First Semester Examination
2022/2023 Academic Session

February 2023

EMH211 – Thermodynamics
(Termodinamik)

Duration: 3 hours
(Masa: 3 Jam)

Please check that this examination paper consists of <u>SEVEN</u> (7) pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi <u>TUJUH</u> (7) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

<u>Instructions</u>: Answer ALL **FIVE (5)** questions.

*[**<u>Arahan</u>**: Jawab **LIMA (5)** soalan]*

Note: Thermodynamic Formula Booklet is given in the Appendix.

1. Figure Q1 shows an ideal piston-cylinder assembly containing 2.5 kg of steam. The steam is expanded by adding work and heat into the piston-cylinder. The work added by the wheel paddle is 50 kJ and the amount of heat added into the piston-cylinder is 150 kJ. Initially, the steam has a pressure and temperature of 3 bar and 260°C, respectively. At the final state, the pressure and specific volume of steam are measured to be 1.0 bar and 2 m^3/kg, respectively. Calculate the work done by the steam during the expansion process.

(100 marks)

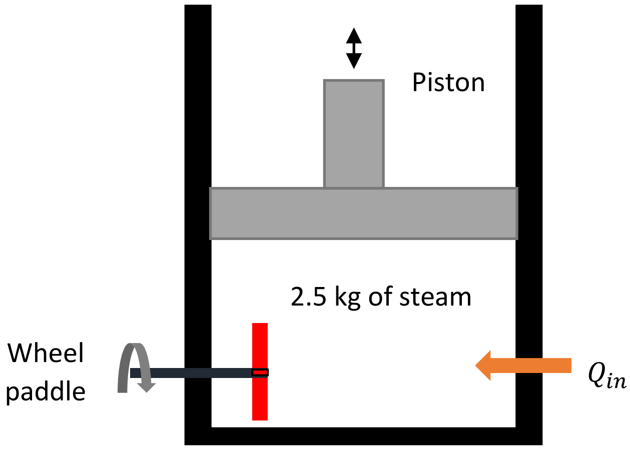

Figure Q1

2. (a) List the **FIVE (5)** thermodynamics processes for a non-flow, closed system. Indicate their terminologies and respective mathematical representations.

(30 marks)

(b) An amount of air is contained in a rigid cylinder with dimension of 0.3 m diameter by 1.2 m long. It is subjected to an initial pressure of 10 bar at temperature of 250°C. If the container is cooled to decrease the pressure to 3.5 bar, calculate the final temperature and amount of heat transferred.

(70 marks)

3. (a) Define the second law of thermodynamics and briefly describe its corollaries.

(20 marks)

(b) Steam enters a turbine at a pressure of 70 bar and temperature of 500°C with a mass flow rate of 36 tonne per hour. The exit pressure is at 2 bar and dry saturated temperature. Heat loss from the turbine is 200 kW and the ambient is at a pressure of 1 bar and temperature of 27°C. Neglect the kinetic and the potential energy losses.

Sketch the process in a T–s diagram showing the important points with proper labels.

(20 marks)

Calculate the:

(i) actual power output

(ii) exergy change in the process

(iii) exergy destroyed

(iv) maximum exergy of the steam (exergy at the inlet)

(v) exergy conversion efficiency of the turbine

(vi) overall efficiency of the system

(60 marks)

4. A single cylinder engine operating with Diesel Cycle has a compression ratio of 20 and heat addition of 2000 kJ in each combustion event. Given that the inlet conditions are 101.325 kPa and 77°C. Consider that 1 kg of air is taken in each Diesel cycle and the air can be modelled as an ideal gas. Given that γ = 1.4, R = 0.287 kJ/kgK c_p= 1.005 kJ/kgK and c_v = 0.718 kJ/kgK:

(i) Sketch the cycle on a P-v diagram.

(20 marks)

(ii) Calculate the thermal efficiency of the cycle.

(60 marks)

(iii) Calculate the mean effective pressure, in MPa for the cycle.

(20 marks)

5. Consider a steam power plant operating on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPa. Given the moisture content of the steam at the exit of the low-pressure turbine is not to exceed 10.4%. Assume the steam is reheated to the inlet temperature of the high-pressure turbine.

   (a) Sketch the process in a T–s diagram showing the important points with proper labels.

