UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
MARCH 2025 SEMESTER SESSION

SUBJECT CODE	:	**LGB23803**
SUBJECT TITLE	:	**THERMODYNAMICS**
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	**BET IN (OFFSHORE) WITH HONOURS & BET IN NAVAL ARCHITECTURE AND SHIPBUILDING WITH HONOURS**
TIME / DURATION	:	**2.00 PM - 5.00 PM (3 HOURS)**
DATE	:	**23 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 ONE (1) Section ONLY. Answer FOUR (4) questions ONLY.
4. Please write your answers on the answer booklet provided.
5. Answer all questions in English language ONLY.
6. Answer should be written in blue or black ink except for sketching, graphic and illustration.
7. Refer to the attached formula / appendices

THERE ARE 4 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 100 marks)

Answer FOUR (4) questions.

Please use the answer booklet provided.

Question 1

a) Water at a depth of 5 meters has absolute pressure reading of 145 kPa. Determine the local atmospheric pressure at this location and the absolute pressure at the same depth in a liquid with a specific gravity of 0.85. In a different calculation, convert the local atmospheric pressure and the absolute pressure into kN/m^2 and lbf/in^2. Show the necessary unit conversion used in your solution.

(21 marks)

b) Define absolute pressure and gage pressure. Explain how they are measured and describe the meaning of vacuum pressure.

(4 marks)

Question 2

a) A rigid 80-liter container holds 4 kg of R-134a refrigerant at a pressure of 160 kPa. Determine the temperature, the quality, the specific enthalpy, and the volume occupied by the vapor phase. Also, draw a complete P-v diagram with respect to the saturation lines.

(21 marks)

b) Define the term 'quality' as it applies to saturated mixtures in thermodynamics and explain what the values of 0 and 1 signify.

(4 marks)

Question 3

a) Steam enters a nozzle steadily at 1.8 MPa and 400°C with an inlet cross-sectional area of 0.02 m^2 as shown in Figure 1. The mass flow rate of the steam is 5 kg/s. The steam exits the nozzle at 1.4 MPa with a velocity of 275 m/s. Heat loss from the nozzle is estimated to be 2.8 kJ per kilogram of steam. Determine the velocity of the steam at the nozzle inlet and the temperature of the steam at the nozzle exit.

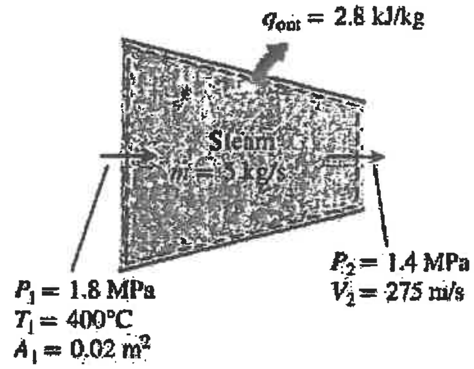

Figure 1 Steam entering a nozzle

(21 marks)

b) Explain why heat transfer, work interactions, and potential energy changes are typically neglected in their analysis and identify which form of energy change must be considered.

(4 marks)

Question 4

a) An ideal Otto cycle has a compression ratio of 8. At the start of the compression stroke, the air is at 100 kPa and 17°C. During the constant-volume heat addition process, 800 kJ/kg of heat is added to the air. Considering the variation of specific heats with temperature, determine the temperature, pressure and internal energy at the end of isentropic compression and the maximum temperature and pressure in the cycle.

(21 marks)

b) Explain how high compression ratios can lead to engine knocks in spark-ignition engines and discuss why autoignition is undesirable in such engines by referring to Figure 2.

