SEKOLAH KEJURUTERAAN MEKANIKAL
UNIVERSITI TEKNOLOGI MALAYSIA

SKMM 2413 THERMODYNAMICS
TEST 2

QUESTION 1

a) An ideal gas undertaken an expansion process according PV = constant law. Prove that the boundary work, W_{12}, for such process is given by

$$W_{12} = P_1 V_1 \ln \frac{V_2}{V_1}$$

where P = pressure (kPa) and V = volume (m^3)

b) Air initially at 800 kPa, 600 K and 0.25 m^3 contain in a piston-cylinder assembly undergoes a thermodynamics cycle as follows

1 – 2 : expansion process according to polytropic law, PV^n = constant, (where n = 1) until the volume increased to 0.5 m^3;
2 – 3 : isobaric compression until initial volume is achieved; and
3 – 1 : isochoric(isometric) process to initial pressure.

i) Determine the pressure (kPa), temperature (K) and volume (m^3) for state 2 and 3.
ii) Sketch the cycle on a $P - V$ diagram and label all the pressure, temperature and volume.
iii) Calculate the boundary work (kJ) for each process.
iv) Evaluate the heat transfer (kJ) involved for each process.
v) Determine the change of internal energy (kJ) for each process.
vi) Show that the change of internal energy (kJ) for the entire cycle is positive, negative or zero.

Table Q1: Properties of air

Property	**R (kJ/kg.K)**	**c_p (kJ/kg.K)**	**c_v (kJ/kg.K)**	**k**
Value	0.2870	1.005	0.718	1.4000

(20 marks)

QUESTION 2

a) Steam flows steadily into a well-insulated turbine with a mass flow rate of 6 kg/s and a negligible velocity at 600 kPa and 550°C. The steam leaves the turbine through a 1.12 m diameter opening at 10 kPa with a velocity of 18 m/s. If the changes of kinetic and potential energies were neglected, determine the power output produced (*MW*).

(*16 marks*)

b) If the turbine was not insulated, what would be the effect on the power output? Discuss briefly.

(*4 marks*)

QUESTION 3

a) i) State the four processes that make up the Carnot cycle?

ii) *'It might be possible to develop an updated heat-engine that could be more efficient than a Carnot heat engine operating between the same temperature limits.*'

Is the statement true or false? Why?

(4 marks)

b) An inventor claims to have developed a refrigeration system that removes heat from the closed region at -12°C and transfers it to the surrounding air at 25°C while maintaining a COP of 7.0. Is this claim reasonable or not? Justify your answer with calculation.

(6 marks)

c) A steam power plant receives heat from a furnace at a rate of 280 GJ/h. Heat losses to the surrounding air from the steam as it passes through the pipes and other components are estimated to be about 8 GJ/h. If the waste heat is transferred to the cooling water at a rate of 145 GJ/h, determine

(i) the net power output (MW), and

(ii) the thermal efficiency of this power plant (%).

(12 marks)

ATTACHMENT

TABLE A–5

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
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
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356	6.8561
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603	6.8207
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916	6.7886
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285	6.7593
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322

