CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
FEBRUARY 2025 SEMESTER SESSION

SUBJECT CODE	:	LMB12103
SUBJECT TITLE	:	APPLIED THERMODYNAMICS
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	BACHELOR OF MARINE ENGINEERING TECHNOLOGY WITH HONOURS
TIME / DURATION	:	2.00 PM – 5.00 PM (3 HOURS)
DATE	:	28 JUNE 2025

INSTRUCTIONS TO CANDIDATES

1. Please CAREFULLY read the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper consists of TWO (2) section A and Section B.
4. Answer ALL questions in Section A, and THREE (3) questions in Section B.
5. Please write your answers on the answer booklet provided.
6. Answer all questions in English language ONLY.
7. Answer should be written in blue or black in except for sketching, graphic and illustration.
8. Steam Table of Properties and Formula has been appended for your reference.

THERE ARE 6 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer ALL questions.
Please use the answer booklet provided.

Question 1

With reference to the concept concerning marine heat engines cycles.

(a) An air-standard cycle is executed within a closed piston–cylinder system and consists of 4 (FOUR) processes as follows:

1-2	V = constant heat addition from 100 kPa and 27°C
2-3	P = constant heat addition to 1800K
3-4	Isothermal expansion to 100 kPa
4-1	P = constant heat rejection to the initial state

Based on your understanding of these processes, sketch and label the cycle on:

i. Pressure – specific volume (P-v) diagram.

(5 marks)

ii. Temperature – entropy (T-s) diagram.

(5 marks)

(b) Explain whether it decreases, increases or remains constant when the Rankine cycle is modified by lowering its condenser pressure on the following:

i. Pump work input, $(w_{pump,in})$.

(1 mark)

ii. Heat rejected, (q_{out}).

(1 mark)

iii. Moisture content.

(1 mark)

iv. Turbine work output, $(w_{turb,out})$.

(1 mark)

v. Illustrate the original and the modified cycles on the same temperature - entropy (T-s) diagram.

(6 marks)

Question 2

With reference to the concept concerning marine refrigeration cycles.

(a) Describe FOUR (4) thermodynamic processes in ideal vapor compression refrigeration cycle.

(4 marks)

(b) Explain TWO (2) conditions for effective use of a water-source heat pump system.

(4 marks)

(c) Explain THREE (3) usage of throttling valve instead of turbine in ideal vapor compression refrigeration cycle.

(6 marks)

96 Explain THREE (3) reasons CFCs have been banned.

(6 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer THREE (3) questions ONLY.
Please use the answer booklet provided.

Question 3

With reference to the problem-solving concerning energy in marine heat engine cycles.

Onboard a modern merchant ship, the propulsion system operates on an ideal Otto cycle, using air as the working fluid. The engine operates with a given compression ratio (r) of 9, and operational data is shown in Table 3.

Table 3: Operational data of an ideal Otto cycle

Process	Pressure (kPa)	Temperature (K)
1 – 2	150	300
2 – 3	P_2	T_2
3 – 4	P_3	1926.5797
4 – 1	245	800

Using thermodynamic analysis tools and cold air-standard assumptions:

(a) Calculate the temperature at the beginning of heat addition, (T_2) process.

(4 marks)

(b) Determine the pressure at the end of heat addition (P_3) process.

(4 marks)

(c) Calculate the net work, $(w_{net,out})$ of the cycle.

(7 marks)

(d) Analyze TWO (2) impact of engine cycle selection (Otto and Diesel) on fuel consumption in marine applications.

(5 marks)

Question 4

With reference to the problem-solving concerning energy in marine steam turbines:

You are the lead engineer on a vessel using a reheat Rankine cycle to generate power and propulsion. The system maximizes fuel efficiency by expanding steam in two stages with reheating between turbines. The following operational parameters describe the system:

High-pressure boiler supplies steam at:

- Pressure (P_3) : 3 MPa
- Temperature (T_3): 300°C

The steam is reheated at an intermediate pressure of:

- Reheat Temperature (T_5): 300°C

Steam enters the low-pressure turbine and expands to:

- Condenser Pressure (P_6): 10 kPa
- Moisture content: 5.94 percent

(a) Determine the pressure at the reheater, (P_{reheat}).