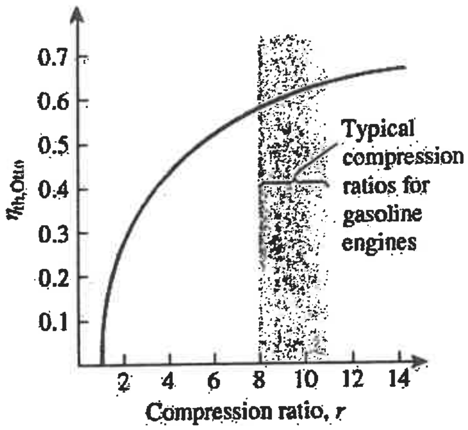

Figure 2 Thermal efficiency versus the compression ratio plot for Otto cycle

(4 marks)

Question 5

a) A steam power plant operates on a basic ideal Rankine cycle. Steam enters the turbine at 3 MPa and 350°C and is condensed in the condenser at 75 kPa. Calculate the amount of heat entering the boiler and the amount of heat rejected by the condenser.

(21 marks)

b) Explain how fluid friction affects the performance of a steam power plant and describe how engineers compensate for its effects in the system.

(4 marks)

Question 6

(a) An ideal vapor-compression refrigeration system uses R-134a as the working fluid and operates between pressures of 0.16 MPa and 900 kPa. Given that the refrigerant has a mass flow rate of 162 kg/h, determine the temperature at the compressor outlet, the rate of heat extraction from the refrigerated space, the compressor's power input, the rate of heat rejection to the surroundings, and the system's coefficient of performance (COP).

(21 marks)

(b) Discuss why refrigerant is slightly superheated before entering the compressor in a real vapor-compression refrigeration cycle and explain the impact of this condition on compressor performance.

(4 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULA

First Law of Thermodynamics
Density, $\rho = \frac{m}{V}$
Specific Gravity, $SG = \frac{\rho}{\rho_{H_2O}}$
Specific Weight, $\gamma_s = \rho g$
Gage Pressure, $P_{gage} = P_{abs} - P_{atm}$
Vacuum Pressure, $P_{vac} = P_{atm} - P_{abs}$
Kinetic Energy, $KE = \frac{mV^2}{2}$
Potential Energy, $PE = mgz$
Total energy, $E = U + KE + PE$
Heat transfer, $Q = \dot{Q}\Delta t$
Work, $W = Fs$
Force, $F = PA$
Spring Force, $F = kx$
Electrical work, $W_e = VI\Delta t$
Shaft work, $W_{sh} = 2\pi nT$
Shaft power, $\dot{W}_{sh} = 2\pi\dot{n}T$
Spring Work, $W_{spring} = \frac{1}{2}k(x_2^{\,2} - x_1^{\,2})$
Enthalpy, $H = U + PV$
Quality, $x = \frac{m_g}{m_{total}}$ $x = \frac{y - y_f}{y_{fg}}$ where $y = v, u$ or h
Mass total $m_{total} = m_f + m_g$
Ideal gas equation $PV = mRT$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

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 $\Delta Q - \Delta W = \Delta U + \Delta KE + \Delta PE$
Energy Balance for a constant pressure process $W_b + \Delta U = \Delta H$ $Q - W_{other} = \Delta H + \Delta KE + \Delta PE$
Conservation of mass and energy equations for steady-flow process $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m}[h + \frac{V^2}{2} + gz] - \sum_{in} \dot{m}[h + \frac{V^2}{2} + gz]$
Boundary work (P = constant), $W_b = mP_0(v_2 - v_1)$
Boundary work (T = constant), $W_b = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$
Energy balance for a steady-flow process $\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$ $\dot{E}_{in} = \dot{E}_{out}$
Mass flow rate, $\dot{m} = \rho AV = \rho\dot{V} = \frac{\dot{V}}{v}$
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 $COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$ $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$
Carnot Heat Engine
$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$

