FACULTY OF MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI MALAYSIA

TEST 2 (6 DECEMBER 2016) **THERMODYNAMICS (SKMM 2413)** **SEM 2016/2017-1**

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Answer All Questions **1 hour and 30 minutes**

Question 1

a) Write the general energy balance equation for a closed system and describe all the terms.

(2 marks)

b) Complete the table below based on the conservation of energy principle for a closed system.

Q_{in} (kJ)	Q_{out} (kJ)	W_{out} (kJ)	E_1 (kJ)	E_2 (kJ)
400	0		1000	700
0	300	500	600	

(4 marks)

c) A piston-cylinder device contains an electrical heater and a paddle wheel as shown in *Figure Q1*. The volume of the cylinder is 1.71 m^3 and the initial pressure inside the cylinder is 500 kPa. The air is heated from the initial temperature of 25°C to 100°C when both the electrical heater and paddle wheel were turned on simultaneously for a period of time. The pressure inside the cylinder is held constant during the process. The total heat loss that occurs during the process is 80 kJ. The electric current that passes through the electrical heater is 2 A from a 240 V source, and the power rating of the paddle wheel is 0.02 kW. For air use gas constant $R = 0.287$ kJ/kg K and $c_v = 0.720$ kJ/kg K. Show the path of process on a *P-V* diagram and determine the

i) mass of air inside the cylinder, *kg*,

ii) final volume of the cylinder, m^3, and

iii) total time taken for the process, *s*.

(14 marks)

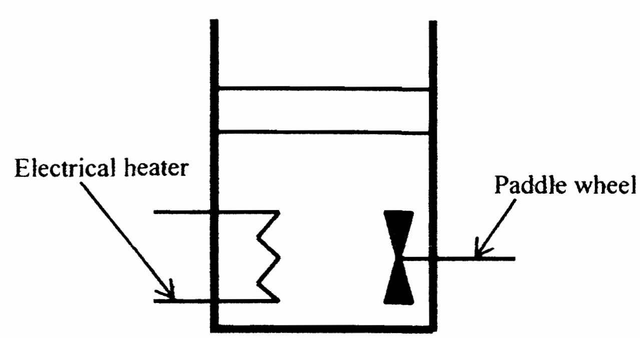


Figure Q1

Question 2

a) State the differences between the following devices:

i) nozzle and diffuser, and

ii) compressor and pump.

(4 marks)

b) Refrigerant-134a enters an adiabatic compressor as saturated vapor at -24 °C and leaves at 0.8 MPa and 60 °C (*Figure Q2*). The refrigerant is then cooled to 0.3 MPa and 30 °C in a condenser by air. The air enters at 100 kPa and 27 °C with a volume flow rate of 600 m^3/min and leaves at 95 kPa and 60 °C. Assume that the flow is steady and changes in both kinetic energy and potential energy are negligible. Determine

i) the mass flow rate of the refrigerant, *kg/s*,

ii) the power input to the compressor, *kW*, and

iii) the volume flow rate of the refrigerant at the compressor inlet, m^3/s.

For air use, c_p = 1.005 kJ/kg K , R = 0.287 kJ/kg K.

(16 marks)

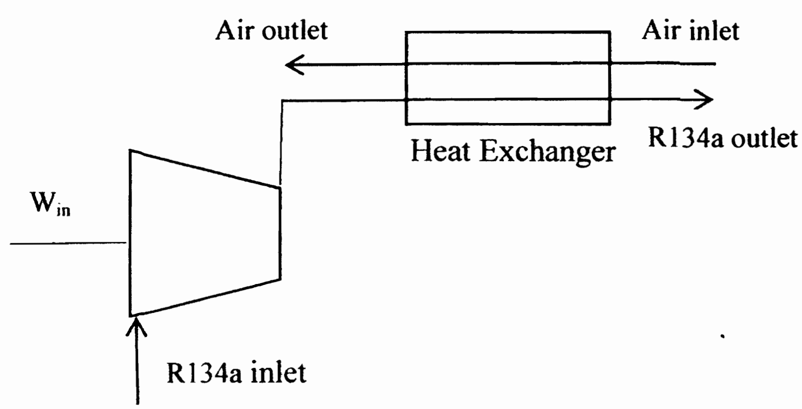


Figure Q2

Question 3

a) Write the Kelvin-Plank statement and Clasius statement of the second law of thermodynamics?

