UTM UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING
Faculty of Engineering

SEMM2413/SKMM2413 THERMODYNAMICS
TEST 2

1 hour 30 min

INSTRUCTION: ANSWER ALL QUESTIONS

QUESTION 1 (*20 marks*)

a) A rigid recovery cylinder has a volume of 0.02 m³, contains Refrigerant R-134a as shown in Figure Q1. Initially, the density and temperature of the refrigerant are 85 kg/m³ and 48°C, respectively. Due to heat transfer to the refrigerant, its pressure and temperature were observed to increase until it becomes saturated vapor. Show the process on a *T*-*v* diagram with respect to saturation lines, and determine,
   i) the final temperature of the refrigerant, *°C*,
   ii) the heat transfer to the refrigerant, *kJ*.

(*14 marks*)

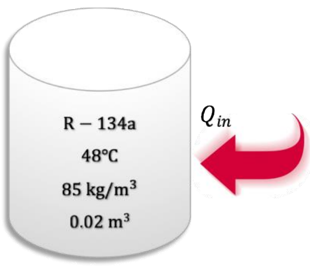

Fig. Q1

b) The United States Environmental Protection Agency (US EPA) has specified that the temperature of recovered refrigerant inside the rigid recovery cylinder must not exceed 52°C for safety reasons. To satisfy this requirement, the saturated vapor in part a) above needs to be cooled to a mixture at 52°C by removing heat from the refrigerant. Determine the amount of heat (kJ) that needs to be removed from the refrigerant.

(*6 marks*)

QUESTION 2 (*20 marks*)

Air enters the compressor of a power plant steadily at ambient conditions of 101 kPa and 30°C with a velocity of 120 m/s. The air leaves at 6 MPa and 300°C with a velocity of 50 m/s. The diameter of the compressor inlet is 40 cm. A cooling liquid is used to cool the compressor at a rate of 1500 kJ/min. Only the change in potential energy can be neglected. Air can be assumed as ideal gas, take R = 0.287 kJ/kg.K and c_p = 1.005 kJ/kg.K.

   i) Determine the mass flow rate of air through the compressor, *kg/s.*
   ii) Determine the outlet diameter of the compressor, *mm.*
   iii) Determine the volume flow rate of the air at compressor inlet, *m³/min*.
   iv) Calculate the power required by the compressor, k*W*.

QUESTION 3 (20 marks)

a) Write down two factors that cause a process to be irreversible. (4 marks)

b) A Carnot heat engine receives 650 kJ of heat from a source of unknown temperature and rejects 250 kJ of heat to a sink at 24 ^oC. Determine,

   i) the temperature of the source , ^oC,

   ii) the thermal efficiency of the heat engine, *%*.

(*4 marks*)

c) A heat engine operates by receiving heat from a reservoir at 900 ^oC at a rate of 800 kJ/min and rejects heat at a rate of 560 kJ/min to the ambient air at 27 ^oC. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at -5 ^oC and rejects heat to the same ambient air at 27 ^oC.

   i) Sketch the schematic diagram of the engine-refrigerator system.

   ii) Determine the thermal efficiency of the heat engine, *%.*

   iii) Determine the maximum thermal efficiency of the engine if it operates on a reversible cycle, *%*.

   iv) Determine the maximum COP of the refrigerator if it operates on a reverse Carnot cycle.

   v) Determine the maximum rate of heat removal from the refrigerated space, *kJ/s*.

   vi) Determine the rate of heat rejection to the ambient air from the refrigerator, *kJ/s*.

(*12 marks*)

APPENDIX (PROPERTY TABLES)

Saturated refrigerant-134a—Temperature table (*Concluded*)

