Semester I, 2017-2018

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SKMM 2413 THERMODYNAMICS
TEST 2

QUESTION 1

A frictionless piston-cylinder assembly initially contains 750 cm^3 of air at 100 kPa and 27°C. The air is then compress according to PV = constant until the volume was reduced to 5% from the initial volume. The following process was isochoric heating where heat is transferred to the air. Finally, the air is expanding in reversible adiabatic manner (PV^k = constant) to the initial state. Assume air as an ideal gas.

a) Sketch the processes on a *P-V* diagram.
b) Determine the pressure, *kPa*, volume, *cm³* and temperature, *K*, at the end of the compression process.
c) Calculate the pressure, *kPa*, volume, *cm³* and temperature, *K*, at the beginning of the expansion process.
d) Find the boundary work for each process, *kJ*.
e) Calculate the heat involve for each process, *kJ*.
f) Will the cycle produce net work output or input? Briefly explain.

Type of Gas	R kJ/kg.K	C_v kJ/kg.K	C_p kJ/kg.K	k
Air	0.287	0.718	1.005	1.400

(*20 marks*)

QUESTION 2

A steady flow system consists of one inlet and two outlets. This system produces an amount of power. Steam at 3000 kPa, 300 $^\circ$C enters the system with a volume flow rate of 2.5 m^3/s. 30 % of the steam (by mass) exits through first outlet at 1000 kPa and 200 $^\circ$C and the rest exits through the second outlet at 100 kPa and dryness fraction of 0.9. It is estimated that 200 kW of heat is lost from the system to the surrounding air. Sketch the system clearly and by neglecting the changes of kinetic and potential energy, determine

a) the total power, *kW*, and
b) the diameter, *mm*, of the first and second outlets if their velocity are 100 m/s and 300 m/s respectively.

(*20 marks*)

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QUESTION 3

a) *Figure Q3a* shows three heat engines operating between the same high-temperature reservoir at a constant temperature of 1000 K and low-temperature reservoir at a constant temperature of 300 K. Write clearly three (3) statements that can be deduced from this figure, with regards to the *thermal efficiency* of the engines.

(*6 marks*)

b) Between "work" and "heat", which one is a more valuable form of energy? Explain briefly.

(*4 marks*)

c) Cold water at a temperature of 10°C flows into a well-insulated water heater with a volume flow rate of 0.02 m^3/min and leaves the water heater at a temperature of 50°C, as shown in *Figure Q3b*. The water heater is working at a constant pressure of 100 kPa. A heat pump absorbs heat from the surrounding, which is at a temperature of 0°C and supply the heat to the water heater. Assume the water to be a compressed liquid that does not change phase during the heat addition.

i) Determine the rate of heat supplied to the water heater, *kW*.

ii) If the water heater acts as a high-temperature reservoir at a constant temperature of 30°C, determine the *minimum* power that needs to be supplied to the heat pump, *kW*.

iii) Calculate the rate of heat absorbed from the surrounding, *kW*.

(*10 marks*)

