NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2016-2017

MA2007 - THERMODYNAMICS

November/December 2016 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **ELEVEN (11)** pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.
5. Appendix for questions 1 and 2 are provided on pages 7 to 11.

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1. A well-insulated tank, as shown in Figure 1, has two separated closed subsystems. The working fluid in Subsystem A is water in a cylinder with a free-moving piston while that Subsystem B is nitrogen in a closed rigid container with a volume of 0.5 m^3. The heat can be transferred through the wall between subsystem A and subsystem B.
Initially, Subsystem A has 0.1996 m^3 vapor and 0.0004 m^3 liquid water, and the pressure is 100 kPa. The temperature of Subsystem B is different from that of Subsystem A, the pressure of Subsystem B is 380 kPa.
Finally, after the tank reaches the thermal equilibrium, the vapor in Subsystem A is compressed at the constant pressure until the quality (dry fraction) reaches 0.1172.
The water properties can be checked from the appendix and the nitrogen properties are: the gas constant (R) with 0.2968 kJ/kg·K and the specific heat at constant pressure (c_p) with 1.039 kJ/ kg·K. The nitrogen can be treated as an ideal gas.

(a) Determine the work done by the free moving piston in Subsystem A and the heat transfer from Subsystem A, and entropy change in Subsystem A from the initial state to the final state of the whole system,

(9 marks)

(b) Calculate the final temperature of Subsystem B and entropy change in Subsystem B from the initial state to the final state.

(8 marks)

(c) Calculate the entropy generation in Subsystem B and overall system respectively.

(8 marks)

Note: Figure 1 appears on page 2.

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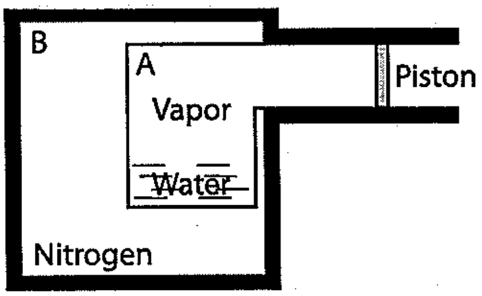

Figure 1

2. A space shuttle is designed for exploring a targeted region with -63 °C (low thermal reservoir), hence a two-stage heat pump system is required to maintain the inner temperature of the shuttle at 17 °C (high thermal reservoir). As illustrated in Figure 2, the first-stage heat pump is gas-compression system with the working fluid of nitrogen and the second-stage heat pump is vapor-compression system with the working fluid of R-134a. A heat exchanger without heat loss to surroundings links two heat pumps.

For the nitrogen cycle, the compression ratio of gas-based heat pump system is 4.0, the inlet temperature of cooling rack is -118 °C (at Point 4) while the outlet temperature of the rack is -63 °C (at Point 1). The compression of compressor II and the expansion of the turbine are isentropic processes. The flow rate of the nitrogen is 0.7 kg/s.

For the R-134a cycle, the inlet of compressor I is saturated vapor at -25 °C. If the isentropic efficiency of the compressor is 85%, the pressure of outlet of compressor I is 900 kPa. After the condenser, the temperature is 30 °C and pressure is 900 kPa. The compressor and expansion valve are adiabatic.

The properties of R134a can be checked from the appendix and the nitrogen properties are constant: specific heat at constant pressure (c_p) with 1.000 kJ/ kg·K and the specific heat at constant volume (c_v) with 0.713 kJ/ kg·K at the operation range. The nitrogen can be treated as an ideal gas. There is no any loss of pressure and heat in pipes.

(a) Calculate the heat transfer from the nitrogen cycle to the R-134a cycle.

(5 marks)

(b) Calculate the mass flow rate of the R-134a cycle.

(5 marks)

(c) Calculate the rate of heat transfer to the high thermal reservoir and from the low thermal reservoir; and determine the rate of entropy change of the two reservoirs.

(7 marks)

(d) Determine the coefficient of performance (COP) of two-stage heat pump system.

(4 marks)

Note: Question 2 continues on page 3.
Figure 2 appears on page 3.

(e) Calculate the maximum COP of two-stage heat pump system.

(4 marks)

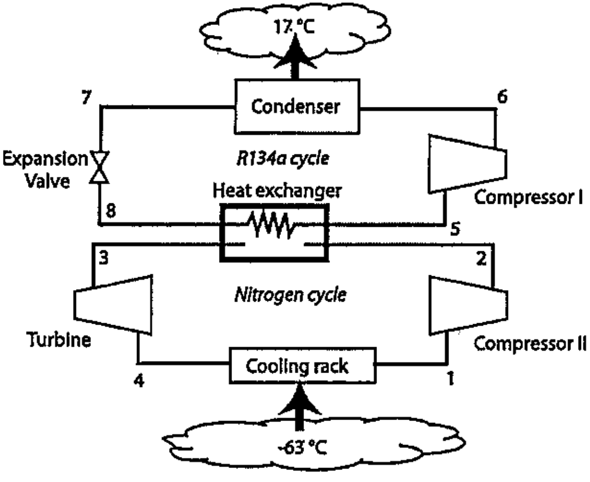

Figure 2

3 (a) Gas-turbine engines have wide applications such as marine propulsion and off-shore oil platforms etc. With the aid of a clearly labeled p-v (pressure-volume) diagram, state one major similarity and difference between the ground based power generation plant and aviation propulsion. What is the most significant design consideration for an application in a jet-propulsion cycle?

(8 marks)

(b) Consider a power plant based on a simple ideal Rankine cycle with ammonia, NH_3, as the working fluid and having the gross power to be developed by the ammonia turbine as 190 MW (Figure 3). The properties table of saturated ammonia is given in Table 1 and the following operating information are known for the vapour power cycle:

State 1: Entry of the turbine with saturated vapour of ammonia at 28°C
State 2: Inlet to the condenser with saturated liquid-vapour mixture of ammonia at 12°C
State 3: Inlet to the ammonia feed pump with saturated liquid of ammonia at 12°C
State 4: Entry to the evaporator with compressed liquid of ammonia (same pressure as State 1)

Note: Question 3 continues on page 4.
Table 1 appears on page 4.
Figure 3 appears on page 4.

Table 1: Properties of saturated ammonia (liquid-vapour): temperature (for question 3 only)

Temp. °C	Press. bar	Specific Volume m³/kg		Enthalpy kJ/kg		Entropy kJ/kgK	
		Sat. Liquid $v_f \times 10^{-3}$	Sat. Vapor v_g	Sat. Liquid h_f	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g
8	5.7395	1.5936	0.2195	217.34	1449.94	0.8438	5.2279
10	6.1529	1.6008	0.2054	226.75	1451.78	0.8769	5.2033
12	6.5890	1.6081	0.1923	236.20	1453.55	0.9099	5.1791
16	7.5324	1.6231	0.1691	255.18	1456.87	0.9755	5.1314
20	8.5762	1.6386	0.1492	274.26	1459.90	1.0404	5.0849
24	9.7274	1.6547	0.1320	293.45	1462.61	1.1048	5.0394
28	10.993	1.6714	0.1172	312.75	1465.00	1.1686	4.9948

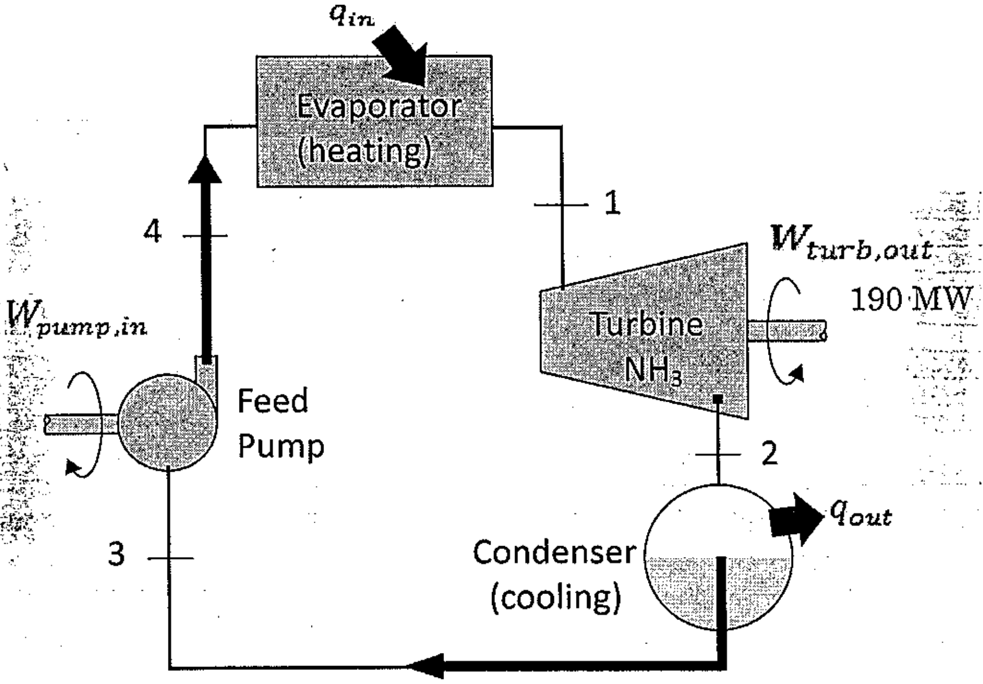

Figure 3

(i) Draw a $T-s$ diagram for the ideal Rankine cycle with state points legibly marked on it.

(4 marks)

(ii) Determine the mass flow rate of the working fluid ammonia and the thermal efficiency of the proposed vapour cycle.

(8 marks)

(iii) Find the work required to drive the ammonia feed pump. (3 marks)

(iv) If the pumps used to circulate heating and cooling agents through the evaporator and condenser heat exchangers respectively require a total power input of 20 MW, calculate the net power output of the plant in MW.

(2 marks)

4 (a) An air-conditioned system is to supply a suitable temperature of air at 24°C to the examination hall. Given that the air enters a heating section at 96 kPa, 13°C, and 28% relative humidity at a rate of 40 m^3/min. Using properties of saturated water as in Table 2, calculate:

(i) The electric power in kW needed for the heating section. (9 marks)

(ii) The relative humidity of the air that entering the examination hall and then comment on this air quality.

(3 marks)

For dry air, take $C_p = 1.005$ kJ/kg·°C, $\gamma = 1.4$ and R = 0.287 kJ/kg·K.

Table 2: Properties of saturated water (liquid-vapour): temperature (for question 4 only)

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg·K	
Temp. °C	Press. bar	Sat. Liquid $v_f \times 10^{-3}$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g
.01	0.00611	1.0002	206.136	0.00	2375.3	0.01	2501.3	2501.4	0.0000	9.1562
4	0.00813	1.0001	157.232	16.77	2380.9	16.78	2491.9	2508.7	0.0610	9.0514
5	0.00872	1.0001	147.120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257
6	0.00935	1.0001	137.734	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003
8	0.01072	1.0002	120.917	33.59	2386.4	33.60	2482.5	2516.1	0.1212	8.9501
10	0.01228	1.0004	106.379	42.00	2389.2	42.01	2477.7	2519.8	0.1510	8.9008
11	0.01312	1.0004	99.857	46.20	2390.5	46.20	2475.4	2521.6	0.1658	8.8765
12	0.01402	1.0005	93.784	50.41	2391.9	50.41	2473.0	2523.4	0.1806	8.8524
13	0.01497	1.0007	88.124	54.60	2393.3	54.60	2470.7	2525.3	0.1953	8.8285
14	0.01598	1.0008	82.848	58.79	2394.7	58.80	2468.3	2527.1	0.2099	8.8048
15	0.01705	1.0009	77.926	62.99	2396.1	62.99	2465.9	2528.9	0.2245	8.7814
16	0.01818	1.0011	73.333	67.18	2397.4	67.19	2463.6	2530.8	0.2390	8.7582
17	0.01938	1.0012	69.044	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351
18	0.02064	1.0014	65.038	75.57	2400.2	75.58	2458.8	2534.4	0.2679	8.7123
19	0.02198	1.0016	61.293	79.76	2401.6	79.77	2456.5	2536.2	0.2823	8.6897
20	0.02339	1.0018	57.791	83.95	2402.9	83.96	2454.1	2538.1	0.2966	8.6672
21	0.02487	1.0020	54.514	88.14	2404.3	88.14	2451.8	2539.9	0.3109	8.6450
22	0.02645	1.0022	51.447	92.32	2405.7	92.33	2449.4	2541.7	0.3251	8.6229
23	0.02810	1.0024	48.574	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011
24	0.02985	1.0027	45.883	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794
25	0.03169	1.0029	43.360	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580
26	0.03363	1.0032	40.994	109.06	2411.1	109.07	2439.9	2549.0	0.3814	8.5367
27	0.03567	1.0035	38.774	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156
28	0.03782	1.0037	36.690	117.42	2413.9	117.43	2435.2	2552.6	0.4093	8.4946
29	0.04008	1.0040	34.733	121.60	2415.2	121.61	2432.8	2554.5	0.4231	8.4739

Note: Question 4 continues on page 6.

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(b) Given the following fuel composition, dry exhaust gas and refuse analysis.

Fuel composition (fraction by mass)
C 0.69; O 0.05; H 0.03; N 0.01; H_2O 0.10; Ash 0.12

Dry exhaust gas analysis (fraction by volume)
CO_2 0.145; CO 0.021; N_2 0.779; O_2 0.055

Refuse analysis (fraction by mass)
C 0.45; Ash 0.55

On the basis of 1 kg of biofuel combustion process, find:

(i) The mass of refuse, per kg of fuel burnt. [Hint: using an ash balance].

(2 marks)

(ii) The mass of dry gaseous products, per kg of fuel burnt. [Hint: consider a carbon balance].

(8 marks)

(iii) Show that the nitrogen in fuel is negligible and then estimate the mass of dry air, per kg of fuel burnt. [Hint: consider a nitrogen balance].

(3 marks)

With Air: dry-bulb temperature 22.8°C, wet-bulb temperature 15.5°C:
The standard compositions for (dry) air are 21% oxygen and 79% nitrogen on a molar basis. Take the molecular weight of dry air as 29 g/mol.
You may assume that the atomic mass of C, H, O and N are 12, 1, 16 and 14, respectively.

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1) For A,

a) $v = \frac{V_g}{v_g} + \frac{V_f}{V_f}$

$= \frac{0.1996}{1.6941} + \frac{0.0004}{0.001043}$

$= 0.5013 m^3/kg$

PA = 100kPa (saturated liquid - vapour mixture)

$P_B = 380kPa$

$V = mv$

$0.2 = m\,(0.5013)$

$\therefore m_A = 0.399kg$

$R = 0.2968,\ c_p = 1.039$

$R = c_p - c_v$

$0.2968 = 1.039 - c_v \quad \therefore c_v = 0.7422$

before $\begin{cases} T_A = 99.61°C \\ T_B = ? \end{cases}$

~~After { T = 99.61°C~~

$\because$ Finally, $x = 0.1172$

~~$x = \frac{u_2 - u_f}{u_{fg}}$~~

$\therefore u_2 = x u_{fg} + u_f$

$= 0.1172(2088.2) + 417.4$

$= 662.14 kJ/kg$

Initially, $x = \frac{v - v_f}{v_{fg}}$

$= \frac{0.5013 - 0.001043}{1.6941 - 0.001043}$

$= 0.2955$

$u_1 = x u_{fg} + u_f$

$= 0.2955(2088.2) + 417.4$

$= 1034.46 kJ/kg$

$v_2 = x v_{fg} + v_f$

$= 0.1172(1.6941 - 0.001043) + 0.001043$

$= 0.19947 m^3/kg$

$W_b = p(V_2 - V_1)$

$= mp(v_2 - v_1)$

$= 0.399 \times 100 \times (0.19947 - 0.5013)$

$= -12.04kJ$

(work done by free moving piston)

$Q - W_b = \Delta U$

$= m(u_2 - u_1)$

$Q - (-12.04) = 0.399(662.14 - 1034.41)$

$\therefore Q = -160.633 kJ$ (heat transfer from subsystem A)

Entropy change, ΔS

$\Delta S = m(s_2 - s_1)$

$= 0.399\,[0.1172 \times 6.0562 + 1.3028 - (0.2955 \times 6.05 + 1.3028)]$

$= -0.4301\ kJ \cdot K$

b) Final temperature of subsystem B is 99.61°C.

