

**FACULTY OF MECHANICAL ENGINEERING  
UNIVERSITI TEKNOLOGI MALAYSIA**

Test 2

SKMM 2413 (Thermodynamics)

Sem 2014/15-01

**Answer all questions**

2 hours

**Question 1**

- (a) Starting from the definition of enthalpy, prove that the enthalpy of an ideal gas is a function of temperature only as follows:

$$h=h(T)$$

where  $h$  is enthalpy and  $T$  is temperature.

(4 marks)

- (b) An ideal gas initially at 900°C and 650 kPa with a volume of 0.500 m<sup>3</sup> is contained in a piston-cylinder device with stops, as shown in Fig. 1 below. The ideal gas undergoes an isothermal expansion process until the piston reaches the stops, and the pressure drops to 250 kPa. Then, the piston is not allowed to move until the temperature of the ideal gas drops to 27°C. For the ideal gas,  $R = 0.287$  kJ/kg.K and  $c_v = 0.776$  kJ/kg.K. The changes in kinetic energy and potential energy are negligible. Sketch the processes on a **Pressure versus Volume ( $P$ - $V$ ) diagram** and determine

- (i) the mass of the ideal gas (kg).
- (ii) the volume occupied by the ideal gas at the final state (m<sup>3</sup>).
- (iii) the total change in internal energy of the ideal gas for the combined processes (kJ).
- (iv) the total boundary work done for the combined processes (kJ).
- (v) the net amount of heat transferred for the combined processes (kJ).

(16 marks)

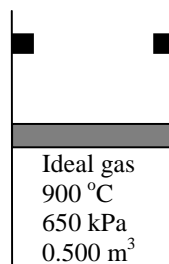


Figure 1

## Question 2

- (a) Steam enters the shell side of the condenser of a steam power plant at 10 kPa and a quality of 95 percent with a mass flow rate of 20,000 kg/h. Cooling water at a constant pressure of 200 kPa enters the tubes side of the condenser at 25°C with a mass flow rate of 295 kg/s and leaves at 35°C. The condenser is not well insulated resulting in some heat losses to the surroundings. If the steam is to leave the condenser as saturated liquid at 10 kPa, determine,
- the rate of heat transfer to the cooling water, kJ/s;
  - the rate of heat loss to the surroundings, kJ/s.
- (16 marks)
- (b) If the steam pressure in the condenser is raised higher than 10 kPa, briefly describe how this alteration will affect the rate of heat loss to the surroundings.
- (4 marks)

## Question 3

- (a) Hot combustion gases enter a turbine operating at steady state and expand adiabatically to a lower temperature. Would you expect the power output to be greater in a reversible expansion or an actual expansion? Please explain your answer briefly.
- (2 marks)
- (b) Refrigerant R134a enters a compressor operating at steady state and is compressed adiabatically to a higher pressure. Would you expect the power input to the compressor to be greater in a reversible compression or an actual compression? Please explain your answer briefly.
- (2 marks)
- (c) A combined cycle power plant consists of a gas power plant and a steam power plant. The gas power plant receives 200 MW of heat from a hot thermal reservoir at a temperature of 800°C and rejects heat to an intermediate thermal reservoir at 500°C. The heat rejected by the gas power plant to the intermediate thermal reservoir is used as a heat source for the steam power plant. The steam power plant receives heat from the intermediate thermal reservoir and rejects heat to a cold thermal reservoir at a temperature of 30°C. Draw the schematic diagram of the combined cycle power plant and determine,
- the maximum efficiency of the gas power plant (%)
  - the maximum efficiency of the steam power plant (%)
  - the total maximum theoretical power that can be produced by the combined cycle power plant (MW)
  - the actual thermal efficiency (%) of the steam power plant and the actual heat rejected (MW) by the steam power plant if the actual power produced by the steam power plant is 80 MW.
- (16 marks)

## PROPERTY TABLE FOR WATER

Saturated water—Temperature table

Temp., $T$ °C	Sat. press., $P_{\text{sat}}$ kPa	Specific volume, $\text{m}^3/\text{kg}$		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
		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, $s_g$
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556