(4 marks)

b) State the four processes that make up the Carnot cycle?

(4 marks)

c) Refrigerant-134a enters the condenser of a residential heat pump (*Figure Q3*) at a pressure of 800 kPa and temperature of 40°C, at a rate of 0.018 kg/s and it leaves at a pressure of 800 kPa as a saturated liquid. If the compressor consumes 1.2 kW of power, determine

i) the COP of the heat pump, and

ii) the rate of heat absorption from the outside air, *kW*.

(12 marks)

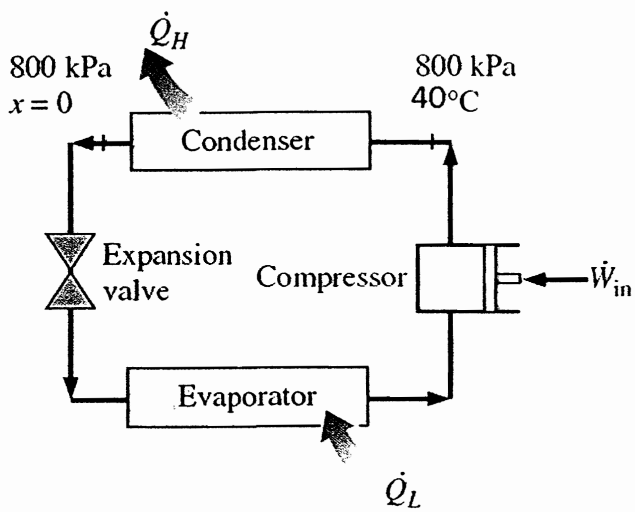


Figure Q3

PROPERTIES OF REFRIGERANT-134a

TABLE A–11

Saturated refrigerant-134a—Temperature table

		Specific volume, m³/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	237.17	0.09441	0.85307	0.94748

TABLE A–12

Saturated refrigerant-134a—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
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

PROPERTIES OF REFRIGERANT-134a

TABLE A-13

Superheated refrigerant-134a

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.28 MPa (T_{sat} = −1.25°C)				P = 0.32 MPa (T_{sat} = 2.46°C)				P = 0.40 MPa (T_{sat} = 8.91°C)			
Sat.	0.07235	229.46	249.72	0.9321	0.06360	231.52	251.88	0.9301	0.051201	235.07	255.55	0.9269
0	0.07282	230.44	250.83	0.9362								
10	0.07646	238.27	259.68	0.9680	0.06609	237.54	258.69	0.9544	0.051506	235.97	256.58	0.9305
20	0.07997	246.13	268.52	0.9987	0.06925	245.50	267.66	0.9856	0.054213	244.18	265.86	0.9628
30	0.08338	254.06	277.41	1.0285	0.07231	253.50	276.65	1.0157	0.056796	252.36	275.07	0.9937
40	0.08672	262.10	286.38	1.0576	0.07530	261.60	285.70	1.0451	0.059292	260.58	284.30	1.0236
50	0.09000	270.27	295.47	1.0862	0.07823	269.82	294.85	1.0739	0.061724	268.90	293.59	1.0528
60	0.09324	278.56	304.67	1.1142	0.08111	278.15	304.11	1.1021	0.064104	277.32	302.96	1.0814
70	0.09644	286.99	314.00	1.1418	0.08395	286.62	313.48	1.1298	0.066443	285.86	312.44	1.1094
80	0.09961	295.57	323.46	1.1690	0.08675	295.22	322.98	1.1571	0.068747	294.53	322.02	1.1369
90	0.10275	304.29	333.06	1.1958	0.08953	303.97	332.62	1.1840	0.071023	303.32	331.73	1.1640
100	0.10587	313.15	342.80	1.2222	0.09229	312.86	342.39	1.2105	0.073274	312.26	341.57	1.1907
110	0.10897	322.16	352.68	1.2483	0.09503	321.89	352.30	1.2367	0.075504	321.33	351.53	1.2171
120	0.11205	331.32	362.70	1.2742	0.09775	331.07	362.35	1.2626	0.077717	330.55	361.63	1.2431
130	0.11512	340.63	372.87	1.2997	0.10045	340.39	372.54	1.2882	0.079913	339.90	371.87	1.2688
140	0.11818	350.09	383.18	1.3250	0.10314	349.86	382.87	1.3135	0.082096	349.41	382.24	1.2942
	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	299.96	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