For subsystem B,

$Q - \cancel{W}^{0} = \Delta U$

$160.633 = m C_v (T_2 - T_1)$

$= \frac{640.16}{T_1} \times 0.7422 \times [(99.61 + 273) - T_1]$

$\therefore T_1 = 278.465\,K$

$= 5.465°C$

$PV = mRT$ (initially)

$m = \frac{PV}{RT}$

$= \frac{380 \times 0.5}{0.2968 \times T_1}$

$= \frac{640.16}{T_1}$

$m = \frac{641.16}{278.465}$

$= 2.3\,kg$

$\therefore$ Entropy change of subsystem B

$\Delta s = m_B (s_2 - s_1)$

$= 2.3 [c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1})$

$= 2.3 \times (1.039 \times \ln \frac{273+99.61}{278.465} - 0.2968 \ln \frac{508.473}{380})$

$= 0.497\,kJ \cdot K$

For B, constant volume

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$

$\therefore p_2 = \frac{T_2}{T_1} \times p_1$

$= \frac{273+99.61}{273+5.465} \times 380$

$= 508.473\,kPa$

c) For subsystem B,

$\Sigma \frac{Q}{T_{surr}} + S_{gen} = \Delta S_{sys}$

$S_{gen} = 0.497 - \frac{160.633}{273+99.61}$

$= 0.06606\,kJ \cdot K$

For subsystem A,

$\Sigma \frac{Q}{T_{surr}} + S_{gen} = \Delta S_{sys}$

$S_{gen} = -0.4301 - (\frac{-160.633}{273+99.61})$

$= 1.00222 \times 10^{-3}\,kJ \cdot K$

For overall system,

$S_{gen} = S_{gen\,A} + S_{gen\,B}$

$= 0.06606 + 1.00222 \times 10^{-3}$

$= 0.06706\,kJ \cdot K$

2)a) $T_4 = -118°C$, $T_1 = -63°C$, $\dot{m}_{N2} = 0.7 kgs^{-1}$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{k-1}{k}}$$

$$T_3 = 4^{\frac{0.4}{1.4}} \times (273-118)$$

$$= 230.33K$$

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

$$k = \frac{cp}{cv} = \frac{1}{0.713} = 1.4$$

$$= 4^{\frac{0.4}{1.4}}$$

$$T_2 = 4^{\frac{0.4}{1.4}} \times (273-63)$$

$$= 312.06 K$$

For N_2 cycle, $Q_H = \dot{m}(h_2 - h_3)$

$$= \dot{m}cp(T_2 - T_3)$$

$$= 0.7 \times 1 \times (312.06 - 230.33)$$

$$= 57.211 kW$$

b) For R-134a cycle,

$\dot{Q} = \dot{m}_{R\text{-}134a}(h_5 - h_8)$

$h_7 \approx h_{f@30°C} = 93.58 kJ/kg$

$\therefore h_8 = h_7 = 93.58 kJ/kg$

5: sat. vapour, $T = -25°C$

6: $p = 900kPa$

7: $T = 30°C$, $p = 900kPa$

8: $h_8 = h_7$

$h_5 = h_{g@-25°C}$

$= (234.68 + 235.92)/2$

$= 235.3 kJ/kg$

$\therefore 57.211 = \dot{m}_{R\text{-}134a}(235.3 - 93.58)$

$\therefore \dot{m}_{R\text{-}134a} = 0.4037 kgs^{-1}$

$s_{6s} = s_5$

$= 0.950425 kJ/kg\text{-}K$ at $900kPa$

c) $n_c = \frac{w_s}{w_a} = \frac{h_{6s} - h_5}{h_{6a} - h_5}$

$s_5 = s_{g@-25°C}$

$= (0.95144 + 0.94941)/2$

$= 0.950425 kJ/kg\text{-}K$

At 900kPa,

0.9327	274.17
0.950425	h_{6s}
0.966	284.77

$\therefore h_{6s} = 279.81 kJ/kg$

$$0.85 = \frac{279.81 - 235.3}{h_{6a} - 235.3}$$

$\therefore h_{6a} = 287.665 kJ/kg$

For R-134a cycle

$Q_H = \dot{m}_{R\text{-}134a}(h_{6a} - h_7)$

$= 0.4037(287.665 - 93.58)$

$= 78.35 kW$

(Rate of heat transfer to the high thermal reservoir)

For N_2 cycle

$Q_L = \dot{m}_{N_2}(h_1 - h_4)$

$= \dot{m}_{N_2}cp(T_1 - T_4)$

$= 0.7 \times 1 \times (-63 + 118)$

$= 38.5kW$

(Rate of heat transfer from the low thermal reservoir)

For high thermal reservoir

$$\Delta S = \frac{Q}{T_{surr}}$$

$$= \frac{78.35}{273+17}$$

$$= 0.2702 \text{ kJ/kg·K}$$

For low thermal reservoir

$$\Delta S = \frac{Q}{T_{surr}}$$

$$= \frac{-38.5}{273-63}$$

$$= -0.1833 \text{ kJ/kg·K}$$

d) $COP = \frac{Q_H}{Q_H - Q_L}$

$$= \frac{78.35}{78.35-38.5}$$

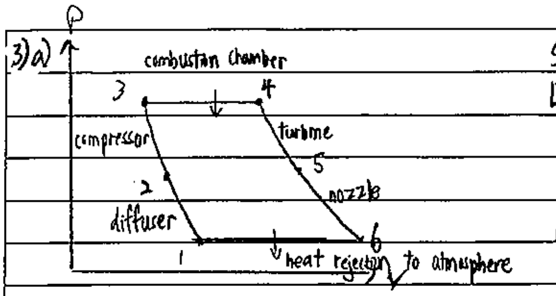
$$= 1.966$$

e) $COP_{max} = \frac{T_H}{T_H - T_L}$

$$= \frac{273+17}{17-(-63)}$$

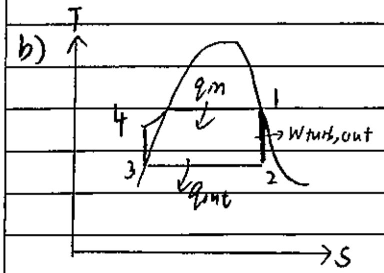
$$= 3.625$$

3) a)



Similarity: Both of them are Brayton Cycle.
Difference: A ground based power generation plant is a closed cycle while a aviation propulsion cycle is a opened cycle.
Design consideration: Since the highest temperature of the jet-propulsion cycle will occur at the turbine-blades, there is a maximum tolerable temperature of the turbine blades, so the most significant design consideration for an application in a jet-propulsion cycle will be the materials of turbine blades.

b)



1: sat. vapour at 28°C, $p = 1.0993\,MPa$
2: liquid-vapor mixture at 12°C
3: sat. liquid at 12°C
4: compressed liquid, $p = 1.0993\,MPa$

$s_1 = s_2$

$s_1 = s_g @ 28°C$
$= 4.9948$
$= s_2$

$x = \frac{s - s_f}{s_{fg}}$, At 2
$= \frac{4.9948 - 0.9099}{5.1791 - 0.9099}$
$= 0.93575$

$h_1 = h_g @ 28°C$
$= 1465\,kJ/kg$

$h_2 = x h_{fg} + h_f$
$= 0.93575(1453.55 - 236.2) + 236.2$
$= 1375.34\,kJ/kg$

$h_3 = h_f @ 12°C$
$= 236.2\,kJ/kg$

$w_{pump,in} = v(p_4 - p_3)$
$h_4 - h_3 = 1.6081 \times 10^{-3}(1.0993 - 0.6589)1000$
$\therefore h_4 = 236.91\,kJ/kg$

$v_3 = v_f @ 12°C$
$= 1.6081 \times 10^{-3}$

$W_{turb,out} = 190\,MW$
$190 \times 1000 = \dot{m}(h_1 - h_2)$
$= \dot{m}(1465 - 1375.34)$
$\dot{m} = 2119.117\,kgs^{-1}$

$\eta_{th} = 1 - \frac{q_{out}}{q_{in}}$
$= 1 - \frac{h_2 - h_3}{h_1 - h_4}$
$= 1 - \frac{1375.34 - 236.2}{1465 - 236.91}$
$= 7.24\%$

iii) $\dot{W}_{pump,in} = \dot{m}\,(h_4 - h_3)$

$= 2119.117\,(236.91 - 236.2)$

$= 1504.57$ kW

iv) $W_{output} = W_{turb,out} - W_{pump,in} - 20$ MW

$= 190$ MW $- 1504.57 \times 10^{-3} - 20$

$= 168.5$ MW

4a) $\phi = \frac{P_v}{P_g}$

$P_v = 0.28 \times P_{sat@13°C}$

$= 0.28 \times 0.01497 \times 100$

$= 0.4192 kPa$

$P = P_a + P_v$

$P_a = P - P_v$

$= 96 - 0.4492$

$= 95.581 kPa$

$P_a \dot{v}_a = RT_a$

$\dot{v}_a = \frac{0.287 \times (273 + 13)}{95.581}$

$= 0.8588 \ m^3/min$

$\dot{V} = \dot{m}v$

$m = \frac{40}{0.8588}$

$= 46.578 kg/min$

$\omega = \frac{m_v}{m_a}$

$= \frac{0.622 P_v}{P - P_v}$

$= \frac{0.622 \times 0.4192}{95.581}$

$= 2.728 \times 10^{-3}$

$h_1 = c_pT_1 + \omega_1 h_{g@13°C}$

$= 1.005 \times 13 + 2.728 \times 10^{-3} \times 2525.3$

$= 19.954 \ kJ/kg$

$h_2 = c_pT_2 + \omega_2 h_{g@24°C}$

$= 1.005 \times 24 + 2.728 \times 10^{-3} \times 2545.4$

$= 31.064 \ kJ/kg$

$\because$ Heating section

$\therefore \omega_2 = \omega_1 = 2.728 \times 10^{-3}$

$Q_{in} = \dot{m}_a (h_2 - h_1)$

$= 46.578 (31.064 - 19.954)$

$= 517.475 kJ/min$

$= 8.625 kW$

$\phi_2 = \frac{P_{v2}}{P_{g2}}$

$= \frac{0.4192}{P_{sat@24°C}}$

$= \frac{0.4192}{0.02985 \times 100}$

$= 14.04 \%$

The relative humidity is actually lower than optimum level which is about 45%, we can feel much cooler than the actual temperature because our sweat evaporates easily, cooling us off.

1) i) Using Ash balance,

$0.55 \times m_{refuce} = 0.12$

$\therefore m_{refuse} = 0.218\ kg$

ii) m_c in refuse

$m_c = 0.45 \times 0.218$

$= 0.0982\ kg$

In dry exhaust gas

	Mole fraction
CO_2	0.145
CO	0.021

Mole fraction of C in CO_2 + Mole fraction of C in CO in dry exhaust gas

$= 0.145 \times \frac{12}{12+2\times16} + 0.021 \times \frac{12}{12+16}$

$= 0.04855$

$mf_i = y_i \cdot \frac{M_i}{M_m}$

$mf_c = y_c \cdot \frac{M_c}{M_M}$

$= 0.04855 \times \frac{12}{30.54}$

$= 0.01908$

$M_M = \Sigma y_i M_i$

$= 0.145 \times 44 + 0.021 \times 28 + 0.779 \times 28 + 0.055 \times 32$

$= 30.54\ kg / kmol$

Initially, m_c in fuel

$= 1 \times 0.69$

$= 0.69\ kg$

Carbon Balance

$0.69 - 0.0982 = 0.01908 \times m_{dry\ exhaust\ gas}$

$m_{dry\ exhaust\ gas} = 31.017\ kg$

iii) mass of dry exhaust gases = 31.017 kg

$mf_{N_2} = y_{N_2} \cdot \frac{M_{N_2}}{M_M}$

$= 0.779 \times \frac{28}{30.54}$

$= 0.7142$

$\therefore m_{N_2}$ in dry exhaust gases $= 31.017 \times 0.7142$

$= 22.153\ kg$

m_{N_2} in fuel $= 0.01 \times 1$

$= 0.01\ kg$

$\therefore$ The nitrogen in fuel is negligible as compared the mass of nitrogen in dry exhaust gas.

Dry air	y_i	mf_i
O_2	0.21	0.23724
N_2	0.79	$0.79 \times \frac{28}{29} = 0.76276$

$\therefore$ Consider nitrogen balance

$0.76276 \times m_{dry\ air} = 22.153$

$\therefore m_{dry\ air} = 29.04\ kg$

~ GOOD LUCK IN EXAM ~

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2016-2017

MA2007 – THERMODYNAMICS

April/May 2017

Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **FOUR** (4) pages.
2. Answer **ALL FOUR** (4) questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.

---

1 A piston-cylinder assembly initially contained 1 kg of saturated liquid water at 100°C. The water undergoes a process to the corresponding saturated vapour state, during which the piston moves freely in the cylinder. This change of state is brought about by the action of a paddle wheel, and there is no heat transfer to the surroundings.

(a) Draw a schematic of the problem complete with all the relevant information clearly indicated on the diagram.

(5 marks)

(b) Provide a list of assumptions.

(5 marks)

(c) Determine the net work done on the water during this process.

(7 marks)

(d) Determine the amount of entropy produced during this process.

(8 marks)

2. As shown in Fig. 1, a direct-coupled adiabatic steam turbine is to power an adiabatic air compressor as well as simultaneously driving a generator. Steam enters the turbine at 12.5 MPa and 500°C at a rate of 25 kg/s and exits at 10 kPa and a quality of 0.92. Air enters the compressor at 98 kPa and 295 K at a rate of 10 kg/s and exits at 1 MPa and 620 K.

(a) Show the process of the steam turbine on a Mollier diagram showing the state points in relation to the vapor dome.

(5 marks)

(b) Determine the power delivered to the compressor by the turbine.

(5 marks)

(c) Determine the power delivered to the generator by the turbine.

(5 marks)

(d) Determine the rate of entropy generation during this process.

(10 marks)

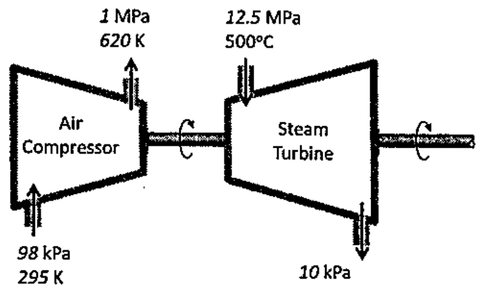


Figure 1

3 (a) An internal combustion engine designer suggests to improve the standard diesel engine thermal efficiency by having a dual combustion process (i.e. splitting the usual heat addition process into reversible constant volume heating followed by reversible constant pressure heating to obtain a two-step power stroke) so that its *T-s* (temperature-entropy) plot is as shown in Figure 2. This modified air standard mixed cycle has the following five processes:

Process 1 to 2: isentropic compression
Process 2 to 3: reversible constant volume heating
Process 3 to 4: reversible constant pressure heating
Process 4 to 5: isentropic expansion
Process 5 to 1: reversible constant volume cooling

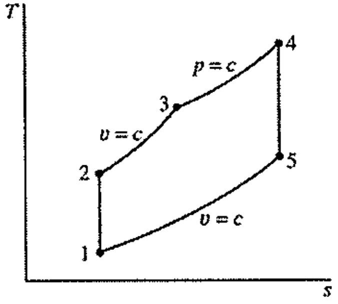


Figure 2

(i) Replot the mixed cycle of operation in the form of a *p-v* (pressure-volume) diagram.
(3 marks)

Given that the air intake pressure and temperature of this mixed cycle engine is 101 kN/m^2 and 300 K, the maximum cycle pressure is 70 x 10^5 kN/m^2 and the compression ratio ($r = v_1/v_2$) is 20/1. Assume that the heat added at constant pressure is equal to the heat added at constant volume. For air, take C_p = 1.005 kJ/kg·K, C_v = 0.718 kJ/kg·K, and $\gamma = 1.40$.

(ii) Calculate the pressure p_2, temperature T_3, T_4, T_5 and 'cut-off' ratio ($r_c = v_4/v_3$), respectively.
(6 marks)

(iii) Calculate the amount of heat supplied.
(2 marks)

(iv) Calculate the amount of heat rejected.
(2 marks)

(v) Find the air standard thermal efficiency, η.
(2 marks)

Note: Question 3 continues on page 4.

(b) Consider a combined gas-stream power plant with thermal efficiency of η_{cc} in which the thermal efficiencies of gas cycle and steam cycle are defined as $\eta_g = W_g / Q_{in}$ and $\eta_s = W_s / Q_{g,out}$, respectively. Q_{in} is the heat supplied to the gas cycle, Q_{out} is the heat rejected by the steam cycle, and $Q_{g,out}$ is the heat rejected from the gas cycle and supplied to the steam cycle. The plant layout and its *T-s* (temperature-entropy) plot are shown in Figure 3. Show that the thermal efficiency of a combined gas-stream power plant η_{cc} can be expressed as $\eta_{cc} = \eta_g + \eta_s - \eta_g \eta_s$.

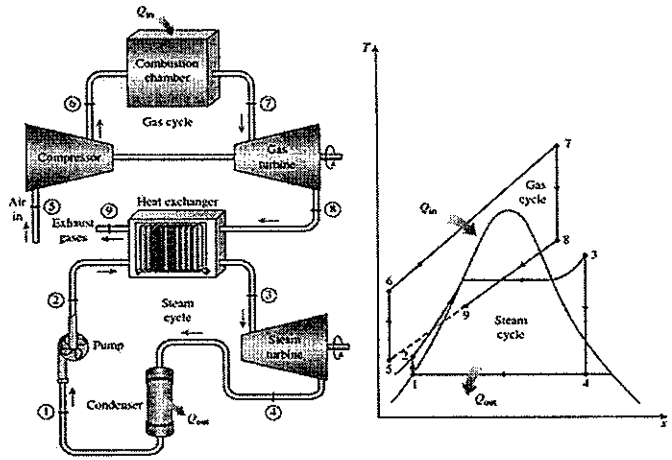


Figure 3

(10 marks)

4. Liquid ethyl alcohol (C_2H_5OH) at 25°C, 1 atm enters a steady-state combustion chamber and burns with air entering the combustion chamber at 500 K, 1 atm. The fuel flow rate is 30 kg/s, and the air-fuel ratio by mass is 7.5. The products, namely, CO_2, CO, H_2O(g) and N_2 leave the combustion chamber at 1000 K, 1 atm. You may consider all species to be ideal gases, and ignore potential and kinetic energy effects. Given molecular masses of air and ethyl alcohol are 28.97 kg/kmol and 46 kg/kmol, respectively,

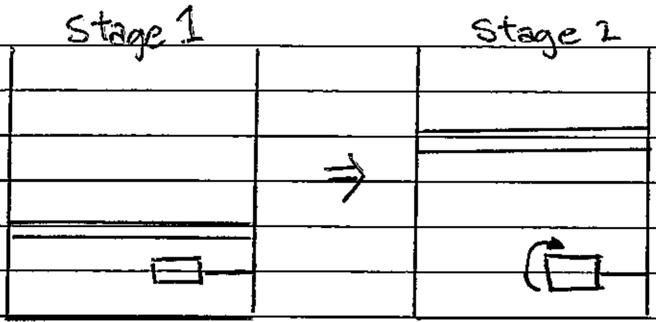
(a) determine the molar air-fuel ratio to 2 decimal places,
(5 marks)

(b) write a balanced chemical reaction to represent the oxidation of the ethyl alcohol, and
(10 marks)

(c) determine the rate of heat transfer from the combustion chamber in kJ/s.
(10 marks)

END OF PAPER

1 a)