TABLE A–6

Superheated water

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 (151.83°C)				P = 0.60 MPa (158.83°C)				P = 0.80 MPa (170.41°C)			
Sat.	0.37483	2560.7	2748.1	6.8207	0.31560	2566.8	2756.2	6.7593	0.24035	2576.0	2768.3	6.6616
200	0.42503	2643.3	2855.8	7.0610	0.35212	2639.4	2850.6	6.9683	0.26088	2631.1	2839.8	6.8177
250	0.47443	2723.8	2961.0	7.2725	0.39390	2721.2	2957.6	7.1833	0.29321	2715.9	2950.4	7.0402
300	0.52261	2803.3	3064.6	7.4614	0.43442	2801.4	3062.0	7.3740	0.32416	2797.5	3056.9	7.2345
350	0.57015	2883.0	3168.1	7.6346	0.47428	2881.6	3166.1	7.5481	0.35442	2878.6	3162.2	7.4107
400	0.61731	2963.7	3272.4	7.7956	0.51374	2962.5	3270.8	7.7097	0.38429	2960.2	3267.7	7.5735
500	0.71095	3129.0	3484.5	8.0893	0.59200	3128.2	3483.4	8.0041	0.44332	3126.6	3481.3	7.8692
600	0.80409	3300.4	3702.5	8.3544	0.66976	3299.8	3701.7	8.2695	0.50186	3298.7	3700.1	8.1354
700	0.89696	3478.6	3927.0	8.5978	0.74725	3478.1	3926.4	8.5132	0.56011	3477.2	3925.3	8.3794
800	0.98966	3663.6	4158.4	8.8240	0.82457	3663.2	4157.9	8.7395	0.61820	3662.5	4157.0	8.6061
900	1.08227	3855.4	4396.6	9.0362	0.90179	3855.1	4396.2	8.9518	0.67619	3854.5	4395.5	8.8185
1000	1.17480	4054.0	4641.4	9.2364	0.97893	4053.8	4641.1	9.1521	0.73411	4053.3	4640.5	9.0189
1100	1.26728	4259.0	4892.6	9.4263	1.05603	4258.8	4892.4	9.3420	0.79197	4258.3	4891.9	9.2090
1200	1.35972	4470.0	5149.8	9.6071	1.13309	4469.8	5149.6	9.5229	0.84980	4469.4	5149.3	9.3898
1300	1.45214	4686.6	5412.6	9.7797	1.21012	4686.4	5412.5	9.6955	0.90761	4686.1	5412.2	9.5625

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No. Kad Pengenalan/No. ISID: ....
I.C. No./ISID No.

No. Soalan .... Q1 $(a)+(b) = \frac{4}{4} + \frac{16}{16} = \frac{20}{20}$
Question No.

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Page

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a) $PV = C, \quad P = C/V$

$W_{12} = \int_1^2 p\,dV = C\int_1^2 \frac{dV}{V}$ — 2

$= C\left[\ln V\right]_1^2 = P_1V_1(\ln V_2 - \ln V_1)$ — 2

$= P_1V_1 \ln V_2/V_1$ *

$\boxed{4}$

b) $P_1 = 800\,kPa$ ~~expansion~~ $V_2 = 0.5\,m^3$

$T_1 = 600\,K \xrightarrow{\quad} T_2 = T_1$

$V_1 = 0.25\,m^3 \quad PV=C,\ T=C$

~~Heating~~ $V=C$ — compression $P=C$

$V_3 = V_1$

$P_3 = P_2$

$P_2 = 400\,kPa$
$T_2 = 600\,kPa$
$V_2 = 0.5\,m^3$
$P_3 = 400\,kPa$
$T_3 = 300\,K$
$V_3 = 0.25\,m^3$

i) $P_2 = \frac{P_1V_1}{V_2} = \frac{800 \times 0.25}{0.5}$

$\rightarrow P_2 = 400\,kPa$ — ½

$\rightarrow T_2 = T_1 = 600\,K$ — ½

$\rightarrow V_2 = 0.5\,m^3$ — ½

$P_3 = P_2 = 400\,kPa$ — ½

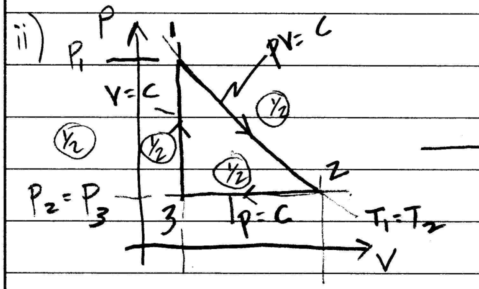
$\frac{\cancel{P_3}V_3}{T_3} = \frac{\cancel{P_2}V_2}{T_2}, \quad T_3 = T_2\frac{V_3}{V_2}$