		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
20	572.07	0.0008161	0.035969	78.86	162.16	241.02	79.32	182.27	261.59	0.30063	0.62172	0.92234
22	608.27	0.0008210	0.033828	81.64	160.42	242.06	82.14	180.49	262.64	0.31011	0.61149	0.92160
24	646.18	0.0008261	0.031834	84.44	158.65	243.10	84.98	178.69	263.67	0.31958	0.60130	0.92088
26	685.84	0.0008313	0.029976	87.26	156.87	244.12	87.83	176.85	264.68	0.32903	0.59115	0.92018
28	727.31	0.0008366	0.028242	90.09	155.05	245.14	90.69	174.99	265.68	0.33846	0.58102	0.91948
30	770.64	0.0008421	0.026622	92.93	153.22	246.14	93.58	173.08	266.66	0.34789	0.57091	0.91879
32	815.89	0.0008478	0.025108	95.79	151.35	247.14	96.48	171.14	267.62	0.35730	0.56082	0.91811
34	863.11	0.0008536	0.023691	98.66	149.46	248.12	99.40	169.17	268.57	0.36670	0.55074	0.91743
36	912.35	0.0008595	0.022364	101.55	147.54	249.08	102.33	167.16	269.49	0.37609	0.54066	0.91675
38	963.68	0.0008657	0.021119	104.45	145.58	250.04	105.29	165.10	270.39	0.38548	0.53058	0.91606
40	1017.1	0.0008720	0.019952	107.38	143.60	250.97	108.26	163.00	271.27	0.39486	0.52049	0.91536
42	1072.8	0.0008786	0.018855	110.32	141.58	251.89	111.26	160.86	272.12	0.40425	0.51039	0.91464
44	1130.7	0.0008854	0.017824	113.28	139.52	252.80	114.28	158.67	272.95	0.41363	0.50027	0.91391
46	1191.0	0.0008924	0.016853	116.26	137.42	253.68	117.32	156.43	273.75	0.42302	0.49012	0.91315
48	1253.6	0.0008996	0.015939	119.26	135.29	254.55	120.39	154.14	274.53	0.43242	0.47993	0.91236
52	1386.2	0.0009150	0.014265	125.33	130.88	256.21	126.59	149.39	275.98	0.45126	0.45941	0.91067
56	1529.1	0.0009317	0.012771	131.49	126.28	257.77	132.91	144.38	277.30	0.47018	0.43863	0.90880
60	1682.8	0.0009498	0.011434	137.76	121.46	259.22	139.36	139.10	278.46	0.48920	0.41749	0.90669
65	1891.0	0.0009750	0.009950	145.77	115.05	260.82	147.62	132.02	279.64	0.51320	0.39039	0.90359
70	2118.2	0.0010037	0.008642	154.01	108.14	262.15	156.13	124.32	280.46	0.53755	0.36227	0.89982
75	2365.8	0.0010372	0.007480	162.53	100.60	263.13	164.98	115.85	280.82	0.56241	0.33272	0.89512
80	2635.3	0.0010772	0.006436	171.40	92.23	263.63	174.24	106.35	280.59	0.58800	0.30111	0.88912
85	2928.2	0.0011270	0.005486	180.77	82.67	263.44	184.07	95.44	279.51	0.61473	0.26644	0.88117
90	3246.9	0.0011932	0.004599	190.89	71.29	262.18	194.76	82.35	277.11	0.64336	0.22674	0.87010
95	3594.1	0.0012933	0.003726	202.40	56.47	258.87	207.05	65.21	272.26	0.67578	0.17711	0.85289
100	3975.1	0.0015269	0.002630	218.72	29.19	247.91	224.79	33.58	258.37	0.72217	0.08999	0.81215

Solution for Q1(a):

Refrigerant R-134a is filled in a recovery cylinder with initial conditions of 20 L, 85 kg/m^3, and 48°C. After sometimes, the temperature and pressure of the refrigerant increase due to heat transfer until it becomes saturated vapor. The cylinder is a closed system. Thus its volume is constant. The final temperature, pressure, and heat transfer are to be determined.

TABLE A–11

Saturated refrigerant-134a—Temperature table (*Continued*)

		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
20	572.07	0.0008161	0.035969	78.86	162.16	241.02	79.32	182.27	261.59	0.30063	0.62172	0.92234
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100	3975.1	0.0015269	0.002630	218.72	29.19	247.91	224.79	33.58	258.37	0.72217	0.08999	0.81215

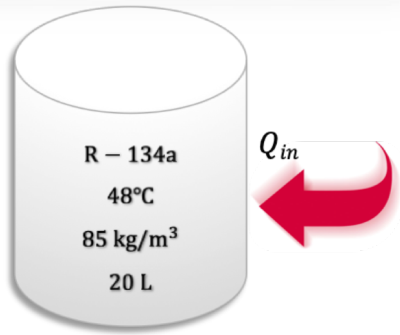
Assumptions:

1) The system is stationary and thus the kinetic and potential energy changes are zero.
2) The direction of heat transfer is to the system (heat gain, Q_{in}).
3) The volume of the rigid tank is constant, and thus there is no energy transfer as boundary work.
4) There is no electrical, shaft, or any other kind of work involved.