1 Kg sat liquid Sat Vapour
100°c

b) Assumptions →
1) Mass is constant
2) Steady operating conditions exist
3) KE and PE negligible
4) adiabatic process [Q = 0]
5) Piston weight negligible

c) State 1

@ 100°c

$V_1 = 0.001043$

$U_1 = 419.06$

State 2

Same °c @ 100°c as no heat transfer to surrounding

$V_2 = 1.6720$

$U_2 = 2506$

$$\cancelto{0}{Q} - w = \Delta U \text{ (closed system)}$$

$$-w = [U_2 - U_1]\, m$$

$$-w = [2506 - 419.06]\, 1$$

$$w = -2086.94 \text{ KJ} \ast$$

d) State 1

$S_1 = 1.3072$

State 2

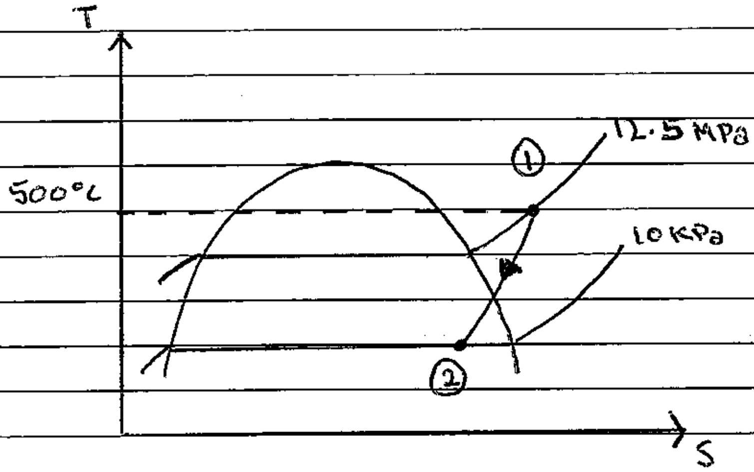
$S_2 = 7.3542$

$$\Delta S \Rightarrow m[S_2 - S_1]$$

$$= 1\,[7.3542 - 1.3072]$$

$$= 6.047 \text{ KJ/K} \ast$$

2a)



b) $\dot{m}_{air} = 10$ Kg/s

$W \Rightarrow \dot{m}_{air} C_p [T_2 - T_1]$

$= 10[1.005][620 - 295]$

$= 3266.25$ Kw ✱

c) @ 12.5 MPa [Superheated]

500°C

$h_1 = 3343.6$ $S_1 = 6.4651$

@ 10 KPa $x = 0.92$

$S_2 = 0.6492 + 0.92[8.1488]$

$= 8.1461$

$h_2 = 191.81 + 0.92[2392.1]$

$= 2392.5$

Workdone by turbine

$\Rightarrow \dot{m}_s [h_2 - h_1]$

$= 25[2392.5 - 3343.6]$

$= -23777.5$ KW

∴ Power to generator

$23777.5 - 3266.25$

$= 20511.25$ Kw ✱

d) ΔS by air $\Rightarrow \dot{m}_a [C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}]$

$\Rightarrow 10 [1.005 \ln \frac{620}{295}$

$- 0.287 \ln \frac{1000}{98}]$

$= 0.7985$ KJ/K

ΔS by steam $\Rightarrow \dot{m}_s [S_2 - S_1]$

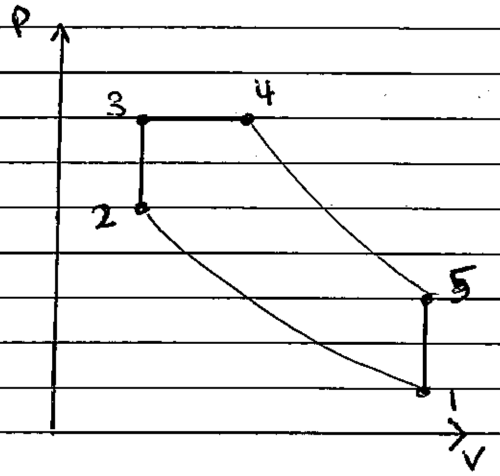
$= 25[8.1461 - 6.4651]$

$= 42.025$ KJ/K

∴ Sgen $\Rightarrow 42.025 + 0.7985$

$= 42.8235$ KJ/K ✱

3a)
i)



① 101 KPa

$T_1 = 300K$

$P_3 = P_4 = 70 \times 10^5 \ KN/m^2$

$= 70 \times 10^5 \ KPa$

$r = \frac{V_1}{V_2} = 20$

ii) $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^K$ $\quad \frac{T_2}{T_1} = \left[\frac{P_2}{P_1}\right]^{\frac{K-1}{K}}$

① $\frac{P_2}{101} = (20)^{1.4}$ $\quad$ ② $\frac{T_2}{300} = \left[\frac{6695}{101}\right]^{\frac{0.4}{1.4}}$

$P_2 = 6695 \ KPa$ ⁂ $\quad T_2 = 994K$

$\frac{P_2}{T_2} = \frac{P_3}{T_3}$ $\quad Q_{IN}$ along ② to ⑥ is equal to ③ - ④

③ $\frac{6695}{994} = \frac{70 \times 10^5}{T_3}$ $\quad$ ④ $C_v[T_2 - T_3] = C_p[T_3 - T_4]$

$0.718[994 - 1039283] = 1.005[1039283 - T_4]$

$T_3 = 1039283K$ ⁂ $\quad T_4 = 1781065.589K$ ⁂

⑤ Cut off ratio

P = constant

$\frac{T_4}{V_4} = \frac{T_3}{V_3}$

$\frac{T_4}{T_3} = \frac{V_4}{V_3}$

$\therefore \frac{V_4}{V_3} = 1.7137$ ⁂

⑥ $\frac{T_5}{T_4} = \left[\frac{V_4}{V_5}\right]^{0.4}$ $\quad V_5 = V_1$

$\frac{T_5}{T_4} = \left[\frac{V_4}{V_1}\right]^{0.4}$ $\quad V_4 = 1.7137 V_3$

$\frac{T_5}{T_4} = \left[\frac{1.7137V_3}{V_1}\right]^{0.4}$ $\quad V_3 = V_2$

$\frac{T_5}{T_4} = \left[1.7137\left[\frac{V_2}{V_1}\right]\right]^{0.4}$ $\quad \frac{V_2}{V_1} = \frac{1}{20}$

$\frac{T_5}{T_4} = \left[\frac{1.7137}{20}\right]^{0.4}$

$T_5 = 666563.9K$ ⁂

iii) ② - ③ ③ - ④

$Q_1 = C_v [T_2 - T_3]$ $Q_2 = C_p [T_3 - T_4]$

$= 745491$ KJ/Kg $= 745491$ KJ/Kg

$\therefore Q_{total} = 745491 \times 2$

$= 1490983$ KJ/Kg ※

iv) $Q_{out} = C_v [T_5 - T_1]$

$= 0.718 [666563.9 - 300]$

$= 478377$ KJ/Kg ※

v) $\eta_{th} = \frac{W}{Q_{IN}} = \frac{Q_{total} - Q_{out}}{Q_{total}} = 0.679 \times 100\% = 67.9\%$ ※

b) $\eta_{cc} = \frac{W_{net}}{Q_{IN}} = \frac{W_g + W_s}{Q_{IN}}$

$W_g = Q_{IN} - Q_{g,out}$

$W_s = Q_{g,out} - Q_{out}$

$$= \frac{[Q_{IN} - Q_{g,out}] + [Q_{g,out} - Q_{out}]}{Q_{IN}}$$

$$= \left[1 - \frac{Q_{g,out}}{Q_{IN}}\right] + \left[1 - \frac{Q_{out}}{Q_{g,out}}\right]\left[\frac{Q_{g,out}}{Q_{IN}}\right]$$

$$= \eta_g + \eta_s - \eta_g \eta_s$$

4. a/F ratio by mass ⇒ 7.5
mole of C_2H_5OH ⇒ 46

a) a/F ratio by molar ⇒ $\frac{7.5 \times 46}{28.97} = 11.908$ ※

$a_{th} = \frac{11.908}{4.76} = 2.5$

b) $C_2H_5OH + 2.5[O_2 + 3.76N_2] = xCO_2 + yCO + zH_2O + wN_2$

$C: 2 = x + y$ $\quad O: 1 + 5 = 2x + y + z$ $\quad N_2: 9.4 = w$
$H: 6 = 2z$ $\quad 6 = 2x + y + 3$
$z = 3$ $\quad 6 = 2x + 2 - x + 3$
$x = 1$
$y = 1$

$\therefore C_2H_5OH + 2.5[O_2 + 3.76N_2] = CO_2 + CO + 3H_2O + 9.4N_2$ ※

c) $[\Delta \bar{h}]_{CO_2} = -393520 + 42769 - 17618 = -368369$

$[\Delta \bar{h}]_{CO} = -110530 + 30355 - 14600 = -94775$

$[\Delta \bar{h}]_{H_2O} = 3[-241820 + 35882 - 16828] = -668298$

$[\Delta \bar{h}]_{N_2} = 9.4[30129 - 14581] = 146151.7$

$[\bar{h}]_{C_2H_5OH} = -277690$

$Q_{out} \Rightarrow [\Sigma \Delta \bar{h} - \bar{h}_{C_2H_5OH}] \cdot 30Kg/s$

$\Rightarrow -21228009$ KJ/s ※

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2017-2018

MA2007 - THERMODYNAMICS

November/December 2017 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **NINE (9)** pages inclusive of **FIVE (5)** pages of Appendix.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.
5. Appendix for questions 1 and 2 are provided on pages 5 to 9.

---

1. As shown in Figure 1, the well insulted setup includes two parts, Container A is a control volume and Container B is a piston-cylinder closed system. The working fluid water flows into Container A at inlet Point 1 and leaves at outlet Point 2. Nitrogen is initially filled in Container B. Nitrogen has the volume of 0.5 m^3, the temperature of 77 °C and the pressure of 100 kPa at the initial state. Nitrogen in Container B is isothermally and slowly expanded finally with three times from its initial volume. The whole expansion process takes 2 min. The heat can be transferred across the cylinder wall between Containers A and B. In the period of piston expansion in Container B, the fluid in Container A can be assumed in a steady state. The saturated vapor with a flow rate 0.01 kg/s and 100 kPa goes into Chamber A at Point 1. The pressure at Point 2 is as same as that in Point 1. The kinetic and potential energy changes in the system are negligible. The nitrogen properties are: the gas constant (R) is 0.2968 kJ/kg·K, and the specific heat at constant pressure (c_p) is 1.039 kJ/kg·K. The nitrogen can be treated as an ideal gas. The properties of water can be obtained from the appendices.

(a) Determine the work done by the moving piston in Container B and the heat transfer between Containers A and B, and the entropy change in Container B from the initial state to the final state.

(10 marks)

(b) Calculate the entropy change rate in kW/K in Container A from the inlet to outlet in the process.

(5 marks)

Note: Question 1 continues on page 2.
Figure 1 appears on page 2.

(c) Calculate the entropy generation in Container A and Container B respectively. Please justify the overall process is reversible, irreversible or impossible.

(10 marks)

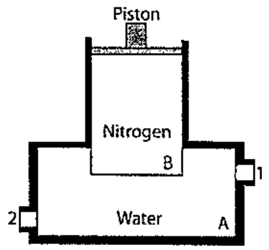


Figure 1

2. As illustrated in Figure 2, a two-condenser vapor-compression heat pump system is designed for heating the product space at 20 °C (high thermal reservoir) while receiving the heat from a low thermal reservoir at -8 °C. For the special design, the two condensers are required to be arranged in series but operated under the different pressure. A low expansion valve I is used to regulate the pressure between Condenser I and Condenser II. Then the condensed fluid is expended to a low pressure through a high expansion valve II before the liquid moves into an evaporator. After evaporation, the working fluid is compressed to a higher pressure. The vapor is condensed in Condensers I and II. The working fluid is R-134a with the mass flow rate at 2 kg/s. In the steady state, the inlet of the compressor is saturated R-134a vapor at -10 °C at Point 1. If the isentropic efficiency of the compressor is 90%, the pressure of outlet of the compressor is 800 kPa at Point 2. After the condensation in Condenser I, the temperature is 30 °C and pressure is 800 kPa at Point 3. The working fluid is expanded to 700 kPa at Point 4 by Expansion valve I, and cooled to the saturated liquid by Condenser II at Point 5. The fluid is then expanded by Expansion valve II before the fluid is evaporated in the evaporator. The compressor and expansion valves are adiabatic. There is no loss of pressure and heat in the pipes. The properties of R-134a can be obtained from the appendices.

(a) Calculate the power to maintain the compressor under the steady state operation.

(5 marks)

(b) Calculate the rate of heat transfer to the high thermal reservoir and from the low thermal reservoir. Determine the rate of entropy change to high temperature and low temperature reservoirs respectively.

(8 marks)

(c) Determine the rate of entropy generation at the low expansion valve I.

(3 marks)

Note: Question 2 continues on page 3.
Figure 2 appears on page 3.

(d) Determine the coefficient of performance (COP) of two-condenser vapor compression heat pump system.

(5 marks)

(e) Calculate the maximum COP of the heat pump system.

(4 marks)

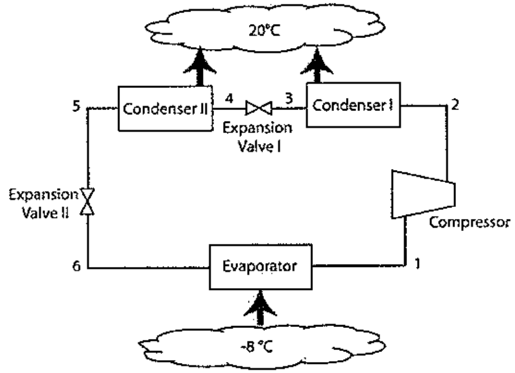


Figure 2

3 (a) Air at 285 K enters a simple turbojet engine at a mass flow rate of 20 kg/s and at a velocity of 300 m/s (relative to the engine without any angle of attack). Air is heated in the staggered combustion chamber at a rate 20,000 kJ/s and it leaves the engine at 703 K. State clearly the four assumptions being applied here and determine the jet exit velocity and find the thrust produced by a jumbo aircraft with a total of four such identical turbojet engine. (*Hint:* select the each entire engine as your control volume).
For air: at 12 °C, take Cp = 0.9829 kJ/kg·°C; at 430 °C, take Cp = 1.0132 kJ/kg·°C.

(15 marks)

(b) Plot the ideal Rankine cycle with three stages of reheating on a $T - s$ diagram. Assume the turbine inlet temperature is the same for all stages. How does the cycle thermal efficiency vary with the number of reheat stages?

(6 marks)

(c) Given a simple ideal Rankine cycle and an ideal Rankine cycle with four reheat stages. Assuming that both cycles operate between the same pressure limits. The maximum temperature is 850 °C in the simple cycle and 300 °C in the reheat cycle. Which cycle do you think will have a higher thermal efficiency and why?

(4 marks)

---

4 (a) A cold water pipe at 17.5 °C passes through an examination hall in which the air is at 24.08 °C. What is the maximum relative humidity the air can have before condensation occurs on the pipe? State the necessary assumptions for your calculation and illustrate your work using the temperature-volume (T-v) plot. You may use properties of saturated water as in Table 1.

(9 marks)

Table 1: Properties of saturated water: pressure

Saturated water—Pressure table

		Specific volume, m³/kg		*Internal energy, kJ/kg*			*Enthalpy, kJ/kg*			*Entropy, kJ/kg · K*		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071

(b) Consider the stoichiometric combustion of methane (CH_4) in air, find the balanced chemical equation and calculate the air-fuel (AF) ratio on a mass basis.

(6 marks)

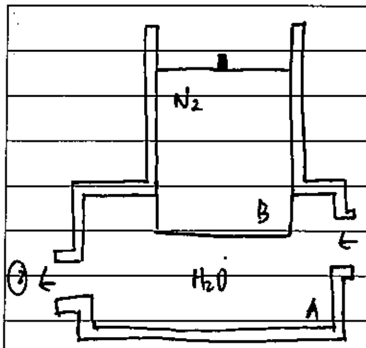
Instead of stoichiometric combustion, the methane burns with air but now to form products consisting of CO_2, CO, H_2O, and N_2 only. Given that the equivalence ratio (defined as theoretical AF over the actual AF) is 1.40, determine the new balanced reaction equation.

The standard compositions for (dry) air are 21 % oxygen and 79 % nitrogen on a molar basis. Take the molecular weight of dry air as 29 g/mol.

You may assume that the atomic mass of C, H, O and N are 12, 1, 16 and 14, respectively.

(10 marks)

1.



Initial $\xleftarrow{120s}$ Final

$\boxed{N_2}$ $T = 77°C = 350.15K$ $T = 350.15K$

$V = 0.5m^3$ $V = 1.5m^3$

$P = 100kPa$

$\boxed{H_2O}$ sat. vapour , $\dot{m} = 0.01kg/s$

$P_1 = 100kPa \Rightarrow T_1 = 99.61°C$

$h_1 = 2675.0 kJ/kg$ $P_2 = 100kPa$

$s_1 = 7.3589 kJ/kgK$

(a) $PV = mRT$

$W = \int P\,dV = \int \frac{mRT}{V}\,dV = mRT \ln\frac{V_2}{V_1}$ ← constant T $m_{N_2} = \frac{P_1V_1}{RT} = 0.4811184117 kg$

$= 54.9306443 kJ \approx 54.9 kJ$ // work is done by the gas

$\Delta T = 0 \Rightarrow \Delta U = Q + W = 0$

$Q \approx 54.9kJ$ // heat is transferred from A to B

$\Delta S = m\left[c_v \cancel{\ln\frac{T_2}{T_1}}^{0} + R\ln\frac{V_2}{V_1}\right] = mR\ln 3 = 0.1568713795 kJ/K$

$\approx 0.157 kJ/K$ //

(b) A: H_2O

$t = 120s$ $Q = \dot{m}t(h_2 - h_1) \approx -54.9kJ$

$h_g > h_2 = 2629.224488 kJ/kg > h_f$ @100kPa $\Rightarrow$ sat. mixture

$x_2 = \frac{h_2 - h_f}{h_{fg}} = 0.9797184886$

$s_2 = s_f + x_2 s_{fg} = 7.23617111 kJ/kgK$

$\Delta\dot{S} = \dot{m}(s_2 - s_1) = -0.0012272889 kW/K \approx -0.00123 kW/K$ //

(c) B: $\Delta S = \Sigma\frac{Q}{T} + S_{gen}$, $T_{surr} = 99.61°C \Rightarrow S_{gen} = 0.00951549938 kJ/K$

$\approx 9.5 J/K$ //

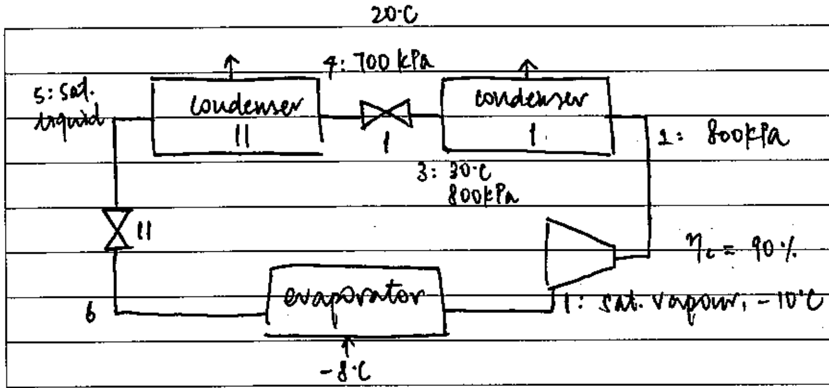
A: $\Delta S = \Sigma\frac{Q}{T} + S_{gen} = 120(-0.00123) \Rightarrow S_{gen} = 0.00960271269 kJ/K$

$\approx 9.6 J/K$ //

overall: $\Delta S = \Sigma\cancel{\frac{Q}{T}}^{0} + S_{gen} = 0.009602127 kJ/K \Rightarrow S_{gen} \approx 9.6 J/K > 0$

$\Rightarrow$ possible //

2.