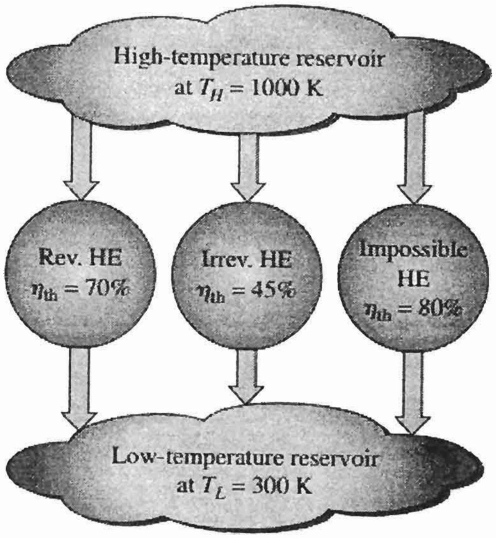


Figure Q3a

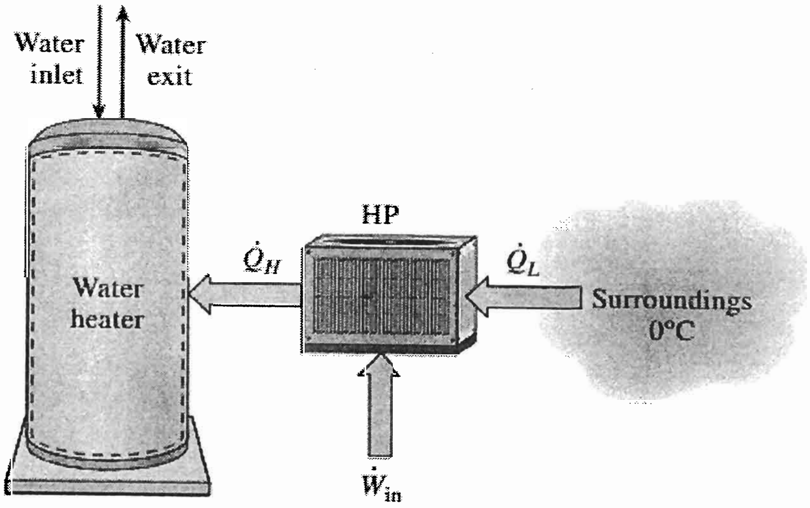


Figure Q3b

Q1/ $V_1 = 750 cm^3$, $P_1 = 100 kPa$, $T_1 = 300 K$

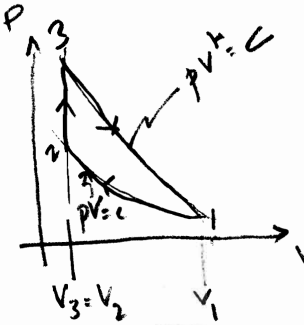
1-2 : Compression process, $PV = C$

$V_2 = 0.05 V_1$, $P_1V_1 = P_2V_2$ @ $T_1 = T_2$

2-3 : Heating process, $V = C$, $V_2 = V_3$

3-1 : Expansion process, $PV^k = C$

a)



———— 3

b) 2: $V_2 = 0.05V_1 = 0.05 \times 750 = 37.5 cm^3$ ← 1/2

$T_2 = T_1 = 300 K$ ———— 1/2

$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1}$; $P_2 = P_1 \frac{V_1}{V_2}$ ———— 1/2

$P_2 = 100\left(\frac{1}{0.05}\right) = 2000 kPa$ ———— 1/2

c) 3: $V_3 = V_2 = 37.5 cm^3$

3-1 : $P_3V_3^k = P_1V_1^k$, $P_3 = P_1\left(\frac{V_1}{V_2}\right)^k$ ———— 1/2

$P_3 = 100\left(\frac{750}{37.5}\right)^{1.4} = 6628.9 kPa$ ———— 1/2

$T_3 = T_1 \left(\frac{V_1}{V_3}\right)^{k-1}$ ———— 1/2

$= 300\left(\frac{750}{37.5}\right)^{0.4} = 994.3 K$ ———— 1/2

d) $W_{12} = P_1V_1 \ln \frac{V_2}{V_1}$ ———— 1

$= 100 \times 750 \times 10^{-6} \ln \frac{37.5}{750}$

$= -0.2248 kJ$ ———— 1

$W_{23} = 0$ ———— 1

$W_{31} = \frac{P_1V_1 - P_3V_3}{1-k}$ ———— 1

$W_{31} = \frac{100 \times 750 \times 10^{-6} - 6628.9 \times 37.5 \times 10^{-6}}{1-1.4}$

$= 0.4340 kJ$ ———— 1

e) $Q_{12} = m C_v (\cancel{T_2 - T_1})^{0} + W_{12}$ ———— 1

$= -0.2248 kJ$ ———— 1

$Q_{23} = m C_v (T_3 - T_2) + \cancel{W_{23}}^{0}$ ———— 1

$m = \frac{P_1V_1}{RT_1} = \frac{100 \times 750 \times 10^{-6}}{0.287 \times 300}$

$m = 8.7108 \times 10^{-4} kg$ ———— 1

$Q_{23} = 8.7108 \times 10^{-4} \times 0.718 (994.3 - 300)$

$= 0.4342 kJ$ ———— 1

$Q_{31} = 0$ ———— 1

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

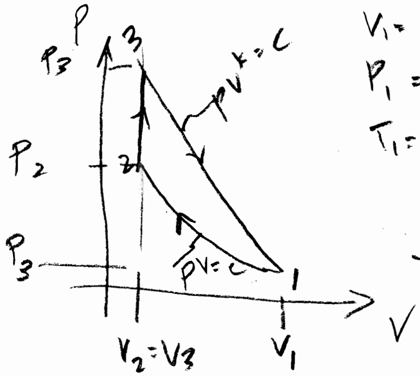
$= -0.2248 + 0 + 0.4340$

$= 0.2092 kJ$. ———— 1

The value of $\Sigma W = W_{net}$ is positive. Therefore the cycle is producing work output. ———— 1