2

Analysis:

Consider the contents of the cylinder as the system. This is a closed system since no mass crosses the system boundary during the process.



State 1:

$$T_1 = 48°\text{C}$$

$$v_{f@48°\text{C}} = 0.0008996\ \text{m}^3/\text{kg}$$

$$v_{g@48°\text{C}} = 0.015939\ \text{m}^3/\text{kg}$$

$$v_1 = \frac{V_1}{m_1} = \frac{V_1}{\rho_1 \times V_1} = \frac{1}{\rho_1} = \frac{1}{85} = 0.011764\ \ \text{m}^3/\text{kg}$$

4

Since $v_f < v_1 < v_g$, the R – 134a is a saturated liquid– vapor mixture

$$x_1 = \frac{v_1 - v_f}{v_g - v_f} = \frac{0.011764 - 0.0008996}{0.015939 - 0.0008996} = 0.7224$$

$$u_{f@48°\text{C}} = 119.26\ \text{kJ/kg}$$

$$u_{fg@48°\text{C}} = 135.29\ \text{kJ/kg}$$

$$u_1 = u_f + (x_1 \times u_{fg}) = 119.26 + (0.7224 \times 135.29) = 216.99\ \text{kJ/kg}$$

1

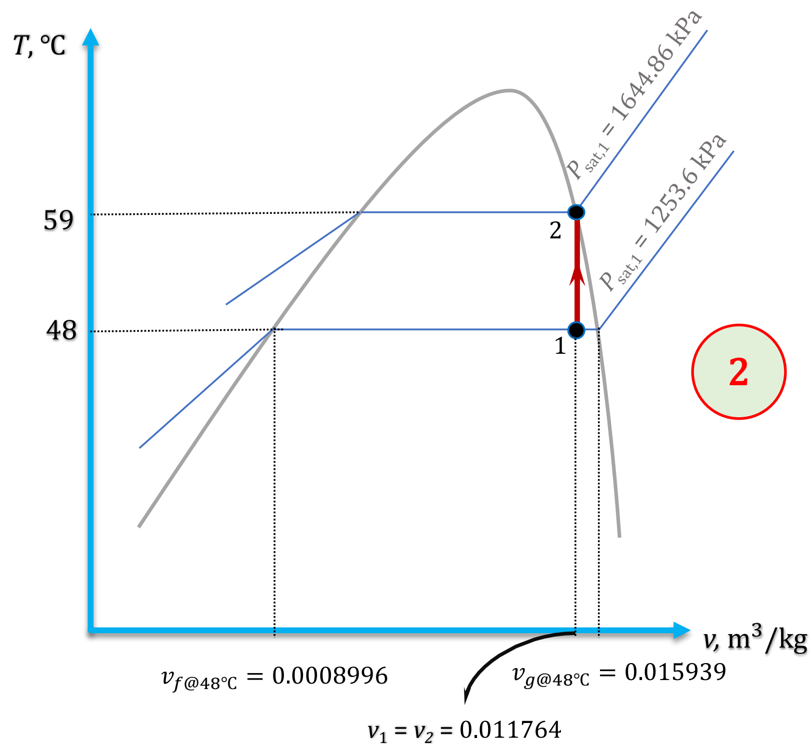
State 2:

Saturated vapor, therefore,

$$v_2 = v_1 = v_{g,2} = 0.011764\ \text{m}^3/\text{kg}$$

$v_{g,2}$ (m^3/kg)	$u_2 = u_{g,2}$ (kJ/kg)	T_2 (°C)	~~P_2 (kPa)~~
0.012771	257.77	56	~~1529.1~~
0.011764	258.86	59.01	~~1644.86~~
0.011434	259.22	60	~~1682.8~~

