CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
JULY 2025 SEMESTER SESSION

SUBJECT CODE	:	**LMB11603**
SUBJECT TITLE	:	**FUNDAMENTALS OF THERMODYNAMICS**
PROGRAMME NAME **(FOR MPU: PROGRAMME LEVEL)**	:	**BET IN MARINE ENGINEERING**
TIME / DURATION	:	**09.00 AM - 12.00 PM** **(3 HOURS)**
DATE	:	**16 DECEMBER 2025**

INSTRUCTIONS TO CANDIDATES

1. Please read **CAREFULLY** 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)** sections; Section A and Section B.
4. Answer **ALL** question in Section A, and **THREE (3)** questions ONLY in Section B.
5. Please write your answers on this answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. Answer should be written in blue of black ink except for sketching, graphic and illustration.
8. Thermodynamics 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 basic concept of thermodynamics to systems and processes.

(a) Define the following:
  i. Thermal equilibrium
  ii. Mechanical equilibrium
  iii. System

(6 marks)

(b)
  i. Convert a volume flow rate of **8000** liters per minute (ℓ /min) into cubic meters per second (m^3/s)
  ii. A pressure gauge reads **15** psi. Convert this pressure into Pascals (Pa).
  iii. The density of a substance is **0.7** lbm/ft^3. Convert this value into kilograms per cubic meter (kg/m^3).

(6 marks)

(c) A deep-sea diver descends into a freshwater lake and experiences a gauge pressure of **80,000** kPa. Given that the atmospheric pressure at the surface is **101** kPa and the density of freshwater is **1000** kg/m^3, determine the:

  i. depth (**h**) of the diver in meters.

(5 marks)

  ii. absolute pressure, ($\mathbf{P_{abs}}$) acting on the diver in kPa

(3 marks)

Question 2

With reference to forms of energy and energy transfer of a system.

(a) Define the following:

i. Kinetic energy

ii. Potential energy

iii. Mechanical energy,

(6 marks)

(b) A piston-cylinder device containing water is being heated, causing the piston to rise. During this heating process:

- **1200 kJ** of heat is transferred to the water, $\mathbf{Q_{in}}$.
- **25 kJ** of heat is lost to the surroundings, $\mathbf{Q_{out}}$.
- The vapor does **15 kJ** of work as it expands, $\mathbf{W_{out}}$.

Calculate the change in the **internal energy** of the water for this process.

(6 marks)

(c) A waterfall is located at a height of **90 meters (z)** above a hydroelectric power plant. Water flows over the fall with a velocity of **10 m/s (V)** and a flow rate of **45 m³/s** ($\dot{V}$). Determine the:

i. total mechanical energy ($\mathbf{e_{mech}}$) of the water at the top of the waterfall per unit mass and

(2 marks)

ii. the maximum theoretical power generation potential ($\dot{E}$) of the falling water at that location

(6 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer only THREE questions.
Please use the answer booklet provided.

Question 3

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) A closed, well-insulated vessel contains water at a pressure of **500** kPa and a temperature **200°C**.

i. Based on the given properties, **determine the phase** of the water (compressed liquid, saturated mixture, or superheated vapor).

(3 marks)

ii. **Explain briefly** how you determined the phase using thermodynamic property tables.

(2 marks)

(b) Complete Table 1 below of thermodynamics properties for refrigerant-134a (**R-134a**). Show all the calculations involved. Use the following abbreviations where needed:

- CL – Compressed (Subcooled) liquid
- SL – Saturated liquid
- SM – Saturated Mixture
- SV – Saturated Vapor
- SHV – Superheated Vapor
- NA – Not applicable

Table 1: Thermodynamics properties for **R-134a**

P (kPa)	T(°C)	v, m^3/kg	u, kJ/kg	Phase Description	Quality (x)
900	20	(a)	(b)	(c)	(d)
(e)	30	0.0008421	(f)	(g)	(h)
60	(i)	(j)	80	(k)	(l)
500	20	(m)	(n)	(o)	NIL

(15 marks)

Question 4

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) Describe the main characteristics of a T–v diagram for pure substances during a constant-pressure phase-change process. In your description, identify the phases present and state the meaning of key points such as saturated liquid (SL), saturated mixture (SM), and saturated vapor (SV).

(5 marks)

(b) A **0.4 m³** rigid tank contains **1.5 kg** of **air** at **25°C.** Determine the reading on the pressure gage, **P_{gage}** if the atmospheric pressure, **P_{atm}** is **97 kPa.**

(6 marks)

(c) A **2 kg** sample of water is contained in a rigid tank with a volume of **500 liters**, and the pressure is measured to be **1400 kPa.**

i. Identify the **phase** of the water at this state.

(3 marks)

ii. Determine the temperature, **T** (°C).