(5 marks)

(b) Calculate the work produced ($w_{turb,out}$) of this cycle.

(10 marks)

(c) Analyze TWO (2) impact of the reheat Rankine cycle on emission reduction in marine applications.

(5 marks)

Question 5

With reference to the problem-solving concerning energy in marine refrigeration cycles.

An ideal gas refrigeration cycle using air as a refrigerant is designed to maintain a refrigerated space at -13°C (T_1) while rejecting heat to the surrounding medium at 27°C (T_3). The pressure ratio (r_p) of the compressor is 3.

(a) Calculate the maximum temperature, T_2 in Kelvin unit.

(6 marks)

(b) Determine the heat removal from the refrigerated space, (q_L) in kJ/kg unit.

(7 marks)

(c) Evaluate TWO (2) effects of changes in refrigeration system performance on heat rejection and overall efficiency.

(5 marks)

Question 6

With reference to problem solving concerning energy in combustion in marine engines.

As the onboard engineer of a marine vessel utilizing a two-stroke diesel engine powered by heavy fuel oil, you are tasked with evaluating the combustion process as shown in Figure 6 to enhance fuel efficiency and ensure compliance with IMO emission standards. Assume complete combustion of carbon and hydrogen, neglecting sulfur for this calculation.

[Given: $M_{air} = 29\frac{kg}{kmol}$; $M_c = 12\frac{kg}{kmol}$; $M_{H_2} = 2\frac{kg}{kmol}$).

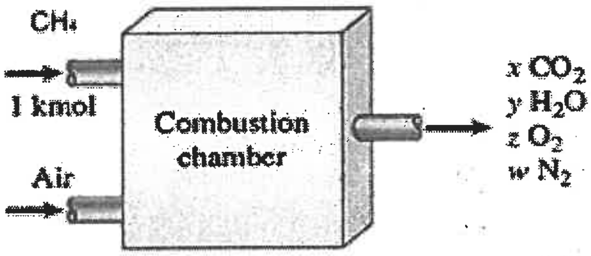

Figure 6: Product of combustion

(a) Derive the chemical equation for the complete combustion of 1 kmol of C_8H_{18} when reacting with 10 kmol of air.

(5 marks)

(b) Calculate the mole number of each gaseous product (x, y, z, w) formed in the combustion process.

(10 marks)

(c) Compute the air–fuel ratio (AF) for this combustion process.

(5 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULAE

First Law of Thermodynamics
Quality, $x = \frac{m_g}{m_{total}} = \frac{v - v_f}{v_{fg}}$ $v = v_f + (x)v_{fg}$; $u = u_f + (x)u_{fg}$; $h = h_f + (x)h_{fg}$
Mass total, $m_{total} = m_f + m_g$
Ideal gas equation $PV = mRT$; $Pv = RT$ $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
General Energy Balance $E_{in} - E_{out} = \Delta E_{system}$
$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
Energy Balance for a closed system, constant volume process $Q - W = \Delta U + \Delta KE + \Delta PE$ Ideal gas: $Q - W = mc_v(T_2 - T_1)$
Energy Balance for a constant pressure process $W_b + \Delta U = \Delta H$ $Q - W_{other} = \Delta H + \Delta KE + \Delta PE$ Ideal gas: $Q - W = mc_p(T_2 - T_1)$
Conservation of mass and energy equations for steady-flow process $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m}[h + V^2/2 + gz] - \sum_{in} \dot{m}[h + V^2/2 + gz]$ $\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(h_1 + \frac{V_1^2}{2} + gz_1\right) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(h_2 + \frac{V_2^2}{2} + gz_2\right)$
Boundary work (P = constant), $W_b = mP_0(v_2 - v_1)$
Boundary work (T = constant), $W_b = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
Polytropic Process, $PV^n = C$ Boundary work (Polytropic), $W_b = \frac{P_1V_1 - P_2V_2}{1-n}$

Mass flow rate

$$\dot{m} = \rho A V = \rho \dot{V} = \frac{\dot{V}}{v}$$

Volume flow rate

$$\dot{V} = VA = \frac{\dot{m}}{\rho}$$

Thermal efficiency of a Heat Engine

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Coefficient of Performance of a Refrigerator and Heat Pump