$\dot{m}$ = 2kg/s

(a) $1 \to 2s$: $T_1 = -10°C$ $P_1 = 200.74 kPa$ $h_1 = 244.51 kJ/kg$ $s_1 = 0.93766 kJ/kgK$

$P_2 = 800 kPa$ $s_{2s} = 0.93766 kJ/kgK$ ⇒ superheated

$h_{2s} = 273.260962 kJ/kg$

$w_s = h_{2s} - h_1 = 28.75096296 kJ/kg$

$\eta_c = \frac{w_s}{w_a} = 0.9 \Rightarrow w_a = 31.9455144 kJ/kg$

Power required = $\dot{m} w_a = 63.89102881 kW \approx 63.9 kW$ ✓

(b) $1 \to 2a$: $h_2 = 276.4555144 kJ/kg$ $P_2 = 800kPa$ $T_2 \approx 40°C$ $s_2 = 0.9480 kJ/kgK$

$2 \to 3$: $T_3 = 30°C$ $P_3 = 800kPa$ $h_3 = 93.58 kJ/kg$ $s_3 = 0.34789 kJ/kgK$

$3 \to 4$: throttling, $h_4 = h_3$ $P_4 = 700kPa$

$4 \to 5$: $P_5 = 700 kPa$ $h_5 = 88.82 kJ/kg$ $s_5 = 0.33230 kJ/kg$

$\dot{Q}_H = \dot{m}(h_2 - h_3 + h_4 - h_5) = 375.2710288 kW \approx 375 kW$ ✓

$5 \to 6$: $P_6 = 200.74 kPa$ $h_6 = h_5 = 88.82 kJ/kg$

$\dot{Q}_L = \dot{m}(h_1 - h_6) = 311.38 kW$ ✓

High temp: $x_4 = \frac{h_4 - h_f}{h_{fg}} = 0.0270132286$

$s_4 = s_f + x_4 s_{fg} = 0.3481737801 kJ/kgK$

$\Delta\dot{S}_H = \dot{m}(s_3 - s_2 + s_5 - s_4) = -0.6159837801 kW/K \approx -0.62 kW/K$ ✓

Low temp: $x_6 = 0.2445760326 \Rightarrow s_6 = 0.3461121657 kJ/kgK$

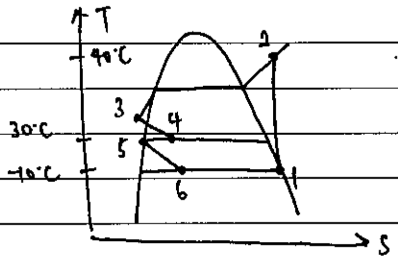
$\Delta\dot{S}_L = \dot{m}(s_1 - s_6) = 1.183095669 kW/K \approx 1.18 kW/K$ ✓

(c) ⋈ I : $\Delta\dot{S} = \cancel{\Sigma\frac{\dot{Q}}{T}}^{0} + \dot{S}_{gen} = \dot{m}(s_4 - s_3)$

$\dot{S}_{gen} = 0.0002837801 kW/K \approx 0.28 W/K$ ✓

(d) $COP = \frac{\dot{Q}_H}{\dot{W}_{in}} = 5.873610674 \approx 5.87$ ✓

(e) $COP_{max} = \frac{T_H}{T_H - T_L} = 10.46964286 \approx 10.5$ ✓



3\. (a) $\dot{m} = 20kg/s$

$V_i = 300m/s$

$T_e = 703K$

$T_i = 285K$

Assumptions:

① steady air flow

② negligible changes in potential energy

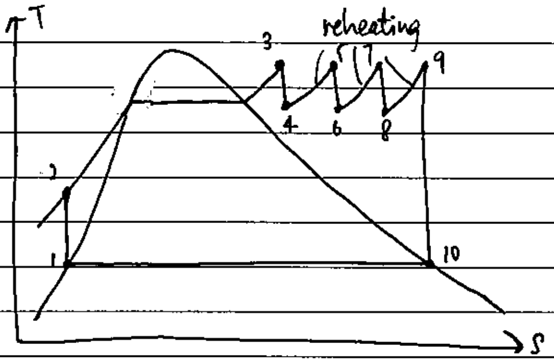
③ air is ideal

④ no pressure drops by frictional effects

$\dot{Q} = \dot{m}c_p\Delta T + \Delta \dot{KE} = \dot{m}c_p\Delta T + \frac{\dot{m}}{2}(V_e^2 - V_i^2)$

$V_e = 1120.549062 m/s \approx 1121 m/s$ ✓

(b)



The more the number of reheat stages, the higher the thermal efficiency.

(c) The reheat cycle has a higher thermal efficiency.
Thermal efficiency in dependent on the turbine output. The more reheat stages, the higher the turbine output and hence, thermal efficiency.

(a) continued: $T = \dot{m}(V_e - V_i) \times 4$

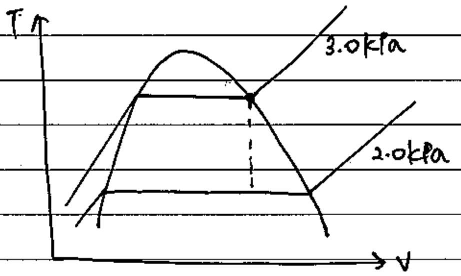
$= 65643.92495 N \approx 65.6 kN$ ✓

DISCLAIMER: might not be correct ∵

4. (a) $P_v = \phi P_g = 2.0 \text{kPa}$

$P_g = 3.0 \text{kPa}$

$\therefore \phi = \frac{2}{3} \approx 66.7\%$ ✓



(b) $CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$

$AF = \frac{M_{air}}{M_{fuel}} = \frac{2 \times 29}{12 + 4} = 3.625$ ✓

$\frac{AF_{th}}{AF_{act}} = 1.40 \Rightarrow$ for 1 mole of CH_4, only $\frac{2}{1.40}$ moles of dry air

$CH_4 + \frac{10}{7}(O_2 + 3.76N_2)$ can be simplified to $7CH_4 + 10(O_2 + 3.76N_2)$

$7CH_4 + 10(O_2 + 3.76N_2) \rightarrow 6CO + C + 14H_2O + 37.6N_2$ ✓ ← more logical answer

or

$7CH_4 + 10(O_2 + 3.76N_2) \rightarrow 8CO - CO_2 + 14H_2O + 37.6N_2$ ✓

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2017-2018

MA2007 – THERMODYNAMICS

April/May 2018 Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **FOUR** (4) pages.
2. Answer **ALL FOUR** (4) questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.

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1. A compressor takes 1 kg/s of air from the atmosphere at 100 kPa and 17°C, and compresses it to 500 kPa. During the process, the compressor rejects 100 kW of heat to the surrounding air, and irreversibilities in the compressor increase the entropy of the air flowing through it by 0.2 kW/K.

   Given c_p =1.005 kJ/kg·K and c_v = 0.718 kJ/kg·K, determine

   (a) the final temperature of the air in the compressor, (8 marks)

   (b) the rate of work done on the compressor, (7 marks)

   (c) the rate of entropy change of the surrounding air, and (5 marks)

   (d) the rate of entropy generated during this process. (5 marks)

2. A heat pump, working on an ideal vapour-compression cycle, uses refrigerant 134a with a mass flowrate of 0.1 kg/s. The refrigerant leaves the evaporator as saturated vapour at a temperature of -8°C. It leaves the condenser as saturated liquid at a pressure of 0.8 MPa.

   (a) Indicate the processes of the heat pump on a *T-s* diagram showing each state point in relation to the saturation lines. (8 marks)

   (b) Calculate the power, $\dot{W}_C$, required to drive the compressor. (7 marks)

   (c) Determine the coefficient of performance, COP_{HP}, of the heat pump. (5 marks)

   (d) Determine the Carnot coefficient of performance, COP_{HP_Carnot}, operating between the same temperatures. (5 marks)

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3. An aircraft powered by a turbojet engine has a pressure ratio of 10 across its compressor. The aircraft is stationary on the ground and held in position by its brakes. The ambient air is at 25°C and 1 bar and enters the engine at a rate of 20 kg/s. The jet fuel has a heating value of 42,000 kJ/kg and is assumed to be burned completely at a rate of 0.5 kg/s. Given: c_v = 0.718 kJ/kg·K; c_p= 1.005 kJ/kg·K; Molecular masses of C and H are 12 and 1, respectively, and neglecting the effect of the diffuser and applying cold-air standard assumption,

(a) sketch the *T-s* diagram for the ideal jet-propulsion cycle. (5 marks)

(b) Determine the temperature, in K, at each state point below:

(i) compressor outlet (or combustor inlet).
(ii) turbine inlet (or combustor outlet).
(iii) turbine outlet (nozzle inlet).
(iv) nozzle outlet.

(8 marks)

(c) The force, in N, that must be applied on the brakes to hold the aircraft stationary.

(8 marks)

(d) If the fuel is kerosene with a chemical formula of $C_{12}H_{26}$, show that burning 1 kg of kerosene would produce 3.11 kg of CO_2 under the condition of completion combustion.

(4 marks)

4. Based on mass analysis, a 100-kg coal contains 60% carbon (C), 12% hydrogen (H_2), 16% oxygen (O_2), 2.8% nitrogen (N_2), 3.2% sulfur (S) and 6% non-combustible ash. The coal is burned with 20% of excess in an industrial boiler. Assuming complete combustion for carbon, hydrogen and sulfur into CO_2, H_2O and SO_2, respectively, and the pressure in the boiler smokestack is 100 kPa, calculate

(a) the air-fuel ratio by mass, and (10 marks)

(b) the minimum temperature, in °C, of the combustion products before liquid water begins to form in the smokestack.

(15 marks)

Given: atomic/molecular masses of C, H_2, O_2, N_2, S, ash and air are 12, 2, 32, 28, 32, unknown and 29, respectively.

Table 1 – Saturated Water (Pressure) Table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931

Table 2 – Saturated refrigerant-134a (Temperature) Table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
−40	51.25	0.0007054	0.36081	−0.036	207.40	207.37	0.000	225.86	225.86	0.00000	0.96866	0.96866
−38	56.86	0.0007083	0.32732	2.475	206.04	208.51	2.515	224.61	227.12	0.01072	0.95511	0.96584
−36	62.95	0.0007112	0.29751	4.992	204.67	209.66	5.037	223.35	228.39	0.02138	0.94176	0.96315
−34	69.56	0.0007142	0.27090	7.517	203.29	210.81	7.566	222.09	229.65	0.03199	0.92859	0.96058
−32	76.71	0.0007172	0.24711	10.05	201.91	211.96	10.10	220.81	230.91	0.04253	0.91560	0.95813
−30	84.43	0.0007203	0.22580	12.59	200.52	213.11	12.65	219.52	232.17	0.05301	0.90278	0.95579
−28	92.76	0.0007234	0.20666	15.13	199.12	214.25	15.20	218.22	233.43	0.06344	0.89012	0.95356
−26	101.73	0.0007265	0.18946	17.69	197.72	215.40	17.76	216.92	234.68	0.07382	0.87762	0.95144
−24	111.37	0.0007297	0.17395	20.25	196.30	216.55	20.33	215.59	235.92	0.08414	0.86527	0.94941
−22	121.72	0.0007329	0.15995	22.82	194.88	217.70	22.91	214.26	s237.17	0.09441	0.85307	0.94748
−20	132.82	0.0007362	0.14729	25.39	193.45	218.84	25.49	212.91	238.41	0.10463	0.84101	0.94564
−18	144.69	0.0007396	0.13583	27.98	192.01	219.98	28.09	211.55	239.64	0.11481	0.82908	0.94389
−16	157.38	0.0007430	0.12542	30.57	190.56	221.13	30.69	210.18	240.87	0.12493	0.81729	0.94222
−14	170.93	0.0007464	0.11597	33.17	189.09	222.27	33.30	208.79	242.09	0.13501	0.80561	0.94063
−12	185.37	0.0007499	0.10736	35.78	187.62	223.40	35.92	207.38	243.30	0.14504	0.79406	0.93911
−10	200.74	0.0007535	0.099516	38.40	186.14	224.54	38.55	205.96	244.51	0.15504	0.78263	0.93766
−8	217.08	0.0007571	0.092352	41.03	184.64	225.67	41.19	204.52	245.72	0.16498	0.77130	0.93629
−6	234.44	0.0007608	0.085802	43.66	183.13	226.80	43.84	203.07	246.91	0.17489	0.76008	0.93497
−4	252.85	0.0007646	0.079804	46.31	181.61	227.92	46.50	201.60	248.10	0.18476	0.74896	0.93372
−2	272.36	0.0007684	0.074304	48.96	180.08	229.04	49.17	200.11	249.28	0.19459	0.73794	0.93253
0	293.01	0.0007723	0.069255	51.63	178.53	230.16	51.86	198.60	250.45	0.20439	0.72701	0.93139
2	314.84	0.0007763	0.064612	54.30	176.97	231.27	54.55	197.07	251.61	0.21415	0.71616	0.93031
4	337.90	0.0007804	0.060338	56.99	175.39	232.38	57.25	195.51	252.77	0.22387	0.70540	0.92927
6	362.23	0.0007845	0.056398	59.68	173.80	233.48	59.97	193.94	253.91	0.23356	0.69471	0.92828
8	387.88	0.0007887	0.052762	62.39	172.19	234.58	62.69	192.35	255.04	0.24323	0.68410	0.92733
10	414.89	0.0007930	0.049403	65.10	170.56	235.67	65.43	190.73	256.16	0.25286	0.67356	0.92641
12	443.31	0.0007975	0.046295	67.83	168.92	236.75	68.18	189.09	257.27	0.26246	0.66308	0.92554
14	473.19	0.0008020	0.043417	70.57	167.26	237.83	70.95	187.42	258.37	0.27204	0.65266	0.92470
16	504.58	0.0008066	0.040748	73.32	165.58	238.90	73.73	185.73	259.46	0.28159	0.64230	0.92389
18	537.52	0.0008113	0.038271	76.08	163.88	239.96	76.52	184.01	260.53	0.29112	0.63198	0.92310

Table 3 – Saturated refrigerant-134a (Pressure) Table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
60	−36.95	0.0007098	0.31121	3.798	205.32	209.12	3.841	223.95	227.79	0.01634	0.94807	0.96441
70	−33.87	0.0007144	0.26929	7.680	203.20	210.88	7.730	222.00	229.73	0.03267	0.92775	0.96042
80	−31.13	0.0007185	0.23753	11.15	201.30	212.46	11.21	220.25	231.46	0.04711	0.90999	0.95710
90	−28.65	0.0007223	0.21263	14.31	199.57	213.88	14.37	218.65	233.02	0.06008	0.89419	0.95427
100	−26.37	0.0007259	0.19254	17.21	197.98	215.19	17.28	217.16	234.44	0.07188	0.87995	0.95183
120	−22.32	0.0007324	0.16212	22.40	195.11	217.51	22.49	214.48	236.97	0.09275	0.85503	0.94779
140	−18.77	0.0007383	0.14014	26.98	192.57	219.54	27.08	212.08	239.16	0.11087	0.83368	0.94456
160	−15.60	0.0007437	0.12348	31.09	190.27	221.35	31.21	209.90	241.11	0.12693	0.81496	0.94190
180	−12.73	0.0007487	0.11041	34.83	188.16	222.99	34.97	207.90	242.86	0.14139	0.79826	0.93965
200	−10.09	0.0007533	0.099867	38.28	186.21	224.48	38.43	206.03	244.46	0.15457	0.78316	0.93773
240	−5.38	0.0007620	0.083897	44.48	182.67	227.14	44.66	202.62	247.28	0.17794	0.75664	0.93458
280	−1.25	0.0007699	0.072352	49.97	179.50	229.46	50.18	199.54	249.72	0.19829	0.73381	0.93210
320	2.46	0.0007772	0.063604	54.92	176.61	231.52	55.16	196.71	251.88	0.21637	0.71369	0.93006
360	5.82	0.0007841	0.056738	59.44	173.94	233.38	59.72	194.08	253.81	0.23270	0.69566	0.92836
400	8.91	0.0007907	0.051201	63.62	171.45	235.07	63.94	191.62	255.55	0.24761	0.67929	0.92691
450	12.46	0.0007985	0.045619	68.45	168.54	237.00	68.81	188.71	257.53	0.26465	0.66069	0.92535
500	15.71	0.0008059	0.041118	72.93	165.82	238.75	73.33	185.98	259.30	0.28023	0.64377	0.92400
550	18.73	0.0008130	0.037408	77.10	163.25	240.35	77.54	183.38	260.92	0.29461	0.62821	0.92282
600	21.55	0.0008199	0.034295	81.02	160.81	241.83	81.51	180.90	262.40	0.30799	0.61378	0.92177
650	24.20	0.0008266	0.031646	84.72	158.48	243.20	85.26	178.51	263.77	0.32051	0.60030	0.92081
700	26.69	0.0008331	0.029361	88.24	156.24	244.48	88.82	176.21	265.03	0.33230	0.58763	0.91994
750	29.06	0.0008395	0.027371	91.59	154.08	245.67	92.22	173.98	266.20	0.34345	0.57567	0.91912
800	31.31	0.0008458	0.025621	94.79	152.00	246.79	95.47	171.82	267.29	0.35404	0.56431	0.91835
850	33.45	0.0008520	0.024069	97.87	149.98	247.85	98.60	169.71	268.31	0.36413	0.55349	0.91762
900	35.51	0.0008580	0.022683	100.83	148.01	248.85	101.61	167.66	269.26	0.37377	0.54315	0.91692
950	37.48	0.0008641	0.021438	103.69	146.10	249.79	104.51	165.64	270.15	0.38301	0.53323	0.91624
1000	39.37	0.0008700	0.020313	106.45	144.23	250.68	107.32	163.67	270.99	0.39189	0.52368	0.91558
1200	46.29	0.0008934	0.016715	116.70	137.11	253.81	117.77	156.10	273.87	0.42441	0.48863	0.91303
1400	52.40	0.0009166	0.014107	125.94	130.43	256.37	127.22	148.90	276.12	0.45315	0.45734	0.91050