Q1/

a)



$V_1 = 750 cm^3$

$P_1 = 100 kPa$

$T_1 = 300 K$

— 3

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b) $V_2 = V_1 - 0.05V_1 = 0.95V_1$

$= 0.95 \times 750 = 712.5 cm^3$ — ½

$T_2 = T_1 = 300 K$ — ½

$P_2 = P_1 \frac{V_1}{V_2}$ — ½

$= 100 \times \frac{750}{712.5} = 105.3 kPa$ — ½

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c) $V_3 = V_2 = 712.5 cm^3$

$P_3 = P_1 \left(\frac{V_1}{V_3}\right)^k$ — ½

$= 100 \left(\frac{750}{712.5}\right)^{1.4} = 107.4 kPa$ — ½

$T_3 = T_1 \left(\frac{V_1}{V_3}\right)^{k-1}$ — ½

$= 300 \left(\frac{750}{712.5}\right)^{0.4} = 306.2 K$ — ½

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d) $W_{12} = P_1 V_1 \ln \frac{V_2}{V_1}$ — 1

$= 100 \times 750 \times 10^{-6} \ln \frac{712.5}{750}$

$= -3.846997 \times 10^{-3} kJ$. — 1

$W_{23} = 0$ — 1

$W_{31} = \frac{P_1 V_1 - P_3 V_3}{1-k}$ — 1

$= \frac{100 \times 750 \times 10^{-6} - 107.4 \times 712.5 \times 10^{-6}}{1 - 1.4}$

$= 3.806250 \times 10^{-3} kJ$ — 1

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e) $Q_{12} = m C_v (\cancel{T_2 - T_1})^{0} + W_{12}$ — 1

$= -3.85 \times 10^{-3} kJ$. — 1

$Q_{23} = m C_v (T_3 - T_2) + \cancel{W_{23}}$ — 1

$m = \frac{P_1 V_1}{R T_1}$

$= \frac{100 \times 750 \times 10^{-6}}{0.287 \times 300} = 8.7108 \times 10^{-4} kg$ — 1

$Q_{23} = 8.7108 \times 10^{-4} (306.2 - 300)$

$= 5.40 \times 10^{-3} kJ$. — 1

$Q_{31} = 0$. — 1

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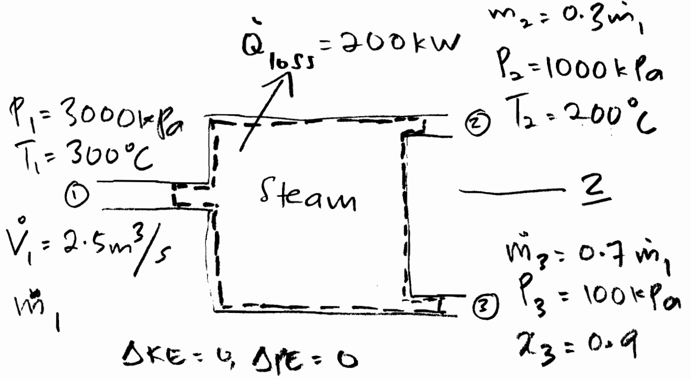
f) $\Sigma W = W_{12} + W_{23} + W_{31}$

$= -3.8470 + 0 + 3.8063$

$= -0.0407 kJ$. — 1

The value of $\Sigma W = W_{net}$ is negative. Therefore the cycle is requiring work input. — 1

Q2/



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

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a) $\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3 + \dot{Q}_{loss} + \dot{W}_{out}$ —— 1

$\dot{W}_{out} = \dot{m}_1 h_1 - 0.3\dot{m}_1 h_2 - 0.7\dot{m}_1 h_3 - \dot{Q}_{loss}$

$= \dot{m}_1 (h_1 - 0.3h_2 - 0.7h_3) - \dot{Q}_{loss}$ —— 1

State 1 : $T_1 > T_{sat}$ @ 3000 kPa ∴ s.h.v.