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L}$$

Carnot Heat Engine

$$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

Carnot Refrigerators and Heat Pumps

$$COP_{R,carnot} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$COP_{HP,carnot} = \frac{1}{1 - \frac{T_L}{T_H}}$$

Isentropic Process (Cold-air standard)

$$s_2 = s_1$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k}$$

$\left(\frac{P_2}{P_1}\right)_{s=const.} = \frac{P_{r2}}{P_{r1}}$
$\left(\frac{v_2}{v_1}\right)_{s=const.} = \frac{v_{r2}}{v_{r1}}$
Power Cycles
Compression ratio, $r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2} = \frac{v_{r1}}{v_{r2}}$
$MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}} = \frac{w_{net}}{v\left(1 - \frac{1}{r}\right)}$
Otto Cycle
$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$
$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
Thermal efficiency, $\eta_{th,Otto} = \frac{W_{net}}{Q_{in}} = 1 - \frac{q_{out}}{q_{in}}$
$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$ = cold-air standard
Diesel Cycle
$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
Cutoff ratio, $r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$
$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$ = cold-air standard
Joule-Brayton Cycle
$q_{in} = w_{b,out} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$q_{out} = h_4 - h_1 = c_p(T_4 - T_1)$
Pressure ratio, $r_p = \frac{P_2}{P_1} = \frac{P_{r2}}{P_{r1}}$

$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}}$ = cold-air standard
Rankine Cycle
$w_{pump,in} = h_2 - h_1 = v_1(P_2 - P_1)$
$q_{in} = h_3 - h_2$
$w_{turb,out} = h_3 - h_4$
$q_{out} = h_4 - h_1$
$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$
$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$
Reheat Rankine Cycle
Total heat input, $q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$
$q_{out} = h_6 - h_1$
$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$
Refrigeration Cycle
$W_{net,out} = Q_H - Q_L$
$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$
$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$
$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$
$COP_{HP} = COP_R + 1$
Combustion
$Air\ Fuel\ Ratio\ (AF) = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H_2}}$

Conversion Factors

DIMENSION	METRIC	METRIC/ENGLISH
Acceleration	1 m/s² = 100 cm/s²	1 m/s² = 3.2808 ft/s² 1 ft/s² = 0.3048* m/s²
Area	1 m² = 10⁴ cm² = 10⁶ mm² = 10⁻⁶ km²	1 m² = 1550 in² = 10.764 ft² 1 ft² = 144 in² = 0.09290304* m²
Density	1 g/cm³ = 1 kg/L = 1000 kg/m³	1 g/cm³ = 62.428 lbm/ft³ = 0.036127 lbm/in³ 1 lbm/in³ = 1728 lbm/ft³ 1 kg/m³ = 0.062428 lbm/ft³
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 N · m = 1 kPa · m³ 1 kJ/kg = 1000 m²/s² 1 kWh = 3600 kJ 1 cal[†] = 4.184 J 1 IT cal[†] = 4.1868 J 1 Cal[†] = 4.1868 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia · ft³ = 778.169 lbf · ft 1 Btu/lbm = 25,037 ft²/s² = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10⁵ Btu = 1.055 × 10⁵ kJ (natural gas)
Force	1 N = 1 kg · m/s² = 10⁵ dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbm · ft/s² = 4.44822 N
Heat flux	1 W/cm² = 10⁴ W/m²	1 W/m² = 0.3171 Btu/h · ft²
Heat transfer coefficient	1 W/m² · °C = 1 W/m² · K	1 W/m² · °C = 0.17612 Btu/h · ft² · °F
Length	1 m = 100 cm = 1000 mm = 10⁶ μm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp[‡] = 745.7 W	1 kW = 3412.14 Btu/h = 737.56 lbf · ft/s 1 hp = 550 lbf · ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 boiler hp = 33,475 Btu/h 1 Btu/h = 1.055056 kJ/h 1 ton of refrigeration = 200 Btu/min
Pressure	1 Pa = 1 N/m² 1 kPa = 10³ Pa = 10⁻³ MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mm Hg at 0°C = 1.03323 kgf/cm² 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10⁻⁴ psia = 0.020886 lbf/ft² 1 psi = 144 lbf/ft² = 6.894757 kPa 1 atm = 14.696 psia = 29.92 in Hg at 30°F 1 in Hg = 3.387 kPa
Specific heat	1 kJ/kg · °C = 1 kJ/kg · K = 1 J/g · °C	1 Btu/lbm · °F = 4.1868 kJ/kg · °C 1 Btu/lbmol · R = 4.1868 kJ/kmol · K 1 kJ/kg · °C = 0.23885 Btu/lbm · °F = 0.23885 Btu/lbm · R

*Exact conversion factor between metric and English units.