Table 4 – Superheated refrigerant-134a Table

T °C	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.80 MPa (T_{sat} = 31.31°C)				P = 0.90 MPa (T_{sat} = 35.51°C)				P = 1.00 MPa (T_{sat} = 39.37°C)			
Sat.	0.025621	246.79	267.29	0.9183	0.022683	248.85	269.26	0.9169	0.020313	250.68	270.99	0.9156
40	0.027035	254.82	276.45	0.9480	0.023375	253.13	274.17	0.9327	0.020406	251.30	271.71	0.9179
50	0.028547	263.86	286.69	0.9802	0.024809	262.44	284.77	0.9660	0.021796	260.94	282.74	0.9525
60	0.029973	272.83	296.81	1.0110	0.026146	271.60	295.13	0.9976	0.023068	270.32	293.38	0.9850
70	0.031340	281.81	306.88	1.0408	0.027413	280.72	305.39	1.0280	0.024261	279.59	303.85	1.0160
80	0.032659	290.84	316.97	1.0698	0.028630	289.86	315.63	1.0574	0.025398	288.86	314.25	1.0458
90	0.033941	299.95	327.10	1.0981	0.029806	299.06	325.89	1.0860	0.026492	298.15	324.64	1.0748
100	0.035193	309.15	337.30	1.1258	0.030951	308.34	336.19	1.1140	0.027552	307.51	335.06	1.1031
110	0.036420	318.45	347.59	1.1530	0.032068	317.70	346.56	1.1414	0.028584	316.94	345.53	1.1308
120	0.037625	327.87	357.97	1.1798	0.033164	327.18	357.02	1.1684	0.029592	326.47	356.06	1.1580
130	0.038813	337.40	368.45	1.2061	0.034241	336.76	367.58	1.1949	0.030581	336.11	366.69	1.1846
140	0.039985	347.06	379.05	1.2321	0.035302	346.46	378.23	1.2210	0.031554	345.85	377.40	1.2109
150	0.041143	356.85	389.76	1.2577	0.036349	356.28	389.00	1.2467	0.032512	355.71	388.22	1.2368
160	0.042290	366.76	400.59	1.2830	0.037384	366.23	399.88	1.2721	0.033457	365.70	399.15	1.2623
170	0.043427	376.81	411.55	1.3080	0.038408	376.31	410.88	1.2972	0.034392	375.81	410.20	1.2875
180	0.044554	386.99	422.64	1.3327	0.039423	386.52	422.00	1.3221	0.035317	386.04	421.36	1.3124

END OF PAPER

1.(a) Assuming air is ideal gas,

$\Delta S = C_p \ln\left(\frac{T_2}{T_1}\right) - R_m \ln\left(\frac{P_2}{P_1}\right)$

$C_p \ln\left(\frac{T_2}{T_1}\right) = \Delta S + R_m \ln\left(\frac{P_2}{P_1}\right)$

$\ln\left(\frac{T_2}{T_1}\right) = \frac{\Delta S + R_m \ln\left(\frac{P_2}{P_1}\right)}{C_p}$

$= \frac{(0.2)(1000) + (0.287)(1000)\ln\left(\frac{500}{100}\right)}{(1.005)(1000)}$

$= 0.6586156$

$\frac{T_2}{T_1} = e^{0.6586156}$

$\therefore T_2 = T_1 \times e^{0.6586156}$

$= 290 \times e^{0.6586156}$

$= 560.31\ K$ #

$C_p = 1.005\ kJkg^{-1}K^{-1}$

$C_v = 0.718\ kJkg^{-1}K^{-1}$

$R_m = C_p - C_v = 0.287\ kJkg^{-1}K^{-1}$

$T_1 = 17°C = 290K$

$P_1 = 100kPa$, $P_2 = 500kPa$

$\dot{m}_{air} = 1\ kgs^{-1}$

$\dot{Q}_{out} = 100kW$

$\Delta S = 0.2\ kJs^{-1}K^{-1}$.

1.(b) assuming steady state, steady flow

$\Delta \dot{H} = \Delta \dot{Q}_{in} + \Delta \dot{W}_{in}$

where $\Delta \dot{Q}_{in} = -\Delta \dot{Q}_{out}$

$= -100kJs^{-1}$

and $\Delta \dot{W}_{in}$ is work supplied to compressor

$\therefore \Delta \dot{W}_{in} = \Delta \dot{H} - \Delta \dot{Q}_{in}$

$\Delta \dot{H} = \dot{m} C_p \Delta T$

$= (1)(1.005)(560.31 - 290)$

$= 271.66\ kJs^{-1}$

$\therefore \Delta \dot{W}_{in} = \Delta \dot{H} - \Delta \dot{Q}_{in}$

$= 271.66 - (-100)$

$= 371.7\ kJs^{-1}$

$= 371.7\ kW$ #

1.(c) $\dot{Q}_{out}$ from compressor = $\dot{Q}_{in}$ to surrounding air

assuming surrounding air (atmosphere) is thermal reserve

$\therefore T = 290K$ is constant.

$\therefore \Delta \dot{S}_{air} = \frac{\Delta \dot{Q}_{in}}{T_{air}}$

$= \frac{+100}{290}$

$= 0.34483\ kJs^{-1}K^{-1}$

$= 0.3448\ kWK^{-1}$ #

1.(d) $\Delta \dot{S}_{sys} = \dot{S}_{gen} + \dot{S}_{transfer}$

for closed system considered, and steady flow, steady state

$\Delta \dot{S}_{sys} = 0$

$\dot{S}_{transfer}$

$= (\dot{S}_{in} - \dot{S}_{out})_{air} + (\dot{S}_{in} - \dot{S}_{out})_{heat\ transfer}$

$\therefore \dot{S}_{gen}$

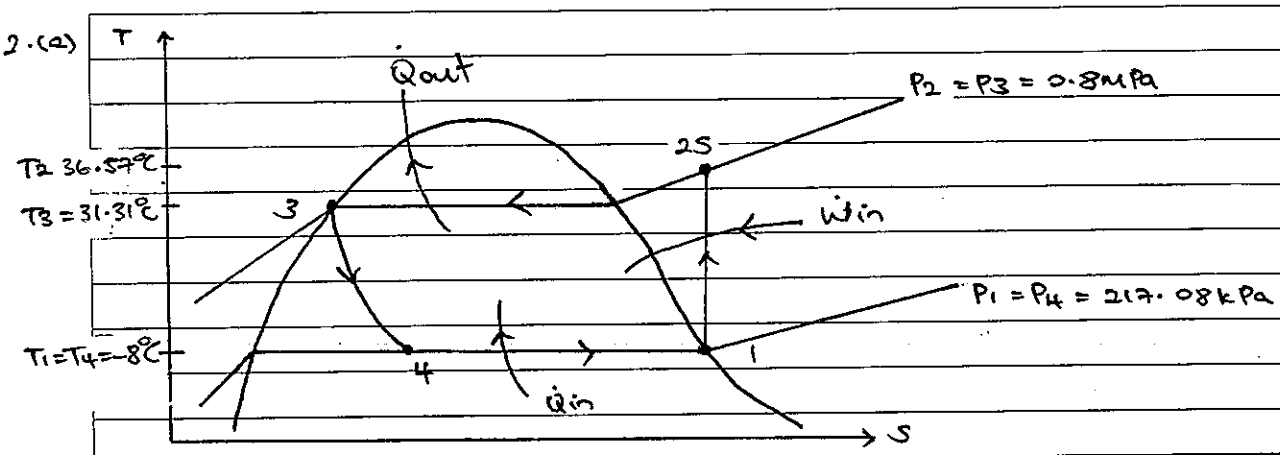
$= -\dot{S}_{transfer}$

$= (\dot{S}_{out} - \dot{S}_{in})_{air} + (\dot{S}_{out})_{heat\ transfer}$

$= 0.2 + 0.3448$

$= 0.5448\ kWK^{-1}$ #

2.(a)



2.(b) state 1 : $T_1 = -8°C$, sat. vapour

$s_1 = s_g = 0.93629$

$1 \rightarrow 2$: isentropic compression

$s_2 = s_1 = 0.93629$

state 2 : $P_2 = 0.8MPa$, superheated vapour

by interpolation,

$$\frac{T_2 - 304.31}{313 - 304.31} = \frac{0.93629 - 0.9183}{0.9480 - 0.9183}$$

$T_2 = 309.57K$

$h_1 = h_g = 245.72$

by interpolation,

$$\frac{h_2 - 267.29}{276.45 - 267.29} = \frac{309.57 - 304.31}{313 - 304.31}$$

$h_2 = 272.83 \ KJkg^{-1}$

$\dot{W}_{in} = \dot{m}(h_2 - h_1)$

$= (0.1)(272.83 - 245.72)$

$= 2.711 \ KJs^{-1}$

$= 2.71 \ kW$ #

2.(c) state 3 : $P_3 = 0.8MPa$, sat. liquid

$h_3 = h_f = 95.47$

$\dot{Q}_{out} = \dot{m}(h_2 - h_3)$

$= (0.1)(272.83 - 95.47)$

$= 17.736 \ KJkg^{-1}s^{-1}$

$\therefore COP_{HP} = \frac{\dot{Q}_{out}}{\dot{W}_{in}}$

$= \frac{17.736}{2.711}$

$= 6.54$ #

2.(d) $COP_{HP-carnot}$

$= \frac{T_H}{T_H - T_C}$

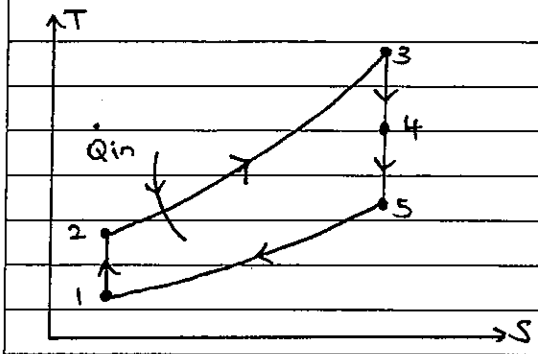
$= \frac{304.31}{304.31 - 265}$

$= 7.74$ #

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32

3.(a)



3.(b)(i) assuming air is ideal gas,

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

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

$$= 298 \times (10)^{\frac{0.4}{1.4}}$$

$$= 575.35K$$ #

3.(b)(ii) heat value = 42000 $kJkg^{-1}$

$\dot{m}_{fuel} = 0.5 kgs^{-1}$

$\dot{Q}_{in} = 42000 \times 0.5$

$= 21\,000 \; kJs^{-1}$

from 2 → 3:

$\dot{Q}_{in} = \dot{m}_{air} C_p \Delta T$

$= \dot{m}_{air} C_p (T_3 - T_2)$

$\therefore T_3 = \frac{\dot{Q}_{in}}{\dot{m}_{air} C_p} + T_2$

$= \frac{(21000)}{(20)(1.005)} + 575.35$

$= 1620.13K$ #

3.(b)(iii) $W_{out} (3 \to 4) = W_{in} (1 \to 2)$

$h_3 - h_4 = h_2 - h_1$

$\dot{m} C_p (T_3 - T_4) = \dot{m} C_p (T_2 - T_1)$

$T_4 = T_3 + T_1 - T_2$

$= 1620.13 + 298 - 575.35$

$= 1342.78K$ #

3.(b)(iv) from 3 → 5: isentropic expansion

$$\frac{T_5}{T_3} = \left(\frac{P_5}{P_3}\right)^{\frac{k-1}{k}}$$

$P_5 = P_1$ and $P_3 = P_2$ and $\frac{P_2}{P_1} = 10$

$$\therefore \frac{T_5}{T_3} = \left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}}$$

$$T_5 = 1620.13 \times \left(\frac{1}{10}\right)^{\frac{0.4}{1.4}}$$

$$= 839.14 K$$ #

3.(c) from 4 → 5:

$h_4 + \frac{1}{2}V_4^2 = h_5 + \frac{1}{2}V_5^2$

$V_4 = 0$

$\therefore V_5^2 = 2(h_4 - h_5)$

$= 2c_p (T_4 - T_5)$

$V_5 = \sqrt{(2)(1.005)(1000)(1342.78 - 839.14)}$

$= 1006.14 \; ms^{-1}$

∴ drag force require

= thrust produced

$= (\dot{m}V)_{exit} - (\dot{m}V)_{inlet}$

$= \dot{m}_{air} V_5 - \dot{m}_{air} V_1$

$= \dot{m}_{air} V_5 \qquad (V_1 = 0)$

$= (20)(1006.14) = 20122.8 N$ #

3.(d) complete combustion of $C_{12}H_{26}$

$C_{12}H_{26} + a[O_2 + 3.76N_2] \to xCO_2 + yH_2O + zN_2$

C: $x = 12$ O: $2x + y = 2a$

H: $2y = 26$ $a = 18.5$

$y = 13$ N: $z = 3.76a = 69.56$.

$M_{C_{12}H_{26}} = (12)(12) + (26)(1) = 170$

$M_{CO_2} = (12) + (2)(16) = 44$

$N_{C_{12}H_{26}} = \frac{1000}{170} = 5.8823$

$\therefore m_{CO_2}$ produced

$= 12 \times 5.8823 \times 44$

$= 3105.85 g = 3.11 kg$ # (shown)

	% mass	mass (kg)	(kg/kmol) Mr	N (kmol)
C	60	60	12	5
H_2	12	12	2	6
O_2	16	16	32	0.5
N_2	2.8	2.8	28	0.1
S	3.2	3.2	32	0.1
ash	6	6	/	/

4.(a) for complete combustion,

$5C + 6H_2 + 0.1S + aO_2 \rightarrow xCO_2 + yH_2O + zSO_2$

C: $5 = x$ $x = 5$ O: $2a = 2x + y + 2z$

H: $12 = 2y$ $y = 6$ $= 16.2$

S: $0.1 = z$ $z = 0.1$ $a = 8.1$

∴ stoichiometric combustion:

$5C + 6H_2 + 0.1S + 0.5O_2 + 7.6O_2(\text{air}) \rightarrow 5CO_2 + 6H_2O + 0.1SO_2$

∴ full equation is 20% excess air:

$[5C + 6H_2 + 0.1S + 0.5O_2 + 0.1N_2 + \text{Ash}]$ 100kg fuel

$+ (1.2)(7.6)[O_2 + 3.76N_2]$ total air

$\rightarrow [5CO_2 + 6H_2O + 0.1SO_2 + 28.676N_2]$ stoichiometric comb. products

$+ (0.2)(7.6)[O_2 + 3.76N_2]$ excess air

$$\therefore AF = \frac{7.6 \times 4.76 \times 1.2 \times 29}{100} = 12.59 \#$$

4.(b) total N (products) $= 5 + 6 + 0.1 + 28.676 + (0.2)(7.6)(1 + 3.76)$

$= 47.0112$

total N (H_2O) $= 6$

$$\therefore \text{vapour pressure of } H_2O = \frac{6}{47.0112} \times 100 = 12.76\text{ kPa}$$

∴ by interpolation,

$$\frac{12.76 - 10}{15 - 10} = \frac{T_{sat} - 45.81}{53.97 - 45.81}$$

∴ minimum temperature

$= T_{sat}$

$= 50.31\ °C \#$

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2018-2019

MA2007 - THERMODYNAMICS

November/December 2018 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **NINE (9)** pages including **FOUR (4)** pages of Appendices.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.
5. Appendix for questions 1 and 2 are provided on pages 6 to 8.

---

1. A refrigeration system used for home air conditioning uses R-134a as the working fluid. The refrigerant enters the compressor at a pressure of 0.5 MPa and temperature of 30°C, and is compressed adiabatically to a pressure of 1.2 MPa with an isentropic compressor efficiency of 0.9. The refrigerant is then condensed, exiting the condenser at a pressure of 1.13 MPa and temperature of 40°C. After throttling through the expansion valve, it enters the evaporator at 0.53 MPa.

(a) What is the temperature at the end of the compression process, and the work done during the compression process?

(6 marks)

(b) How much entropy is generated during the compression process?

(4 marks)

(c) What is the COP (coefficient of performance) of the refrigeration system?

(4 marks)

(d) Show the refrigeration cycle on a T-s diagram, indicating clearly the 4 main state points of the cycle using the information given above.

(4 marks)

(e) It is proposed to reduce the work input at the compressor by cooling the compressor such that the exit temperature at the compressor is 50°C. If heat is removed during compression at a constant temperature of 37°C, what is the amount of heat that has to be removed to approach a reversible process? What is the new compression work that results from removing heat during compression in the way described above?

(7 marks)

(Note: Tables for R134a are provided in the Appendix from pages 6 to 8).

2. The energy efficiency (EE) of a data centre is often expressed in terms of its PUE (Power Usage Effectiveness), which is the ratio of the total amount of energy used by the data centre, to the energy used by the computing or IT equipment.

(a) A data centre operates with a PUE of 1.5, and only uses electricity for its energy needs. If the total power consumption of the data centre is 10 MW, and cooling accounts for 80% of the non-IT power consumption, what is the amount of power used (i) by the computing equipment, and (ii) for cooling? Assuming a reversible Carnot refrigeration cycle is used to provide cooling for the data centre, what is the cooling load if the data centre operates at a temperature of 20°C, and rejects heat to the environment at 33°C?