$T_3 = 600 \times \frac{0.25}{0.5} = 300\,K$ — ½

$V_3 = V_1 = 0.25\,m^3$ — ½

$\boxed{3}$

ii)



— $\boxed{2}$

iii) $W_{12} = P_1V_1 \ln V_2/V_1$ — ½

$= 800 \times 0.25 \ln \frac{0.5}{0.25}$

$= 138.63\,kJ$ — ½

$W_{23} = P_2(V_3 - V_2)$ — ½

$= 400(0.25 - 0.5)$

$= -100.00\,kJ$ — ½

$W_{31} = 0$ — 1

$\boxed{3}$

iv) $Q_{12} = mC_v(\cancel{T_2 - T_1})^{0} + W_{12}$ — ½

$Q_{12} = W_{12} = 138.63\,kJ$ — ½

$Q_{23} = mC_v(T_3 - T_2) + W_{23}$ — ½

$m = \frac{P_1V_1}{RT_1} = \frac{800 \times 0.25}{0.287 \times 600} = 1.1614\,kg$ — 1

$Q_{23} = 1.1614 \times 0.718(300 - 600) + (-100.00)$

$= -350.17\,kJ$ — ½

~~OR $Q_{23} = mC_p(T_3 - T_2)$~~

~~$Q_{23} = 1.1614 \times 1.005(300 - 600) = -350.16\,kJ$~~

$Q_{31} = mC_v(T_1 - T_3) + \cancel{W_{31}}^{0}$ — ½

$= 1.1614 \times 0.718(600 - 300)$

$= 250.17\,kJ$ — ½

$\boxed{4}$

v) $\Delta U_{12} = mC_v(\cancel{T_2 - T_1})^{0} = 0$ — 1

$\Delta U_{23} = Q_{23} - W_{23}$ — ½

$= -350.17 - (-100.00)$

$= -250.17\,kJ$ — ½

$\Delta U_{31} = Q_{31} - \cancel{W_{31}}^{0}$ — ½

$= 250.17\,kJ.$ — ½

$\boxed{3}$

vi) $\Sigma\Delta U = \Delta U_{12} + \Delta U_{23} + \Delta U_{31}$

$= 0 + (-250.17) + 250.17$

$= 0$ — $\boxed{1}$

OR $\Sigma Q = Q_{12} + Q_{23} + Q_{31}$

$= 138.63 + (-350.17) + 250.17$

$= 38.63\,kJ$

$\Sigma W = W_{12} + W_{23} + W_{31}$

$= 138.63 + (-100.00) + 0$

$= 38.63\,kJ \rightarrow \Sigma Q = \Sigma W$

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I.C. No./ISID No.

No. Soalan Q2
Question No.

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Page

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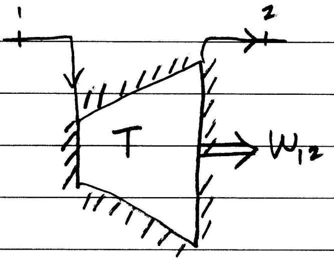
a)