   (10 marks)

   (b) Calculate the:

      i. pressure at which the steam should be reheated

      (30 marks)

      ii. specific pump work input

      (30 marks)

      iii. cycle thermal efficiency

      (30 marks)

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Appendix 1

Thermodynamic Formulae Booklet 2023

First law for closed cycle $\oint \delta Q = \oint \delta W \quad \Rightarrow Q_{net} = W_{net}$	**Ideal gas**
Non-flow energy equation $q - w = (u_2 - u_1)$	**Characteristics equation** $PV = mRT$
Enthalpy equation $h = u + Pv$	**specific heat of an ideal gas** $\gamma\ (or\ k) = \frac{Cp}{Cv}\ ; Cp = \frac{\gamma R}{\gamma - 1}\ ;$ $Cv = \frac{R}{\gamma - 1}$
Steady flow energy equation $q - w = (h_2 - h_1) + 1/2\ (C_2^2 - C_1^2) + g\ (z_2 - z_1)$	
specific heat equation $q = c_p\ (T_2 - T_1)$	**Polytrophic process** $(PV^n = \text{constant})$ $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n$ and $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{n-1/n} = \left(\frac{V_1}{V_2}\right)^{n-1}$
Joule Law $du = c_v\ dT$ $dh = c_p\ dT$	
Dryness Fraction equations $v = v_f + x\ (v_f - v_g)$ or $v = x\ v_g$ (P<20bar) $h = h_f + x\ h_{fg}$; $u = u_f + x\ u_{fg}$ $s = s_f + x\ s_{fg}$	$W(kJ) = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}; (n > 1)$ $W(kJ) = P_1V_1.\ln\frac{V_2}{V_1} = mRT.\ln\frac{V_2}{V_1}; (n = 1)$ $Q(kJ) = W(\gamma - n)/(\gamma - 1); (n > 1)$
Cycle efficiency $\eta = \frac{w_{net}}{q_h} = \frac{q_h - q_c}{q_h} = 1 - \frac{q_c}{q_h}$ $COP_{refrigerator} = \frac{q_c}{w_{net}}$ $COP_{heat\ pump} = \frac{q_h}{w_{net}}$	**Adiabatic process** $(PV^\gamma = \text{constant})$ **Specific entropy of an ideal gas** $s_2 - s_1 = R\ \ln(v_2/v_1) + c_v\ \ln(T_2/T_1)$ $s_2 - s_1 = c_p\ln(v_2/v_1) + c_v\ \ln(P_2/P_1)$ $s_2 - s_1 = c_p\ln(T_2/T_1) - R\ \ln(P_2/P_1)$
Entropy $q = T\ (s_2 - s_1)$; (Isothermal) **Gibbs Equation** $Tds = Pdv + du$ $Tds = dh - vdP$ $\eta_{isentropic\ expantion} = \frac{W_{actual}}{W_{isentropic}}$ $\eta_{isentropic\ compression} = \frac{W_{isentropic}}{W_{actual}}$	**Specific exergy of a closed system** $x = (u - u_o) + P_o(v - v_o) - T_o(s - s_o)$ **Specific exergy of an open system** $x = (h - h_o) - T_o(s - s_o) + K.E + P.E$ **Specific exergy change of the process** $\Delta x = x_2 - x_1 = (h_1 - h_2) - T_0(s_1 - s_2) + \Delta KE + \Delta PE$ **Second Law Efficiency:** $\eta_{II} = \frac{W_{irr}}{X} = \frac{\eta}{\eta_{rev}} = \frac{W}{W_{rev}} = \frac{COP_{rev}}{COP}$

Carnot Cycle

$Q_{12} = m\,R\,T_1 \ln(v_1/v_2) = W_{12}$
$Q_{23} = m\,c_v\,(T_3 - T_2)$
$Q_{34} = mRT_3 \ln(v_4/v_3) = W_{34}$
$Q_{41} = m\,c_v\,(T_4 - T_1) = Q_{23}$

$$\eta_{carnot} = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{T_c}{T_h}$$

Stirling Cycle

$Q_c = Q_{12} = mRT_1 \ln(v_1/v_2) = W_{12}$
$Q_{23} = m\,c_v\,(T_3 - T_2)$
$Q_h = Q_{34} = mRT_3 \ln(v_4/v_3) = W_{34}$
$Q_{41} = mc_v\,(T_4 - T_1) = Q_{23}$

$$\eta_c = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{T_1}{T_3}$$

$$Work\ ratio = \frac{W_{34} - W_{12}}{W_{34}} = 1 - \frac{T_1}{T_3} = \eta_c$$

Ericsson Cycle

$Q_c = Q_{12} = mRT_1 \ln(P_2/P_1) = W_{12}$
$Q_{23} = m\,c_p\,(T_3 - T_2)$
$Q_h = Q_{34} = mRT_3 \ln(P_3/P_4) = W_{34}$
$Q_{41} = mc_p\,(T_1 - T_4)$

$$\eta_{ericsson} = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{T_1}{T_3}$$