Saturated water—Pressure table

Press., $P$ kPa	Sat. temp., $T_{\text{sat}}$ °C	Specific volume, $\text{m}^3/\text{kg}$		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
		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

a) The definition of enthalpy is given by

$$h = u + Pv \quad \text{Eq. (1)} \quad \text{✓}$$

ideal gas equation of state  $Pv = RT$

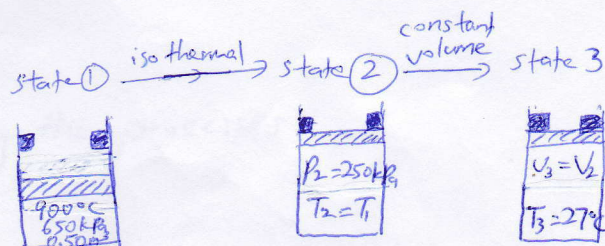
Then, from the ~~ideal gas equation of state~~  $Pv = RT$ , Eq. (1) becomes

$$h - u = RT$$

$$h = u + RT \quad \text{✓}$$

Since  $R$  is constant and  $u = u(T)$ , the enthalpy of an ideal gas is a function of temperature only, that is

$$h = h(T)$$



(b) (i) The mass of the ideal gas

$$Pv = mRT \quad \text{✓}$$

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

$$= \frac{(650 \text{ kPa})(0.500 \text{ m}^3)}{(0.287 \text{ kJ/kg}\cdot\text{K})(900 + 273 \text{ K})}$$

$$= 0.965 \text{ kg} \quad \text{✓}$$

(ii)  $V_{\text{final}} = V_2$

Determination of  $V_2$  ✓

$Pv = mRT = C$  because of isothermal process.

$$P_1 V_1 = P_2 V_2 \quad \text{✓}$$

$$(650 \text{ kPa})(0.500 \text{ m}^3) = (250 \text{ kPa}) V_2$$

$$V_2 = 1.30 \text{ m}^3 \quad \text{✓}$$

$$\Delta U_{\text{system}} = U_3 - U_1 \quad \left[ \begin{array}{l} \text{negligible} \\ \text{Since the changes in kinetic and potential energy are} \end{array} \right]$$

$$= mC_v(T_3 - T_1) \quad (1) /$$

$$= (0.965 \text{ kg}) (0.776 \text{ kJ/kg}\cdot\text{K}) (300 - 1173 \text{ K}) \quad (1)$$

$$\approx -654 \text{ kJ} \quad \# \quad (1) /$$

(iv) Total boundary work done  
Since  $W_{b,2-3} = 0$ ,

$$W_b = P_1 V_1 \ln \frac{V_2}{V_1} \quad (1) /$$

$$= (650 \text{ kPa}) (0.50 \text{ m}^3) \ln \frac{1.3 \text{ m}^3}{0.50 \text{ m}^3} \quad (1) /$$

$$\approx 311 \text{ kJ} \quad \# \quad (1) /$$

(v) The amount of heat transferred during the processes

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}} \quad (1) /$$

Let we assume  $Q_{\text{in}}$  (amount of heat transferred to the system)

