First Semester Examination
2021/2022 Academic Session

February/March 2022

EMH 211 – Thermodynamics

Duration : 3 hours

Please ensure that this examination paper contains **EIGHT (8)** pages and **FIVE (5)** question before you begin the examination.

Instructions : Answer **ALL FIVE (5)** questions.

Answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.

Each question must begin from a new page.

Note: Thermodynamic Formula is provided in the Appendix. Thermodynamic Property Table is given in the elearning.

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1. Steam steadily flows through an adiabatic steam turbine as shown in Figure 1. The steam properties are measured at inlet and exit pipes. Given that at the inlet pipe, the steam pressure (P_1), temperature (T_1) and velocity (V_1) are 8 bar, 315°C and 100 m/s, respectively. At the exit pipe, the steam pressure (P_2) and velocity (V_2) are 75 kPa and 65 m/s, respectively. The inlet pipe diameter (D_1) is 8 inch and power generated by turbine ($\dot{W}out$) is 10 MW.

   Calculate:

   (i) Steam mass flow rate, $\dot{m}$.

   (30 marks)

   (ii) Steam density at the exit, ρ_2

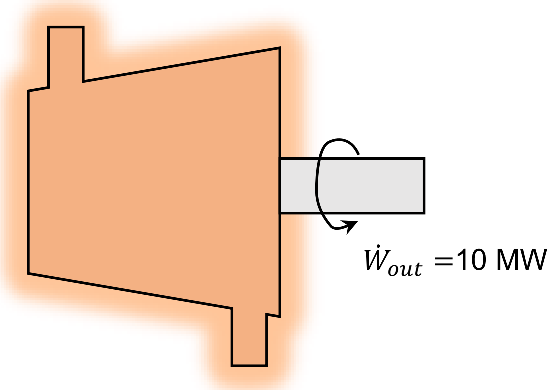
   (70 marks)

P_1 = 8 bar

T_1 = 315°C

D_1 = 8 inch

V_1 = 100 m/s



P_2 = 75 kPa

V_2 = 65 m/s

Figure 1

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2. a) List **FOUR (4)** major components of a steam power plant. Sketch a typical schematic diagram to show the connection between them. Briefly describe thermodynamics processes involved at each component. Support your description with a T-s diagram pointing out the processes in the cycle.

(50 marks)

b) Air, initially at atmospheric pressure and temperature of 27°C is compressed adiabatically by a piston to the pressure of 10 bar. Show the process in a p-V diagram. Calculate the final temperature, final specific volume and work done.

(50 marks)

3. a) Define entropy and briefly describe **THREE (3)** of its concepts in relation to the second law of thermodynamics.

(30 marks)

b) Steam enters a turbine at a pressure of 40 bar and temperature of 5xx °C with a mass flow rate of 10 kg/s. The exit pressure is at 3.5 bar and temperature of 1yy °C. Heat loss from the turbine is 350 kW and the ambient is at a pressure of 1 bar and temperature of 27 °C. The kinetic and the potential energy can be regarded as negligible.

[*NOTE: xx = last 2 digits of your identity card or passport number, yy = last 2 digits of your matriculation number*]

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

(10 marks)

Calculate the:

(i) actual power output

(ii) exergy change in the process

(iii) exergy destroyed

(iv) maximum exergy of the steam at the inlet

(v) efficiency of the turbine

(60 marks)

4. A dual combustion cycle has a maximum pressure of (X bar) and maximum temperature of (Y°C). The compression ratio is Z:1 and the inlet conditions are 1 bar and 25°C. Assume that the air is modelled as an ideal gas. Given that γ=1.4, cp= 1.005 kJ/kgK, cv=0.718 kJ/kgK and R= 0.287kJ/kgK.

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a) Sketch the cycle with a proper label on a P-v diagram

(10 marks)

b) Calculate the cut-off ratio

(30 marks)

c) Calculate the thermal efficiency

(30 marks)

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

(30 marks)

Instruction

Parameter values as follows:
Write the last digits of your student ID as your unique number, K.
(For example, if your student ID is 123456, then your K = 6)
Use your own K to assign the parameter values of X, Y and Z for the question and as follows:

Student matrix last digit, K	X	Y	Z
0	80	1900	18
1	85	1920	18.5
2	90	1940	19
3	95	1960	19.5
4	90	1980	20
5	85	2000	19.8
6	80	2020	19.6
7	75	1990	19.4
8	70	1960	19.2
9	65	1930	19

5. Consider a steam power plant operating on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at (P MPa) and (Q°C) and is condensed in the condenser at a pressure of (R 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 cycle with a proper label on a T-s diagram

(10 marks)

b) Calculate the pressure at which the steam should be reheated

(30 marks)

c) Calculate the specific pump work input

(30 marks)

d) Calculate the thermal efficiency of the cycle

(30 marks)

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Instruction
Parameter values as follows:
Write the last digits of your student ID as your unique number, K.
(For example, if your student ID is 123456, then your K = 6)
Use your own K to assign the parameter values of X, Y and Z for the question and as follows:

Student matrix last digit, K	P	Q	R
0	15	600	10
1	16	620	12
2	17	640	14
3	18	660	16
4	19	655	18
5	20	650	20
6	19.5	645	22
7	19	640	24
8	18.5	635	26
9	18	630	28