2



2

By performing an energy balance on the system:

$$\sum_{in} Q_{in} + \cancel{W_{in}} - \sum_{out} \cancel{Q_{out}} + \cancel{W_{out}} = \Delta U = \text{m}(u_2 - u_1)$$

3

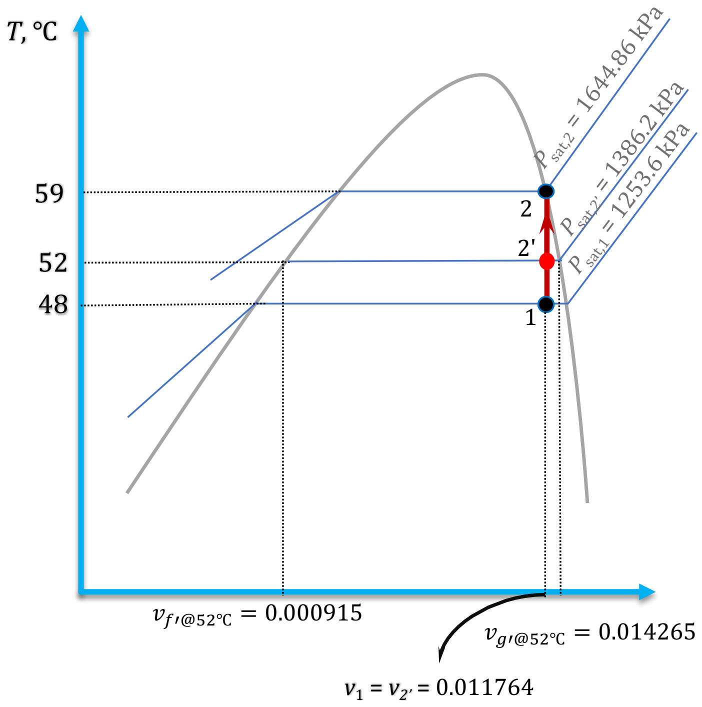
$$m = m_1 = m_2 = \rho_1 \times V_1 = 85 \times 20 \times 10^{-3} = 1.7\ \text{kg}$$

$$Q_{in} = \text{m}(u_2 - u_1) = 1.7 \times (258.86 - 216.99) = \mathbf{71.18\ kJ}$$

TOTAL
14

Solution for Q1(b):

For safety reasons, the temperature of the recovered refrigerant inside the recovery cylinder must not exceed 52°C. To satisfy this requirement, based on Part (a) answer, the amount of heat (kJ) that needs to be rejected from the refrigerant is to be determined.



By performing an energy balance on the system:

$$\sum_{in} \cancel{Q_{in}} + \cancel{W_{in}} - \sum_{out} Q_{out} + \cancel{W_{out}} = \Delta U = \mathrm{m}(u_{2'} - u_2)$$

$$Q_{out} = \mathrm{m}(u_2 - u_{2'})$$

State 2' is in a saturated-vapor mixture, thus

$$u_{2'} = u_{f,2'} + (x_{2'} \times u_{fg,2'})$$

$$x_{2'} = \frac{v_{2'} - v_{f,2'}}{v_{g'} - v_{f,2'}}$$

Where, $v_{2'} = v_1 = 0.011764\ \mathrm{m^3/kg}$

$$x_{2'} = \frac{0.011764 - 0.000915}{0.014265 - 0.000915} = 0.8127$$

$$u_{f,2'@52°C} = 125.33\ \mathrm{kJ/kg}$$

$$u_{fg,2'@52°C} = 130.88\ \mathrm{kJ/kg}$$

$$u_{2'} = u_{f,2'} + (x_{2'} \times u_{fg,2'}) = 125.33 + (0.8127 \times 130.88) = 231.70\ \mathrm{kJ/kg}$$

Therefore,

$$Q_{out} = \mathrm{m}(u_2 - u_{2'}) = 1.7 \times (258.86 - 231.70) = \mathbf{46.17\ kJ}$$