$$Q_{\text{in}} - W_b = \Delta U \quad (1) /$$

$$Q_{\text{in}} - 311 \text{ kJ} = -654 \text{ kJ}$$

$$Q_{\text{in}} = -343 \text{ kJ} \quad (1) /$$

$$\text{or } -Q_{\text{out}} - W_b = \Delta U$$

$$-Q_{\text{out}} = \Delta U + W_b$$

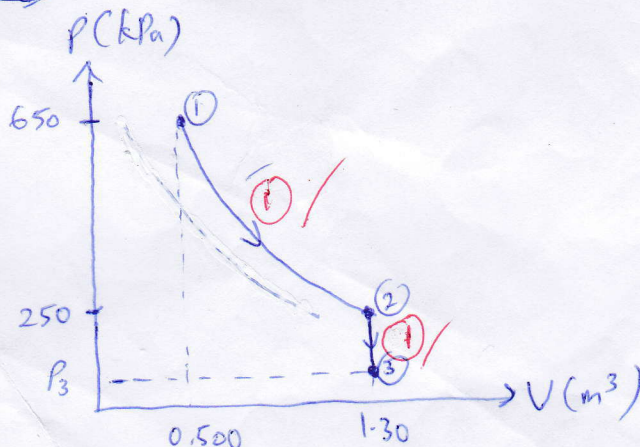
$$= -654 + 311$$

$$-Q_{\text{out}} = -343$$

$$\therefore Q_{\text{out}} = 343 \text{ kJ}$$

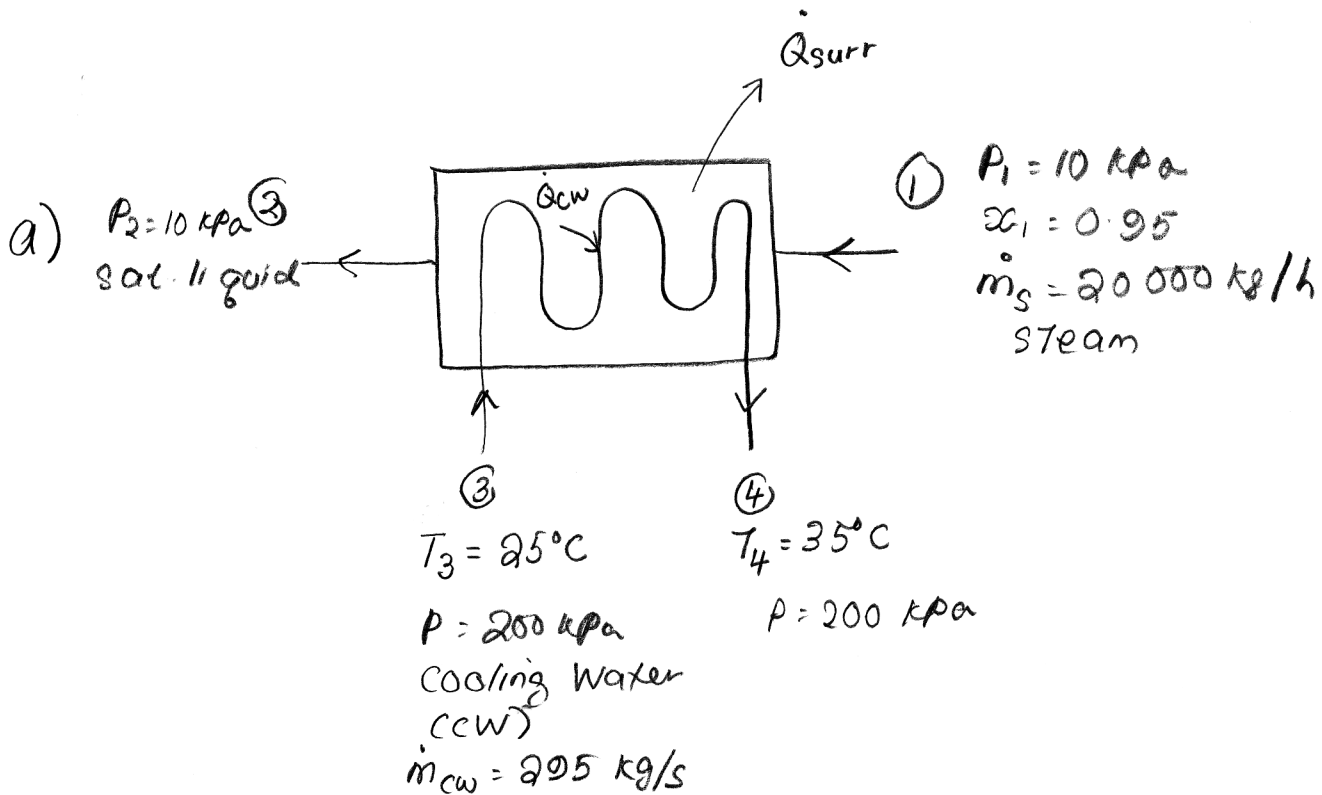
$\therefore Q_{\text{out}} = 343 \text{ kJ}$  (amount of heat transferred from the system (ideal gas))

P-V diagram before b(i)



QUESTION ~ 1st Law OPEN SYSTEM

①



i)  $\dot{Q}_{cw} = ?$

perform the energy balance analysis on the CW:

$$\dot{E}_{in} = \dot{E}_{out} \quad ; \quad \Delta KE \cong \Delta PE \cong 0 \quad ; \quad \dot{W}_{in} = \dot{W}_{out} = 0 \quad ; \quad \dot{Q}_{out} = 0$$

(1)

$$\dot{Q}_{cw, in} = \dot{m}_{cw} (h_4 - h_3) \quad (1)$$

State (3)

$$\begin{aligned}
 P_3 &= 200 \text{ kPa} \\
 T_3 &= 25^\circ\text{C} \quad ; \quad P_3 > P_{sat@25^\circ\text{C}} \\
 &\text{compressed liquid} \\
 h_3 &\cong h_f @ 25^\circ\text{C} \cong 104.83 \frac{\text{kJ}}{\text{kg}} \quad (2)
 \end{aligned}$$