a) $Q_{12} - W_{12} = u_2 - u_1$

Q_{12} - heat supplied

W_{12} - Work output

u_1 - initial internal energy

u_2 - final internal energy

Assume: $\Delta KE = \Delta PE = 0$

b) $E_1 + Q_{in} = E_2 + Q_{out} + W_{out}$

i) $W_{out} = (E_1 - E_2) + Q_{in} - Q_{out}$

$= (1000 - 700) + 400 - 0$

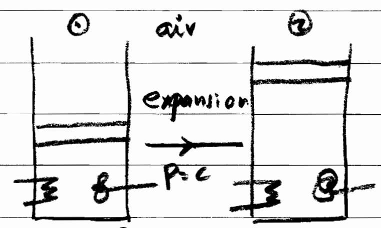
$W_{out} = 700\ kJ$

$E_2 = E_1 + Q_{in} - Q_{out} - W_{out}$

$= 600 + 0 - 300 - 500$

$E_2 = -200\ kJ$

c)



$Q_{12} = 80\ kJ$ (loss)

$V_1 = 1.71\ m^3$ | $P_2 = P_1$

$P_1 = 500\ kPa$ | $T_2 = 373\ K$

$T_1 = 298\ K$ | $I = 2A$, $V = 240\ V$

$\dot{W}_{pw} = 0.02\ kW$

i) $m = \frac{P_1 V_1}{R T_1} = \frac{500 \times 1.71}{0.287 \times 298}$

$m = 9.9970\ kg$

ii) $\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1}$, $V_2 = V_1 \frac{T_2}{T_1}$

$V_2 = 1.71 \times \frac{373}{298}$

$V_2 = 2.1404\ m^3$

iii) $U_1 + W_e + W_{pw} = U_2 + W_{12}$

$W_e + W_{pw} = m(u_2 - u_1) + W_{12}$

$= m C_v (T_2 - T_1) + W_{12}$

$W_{12} = P(V_2 - V_1)$

$= 500(2.1404 - 1.71)$

$= 215.20\ kJ$

$W_e + W_{pw} = 9.9970 \times 0.720 (373 - 298) + 215.20$

$= 755.04\ kJ$ ——— (i)

$W_e + W_{pw} = \frac{(I V \times t)}{10^3} - (\dot{W}_{pw} \times t)$

$= \frac{2 \times 240 \times t}{10^3} - 0.02 \times t$

$W_e + W_{pw} = 0.46\,t$ ——— (ii)

(ii) = (i)

$0.46\,t = 755.04$

$t = 1641.4\ s$

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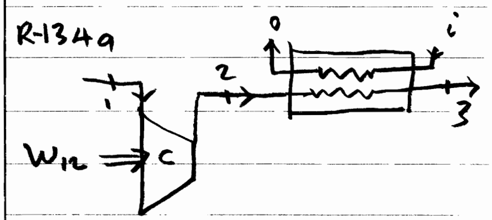
a) i) nozzle - increase velocity
diffuser - decrease velocity

ii) compressor - to increase pressure of vapor or gas
pump - to increase pressure of liquids