(6 marks)

(b) As part of an energy saving measure, it is proposed to operate the data centre at a higher temperature of 27°C instead of 20°C. If it can be assumed that the cooling load remains unchanged, and heat is rejected to the environment at 33°C (as before), what is (i) the new power consumption required for cooling if a reversible Carnot refrigeration cycle is again providing the cooling, and (ii) the new PUE?

(4 marks)

(c) Instead of a Carnot refrigeration cycle, cooling for the data centre is provided by an ideal Gas (Brayton) refrigeration cycle, using nitrogen as the working fluid and operating with a pressure ratio of 4. Assuming the operating temperatures described in (a) above of cooling at 20°C and heat rejection at 33°C, draw the T-s diagram for the cycle and calculate

(i) the lowest and highest temperatures in the cycle, and
(ii) the COP of the gas refrigeration cycle.

You may assume that the C_p (specific heat) and k (ratio of specific heats) of nitrogen are constant and have values of 1.04 kJ/kg.K and 1.4, respectively.

(8 marks)

(d) If the gas refrigeration cycle is non-ideal and the compression process is adiabatic with an isentropic compressor efficiency of 0.8, what would be

(i) the COP of the cycle?
(ii) the entropy generated during the compression process?

(7 marks)

3 (a) Consider an air-standard cycle engine, using constant specific heats at room temperature, is operated in a closed system manner with 1 kg of air and compression ratio of 15. The engine consists of the following processes:

1-2: isentropic compression from 125 kPa and 300 K to 875 kPa
2-3: constant pressure heat addition to initial specific volume
3-1: constant volume heat rejection to initial state

(i) State the three assumptions being applied in your analysis.

(ii) Show clearly all the operating points on the temperature-entropy (T-s) diagram.

(iii) Determine the highest cycle temperature.

(iv) Calculate the heat addition and rejection per unit kg of working fluid, respectively.

(v) Find the thermal efficiency and mean effective pressure.

For air room temperature, take $C_p = 1.005$ kJ/kg·°C; $C_v = 0.718$ kJ/kg·°C, $R = 287$ J/kg·°C and k = 1.4

(13 marks)

(b) From the aspects of second-law analysis of vapour power Rankine cycles, discuss the main difference between the regeneration and cogeneration applications.

(5 marks)

(c) What is the purpose of a typical binary power cycle and why?

(3 marks)

(d) Briefly discuss why either of the gas or steam cycle operated alone is less thermal efficient than their combined gas-steam cycles.

(4 marks)

33

4 (a) Other than heating or cooling of the air, state what does a typical modern air-conditioning system do?

Explain the reason of a simple cooling or heating process appear as a horizontal line on the psychrometric chart?

(7 marks)

(b) Given that the air pressure in a room is at 1 atm, a dry-bulb temperature of 297 K and a relative humidity of 50%. With the psychrometric chart in **Figure 1**, find

(i) the specific or absolute humidity or humidity ratio,

(ii) the wet-bulb temperature,

(iii) the enthalpy (in kJ/kg dry air),

(iv) the specific volume of the air (in m^3/kg dry air),

(v) the dew-point temperature, and

(vi) explain why the enthalpy values obtained from a psychrometric chart at the room of 1 atm cannot be used at other higher elevations.

(8 marks)

(c) A large vapour power plant combustor designer suggests to have 25 kg of air at 304 K and 105 kPa to mix and ignite with 1 kg of butane (C_4H_{10}). Given that the combustion process is complete with the pressure of the products at 105 kPa, find

(i) the percentage of theoretical air required, and

(ii) the expression of complete combustion equation.

(iii) Suggest how to avoid moisture condensation of the products in the burner.

(Hint: evaluate the dew-point temperature of the products) Provide three assumptions being applied in your analysis.

(10 marks)

The standard compositions for (dry) air are 21% oxygen and 79% nitrogen on a molar basis. Take the molecular weight of dry air as 29 g/mol.

You may assume that the atomic mass of C, H, O and N are 12, 1, 16 and 14, respectively.

You may use properties of saturated water in **Table A** on page 9.

Note: Figure 1 appears on page 5.

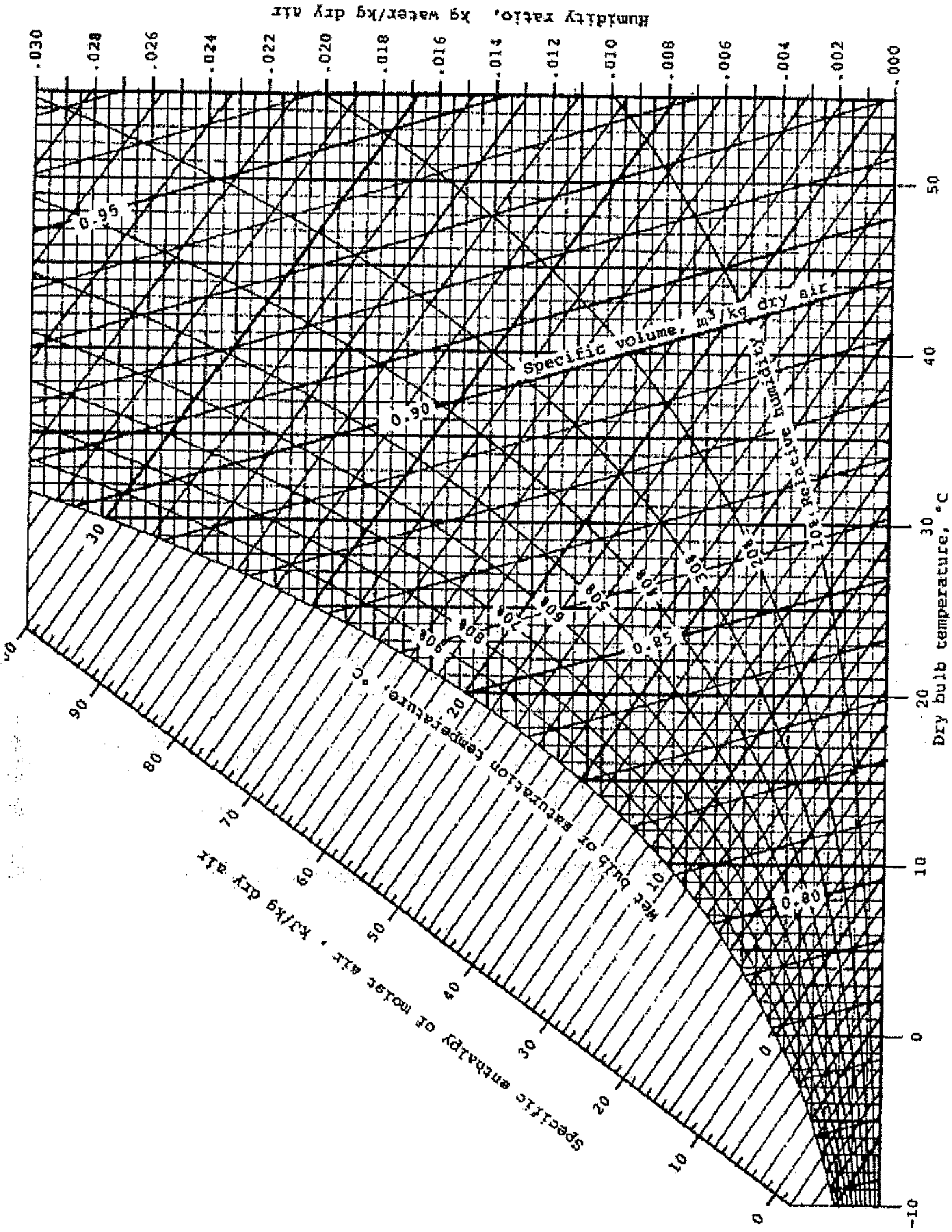


Figure 1: The Psychrometric chart for 1 atm (SI units).

Appendix

Saturated refrigerant-134a—Temperature table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
−40	51.25	0.0007054	0.36081	−0.036	207.40	207.37	0.000	225.86	225.86	0.00000	0.96866	0.96866
−38	56.86	0.0007083	0.32732	2.475	206.04	208.51	2.515	224.61	227.12	0.01072	0.95511	0.96584
−36	62.95	0.0007112	0.29751	4.992	204.67	209.66	5.037	223.35	228.39	0.02138	0.94176	0.96315
−34	69.56	0.0007142	0.27090	7.517	203.29	210.81	7.566	222.09	229.65	0.03199	0.92859	0.96058
−32	76.71	0.0007172	0.24711	10.05	201.91	211.96	10.10	220.81	230.91	0.04253	0.91560	0.95813
−30	84.43	0.0007203	0.22580	12.59	200.52	213.11	12.65	219.52	232.17	0.05301	0.90278	0.95579
−28	92.76	0.0007234	0.20666	15.13	199.12	214.25	15.20	218.22	233.43	0.06344	0.89012	0.95356
−26	101.73	0.0007265	0.18946	17.69	197.72	215.40	17.76	216.92	234.68	0.07382	0.87762	0.95144
−24	111.37	0.0007297	0.17395	20.25	196.30	216.55	20.33	215.59	235.92	0.08414	0.86527	0.94941
−22	121.72	0.0007329	0.15995	22.82	194.88	217.70	22.91	214.26	s237.17	0.09441	0.85307	0.94748
−20	132.82	0.0007362	0.14729	25.39	193.45	218.84	25.49	212.91	238.41	0.10463	0.84101	0.94564
−18	144.69	0.0007396	0.13583	27.98	192.01	219.98	28.09	211.55	239.64	0.11481	0.82908	0.94389
−16	157.38	0.0007430	0.12542	30.57	190.56	221.13	30.69	210.18	240.87	0.12493	0.81729	0.94222
−14	170.93	0.0007464	0.11597	33.17	189.09	222.27	33.30	208.79	242.09	0.13501	0.80561	0.94063
−12	185.37	0.0007499	0.10736	35.78	187.62	223.40	35.92	207.38	243.30	0.14504	0.79406	0.93911
−10	200.74	0.0007535	0.099516	38.40	186.14	224.54	38.55	205.96	244.51	0.15504	0.78263	0.93766
−8	217.08	0.0007571	0.092352	41.03	184.64	225.67	41.19	204.52	245.72	0.16498	0.77130	0.93629
−6	234.44	0.0007608	0.085802	43.66	183.13	226.80	43.84	203.07	246.91	0.17489	0.76008	0.93497
−4	252.85	0.0007646	0.079804	46.31	181.61	227.92	46.50	201.60	248.10	0.18476	0.74896	0.93372
−2	272.36	0.0007684	0.074304	48.96	180.08	229.04	49.17	200.11	249.28	0.19459	0.73794	0.93253
0	293.01	0.0007723	0.069255	51.63	178.53	230.16	51.86	198.60	250.45	0.20439	0.72701	0.93139
2	314.84	0.0007763	0.064612	54.30	176.97	231.27	54.55	197.07	251.61	0.21415	0.71616	0.93031
4	337.90	0.0007804	0.060338	56.99	175.39	232.38	57.25	195.51	252.77	0.22387	0.70540	0.92927
6	362.23	0.0007845	0.056398	59.68	173.80	233.48	59.97	193.94	253.91	0.23356	0.69471	0.92828
8	387.88	0.0007887	0.052762	62.39	172.19	234.58	62.69	192.35	255.04	0.24323	0.68410	0.92733
10	414.89	0.0007930	0.049403	65.10	170.56	235.67	65.43	190.73	256.16	0.25286	0.67356	0.92641
12	443.31	0.0007975	0.046295	67.83	168.92	236.75	68.18	189.09	257.27	0.26246	0.66308	0.92554
14	473.19	0.0008020	0.043417	70.57	167.26	237.83	70.95	187.42	258.37	0.27204	0.65266	0.92470
16	504.58	0.0008066	0.040748	73.32	165.58	238.90	73.73	185.73	259.46	0.28159	0.64230	0.92389
18	537.52	0.0008113	0.038271	76.08	163.88	239.96	76.52	184.01	260.53	0.29112	0.63198	0.92310

Saturated refrigerant-134a—Pressure table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
60	−36.95	0.0007098	0.31121	3.798	205.32	209.12	3.841	223.95	227.79	0.01634	0.94807	0.96441
70	−33.87	0.0007144	0.26929	7.680	203.20	210.88	7.730	222.00	229.73	0.03267	0.92775	0.96042
80	−31.13	0.0007185	0.23753	11.15	201.30	212.46	11.21	220.25	231.46	0.04711	0.90999	0.95710
90	−28.65	0.0007223	0.21263	14.31	199.57	213.88	14.37	218.65	233.02	0.06008	0.89419	0.95427
100	−26.37	0.0007259	0.19254	17.21	197.98	215.19	17.28	217.16	234.44	0.07188	0.87995	0.95183
120	−22.32	0.0007324	0.16212	22.40	195.11	217.51	22.49	214.48	236.97	0.09275	0.85503	0.94779
140	−18.77	0.0007383	0.14014	26.98	192.57	219.54	27.08	212.08	239.16	0.11087	0.83368	0.94456
160	−15.60	0.0007437	0.12348	31.09	190.27	221.35	31.21	209.90	241.11	0.12693	0.81496	0.94190
180	−12.73	0.0007487	0.11041	34.83	188.16	222.99	34.97	207.90	242.86	0.14139	0.79826	0.93965
200	−10.09	0.0007533	0.099867	38.28	186.21	224.48	38.43	206.03	244.46	0.15457	0.78316	0.93773
240	−5.38	0.0007620	0.083897	44.48	182.67	227.14	44.66	202.62	247.28	0.17794	0.75664	0.93458
280	−1.25	0.0007699	0.072352	49.97	179.50	229.46	50.18	199.54	249.72	0.19829	0.73381	0.93210
320	2.46	0.0007772	0.063604	54.92	176.61	231.52	55.16	196.71	251.88	0.21637	0.71369	0.93006
360	5.82	0.0007841	0.056738	59.44	173.94	233.38	59.72	194.08	253.81	0.23270	0.69566	0.92836
400	8.91	0.0007907	0.051201	63.62	171.45	235.07	63.94	191.62	255.55	0.24761	0.67929	0.92691
450	12.46	0.0007985	0.045619	68.45	168.54	237.00	68.81	188.71	257.53	0.26465	0.66069	0.92535
500	15.71	0.0008059	0.041118	72.93	165.82	238.75	73.33	185.98	259.30	0.28023	0.64377	0.92400
550	18.73	0.0008130	0.037408	77.10	163.25	240.35	77.54	183.38	260.92	0.29461	0.62821	0.92282
600	21.55	0.0008199	0.034295	81.02	160.81	241.83	81.51	180.90	262.40	0.30799	0.61378	0.92177
650	24.20	0.0008266	0.031646	84.72	158.48	243.20	85.26	178.51	263.77	0.32051	0.60030	0.92081
700	26.69	0.0008331	0.029361	88.24	156.24	244.48	88.82	176.21	265.03	0.33230	0.58763	0.91994
750	29.06	0.0008395	0.027371	91.59	154.08	245.67	92.22	173.98	266.20	0.34345	0.57567	0.91912
800	31.31	0.0008458	0.025621	94.79	152.00	246.79	95.47	171.82	267.29	0.35404	0.56431	0.91835
850	33.45	0.0008520	0.024069	97.87	149.98	247.85	98.60	169.71	268.31	0.36413	0.55349	0.91762
900	35.51	0.0008580	0.022683	100.83	148.01	248.85	101.61	167.66	269.26	0.37377	0.54315	0.91692
950	37.48	0.0008641	0.021438	103.69	146.10	249.79	104.51	165.64	270.15	0.38301	0.53323	0.91624
1000	39.37	0.0008700	0.020313	106.45	144.23	250.68	107.32	163.67	270.99	0.39189	0.52368	0.91558
1200	46.29	0.0008934	0.016715	116.70	137.11	253.81	117.77	156.10	273.87	0.42441	0.48863	0.91303
1400	52.40	0.0009166	0.014107	125.94	130.43	256.37	127.22	148.90	276.12	0.45315	0.45734	0.91050
1600	57.88	0.0009400	0.012123	134.43	124.04	258.47	135.93	141.93	277.86	0.47911	0.42873	0.90784
1800	62.87	0.0009639	0.010559	142.33	117.83	260.17	144.07	135.11	279.17	0.50294	0.40204	0.90498
2000	67.45	0.0009886	0.009288	149.78	111.73	261.51	151.76	128.33	280.09	0.52509	0.37675	0.90184
2500	77.54	0.0010566	0.006936	166.99	96.47	263.45	169.63	111.16	280.79	0.57531	0.31695	0.89226
3000	86.16	0.0011406	0.005275	183.04	80.22	263.26	186.46	92.63	279.09	0.62118	0.25776	0.87894

Superheated refrigerant-134a (*Continued*)