TOTAL
6

MARKING SCHEME Q2 TEST 2 SKMM 2413 2018/2019-1

i) $$A_1 = \frac{\pi D^2}{4} = \frac{\pi 0.4^2}{4} = 0.1257 \text{ m}^2$$ **2**

$$\upsilon_1 = \frac{RT_1}{P_1} = \frac{0.287(303)}{101} = 0.861 \text{ m}^3 / kg$$ **2**

$$\dot{m} = \frac{A_1 V_1}{\upsilon_1} = \frac{0.1257(120)}{0.8610} = 17.52 \text{ kg/s}$$ **2**

ii) $$\upsilon_2 = \frac{RT_2}{P_2} = \frac{0.287(573)}{6000} = 0.0274 \text{ m}^3 / kg$$ **2**

$$A_2 = \frac{\pi D_2^2}{4} = \frac{\dot{m}\upsilon_2}{V_2} = \frac{17.52(0.0274)}{50} = 0.0096 \text{ m}^2$$ **2**

$$D_2 = \sqrt{\frac{0.0096(4)}{\pi}} = 0.1106 \text{ m} = 110.56 \text{ mm}$$ **2**

iii)
$$\dot{V}_1 = \dot{m}\upsilon_1 = 17.52(0.8610) = 15.08 \text{ m}^3 / s = 905 \text{ m}^3 / \text{min}$$
$$\text{or} \quad \dot{V}_1 = AV = \frac{\pi(0.2)^2}{4}(120) = 15.08 \text{ m}^3 / s = 905 \text{ m}^3 / \text{min}$$ **3**

iv)
$$\dot{E}_{in} = \dot{E}_{out}$$
$$\dot{W}_{in} + \dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{Q}_{out} + \dot{m}\left(h_2 + \frac{V_2^2}{2}\right)$$
$$\dot{W}_{in} = \dot{m}\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right)\right] + \dot{Q}_{out} = \dot{m}\left[c_p(T_2 - T_1) + \left(\frac{V_2^2 - V_1^2}{2}\right)\right] + \dot{Q}_{out}$$ **2**

$$= 17.52\left[1.005(300 - 30) + \left(\frac{50^2 - 120^2}{2000}\right)\right]$$
$$= 4674.8 \text{ kW}$$ **3**

Solution manual

Test2, SKMM2413 2019-2020/1

Q3. (a)

The factors that cause a process to be irreversible are friction, unrestrained expansion, mixing of two fluids, heat transfer across a finite temperature difference, electric resistance, inelastic deformation of solids, and chemical reactions (any two).

4

b)

Here given,

$Qdot_H$= 650 kJ/min

$Qdot_L$= 250 kJ/min

TL= 24+273 K = 297 K

$$\eta_{th} = 1 - \frac{\dot{Q}L}{\dot{Q}H} = 1 - \frac{250}{650} = 0.615 \approx 61.5\%$$

2

The highest thermal efficiency for a cyclical engine operating between two specified temperatures can have is the Carnot efficiency, which is determined from:

$$\eta_{Carnot} = 1 - \frac{TL}{TH} = 1 - \frac{250}{650}$$

$$0.615 = 1 - \frac{297}{TH}$$

TH= 771 K 2

c)

i)

$$\eta_{th} = 1 - \frac{\dot{Q}L}{\dot{Q}H} = 1 - \frac{560}{800} = 0.30 \approx 30\%$$

2

ii)

$$\eta_{th,max} = \eta_{th,rev} = 1 - \frac{TL}{TH} = 1 - \frac{27+273}{900+273} = 0.744 \approx 74.4\%$$

2

iii)

$$COP_{R,max} = COP_{R,revCarnot} = \frac{TL}{TH-TL} = \frac{-5+273}{27+5} = 8.375$$

2

iv)

Wnet,out= Wnet,in= 800-560 kJ/min = 240 kJ/min

$$COP_R = \frac{QL}{Wnet, in}$$

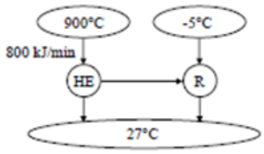
$$COP_{R,revCarnot} = \frac{QL, max}{Wnet, in}$$

$Q_{L,max}$= $COP_{R,revCarnot}$ x $W_{net,in}$

$Q_{L,max}$= 8.375 x 240 kJ/min = 2010 kJ/min = 33.5 kJ/s 2

v)

QH= Wnet,in+QL= 240+2010 kJ/min = 2250 kJ/min= 37.5 kJ/s 2



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