[†]Calorie is originally defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C, but it varies with temperature. The international steam table (IT) calorie (generally preferred by engineers) is exactly 4.1868 J by definition and corresponds to the specific heat of water at 15°C. The thermochemical calorie (generally preferred by physicists) is exactly 4.184 J by definition and corresponds to the specific heat of water at room temperature. The difference between the two is about 0.06 percent, which is negligible. The capitalized Calorie used by nutritionists is actually a kilocalorie (1000 IT calories).

DIMENSION	METRIC	METRIC/ENGLISH
Specific volume	$1\ m^3/kg = 1000\ L/kg = 1000\ cm^3/g$	$1\ m^3/kg = 16.02\ ft^3/lbm$ $1\ ft^3/lbm = 0.062428\ m^3/kg$
Temperature	$T(K) = T(°C) + 273.15$ $\Delta T(K) = \Delta T(°C)$	$T(R) = T(°F) + 459.67 = 1.8T(K)$ $T(°F) = 1.8\ T(°C) + 32$ $\Delta T(°F) = \Delta T(R) = 1.8\ \Delta T(K)$
Thermal conductivity	1 W/m · °C = 1 W/m · K	1 W/m · °C = 0.57782 Btu/h · ft · °F
Velocity	1 m/s = 3.60 km/h	1 m/s = 3.2808 ft/s = 2.237 mi/h 1 mi/h = 1.46667 ft/s 1 mi/h = 1.6093 km/h
Volume	$1\ m^3 = 1000\ L = 10^6\ cm^3$ (cc)	$1\ m^3 = 6.1024 \times 10^4\ in^3 = 35.315\ ft^3$ = 264.17 gal (U.S.) 1 U.S. gallon $= 231\ in^3 = 3.7854\ L$ 1 fl ounce $= 29.5735\ cm^3 = 0.0295735\ L$ 1 U.S. gallon = 128 fl ounces
Volume flow rate	$1\ m^3/s = 60{,}000\ L/min = 10^6\ cm^3/s$	$1\ m^3/s = 15{,}850$ gal/min (gpm) $= 35.315\ ft^3/s$ $= 2118.9\ ft^3/min$ (cfm)

[a]Mechanical horsepower. The electrical horsepower is taken to be exactly 746 W.

Some Physical Constants

Universal gas constant	$R_u = 8.31447$ kJ/kmol · K $= 8.31447$ kPa · m^3/kmol · K $= 0.0831447$ bar · m^3/kmol · K $= 82.05$ L · atm/kmol · K $= 1.9858$ Btu/lbmol · R $= 1545.37$ ft · lbf/lbmol · R $= 10.73$ psia · ft^3/lbmol · R
Standard acceleration of gravity	$g = 9.80665\ m/s^2$ $= 32.174\ ft/s^2$
Standard atmospheric pressure	1 atm = 101.325 kPa = 1.01325 bar = 14.696 psia = 760 mm Hg (0°C) = 29.9213 in Hg (32°F) $= 10.3323$ m H_2O (4°C)
Stefan–Boltzmann constant	$\sigma = 5.6704 \times 10^{-8}\ W/m^2 \cdot K^4$ $= 0.1714 \times 10^{-8}$ Btu/h · $ft^2 \cdot R^4$
Boltzmann's constant	$k = 1.380650 \times 10^{-23}$ J/K
Speed of light in vacuum	$c_o = 2.9979 \times 10^8$ m/s $= 9.836 \times 10^8$ ft/s
Speed of sound in dry air at 0°C and 1 atm	$c = 331.36$ m/s $= 1089$ ft/s
Heat of fusion of water at 1 atm	$h_{if} = 333.7$ kJ/kg $= 143.5$ Btu/lbm
Enthalpy of vaporization of water at 1 atm	$h_{fg} = 2256.5$ kJ/kg $= 970.12$ Btu/lbm