T °C	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.50 MPa (T_{sat} = 15.71°C)				P = 0.60 MPa (T_{sat} = 21.55°C)				P = 0.70 MPa (T_{sat} = 26.69°C)			
Sat.	0.041118	238.75	259.30	0.9240	0.034295	241.83	262.40	0.9218	0.029361	244.48	265.03	0.9199
20	0.042115	242.40	263.46	0.9383								
30	0.044338	250.84	273.01	0.9703	0.035984	249.22	270.81	0.9499	0.029966	247.48	268.45	0.9313
40	0.046456	259.26	282.48	1.0011	0.037865	257.86	280.58	0.9816	0.031696	256.39	278.57	0.9641
50	0.048499	267.72	291.96	1.0309	0.039659	266.48	290.28	1.0121	0.033322	265.20	288.53	0.9954
60	0.050485	276.25	301.50	1.0599	0.041389	275.15	299.98	1.0417	0.034875	274.01	298.42	1.0256
70	0.052427	284.89	311.10	1.0883	0.043069	283.89	309.73	1.0705	0.036373	282.87	308.33	1.0549
80	0.054331	293.64	320.80	1.1162	0.044710	292.73	319.55	1.0987	0.037829	291.80	318.28	1.0835
90	0.056205	302.51	330.61	1.1436	0.046318	301.67	329.46	1.1264	0.039250	300.82	328.29	1.1114
100	0.058053	311.50	340.53	1.1705	0.047900	310.73	339.47	1.1536	0.040642	309.95	338.40	1.1389
110	0.059880	320.63	350.57	1.1971	0.049458	319.91	349.59	1.1803	0.042010	319.19	348.60	1.1658
120	0.061687	329.89	360.73	1.2233	0.050997	329.23	359.82	1.2067	0.043358	328.55	358.90	1.1924
130	0.063479	339.29	371.03	1.2491	0.052519	338.67	370.18	1.2327	0.044688	338.04	369.32	1.2186
140	0.065256	348.83	381.46	1.2747	0.054027	348.25	380.66	1.2584	0.046004	347.66	379.86	1.2444
150	0.067021	358.51	392.02	1.2999	0.055522	357.96	391.27	1.2838	0.047306	357.41	390.52	1.2699
160	0.068775	368.33	402.72	1.3249	0.057006	367.81	402.01	1.3088	0.048597	367.29	401.31	1.2951
	P = 0.80 MPa (T_{sat} = 31.31°C)				P = 0.90 MPa (T_{sat} = 35.51°C)				P = 1.00 MPa (T_{sat} = 39.37°C)			
Sat.	0.025621	246.79	267.29	0.9183	0.022683	248.85	269.26	0.9169	0.020313	250.68	270.99	0.9156
40	0.027035	254.82	276.45	0.9480	0.023375	253.13	274.17	0.9327	0.020406	251.30	271.71	0.9179
50	0.028547	263.86	286.69	0.9802	0.024809	262.44	284.77	0.9660	0.021796	260.94	282.74	0.9525
60	0.029973	272.83	296.81	1.0110	0.026146	271.60	295.13	0.9976	0.023068	270.32	293.38	0.9850
70	0.031340	281.81	306.88	1.0408	0.027413	280.72	305.39	1.0280	0.024261	279.59	303.85	1.0160
80	0.032659	290.84	316.97	1.0698	0.028630	289.86	315.63	1.0574	0.025398	288.86	314.25	1.0458
90	0.033941	299.95	327.10	1.0981	0.029806	299.06	325.89	1.0860	0.026492	298.15	324.64	1.0748
100	0.035193	309.15	337.30	1.1258	0.030951	308.34	336.19	1.1140	0.027552	307.51	335.06	1.1031
110	0.036420	318.45	347.59	1.1530	0.032068	317.70	346.56	1.1414	0.028584	316.94	345.53	1.1308
120	0.037625	327.87	357.97	1.1798	0.033164	327.18	357.02	1.1684	0.029592	326.47	356.06	1.1580
130	0.038813	337.40	368.45	1.2061	0.034241	336.76	367.58	1.1949	0.030581	336.11	366.69	1.1846
140	0.039985	347.06	379.05	1.2321	0.035302	346.46	378.23	1.2210	0.031554	345.85	377.40	1.2109
150	0.041143	356.85	389.76	1.2577	0.036349	356.28	389.00	1.2467	0.032512	355.71	388.22	1.2368
160	0.042290	366.76	400.59	1.2830	0.037384	366.23	399.88	1.2721	0.033457	365.70	399.15	1.2623
170	0.043427	376.81	411.55	1.3080	0.038408	376.31	410.88	1.2972	0.034392	375.81	410.20	1.2875
180	0.044554	386.99	422.64	1.3327	0.039423	386.52	422.00	1.3221	0.035317	386.04	421.36	1.3124
	P = 1.20 MPa (T_{sat} = 46.29°C)				P = 1.40 MPa (T_{sat} = 52.40°C)				P = 1.60 MPa (T_{sat} = 57.88°C)			
Sat.	0.016715	253.81	273.87	0.9130	0.014107	256.37	276.12	0.9105	0.012123	258.47	277.86	0.9078
50	0.017201	257.63	278.27	0.9267								
60	0.018404	267.56	289.64	0.9614	0.015005	264.46	285.47	0.9389	0.012372	260.89	280.69	0.9163
70	0.019502	277.21	300.61	0.9938	0.016060	274.62	297.10	0.9733	0.013430	271.76	293.25	0.9535
80	0.020529	286.75	311.39	1.0248	0.017023	284.51	308.34	1.0056	0.014362	282.09	305.07	0.9875
90	0.021506	296.26	322.07	1.0546	0.017923	294.28	319.37	1.0364	0.015215	292.17	316.52	1.0194
100	0.022442	305.80	332.73	1.0836	0.018778	304.01	330.30	1.0661	0.016014	302.14	327.76	1.0500
110	0.023348	315.38	343.40	1.1118	0.019597	313.76	341.19	1.0949	0.016773	312.07	338.91	1.0795
120	0.024228	325.03	354.11	1.1394	0.020388	323.55	352.09	1.1230	0.017500	322.02	350.02	1.1081
130	0.025086	334.77	364.88	1.1664	0.021155	333.41	363.02	1.1504	0.018201	332.00	361.12	1.1360
140	0.025927	344.61	375.72	1.1930	0.021904	343.34	374.01	1.1773	0.018882	342.05	372.26	1.1632
150	0.026753	354.56	386.66	1.2192	0.022636	353.37	385.07	1.2038	0.019545	352.17	383.44	1.1900
160	0.027566	364.61	397.69	1.2449	0.023355	363.51	396.20	1.2298	0.020194	362.38	394.69	1.2163
170	0.028367	374.78	408.82	1.2703	0.024061	373.75	407.43	1.2554	0.020830	372.69	406.02	1.2421
180	0.029158	385.08	420.07	1.2954	0.024757	384.10	418.76	1.2807	0.021456	383.11	417.44	1.2676

Table A: Properties of saturated water: pressure

Saturated water—Pressure table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071

END OF PAPER

Q1). (a) By extrapolation,

at end of compression,

$$T_2 = \frac{244.835 - 289.64}{300.61 - 289.64}(70 - 60) + 60$$

$= 64.735$

$\approx \underline{\underline{64.7°C}}$

∴ Work done in compression process, $W_{in} = h_2 - h_1$

$= 244.835 - 273.01$

$= 21.825$

$\approx \underline{\underline{21.8 \text{ kJ/kg}}}$

(b) $\Delta S_{sys} = \int \frac{\delta Q}{T} + S_{gen}$.

as compressor is adiabatic, $\Delta Q = 0$.

∴ $S_{gen} = \Delta S_{sys}$.

$= S_2 - S_1$

$= 0.97674 - 0.4703$

$= \underline{\underline{0.00644 \text{ kJ/kg.K}}}$

(c) $COP_R = \frac{Q_L}{W_{net}}$

$= \frac{h_1 - h_4}{W_{in}}$

$= \frac{273.01 - 114.112}{21.825}$

$= 7.2801$

$\approx \underline{\underline{7.28}}$.

state ① (0.5MPa, 30°C).

in superheated region.

$h_1 = 273.01$ kJ/kg.

$S_1 = 0.4703$ kJ/kg.K.

state ② (1.2 MPa).

$\eta_c = 0.9$.

$$0.9 = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$0.9 = \frac{242.653 - 273.01}{h_2 - 273.01}$$

$h_2 = 244.835$ kJ/kg

$$S_2 = \frac{244.835 - 289.64}{300.61 - 289.64}(0.9938 - 0.9614) + 0.9614$$

$= 0.97674$ kJ/kg.K.

state ③ (1.13MPa, 40°C).

at 1.13MPa, $T_{sat} = \frac{1.13 - 1}{1.2 - 1}(46.29 - 39.37) + 39.37$

$= 43.868°C > T = 40°C$ ∴ compressed.

∴ $h_3 \approx \frac{1.13 - 1.0}{0.2}(114.77 - 107.32) + 107.32$

$= 114.112$ kJ/kg

state ④ (0.53 MPa).

$h_3 = h_4 = 114.112$ kJ/kg (throttling process).

state 2s (1.2 MPa).

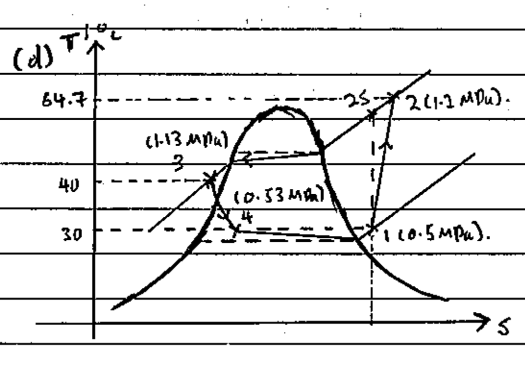
$S_2 = S_1 = 0.9703$ kJ/kg.K

∴ h_{2s}

$$= \frac{0.9703 - 0.9614}{0.9938 - 0.9614}(300.61 - 289.64) + 289.64$$

$= 242.653$ kJ/kg

(d)



Q1) (e) now at 1.2MPa and 50°C, from superheated table,

$h_2 = 278.27$ kJ/kg

$s_2 = 0.9267$ kJ/kg·K.

Thus, $s_1 = 0.9703$ kJ/kg·K

Thus, $\Delta S_{sys} = \int \frac{Q}{T} + S_{gen}$.

for reversible reaction, $S_{gen} = 0$.

$\therefore \Delta S_{sys} = \int \frac{Q}{T}$.

$s_2 - s_1 = \frac{Q}{T}$

$0.9267 - 0.9703 = \frac{Q}{37+273}$

$Q = -13.516$

≈ -13.5 kJ/kg

new compressor work

$= h_2 - h_1$

$= 278.27 - 273.01$

$= 5.26$ kJ/kg

Q2) (a). $PUE = \frac{\text{total energy}}{\text{energy by computer}}$

(i). $1.5 = \frac{10\times10^6}{E_c}$

$E_c = 6.666\times10^6$

≈ 6.67 MW.

(ii) $E_{others} = 10\times10^6 - 6.666\times10^6$

$= 3.333\times10^6$

$\therefore E_{cooling} = 3.333\times10^6 \times 0.8$

$= 2.666\times10^6$

≈ 2.67 MW

$COP = \frac{Q_L}{W_{net}} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$

$\therefore$ for carnot cycle, $COP = \frac{1}{T_H/T_L - 1} = \frac{1}{\frac{33+273}{20+273} - 1} = 22.538$ 4.

as $COP = \frac{Q_L}{W_{net}} \Rightarrow$ cooling load, $Q_L = COP \times W_{net}$

$= 22.538 \times 2.66$

$= 60.1025$

≈ 60.1 MW

(b) (i). new $COP = \frac{1}{\frac{33+273}{27+273} - 1} = 50$.

$W_{net} = \frac{Q_L}{COP} = \frac{60.1025}{50} = 1.202$ MW.

≈ 1.20 MW

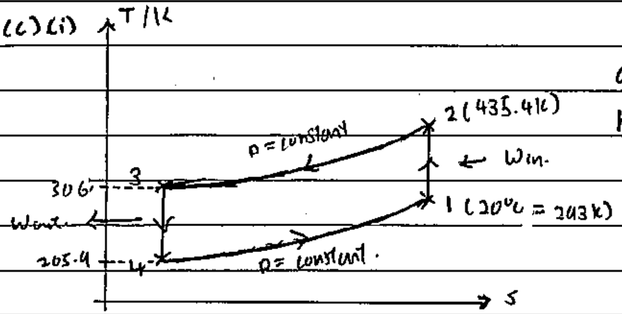
(ii). $E_{non\ it} = \frac{1.202}{0.8} = 1.5025$ MW.

$PUE_{new} = \frac{1.50256 + 6.666}{6.666}$

$= 1.2253$

≈ 1.23

Q2(c)(i)



Pressure ratio = 4. = $\frac{p_2}{p_1}$

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

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

$= (20+273)(4)^{\frac{1.4-1}{1.4}}$

$= 435.396$

$\approx \underline{\underline{435.4K}}$

lowest temperature, $T_4 = T_3 \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}}$

$= 306 \left(\frac{1}{4}\right)^{\frac{1.4-1}{1.4}}$

$= 205.9227$

$\approx \underline{\underline{205.9K}}$

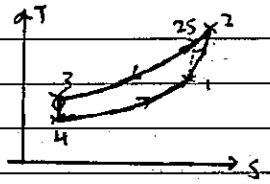
(ii) $COP = \frac{Q_L}{W} = \frac{c_p(T_1 - T_4)}{c_p(T_2 - T_1) - c_p(T_3 - T_4)}$

$= \frac{293 - 205.9}{(435.4 - 293) - (306 - 205.9)}$

$= 2.058$

$\approx \underline{\underline{2.06}}$

(d)



$\eta_c = \frac{W_{ideal}}{W}$

$0.8 = \frac{c_p(T_{2s} - T_1)}{c_p(T_2 - T_1)}$.

$0.8 = \frac{435.396 - 293}{T_2 - 293}$

$T_2 = 470.993K$.

$COP = \frac{Q_L}{W}$

$= \frac{293 - 205.9}{\cancel{(470.993 - 293) - (306 - 205.9)}}$

$= 1.117$

$\approx \underline{\underline{1.12}}$

(ii) $\Delta s = \int \frac{Q}{T} + s_{gen}$. As compression is adiabatic, $Q = 0$.

$s_{gen} = \Delta s$

$= c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

$= 1.04 \ln \left(\frac{470.98}{293}\right) - 0.297 \ln 4$

$= 0.081794$

$\approx \underline{\underline{0.0818}}$ ∴ irreversible as $s_{gen} > 0$.

$k = \frac{c_p}{c_v}$ and $c_p = c_v + R$.

$\therefore R = 0.2971.4$ kJ/kg·K.

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

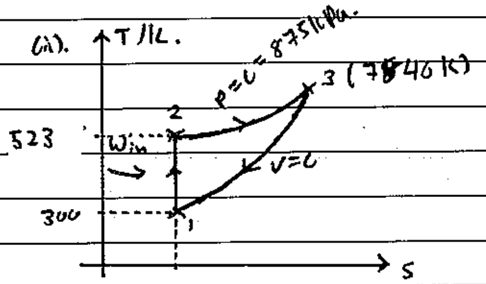
Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32

Q3) (a). (i) ① ideal gas

② cold air assumption (air with constant specific heat at 25°C).

③ all process internally reversible

(ii).



(iii) compression ratio, $\frac{\forall_1}{\forall_2} = \frac{\forall_3}{\forall_2} = 15.$

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

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

$= 300 \left(\frac{875}{125}\right)^{\frac{1.4-1}{1.4}}$

$= 523.091 K.$

Thus, assuming ideal gas, $p\forall = mR_mT.$

from 2 to 3, we have constant pressure. process.

$\therefore \forall \propto T.$

$\frac{T_3}{T_2} = \frac{\forall_3}{\forall_2}$

$T_3 = \frac{\forall_3}{\forall_2}(T_2)$

$= 15(523.091)$

$= 7846.37$

$\approx \underline{\underline{7846 K}}$

(iv) heat addition Q_{in},

$Q_{in} = C_p(T_3 - T_2)$

$= 1.005(7846.37 - 523.09)$

$= 7359.89$

$\approx \underline{\underline{7359.9 kJ/kg}}$

heat rejection Q_{out},

$Q_{out} = C_v(T_3 - T_1)$

$= 0.718(7846.37 - 300)$

$= 5418.29$

$\approx \underline{\underline{5418.3 kJ/kg}}$

(v) $\eta_{th} = \frac{W_{net}}{Q_{in}}$

$= \frac{Q_{in} - Q_{out}}{Q_{in}}$

$\therefore \eta_{th} = \frac{7359.89 - 5418.29}{7359.89} \times 100\%$

$= 26.3807$

$\approx \underline{\underline{26.4\%}}$

$pV = R_mT$

$v_1 = \frac{R_mT}{P} = \frac{0.287(300)}{125}$

$= 0.6888 m^3/kg$

$MEP = \frac{W_{net}}{v_1 - v_2}$

$= \frac{W_{net}}{v_1(1 - \frac{v_2}{v_1})} = \frac{7359.9 - 5418.29}{0.6888(1 - \frac{1}{15})}$

$= 3019.82$

$\approx \underline{\underline{3019.8 kPa}}$

(b) A regeneration cycle makes use of the hot fluid after condenser to heat up the fluid by extracting steam from turbine.

Cogeneration is the production of more than one useful form of energy (such as process heat, cooling and electric power from the same energy source.

(c) A binary cycle typically comprises of two different fluid cycle, such as a mercury cycle and steam cycle. Thus, having two cycle allows the two system to be able to operate over a larger range of temperature.

(d) A combined cycle is able to exploit the advantage of both air and water fluid properties to have a higher efficiency the cycle. Thus, the cycle allows more work to be produced with a smaller heat input, increasing thermal efficiency.

Q4) (a). A typical modern air-conditioning have the purpose of helping to regulate humidity of air. If air is too dry, it may cause cracking of skin. If too humid, it will promote mold and growth of bacteria.

Simple cooling and heating only serve to add heat to system, without increasing the mass of water vapour. Thus, as mass of water vapour does not change, specific humidity is constant and process is a straight line.

(b) (i) From psychrometric chart.

specific humidity = $\underline{\underline{0.044}}$ kg water/kg dry air.

(ii) Wet bulb temperature = $\underline{\underline{17^{\circ}C}}$.

(v) dew point T = $\underline{\underline{13^{\circ}C}}$

(iii) enthalpy = $\underline{\underline{47.3}}$ kJ/kg dry air.

(iv) specific volume = $\underline{\underline{0.855}}$ m³/kg dry air.

(vi) The psychrometric chart is for values at 1 atm. Thus, at higher elevation, pressure would be less than 1 atm, thus values would be not valid.

(c) $N_{C_4H_{10}} = \frac{1}{4\times12+10} = 0.0172413$ mol.

$N_{air} = \frac{25}{29} = 0.862068$ mol.

$\therefore 0.0172413\ C_4H_{10} + 0.862068(O_2 + 3.76\ N_2) \rightarrow xCO_2 + yH_2O + zO_2 + wN_2.$

Hence, by mole ratio,

$0.0172413 \times 4 = x \Rightarrow x = 0.068465.$

$0.0172413(10) = 2y \Rightarrow y = 0.0862068$

$0.862068(3.76) = w = 3.2413$

$0.862068 \times 2 = 0.068465 \times 2 + 0.0862068 + 2z$

$z = 0.75.$

Hence, $0.0172413\ C_4H_{10} + 0.862068(O_2 + 3.76N_2) \rightarrow 0.068465\ CO_2 + 0.0862068\ H_2O$

(ii). $+ 0.75\ O_2 + 3.2413\ N_2$

(i) % theoretical air $= \frac{0.862068 - 0.75}{0.862068} \times 100\% = 12.44$

$\approx \underline{\underline{13\%}}$

(iii) $\frac{N_v}{N} = \frac{0.0862068}{0.068465 + 0.0862068 + 0.75 + 3.2413} = 0.02074.$

$P_v = 0.02074 \times 105$

$= 2.18244$ kPa.

