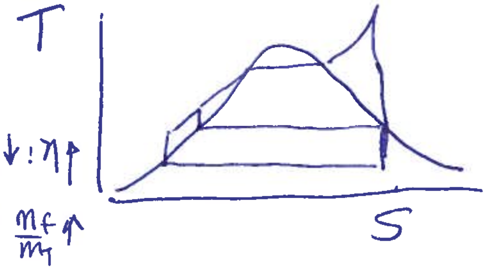
$= 0.023\,\frac{kW}{K} \times 1000\,\frac{W}{kW}$

$= 23\,W/K$

- [✓ a. 23 W/K]
- b. 55 W/K
- c. 68 W/K
- d. 220 W/K
- e. 443 W/K

8. For an ideal Rankine cycle, if the condenser pressure is lowered while the turbine inlet temperature and pressure are the same,

- a. The turbine work output will decrease × w_T ↑
- [✓ b. The amount of heat rejected will decrease] $T\Delta s$ ↓ ✓
- c. The cycle efficiency will decrease × q_H small increase, q_L ↓ ∴ η ↑
- d. The moisture content at the turbine exit will decrease × x ↓ $\frac{m_f}{m_T}$ ↑
- e. The pump work input will decrease × $w = v(P_2 - P_1)$



9. An ideal Rankine cycle operates with boiler pressure = 3 MPa and condenser pressure = 10 kPa. The turbine inlet temperature = 600 °C and the quality of the steam at the turbine outlet is 0.915. Neglecting the pump work and assuming $h_2 \approx h_1$, the cycle efficiency is

$\eta \cong \frac{h_3 - h_4}{h_3 - h_1}$

$h_3 = 3682.8\,kJ/kg$

$h_1 = 191.81\,kJ/kg$

$h_4 = 0.915(2392.1) + 191.81$

$= 2380.3$

$\eta = \frac{3682.8 - 2380.3}{3682.8 - 191.81}$

$= 0.37$

note $\eta_c = 1 - \frac{273+45.81}{273+600}$

$= 0.63$

- a. 24%
- [✓ b. 37%]
- c. 52%
- d. 63%
- e. 71%

10. A heat pump operates with an ideal vapor compression refrigeration cycle using R-134a. The condenser pressure is 1.2 MPa and the evaporator pressure is 0.32 MPa. Refrigerant is saturated vapor at the compressor inlet and saturated liquid at the condenser outlet. During isentropic compression, the enthalpy of the R-134a increases by 27.5 kJ/kg. The coefficient of performance of the heat pump is

a. 0.17

b. 1.2

c. 3.1

d. 4.9

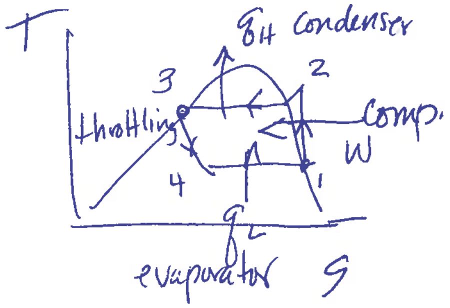
e. [✓ 5.9]

$$COP_{HP} = \frac{q_H}{w} = \frac{h_2 - h_3}{27.5\ \text{kJ/kg}}$$

$$h_2 = h_1 + 27.5 = h_g)_{320} + 27.5 = 251.88 + 27.5 = 279.4\ \text{kJ/kg}$$

$$h_3 = h_f)_{1200} = 117.77\ \text{kJ/kg}$$

$$COP_{HP} = \frac{279.4 - 117.77}{27.5} = 5.9$$



Useful property information

Helium: $R = 2.0769$ kJ/kg-K, $C_p = 5.1926$ kJ/kg-K, $C_v = 3.1156$ kJ/kg-K

Liquid water: $C_p = 4.184$ kJ/kg-K

Saturated Water/steam properties

P	Tsat	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
(kPa)	(°C)		(kJ/kg)			(kJ/kg-K)	
10	45.81	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
400	143.61	604.66	2133.4	2738.1	1.7765	5.1191	6.8955
1000	179.88	762.51	2014.6	2777.1	2.1381	4.4470	6.5850

Superheated steam properties

P (MPa)	T (°C)	h (kJ/kg)	s (kJ/kg-K)
3	600	3682.8	7.5103

Saturated liquid/vapor Refrigerant (R-134a) properties

P	T_{sat}	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
(kPa)	(°C)		(kJ/kg)			(kJ/kg-K)	
320	2.46	55.16	196.71	251.88	0.21637	0.71369	0.93006
1200	46.29	117.77	156.1	273.87	0.42441	0.48863	0.91303