Closed Brayton/Joule Cycle

$W_{12} = m\,c_p\,(T_1 - T_2)$
$Q_h = Q_{23} = m\,c_p\,(T_3 - T_2)$
$W_{34} = m\,c_p\,(T_3 - T_4)$
$Q_c = Q_{41} = m\,c_p\,(T_1 - T_4)$

$$\eta_c = \frac{W_{net}}{Q_h} = \frac{Q_{net}}{Q_h} = 1 - \frac{(T_1 - T_4)}{(T_3 - T_2)}$$

$\eta = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}$ (Applicable for isentropic processes only)

$$Work\ ratio = \frac{W_{34} - W_{12}}{W_{34}} = 1 - \frac{T_1}{T_3}\left(r_p\right)^{\frac{\gamma-1}{\gamma}}$$

Otto Air Standard Cycle

$W_{12} = mc_v\,(T_1 - T_2)$
$Q_h = Q_{23} = m\,c_v\,(T_3 - T_2)$
$W_{34} = m\,c_v\,(T_3 - T_4)$
$Q_c = Q_{41} = m\,c_v\,(T_1 - T_4)$

$$\eta_c = 1 - \frac{|T_1 - T_4|}{(T_3 - T_2)}$$

Diesel Standard Air Cycle

$Q_{12} = Q_{34} = W_{41} = 0$
$Q_p = Q_{23} = mc_p(T_3 - T_2)$
$Q_s = Q_{41} = mc_v(T_1 - T_4)$
Cycle efficiency,

$$\eta_D = 1 - \frac{|Qs|}{Qp} = 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} = 1 - \frac{1}{r_v^{\gamma-1}}\left(\frac{\beta^{\gamma} - 1}{\gamma(\beta - 1)}\right)$$

$r_v = (v_1/v_2)$ = compression ratio
$\beta = (v_3/v_2)$ = volume ratio or cut-off ratio

Mixed Cycle (Dual combustion cycle)

$Q_{12} = 0$
$Q_{23} = mc_v\,(T_3 - T_2)$
$Q_{34} = mc_p\,(T_4 - T_3)$
$Q_{51} = mc_v\,(T_1 - T_5)$
$r_v = (v_1/v_2)$ = compression ratio
$r_p = (P_3/P_2)$ = pressure ratio
$\beta = (v_4/v_3)$ = volume ratio, cut-off ratio
Cycle efficiency,

$$\eta_m = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{|Q_{51}|}{(Q_{23} - Q_{34})}$$

Mean Effective Pressure – MEP (P_m)

$w_{net} = P_m\,(v_1 - v_2)$

Rankine Cycle (Simple & Superheated Cycle)

$w_{12} = -(h_2 - h_1)$
$q_{23} = -(h_3 - h_2)$
$w_{34} = -(h_4 - h_3) = -v_{f3}\,(P_4 - P_3)$
$q_{41} = h_1 - h_4$

Efficiency,

$$\eta = \frac{w_{12} - |w_{34}|}{q_{41}}$$

$$Work\ Ratio = \frac{w_{12} - |w_{34}|}{w_{12}}$$

Rankine Reheat Cycle:

$$\eta = \frac{(w_{12} + w_{78}) - |w_{34}|}{q_{41} + q_{27}}$$

Specific Steam Consumption = 1 /w_{net} (kg/kJ)
or

$\eta_o = \frac{w_{net}}{q_{net}} = 1 - \frac{q_c}{q_h}$	Specific steam consumption=3600/w_{net} (kg/kWh)
$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = r_v^{\gamma-1}$ $pv^{\gamma} = Tv^{\gamma-1} = \text{constant}$ $r_v = \frac{Swept\ volume + Clearance\ volume}{Clearance\ volume} = \frac{v_1}{v_2}$ Otto cycle efficiency, $\eta = 1 - \frac{1}{r_v^{\gamma-1}}$	**Vapour Compression Cycle** $\text{COP} = \frac{\lvert q_{41} \rvert}{\lvert w \rvert} = \frac{h_1 - h_4}{h_2 - h_1}$ Refrigerating effect: $q_{41} = (h_1 - h_4)$ (kJ/kg)