$T_{dp} = T_{sat@P_v}$

$= \frac{2.18244 - 2}{2.5 - 2}(21.08 - 17.50) + 17.50$

$= 18.810\ ^\circ C$

$= \underline{291.8K}$

Thus to prevent moisture condensation, we must not allow temperature in burner to drop below dew point of $\underline{\underline{291.8K}}$

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2018-2019

MA2007 – THERMODYNAMICS

April/May 2019

Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **SEVEN** (7) including **THREE** (3) pages of Appendix.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.

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1. As shown in Figure 1, an insulated cylinder is separated into two piston-cylinder subsystems with the well thermal conducted partition. The working fluid in Subsystem A is water while that in Subsystem B is nitrogen. The two pistons are insulated as well.

   Initially, Subsystem A has the saturated vapour under 100 kPa with the volume 0.6 m^3. Two kilogram nitrogen at a temperature 17°C of is injected in Subsystem B with the pressure at 300 kPa. Then Subsystem A is slowly compressed at a constant pressure while Subsystem B is expanded polytropically by following PV^n = constant. Finally, the two subsystems reach thermal equilibrium such that Subsystem A has a dryness fraction at 0.3.

   The water properties can be obtained from the Appendix and the air properties are: the gas constant (R) with 0.2968 kJ/kg·K and the specific heat at constant pressure (c_p) of 1.039 kJ/ kg·K. Nitrogen can be treated as an ideal gas.

(a) For Subsystem A, determine the work done by the piston and the entropy change from the initial state to the final state.

(8 marks)

(b) For Subsystem B, determine the work done by the piston and the entropy change from the initial state to the final state.

(9 marks)

(c) Calculate the entropy generation in Subsystem B and the overall system.

(8 marks)

Note: Figure 1 appears on page 2.

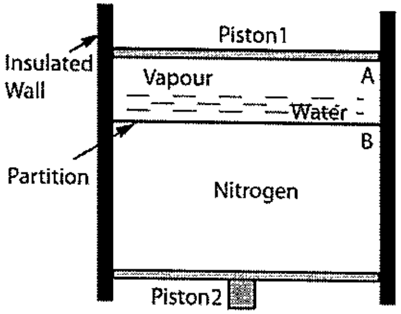


Figure 1

2. An observatory will be designed to investigate the deep sea at the bottom of an ocean. A heat pump system is planned to be built for using the surrounding sea water to heat the observatory. The heat pump system is also required to heat a storage facility at 5 kW, which is attached to the observatory. Thus, the heat pump system is proposed with two condensers. As illustrated in Figure 2, Condenser 1 will be applied to maintain the observatory at 27 °C. Condenser 2 is used for the storage heating. The evaporator will absorb the heat from the sea water at 4 °C. The working fluid in the heat pump system will be R-134a. The inlet of compressor is saturated vapour at 180 kPa at Point 1. If the isentropic efficiency of the compressor is 80%, the pressure of outlet of compressor is 900 kPa. By justifying Isenthalpic Valve 1, the flow rate to Condenser 2 will be half that of Condenser 1. At the outlet of Condenser 2 (Point 9), the refrigerant is a saturated liquid. After Condenser 1, the temperature is 28 °C and pressure is 900 kPa at Point 4. The compressor and expansion valves are adiabatic. There is no loss of pressure and heat in the pipes. The properties of R-134a can be found in the Appendix.

(a) Calculate the mass flow rate of the R-134a at the evaporator.

(5 marks)

(b) Determine the specific entropy at inlet of the evaporator (Point 6).

(5 marks)

(c) What is the rate of enthalpy change for the surrounding sea water?

(4 marks)

(d) Determine the coefficient of performance (COP) of the heat pump system.

(7 marks)

(e) Calculate the maximum COP of the heat pump system.

(4 marks)

Note: Figure 2 appears on page 3.

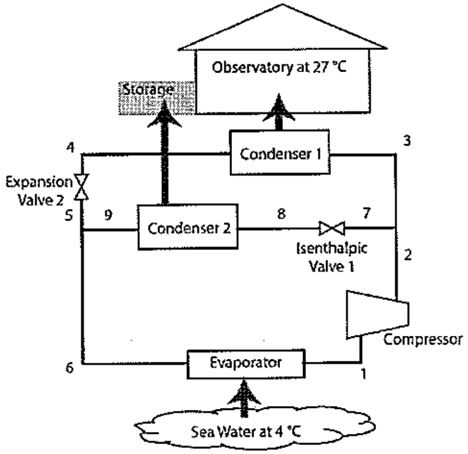


Figure 2

3. Air at 7°C enters a turbojet engine at a rate of 15 kg/s and a velocity of 900 km/h (relative to the engine). Air is heated in the combustion chamber at a rate of 15 MJ/s and it leaves the engine at 427°C.
Consider the entire engine as a control volume and assume Cold Air Standard assumptions apply with $R = 0.287$ kJ/kg K and $k = 1.4$. Determine

(a) the velocity at the exit of the engine in kilometres per hour (10 marks)

(b) the thrust produced by the turbojet engine in kN. (5 marks)

(c) Assuming that the mass flow rate of air is maintained rather constant and all given conditions above remain the same, except a reduced air velocity (i.e., lower than 900 km/h) entering the turbojet engine, will the engine thrust increase or decrease? Please explain.

(10 marks)

4 (a) On a $T - v$ diagram, indicate the following three different moist air condensation processes with state points and arrows legibly marked on the diagram:

(i) Constant pressure process
(ii) Constant volume process
(iii) Constant temperature process

(6 marks)

(b) A fuel mixture consisting of octane (C_8H_{18}) and methanol (CH_3OH) is burned with 10% of excess air. The combustion is incomplete with 5% of the carbon being oxidised to carbon monoxide (CO), while the rest of the carbon to carbon dioxide (CO_2). Given that the mole fractions of the octane and methanol are 0.9 and 0.1, respectively,

(i) write a chemical balanced equation for the stoichiometric reactions, and (6 marks)

(ii) a chemical balanced equation for the real reactions. (6 marks)

(iii) Assuming atmospheric pressure of 100 kPa, determine the dew point temperature of the product below which condensation will occur.

(7 marks)

MA2007

1.a) Subsystem A : Initial : $P_{A1} = 100kPa$, $\forall_{A1} = 0.6m^3$, saturated vapour.

Final : $P_{A2} = 100kPa$, $x_{A2} = 0.3$

From table, $s_{A1} = 7.3589 kJ/kgK$ $\quad$ $u_{A1} = 2505.6 kJ/kg$.

$s_{A2} = 1.3028 + 0.3(6.0562)$ $\quad$ $u_{A2} = 417.40 + 0.3(2088.2)$

$= 3.11966 kJ/kgK$ $\quad$ $= 1043.86 kJ/kg$

$v_{A1} = 1.6941 m^3/kg \Rightarrow m_A = 0.6 \div 1.6941 = 0.35417 kg$.

$v_{A2} = 0.001043 + 0.3(1.6941 - 0.001043) \Rightarrow \forall_{A2} = 0.180258 m^3$

$= 0.50896 m^3/kg$

$\therefore$ Workdone BY piston $= -Pd\forall = -100(0.180258 - 0.6) = 41.9742 kJ$

Entropy Change of A, $\Delta S_A = 0.35417(3.11966 - 7.3589)$

$= -1.5014 kJ/K$

1.b) Subsystem B: $T_{B1} = 17°C$, $P_{B1} = 300kPa$, $T_{B2} = T_{A2} = 99.61°C$ (from table).

For subsystem A : $\Delta U = m_A(U_{A2} - U_{A1}) = -517.7045 kJ$

$Q - W = \Delta U \Rightarrow -517.7045 = Q - (-41.9742)$

$Q = -559.6787 kJ$ $\Rightarrow$ Implies heat transfered from A to B.

$C_v = C_p - R = 0.7422 kJ/kg.K$

For subsystem B : $\Delta U_B = m_B C_v(T_{B2} - T_{B1}) = 2(0.7422)(99.61 - 17) = 122.626 kJ$

$Q - W = \Delta U \Rightarrow W = Q - \Delta U_B = 559.6787 - 122.626 = 437.0527 kJ$. (workdone by gas)

[specific] $w = \int_1^2 P dv = -\frac{1}{n-1}(P_2v_2 - P_1v_1) = -\frac{R}{n-1}(T_2 - T_1)$

$\therefore \frac{437.0527}{2} = \frac{-0.2968}{n-1}(99.61 - 17) \Rightarrow n = 0.8878$.

$Pv^n = C \Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(n-1)/n}$, $\therefore P_{B2} = 41.2836 kPa$.

$\Delta S_B = m\left[C_p \ln\frac{T_{B2}}{T_{B1}} - R \ln\frac{P_{B2}}{P_{B1}}\right] = 1.69815 kJ/K$

Workdone by piston $= -437.0527 kJ$

1.c) Subsystem B: $\sum\frac{Q_K}{T_K} + S_{gen} = \Delta S$.

$\frac{475.7303}{99.61+273} + S_{gen} = 1.69815 \Rightarrow S_{gen,B} = 0.4213967 kJ/K$.

System: $S_{gen} = \Delta S_{sys} = 1.69815 - 1.5014$

$= 0.19675 kJ/K$

2.a) Point 1 : Sat. Vapor , $P_1 = 180 kPa$

Point 2 : $P_2 = 900 kPa$.

Point 9 : Sat. liquid

Point 4 : $T_4 = 28°C$, $P_4 = 900 kPa$.

$\eta_c = 0.8$

$\dot{m}_8 = \frac{1}{2}\dot{m}_3$

From table, $v_1 = 0.11041 m^3/kg$, $h_1 = 242.86 kJ/kg$, $T_1 = -12.73°C$, $s_1 = 0.93965 kJ/kg.K$

$h_4 = 90.69 kJ/kg$.

$\dot{m}_8(h_8 - h_9) = 5$

To find h_{2s}, use table, $\frac{0.93965 - 0.9327}{0.9660 - 0.9327} = \frac{h_{2s} - 274.17}{284.77 - 274.17}$ $\Rightarrow$ $h_{2s} = 276.3823 kJ/kg$.

$\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1}$ $\Rightarrow$ $h_{2a} = 284.7628 kJ/kg$.

$h_9 = h_5 = h_4 = 90.69$, $h_8 = h_7 = h_3 = h_2 = 284.7628$

$\therefore \dot{m}_8 = 0.02576 kg/s$, $\dot{m}_3 = 0.051527 kg/s$, $\dot{m}_1 = 0.07729 kg/s$ ✓

2.b) $h_6 = 90.69 kJ/kg$. $T_6 = T_1 = -12.73°C$, $P_6 = P_1 = 180 kPa$.

(We assume that from pt 6 to 1, we move along the constant pressure line between sat. liq and sat vap.)

$x_6 = \frac{90.69 - 34.97}{207.90} = 0.26801$

$s_6 = 0.14139 + 0.26801(0.79826) = 0.35533 kJ/kg.K$ ✓

2.c) $\Delta\dot{H} = \dot{m}_1(h_1 - h_6) = 11.7612 kJ/s$ ✓

2.d) $COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{in}}$, $\dot{Q}_H = \dot{Q}_L + \dot{W}_{in}$

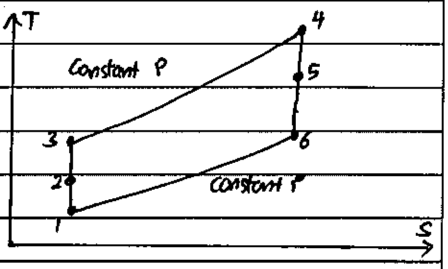
$\dot{Q}_L = 11.7612 kW$ $\dot{W}_{in} = \dot{m}_1(h_2 - h_1) = 3.238667 kW$

$\dot{Q}_H = 14.999867 kW$

$\therefore COP_{HP} = 4.63149$ ✓

2.e) $COP_{HP,max} = \frac{1}{1 - T_L/T_H} = 13.04348$ ✓

3.a) Given : $\dot{m} = 15 kg/s$ $V_1 = 900 km/hr = 250 m/s$.



$C_p = \frac{kR}{k-1} = 1.0045$

To find T_2, $h_2 + \cancel{\frac{V_2^2}{2}}^{\to 0} = h_1 + \frac{V_1^2}{2}$

$T_2 = T_1 + \frac{V_1^2}{2C_p} = 7+273 + \frac{(250)^2}{2(1.0045\times10^3)}$

$= 311.11 K$

$\frac{T_3}{T_1} = \left(\frac{P_3}{P_1}\right)^{(k-1)/k}$ $\frac{T_6}{T_4} = \left(\frac{P_6}{P_4}\right)^{(k-1)/k}$

Since $P_6 = P_1$ and $P_3 = P_4$, $\frac{T_6}{T_4} = T_1/T_3 \Rightarrow T_6 T_3 = T_1 T_4$

$\Delta \dot{H}_{comb} = \dot{m} C_p (T_4 - T_3) \Rightarrow 15000 = 15(1.0045)(T_4 - T_3) \Rightarrow T_4 - T_3 = 995.52$

$(427+273) T_3 = (7+273)(995.52 + T_3)$

$\therefore T_3 = 663.68 K \Rightarrow T_4 = 1659.2 K$

$h_6 + V_6^2/2 = h_5 + V_5^2/2 \Rightarrow V_6 = \sqrt{2C_p(T_5 - T_6)}$

$\omega_{comp,in} = \omega_{turb,out} \Rightarrow h_3 - h_2 = h_4 - h_5 \Rightarrow T_3 - T_2 = T_4 - T_5$

$\therefore T_5 = 1306.63 K$

$\therefore V_6 = 1103.929 m/s$

3.b) Thrust $= 15(1103.929 - 250) = 12.809 kN$.

3.c) Thrust $= \dot{m}(V_6 - V_1)$

$V_6 = \sqrt{2C_p(T_5 - T_6)}$

$\omega_{comp,in} = \omega_{turb,out} \Rightarrow T_3 - T_2 = T_4 - T_5$

From (0), $15000 = \dot{m} C_p (T_4 - T_3)$ $T_2 = T_1 + \frac{V_1^2}{2C_p}$

$T_4 - T_3 = \frac{15000}{\dot{m} C_p} = C_1$

$T_4 = C_1 + T_3$

$\therefore T_5 - T_6 = T_4 - T_3 + T_2 - T_6$

$= C_1 + T_2 - T_6$

$= C_1 + T_1 + \frac{V_1^2}{2C_p} - T_6$

$\therefore V_6 = \left[2C_p\left(C_1 + T_1 + \frac{V_1^2}{2C_p} - T_6\right)\right]^{1/2}$

$\therefore$ Thrust $= \dot{m}\left[\left(2C_p\left(C_1 + T_1 + \frac{V_1^2}{2C_p} - T_6\right)\right)^{1/2} - V_1\right]$

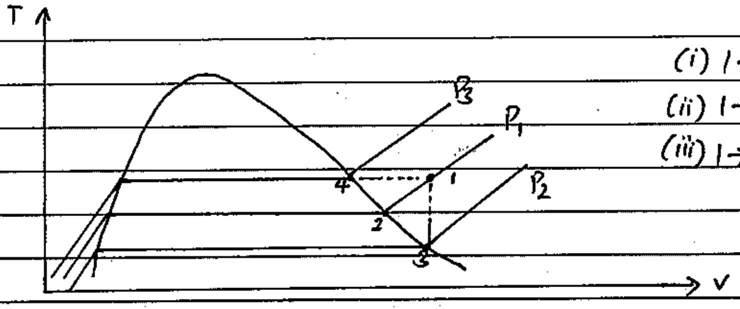
$= \dot{m}\left[\sqrt{C_2 + V_1^2} - V_1\right]$

Let $T = \sqrt{C_2 + V_1^2} - V_1$, $\frac{dT}{dV_1} = \frac{V_1}{\sqrt{C_2 + V_1^2}} - 1$.

Since $\sqrt{C_2 + V_1^2} > V_1$, $\frac{dT}{dV_1} < 0$, for all $V_1 > 0$.

$\therefore$ As V_1 decreases, thrust will increase.

4. a)



(i) 1→2

(ii) 1→3

(iii) 1→4

4.b.i) $0.9C_8H_{18} + 0.1\,CH_3OH + a(O_2 + 3.76N_2) \rightarrow x\,CO_2 + y\,H_2O + z\,N_2$.

$x = 0.9(8) + 0.1 = 7.3$

$0.9(18) + 0.1(4) = 2y \Rightarrow y = 8.3$

$0.1 + 2a = 7.3(2) + 8.3 \Rightarrow a = 11.4$

$z = 11.4(3.76) = 42.864$.

$\therefore 0.9C_8H_{18} + 0.1CH_3OH + 11.4(O_2 + 3.76N_2) \rightarrow 7.3CO_2 + 8.3H_2O + 42.864N_2$

4.b.ii) $0.9C_8H_{18} + 0.1CH_3OH + 12.54(O_2 + 3.76N_2) \rightarrow 0.365CO + 6.935CO_2 + 8.3H_2O + AO_2 + BN_2$

Amt of CO = $\frac{5}{100}(7.3) = 0.365$ Amt of $CO_2 = 7.3 - 0.365 = 6.935$.

Amt of air = $1.1(11.4) = 12.54$

Balancing equation, $0.1 + 2(12.54) = 0.365 + 6.935(2) + 2A + 8.3$

$A = 1.3225$

$B = 12.54(3.76) = 47.1504$.

$0.9C_8H_{18} + 0.1CH_3OH + 1254(O_2 + 3.76N_2) \rightarrow 0.365CO + 6.935CO_2 + 8.3H_2O + 1.3225O_2 + 47.1504N_2$

4.b.iii) $y_v = \frac{8.3}{0.365 + 6.935 + 1.3225 + 47.1504 + 8.3} = 0.1295399$

$P_v = y_v(P_m)$

$= 0.1295399(100)$

$= 12.95\,kPa$

T_{sat} @ $P = 12.95kPa$ $= 51.2144°C$