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Appendix 1

Thermodynamic Formulae Booklet 2022

First law for closed cycle

$$\oint \delta Q = \oint \delta W \quad \Rightarrow \quad Q_{net} = W_{net}$$

Non-flow energy equation

$q - w = (u_2 - u_1)$

Enthalpy equation

$h = u + Pv$

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

$q = cp\,(T_2 - T_1)$

Joule Law

$du = cv\,dT$

$dh = cp\,dT$

Dryness Fraction equations

$v = v_f + x\,(v_f - v_g)$ or $v = x\,v_g$ (P<20bar)

$h = h_f + x\,h_{fg}$; $u = u_f + x\,u_{fg}$

$s = s_f + x\,s_{fg}$

Cycle efficiency

$$\eta = \frac{w_{net}}{q_h} = \frac{q_h - q_c}{q_h} = 1 - \frac{q_c}{q_h}$$

$$COP_{refrigerator} = \frac{q_c}{w_{net}}$$

$$COP_{heat\ pump} = \frac{q_h}{w_{net}}$$

Entropy

$q = T\,(s_2 - s_1)$; (Isothermal)

Gibbs Equation

$Tds = Pdv + du$

$Tds = dh - vdP$

Ideal gas

Characteristics equation

$PV = mRT$

specific heat of an ideal gas

$$\gamma\,(or\ k) = \frac{Cp}{Cv}\ ;\ Cp = \frac{\gamma R}{\gamma - 1}\ ;$$

$$Cv = \frac{R}{\gamma - 1}$$

Polytrophic process $(PV^n = \text{constant})$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \ \textit{and}\ \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{n-1/n} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

$$W(kJ) = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n};(n>1)$$

$$W(kJ) = P_1V_1.\ln\frac{V_2}{V_1} = mRT.\ln\frac{V_2}{V_1};(n=1)$$

$$Q(kJ) = W(\gamma - n)/(\gamma - 1);(n>1)$$

$(PV^\gamma = \text{constant})$

Adiabatic process

Specific entropy of an ideal gas

$s_2 - s_1 = R\ \ln(v_2/v_1) + cv\ \ln(T_2/T_1)$

$s_2 - s_1 = cp\ln(v_2/v_1) + cv\ \ln(P_2/P_1)$

$s_2 - s_1 = cp\ln(T_2/T_1) - R\ \ln(P_2/P_1)$

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

$$\eta_{isentropic\ expantion} = \frac{W_{actual}}{W_{isentropic}}$$

$$\eta_{isentropic\ compression} = \frac{W_{isentropic}}{W_{actual}}$$

$\Delta x = x_2 - x_1 = (h_1 - h_2) - T_0(s_1 - s_2) + \Delta KE + \Delta PE$

Second Law Efficiency:

$$\eta_{II} = \frac{W_{irr}}{X} = \frac{\eta}{\eta_{rev}} = \frac{W}{W_{rev}} = \frac{COP_{rev}}{COP}$$

Carnot Cycle

$Q_{12} = m\,R\,T_1 \ln(v_1/v_2) = W_{12}$

$Q_{23} = m\,cv\,(T_3 - T_2)$

$Q_{34} = mRT_3 \ln(v_4/v_3) = W_{34}$

$Q_{41} = m\,cv\,(T_4 - T_1) = Q_{23}$

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

Stirling Cycle

$Q_c = Q_{12} = mRT_1 \ln(v_1/v_2) = W_{12}$

$Q_{23} = m\,cv\,(T_3 - T_2)$

$Q_h = Q_{34} = mRT_3 \ln(v_4/v_3) = W_{34}$

$Q_{41} = mcv\,(T_4 - T_1) = Q_{23}$

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

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

Ericsson Cycle

$Q_c = Q_{12} = mRT_1 \ln(P_2/P_1) = W_{12}$

$Q_{23} = m\,cp\,(T_3 - T_2)$

$Q_h = Q_{34} = mRT_3 \ln(P_3/P_4) = W_{34}$

$Q_{41} = mcp\,(T_1 - T_4)$

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

Diesel Standard Air Cycle

$Q_{12} = Q_{34} = W_{41} = 0$

$Q_p = Q_{23} = mcp(T_3 - T_2)$

$Q_s = Q_{41} = mcv(T_1 - T_4)$

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)

$Q_{12} = 0$

$Q_{23} = mcv\,(T_3 - T_2)$

$Q_{34} = mcp\,(T_4 - T_3)$

$Q_{51} = mcv\,(T_1 - T_5)$

$r_v = (v_1/v_2)$ = compression ratio

$r_p = (P_3/P_2)$ = pressure ratio

$\beta = (v_4/v_3)$ = volume ratio, cut-off ratio

Cycle efficiency,

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

Closed Brayton/Joule Cycle

$W_{12} = m\,cp\,(T_1 - T_2)$

$Q_h = Q_{23} = m\,cp\,(T_3 - T_2)$

$W_{34} = m\,cp\,(T_3 - T_4)$

$Q_c = Q_{41} = m\,cp\,(T_1 - T_4)$

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

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

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

Otto Air Standard Cycle

$W_{12} = mcv\,(T_1 - T_2)$

$Q_h = Q_{23} = m\,cv\,(T_3 - T_2)$

$W_{34} = m\,cv\,(T_3 - T_4)$

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:

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

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