b) R-134a



$T_1 = -24°C$, sat. vapor
$P_2 = 0.8 MPa$, $T_2 = 60°C$
$T_3 = 30°C$, $P_3 = 0.3 MPa$
$P_i = 100 kPa$, $T_i = 300 K$, $\dot{V}_i = 600 m^3/min$
$P_o = 95 kPa$, $T_o = 333 K$

i) $\dot{m}_2 h_2 + \dot{m}_i h_i = \dot{m}_3 h_3 + \dot{m}_o h_o$
$\dot{m}_2 = \dot{m}_3$, $\dot{m}_i = \dot{m}_o$
$\dot{m}_2 (h_2 - h_3) = \dot{m}_i (h_o - h_i)$
$\dot{m}_2 = \dfrac{\dot{m}_i C_p (T_o - T_i)}{(h_2 - h_3)}$

$\dot{m}_i = \dfrac{P_i \dot{V}_i}{R T_i}$
$= \dfrac{100 \times 600}{60 \times 0.287 \times 300}$
$= 11.6144 kg$

$h_2 = ?$ State 2:
At 0.8MPa, $T_{sat} = 31.31°C$
$T_2 > T_{sat}$. ∴ s.h.v.
$h_2 = 296.81 kJ/kg$

$h_3 = ?$ State 3:
At 0.3MPa, T_{sat} = interpolate

P	T_{sat}
280	-1.25
300	T_{sat}
320	2.46

$\dfrac{T_{sat} - (-1.25)}{2.46 - (-1.25)} = \dfrac{20}{40}$

$T_{sat} = 0.605°C$

$T_3 > T_{sat}$ ∴ s.h.v.

At 30°C

h	P
277.41	0.28
h_3	0.30
276.65	0.32

$\dfrac{h_3 - 277.41}{276.65 - 277.4} = \dfrac{0.20}{0.40}$

$h_3 = 277.04 kJ/kg$

$\dot{m}_2 = \dfrac{11.6144 \times 1.005 (333 - 300)}{(296.81 - 277.04)}$
$= 19.4836 kg/s$

ii) $h_1 + W_{12} = h_2$
$W_{12} = (h_2 - h_1)$, $\dot{W}_{12} = \dot{m}_2 (h_2 - h_1)$
$h_1 = h_g @ -24°C = 235.92 kJ/kg$

$\dot{W}_{12} = 19.4836 (296.81 - 235.92)$
$= 1186.36 kW$

iii) $\dot{V}_1 = \dot{m} v_1$
$v_1 = v_g @ -24°C$
$= 0.17395 m^3/kg$
$\dot{V}_1 = 19.4836 \times 0.17395$
$= 3.3892 m^3/s$

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I.C. No./ISID No.

No. Soalan Q3
Question No.

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a) Kelvin-Planck :

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.

Clasius :

It is impossible to construct a device that operates on a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.

b) 1-2 : Reversible isothermal expansion
2-3 : Reversible adiabatic expansion
3-4 : Reversible isothermal compression
4-1 : Reversible adiabatic compression

c) $COP_{ref} = \frac{\dot{Q}_H}{\dot{W}_{net,in}}$

$W_{net,in} = 1.2 \text{ kW}$

$\dot{Q}_H = \dot{m}(h_i - h_o)$

State i :

At 800 kPa, $T_{sat} = 31.31°C$

$T_i > T_{sat}$ ∴ s.h.v

$h_i = 276.45 \text{ kJ/kg}$

State o :

$x_o = 0$ ∴ sat liq.

$h_o = h_f @ 800 \text{ kPa}$
$= 95.47 \text{ kJ/kg}$

$\dot{Q}_H = 0.018(276.45 - 95.47)$
$= 3.258 \text{ kW}$

$COP_{ref} = \frac{3.258}{1.2} = 2.715$

ii) $\dot{Q}_L = \dot{Q}_H - \dot{W}_{net,in}$
$= 3.258 - 1.2$
$= 2.058 \text{ kW}$