$\dot{m} = 6 kg/s$ $d_2 = 1.12 m$

$P_1 = 600 kPa$ $P_2 = 10 kPa$

$T_1 = 550°C$ $\bar{V}_2 = 18 m/s$

$\Delta KE = 0$ $\Delta PE = 0$

$\dot{W}_{12} = \dot{m} \dot{W}_{12}$

$h_1 = h_2 + w_{12}$

$w_{12} = h_1 - h_2$ 2

State 1 : At 600kPa, $T_{sat} = 158.83°C$

$T_1 > T_{sat}$. ∴ s.h.v. —— 1

At 0.6 MPa

h	T
3483.4	500
h_1	550
3701.7	600

—— 2

$$\frac{h_1 - 3483.4}{3701.7 - 3483.4} = \frac{50}{100}$$

$h_1 = 3592.6$ kJ/kg

State 2 : $P_2 = 10kPa$

$\dot{m} = \frac{A_2 \bar{V}_2}{v_2}$, $v_2 = \frac{A_2 \bar{V}_2}{\dot{m}}$

$A_2 = \frac{\pi d_2^2}{4} = \frac{\pi \times 1.12^2}{4}$

$= 0.9852 m^3$ —— 1

$v_2 = \frac{0.9852 \times 18}{6}$

$= 2.9556 m^3/kg$ —— 3

At 10kPa, $v_{f_1} < v_2 < v_{g_2}$

∴ sat. mixt. —— 2

$h_2 = h_{f_2} + x_2 h_{fg_2}$

$x_2 = \frac{v_2 - v_{f_2}}{v_{g_2} - v_{f_2}}$

$= \frac{2.9556 - 0.001010}{14.670 - 0.001010}$

$= 0.2014$ —— 2

$h_2 = 191.81 + 0.2014 (2392.1)$

$= 673.6$ kJ/kg —— 2

$w_{12} = 3592.6 - 673.6$

$= 2919.0$ kJ/kg

$\dot{w}_{12} = 6 \times 2919.0$

$= 17514$ kW

@ 17.5 MW —— 1

b) $\dot{W}_{12}$ will decreased !

$\dot{W}_{12}' = (h_1 - h_2) - Q_{loss}$

$\dot{W}_{12}' < \dot{W}_{12}$ —— 4

(a) + (b)

$\frac{16}{16} + \frac{4}{4} = \frac{20}{20}$

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I.C. No./ISID No.

No. Soalan...................... Q3
Question No.

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Page

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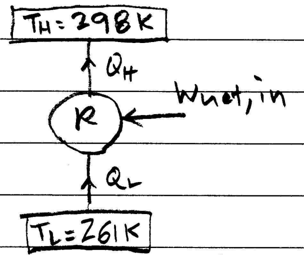
a) i) 1-2 : Reversible isothermal exp.
2-3 : Reversible adiabatic exp.
3-4 : Reversible isothermal comp.
4-1 : Reversible adiabatic comp. 3/

ii) False ! $\eta_{th_{rev}} > \eta_{th_{others}}$. — 1

b)



$COP_R = 7.0$

$$COP_{R_{rev}} = \frac{1}{\frac{Q_H}{Q_L} - 1} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$= \frac{1}{\frac{298}{261} - 1} = 7.05$$

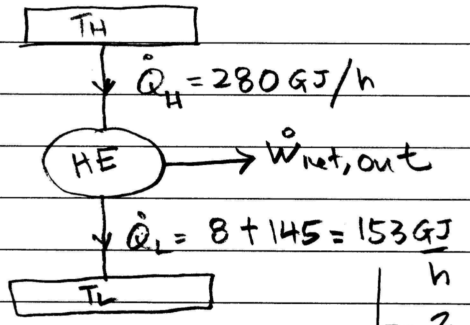
5

$COP_R < COP_{R_{rev}}$

∴ a irreversible cycle!
The claim is reasonable.

1

c)



2

i) $\dot{W}_{net,out} = \dot{Q}_H - \dot{Q}_L$

$= 280 - 153$

$= 127 \left(\frac{GJ}{h} \times \frac{h}{3600s} \right)$

$= 0.03528 \left(\cancel{G}W \times \frac{10^3 M}{\cancel{G}} \right)$

$= 35.28MW$ — 4

ii) $$\eta_{th} = \frac{\dot{W}_{net,out}}{\dot{Q}_H}$$

$$= \frac{35.28 \times 10^3}{\left(\frac{280 \times 10^6}{3600} \right)} \times 100$$

$= 45.36\%$ ⟶ 4

(a) + (b)

$\frac{4}{4} + \frac{16}{16} = \frac{20}{20}$