$h_1 = 2994.3$ kJ/kg —— 1

State 2 : $T_2 > T_{sat}$ @ 1000 kPa ∴ s.h.v.

$h_2 = 2828.3$ kJ/kg —— 1

state 3: $0 < x_3 < 1$ ∴ sat. mixture

$h_3 = h_{f_3} + x_3 h_{fg}$

$= 417.51 + 0.9(2257.5)$

$= 2449.3$ kJ/kg —— 1

$\dot{m}_1 = \frac{\dot{V}_1}{v_1}$

$v_1 = 0.08118 \ m^3/kg$ —— 1

$\dot{m}_1 = \frac{2.5}{0.08118} = 30.7958$ kg/s —— 1

$\dot{W}_{out} = 30.7958 [2994.3 - (0.3 \times 2828.3) - (0.7 \times 2449.3)] - 200$

$= \underline{\underline{13082.2 \text{ kW}}}$ —— 3

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b) $A_2 = \frac{\dot{m}_2 v_2}{V} = \frac{0.3\dot{m}_1 v_2}{V_2}$

$v_2 = 0.20602 \ m^3/kg$ —— 1

$A_2 = \frac{0.3 \times 30.7958 \times 0.20602}{100}$

$d_2 = \left(\frac{4A_2}{\pi}\right)^{1/2} = \left(\frac{4 \times 0.0190337}{\pi}\right)^{1/2} \times 10^3$

$= \underline{155.67 \text{ mm}}$ —— 2

$A_3 = \frac{\dot{m}_3 v_3}{V_3} = \frac{0.7\dot{m}_1 v_3}{V_3}$

$v_3 = v_{f_3} + x_3 (v_{g_3} - v_{f_3})$

$= 0.001043 + 0.9(1.6941 - 0.001043)$

$= 1.524794 \ m^3/kg$ —— 1

$A_3 = \frac{0.7 \times 30.7958 \times 1.524794}{300}$

$= 0.1095669 \ m^2$

$d_3 = \left(\frac{4A_3}{\pi}\right)^{1/2}$

$= \left(\frac{4 \times 0.1095669}{\pi}\right)^{1/2} \times 10^3$

$= \underline{\underline{373.50 \text{ mm}}}$ —— 2

$\dot{m}_2 = 0.3\dot{m}_1 = 0.3 \times 30.7958$

$= 9.2387$ kg/s —— 1

$\dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 30.7958 - 9.2387$

$= 21.5571$ kg/s —— 1

SKMM 2413 - TEST 2 – Q3 - ANSWERS

QUESTION 1

a) The following statements can be deduced from the figure:

- Thermal efficiency of a *reversible heat engine* operating between the two reservoirs is theoretically the highest possible thermal efficiency that can be attained. ②
- The thermal efficiency of *actual* or *irreversible heat engine* working between the same constant temperature reservoirs will always be lower than that of the reversible one. ②
- It is impossible to construct a heat engine that operates between the same constant temperature reservoirs and has a thermal efficiency greater than that of the reversible one. ②

b) Work is a more valuable form of energy than heat since 100 percent of work can be converted to heat, but only a fraction of heat can be converted to work. When heat is transferred from a high-temperature body to a lower temperature one, it is degraded since less of it now can be converted to work. ④

c) i) Heat supplied to the water heater

Energy balance on the water heater gives,

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_H = \dot{Q}_{water} = \dot{m}_w c_p (T_e - T_i) = \rho \dot{V} (h_e - h_i)$$

$$\dot{Q}_H = 1000 \times \frac{0.02}{60} \times (209.34 - 42.02)$$

$$\dot{Q}_H = 55.77 \text{ kW}$$ ④

ii) The COP of a *reversible* heat pump working between the specified temperature limit is given by

$$COP_{\max} = \frac{1}{1-\left(T_L / T_H\right)} = \frac{1}{1-((0+273)/(30+273))}$$

$$COP_{\max} = 10.1$$ ②

Therefore, the *minimum* power input to the heat pump is

$$\dot{W}_{in,\min} = \frac{\dot{Q}_H}{COP_{\max}} = \frac{55.73}{10.1}$$

$$\dot{W}_{in,\min} = 5.52 \text{ kW}$$ ②

iii) The rate of heat absorbed from the surrounding is

$$\dot{Q}_L = \dot{Q}_H - \dot{W}_{in,\min} = 55.73 - 5.52 = 50.21 \text{ kW}$$ ②