(3 marks)

iii. Determine its internal energy, **u** (kJ/kg)

(3 marks)

Question 5

With reference to Laws of thermodynamics, energies, systems, pure substance properties and entropy.

(a) A steady-flow water heater operates at steady state. Cold water enters at 15°C and leaves at 60°C. Describe the heat transfer involved in this process using the energy balance equation.

(5 marks)

(b) A steady-flow water heater heats water from **20°C** to **50°C** at a mass flow rate of **0.05 kg/s**. Assume negligible changes in kinetic and potential energy. Using the steady-flow energy equation and $Cp_{water} = 4.18 kJ/kg.^{o}C$, calculate the rate of heat transfer to the water.

(5 marks)

(c) A steam turbine operates with **1.6 Mpa** (**P_1**) and **350°C** (**T_1**) steam at its inlet and **saturated vapor** at 30°C (**T_2**) at its exit. The mass flow rate of the steam is **22 kg/s** (**$\dot{m}$**), and the turbine produces 12,350 kW $(\dot{W}_{out})$ of power.

i. Determine the enthalpy at the inlet, **h_1** (kJ/kg).

(2 marks)

ii. Determine the enthalpy at the outlet, **h_2** (kJ/kg).

(2 marks)

iii. Calculate the rate of heat lost **$(\dot{Q}_{out})$** through the casing of this turbine

(6 marks)

Question 6

With reference to the second law of thermodynamics to cyclic devices.

(a) Sketch a schematic diagram of the refrigerator with complete label.

(5 marks)

(b) Refrigerant-134a enters the condenser of a residential heat pump at **800 kPa** and **35°C** at a rate of **0.018 kg/s** and leaves at **800 kPa** as a **saturated liquid**. If the compressor consumes **1.2 kW** of power, determine:

i. the COP of the heat pump, $\mathbf{COP_{hp}}$

(8 marks)

ii. rate of heat transfer absorption from the outside air, $\mathbf{Q_L}$ (kW).

(2 marks)

(c) A Carnot heat engine operates between a source at **1000 K** and a sink at **300 K**. If the heat engine is supplied with heat at a rate of **800 kJ/min**, determine:

i. thermal efficiency, η_{th}

(2 marks)

ii. the power output of this heat engine, $\dot{W}_{net\ out}$, kW

(3 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULAE

First Law of Thermodynamics

Quality, $$x = \frac{m_g}{m_{total}} = \frac{v - v_f}{v_{fg}}$$

$$v = v_f + (x)v_{fg}; \quad u = u_f + (x)u_{fg}; \quad h = h_f + (x)h_{fg}$$

Mass total,

$$m_{total} = m_f + m_g$$

Ideal gas equation

$$PV = mRT; \quad Pv = RT$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

$$\text{Ideal gas}: \quad Q - W = mc_v(T_2 - T_1)$$

Energy Balance for a constant pressure process

$$W_b + \Delta U = \Delta H$$

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE$$

$$\text{Ideal gas}: \quad Q - W = mc_p(T_2 - T_1)$$

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

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

Volume flow rate

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

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

$$\mathrm{COP_R, carnot} = \frac{1}{\frac{T_H}{T_L} - 1}$$

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

Isentropic Process

$$s_2 = s_1$$

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

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

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

$$\left(\frac{P_2}{P_1}\right)_{s=const.} = \frac{P_{r2}}{P_{r1}}$$

$$\left(\frac{v_2}{v_1}\right)_{s=const.} = \frac{v_{r2}}{v_{r1}}$$

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, $r_p = \frac{P_2}{P_1}$

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{\frac{k-1}{k}}}$$ = cold-air standard

Rankine Cycle

$$w_{pump,in} = h_2 - h_1 = v(P_2 - P_1)$$

$$q_{in} = h_3 - h_2$$

$$w_{turb,out} = h_3 - h_4$$

$$q_{out} = h_4 - h_1$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$$

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

$$W_{net,out} = Q_H - Q_L$$

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

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$$

$$COP_{HP} = COP_R + 1$$

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 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	$T(\text{K}) = T(°\text{C}) + 273.15$ $\Delta T(\text{K}) = \Delta T(°\text{C})$	$T(\text{R}) = T(°\text{F}) + 459.67 = 1.8\,T(\text{K})$ $T(°\text{F}) = 1.8\,T(°\text{C}) + 32$ $\Delta T(°\text{F}) = \Delta T(\text{R}) = 1.8\,\Delta T(\text{K})$
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 × 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)

[†]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	σ = 5.6704 × 10^{-8} W/m^2 · K^4 = 0.1714 × 10^{-8} Btu/h · ft^2 · R^4
Boltzmann's constant	k = 1.380650 × 10^{-23} J/K
Speed of light in vacuum	c_o = 2.9979 × 10^8 m/s = 9.836 × 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