CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
JULY 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	:	**9.00 AM – 12.00 PM (3 HOURS)**
DATE	:	**16 DECEMBER 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 **ONLY** 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, EXCLUDING 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 THREE (3) processes as follows:

1-2	Volume constant heat addition from 100 kPa and 27°C to 850 kPa
2-3	Isothermal expansion until $V_3 = 7V_2$
3-1	Pressure 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 the effect of energy transfer when the steam is superheated to a higher temperature on the following:

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

(1 mark)

ii. Heat added, (q_{in}).

(1 mark)

iii. Moisture content.

(1 mark)

iv. Thermal efficiency, (η_{th}).

(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) Explain TWO (2) reasons the reversed Carnot cycle is not commonly used as a model for refrigeration cycles.

(4 marks)

(b) Explain TWO (2) usages of throttling valve instead of turbine in an ideal vapor compression refrigeration cycle.

(4 marks)

(c) Explain THREE (3) important properties of refrigerant that make them suitable for used in marine refrigeration cycles.

(6 marks)

(d) Describe THREE (3) air-source factors that cause frosting and affect the performance of heat pump systems.

(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.

As an engineer tasked with evaluating the thermodynamic efficiency of a generator engine within a modern merchant ship's propulsion system, you are to analyse its performance based on the ideal Otto cycle, using air as the working fluid. The engine operates with a given compression ratio (r) of 8, and operational data is shown in Table 1.

Table 1: Operational data of an ideal Otto cycle

State	Pressure (P), (kPa)	Temperature (T), (K)	Internal energy (u), (kJ/kg)
1	95	300	214.07
2	1705	673	491.221
3	P_3	1538.7	1241.221
4	245	774.5	571.722

Using thermodynamic analysis tools and air-standard assumptions:

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

(4 marks)

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

(6 marks)

(c) Calculate the mean effective pressure (MEP) for the cycle.

(5 marks)

(d) Assess 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 turbine cycles:

As the lead engineer on a vessel powered by a reheat Rankine cycle, you are responsible for analyzing the ship's power generation and propulsion systems. 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 Pressure (P_4): 300 kPa
- Reheat Temperature (T_5): 300°C

Steam enters the low-pressure turbine and expands to:

- Condenser Pressure (P_6): 10 kPa

(a) Calculate the enthalpy at the exit of high-pressure turbine, (h_4).

(5 marks)

(b) Calculate the heat added (q_{in}) to the cycle in kJ/kg unit.

(10 marks)

(c) Determine 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.

As a junior marine engineer, you are tasked with evaluating the performance of a refrigeration system on a refrigerated cargo ship. The system uses refrigerant-134a (R-134a) and is designed to handle a cooling load of 250 kW $(\dot{Q}_L)$. The system operates with an evaporator at 400 kPa (P_4), and its condenser at 800 kPa (P_2).

(a) Determine the enthalpy at the condenser, (h_2).

(7 marks)

(b) Determine the refrigerant mass flow rate, $(\dot{m}_{ref})$

(5 marks)

(c) Calculate the rate of heat rejection to the surrounding, $(\dot{Q}_H)$.

(3 marks)

(d) Determine TWO (2) effects of refrigeration system performance changes on heat rejection and overall efficiency.

(5 marks)

Question 6

With reference to problem solving concerning energy in combustion.

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

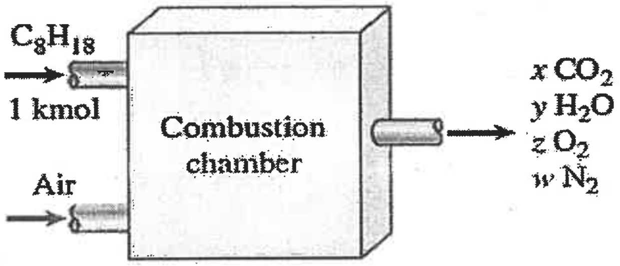

Figure Q (6): Product of combustion

(a) Derive the chemical equation for the complete combustion of 1 kmol of C_8H_{18} when reacting with 20 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 $PV = mRT$; $Pv = RT$ $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
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), $W_b = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$
Polytropic Process, $PV^n = C$ Boundary work (Polytropic), $W_b = \frac{P_1 V_1 - P_2 V_2}{1 - n}$

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/s^2 = 100 cm/s^2	1 m/s^2 = 3.2808 ft/s^2 1 ft/s^2 = 0.3048* m/s^2
Area	1 m^2 = 10^4 cm^2 = 10^6 mm^2 = 10^{-6} km^2	1 m^2 = 1550 in^2 = 10.764 ft^2 1 ft^2 = 144 in^2 = 0.09290304* m^2
Density	1 g/cm^3 = 1 kg/L = 1000 kg/m^3	1 g/cm^3 = 62.428 lbm/ft^3 = 0.036127 lbm/in^3 1 lbm/in^3 = 1728 lbm/ft^3 1 kg/m^3 = 0.062428 lbm/ft^3
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 N · m = 1 kPa · m^3 1 kJ/kg = 1000 m^2/s^2 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 · ft^3 = 778.169 lbf · ft 1 Btu/lbm = 25,037 ft^2/s^2 = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10^5 Btu = 1.055 × 10^5 kJ (natural gas)
Force	1 N = 1 kg · m/s^2 = 10^5 dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbm · ft/s^2 = 4.44822 N
Heat flux	1 W/cm^2 = 10^4 W/m^2	1 W/m^2 = 0.3171 Btu/h · ft^2
Heat transfer coefficient	1 W/m^2 · °C = 1 W/m^2 · K	1 W/m^2 · °C = 0.17612 Btu/h · ft^2 · °F
Length	1 m = 100 cm = 1000 mm = 10^6 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/m^2 1 kPa = 10^3 Pa = 10^{-3} MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mm Hg at 0°C = 1.03323 kgf/cm^2 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10^{-4} psia = 0.020886 lbf/ft^2 1 psi = 144 lbf/ft^2 = 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 m³/kg = 1000 L/kg = 1000 cm³/g	1 m³/kg = 16.02 ft³/lbm 1 ft³/lbm = 0.062428 m³/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 m³ = 1000 L = 10^6 cm³ (cc)	1 m³ = 6.1024×10^4 in³ = 35.315 ft³ = 264.17 gal (U.S.) 1 U.S. gallon = 231 in³ = 3.7854 L 1 fl ounce = 29.5735 cm³ = 0.0295735 L 1 U.S. gallon = 128 fl ounces
Volume flow rate	1 m³/s = 60,000 L/min = 10^6 cm³/s	1 m³/s = 15,850 gal/min (gpm) = 35.315 ft³/s = 2118.9 ft³/min (cfm)

‡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 · m³/kmol · K = 0.0831447 bar · m³/kmol · K = 82.05 L · atm/kmol · K = 1.9858 Btu/lbmol · R = 1545.37 ft · lbf/lbmol · R = 10.73 psia · ft³/lbmol · R
Standard acceleration of gravity	g = 9.80665 m/s² = 32.174 ft/s²
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/m² · K⁴ $= 0.1714 \times 10^{-8}$ Btu/h · ft² · R⁴
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