State (4)

$$\begin{aligned}
 P_4 &= 200 \text{ kPa} \\
 T_4 &= 35^\circ\text{C} \quad ; \quad P_4 > P_{sat@35^\circ\text{C}} \\
 &\text{compressed liquid} \quad (2) \\
 h_4 &\cong h_f @ 35^\circ\text{C} \cong 146.64 \frac{\text{kJ}}{\text{kg}}
 \end{aligned}$$

$$\begin{aligned}
 \therefore \dot{Q}_{cw, in} &= 295 \times (146.64 - 104.83) \left( \frac{\text{kg}}{\text{s}} \times \frac{\text{kJ}}{\text{kg}} \right) \\
 &= 12333.95 \text{ kW} \quad * \quad (2)
 \end{aligned}$$

ii)  $\dot{Q}_{surr} = ?$

Perform the energy balance analysis on the STEAM:

$$\dot{E}_{out} = \dot{E}_{in} ; \Delta ke \cong \Delta pe \cong 0 ; \dot{W}_{in} = \dot{W}_{out} = 0 ; \dot{Q}_{in} = 0 \quad (1)$$

$$\therefore \dot{Q}_{surr, out} + \dot{Q}_{cw, out} + \dot{m}_s h_2 = \dot{m}_s h_1$$

$$\dot{Q}_{surr, out} = \dot{m}_s (h_1 - h_2) - \dot{Q}_{cw} \quad (2)$$

State (1)

$$x_{c1} = 0.95$$

$$P_1 = 10 \text{ kPa}$$

mixture

(2)

$$h_1 = h_f + x_1 h_{fg}$$

$$= 191.81 + 0.95 (2392.1)$$

$$= 2464.31 \frac{\text{kJ}}{\text{kg}}$$

State (2)

sat. liquid

$$P_2 = 10 \text{ kPa}$$

$$h_2 = h_f = 191.81 \frac{\text{kJ}}{\text{kg}} \quad (1)$$

$$\therefore \dot{Q}_{surr, out} = 20000 \frac{\text{kg}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} (2464.31 - 191.81) \frac{\text{kJ}}{\text{kg}}$$

$$= 12333.95$$

$$= 291.05 \text{ kW} \quad (2)$$

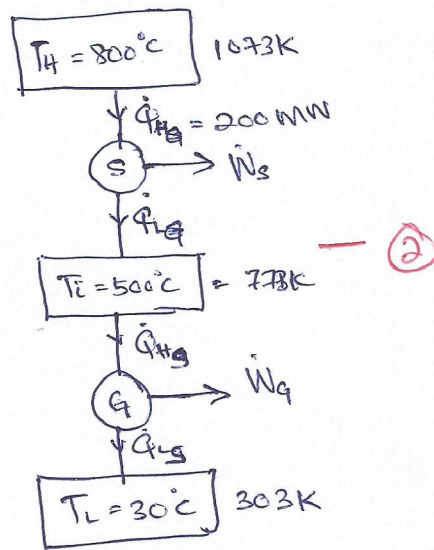
- b) As the steam pressure is raised, its latent heat decreases. Hence the amount of heat loss to the surroundings is less as the heat being transferred to the cooling water remains the same as before.

(4)

a) greater in a reversible expansion  
 - Without any irreversibilities, work producing device will produce maximum work. (2)

b) Greater in an actual compression.  
 - An actual compression involves irreversibilities, thus the compressor requires more work compare to the reversible compression. (2)

c)



$$\begin{aligned} \text{i) } \eta_{\text{max}} &= 1 - \frac{T_C}{T_H} \\ &= 1 - \frac{500 + 273}{800 + 273} \\ &= 0.280 \quad (28.0\%) \quad \# \end{aligned}$$

$$\begin{aligned} \text{ii) } \eta_{\text{max}} &= 1 - \frac{T_L}{T_C} \\ &= 1 - \frac{30 + 273}{500 + 273} \\ &= 0.608 \quad (60.8\%) \quad \# \end{aligned}$$

$$\begin{aligned} \text{iii) } 0.28 &= \frac{W_C}{Q_{H_C}} \\ W_C &= 0.28(200) \\ &= 56 \text{ MW} \end{aligned}$$

$$\dot{Q}_{H_S} = \dot{Q}_{H_C} = 200 - 56 = 144 \text{ MW} \quad \text{--- (1)}$$

$$\therefore 0.608 = \frac{W_S}{\dot{Q}_{H_S}} \quad \text{--- (2)}$$

$$W_S = 0.608(144) = 87.55$$

$$\begin{aligned} \text{Total Power} &= 56 + 87.55 \\ &= 143.55 \text{ MW} \quad \# \end{aligned} \quad \text{--- (1)}$$

$$\begin{aligned} \text{iv) } \eta_s &= \frac{W_S}{\dot{Q}_{H_C}} = \frac{80}{144} \\ &= 0.556 \quad (55.6\%) \end{aligned} \quad \text{--- (2)}$$

$$\begin{aligned} \dot{Q}_{H_{SA}} &= \dot{Q}_{H_S} - W_{SA} \\ &= 200 - 80 \\ &= 120 \text{ MW} \quad \# \end{aligned} \quad \text{--- (2)}$$