Carnot Refrigerators and Heat Pumps
$COP_R, carnot = \frac{1}{T_H / T_L - 1}$
$COP_R, carnot = \frac{1}{1 - T_L / T_H}$
Entropy
$S_{gen} = \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} \geq 0$
$\Delta S = m(s_2 - s_1)$
The Entropy Change of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$s_2 - s_1 = c_{v,avg}\, ln\frac{T_2}{T_1} + R\, ln\frac{v_2}{v_1}$
$s_2 - s_1 = c_{p,avg}\, ln\frac{T_2}{T_1} - R\, ln\frac{P_2}{P_1}$
Variable Specific Heats (Exact Analysis)
$s_2 - s_1 = s_2^o - s_1^o - R\, ln\frac{P_2}{P_1}$
Isentropic Processes of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$\left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{k-1}$
$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$
$\left(\frac{P_2}{P_1}\right) = \left(\frac{v_1}{v_2}\right)^{k}$
Variable Specific Heats (Exact Analysis)
$\left(\frac{P_2}{P_1}\right) = \frac{P_{r2}}{P_{r1}}$
$\left(\frac{v_2}{v_1}\right) = \frac{v_{r2}}{v_{r1}}$
Isentropic Efficiency of Turbine, $\eta_T = \frac{w_a}{w_s} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
Isentropic Efficiency of Compressors, $\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$
Isentropic Efficiency of Pump, $\eta_P = \frac{w_s}{w_a} \cong \frac{v(P_2 - P_1)}{h_{2a} - h_1}$

Isentropic Efficiency of Nozzle, $\eta_N = \frac{V_{2a}^2}{V_{2s}^2} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
Gas Power Cycle
Compression ratio, $r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$
Mean Effective Pressure, $MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}}$
Otto Cycle
$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$
$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$
Diesel Cycle
$q_{in} - w_{b,out} = u_3 - u_2 \rightarrow q_{in} = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$-q_{out} = u_1 - u_4 \rightarrow q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$
$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$
$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$
Rankine Cycle
Pump $(q = 0)$: $w_{pump,in} = h_2 - h_1$ where $h_1 = h_{f@P_1}$
or $w_{pump,in} = v(P_2 - P_1)$ where $v \cong v_1 = v_{f@P_1}$
Boiler $(w = 0)$: $q_{in} = h_3 - h_2$
Turbine $(q = 0)$: $w_{turb,out} = h_3 - h_4$
Condenser $(w = 0)$: $q_{out} = h_4 - h_1$
$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$
Isentropic Efficiencies for Pumps and Turbines
$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$
$\eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$

Ideal Reheat Rankine Cycle
$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$
$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$
Partial Pressure of Dry Air and Water vapor
$P = P_a + P_v$
Enthalpy of Dry Air and Water vapor
$h_{dry\ air} = c_p T = (1.005 kJ/kg.^o C)T$
$\Delta h_{dry\ air} = c_p \Delta T = (1.005 kJ/kg.^o C)\Delta T$
$h_v(T, low\ P) \cong h_g(T)$
$h_g(T) \cong 2500.9 + 1.82T$
Specific and Relative Humidity of Air
$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = \frac{P_v/R_v}{P_a/R_a} = 0.622\frac{P_v}{P_a} = \frac{0.622P_v}{P - P_v}$
$\emptyset = \frac{m_v}{m_g} = \frac{P_v V/R_v T}{P_g V/R_g T} = \frac{P_v}{P_g}$ where $P_g = P_{sat@T}$
$\emptyset = \frac{\omega P}{(0.622 + \omega)P_g}$
$\omega = \frac{0.622\emptyset P_g}{P - \emptyset P_g}$
$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$
$\omega_2 = \frac{0.622P_{g_2}}{P_2 - P_{g_2}}$
Total Enthalpy of Atmospheric Air
$H = H_a + H_v = m_a h_a + m_v h_v$
$h = h_a + \omega h_g$
Dew Point Temperature
$T_{dp} = T_{sat@P_v}$

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	σ = 5.6704 × 10^{-8} W/m² · K⁴ = 0.1714 × 10^{-8} Btu/h · ft² · R⁴
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