CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF MARINE ENGINEERING TECHNOLOGY

FINAL EXAMINATION
JANUARY 2016 SEMESTER

COURSE CODE	:	LMD11203
COURSE NAME	:	FUNDAMENTAL THERMODYNAMICS
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	DIPLOMA OF ENGINEERING TECHNOLOGY IN MARINE ENGINEERING
DATE	:	24 MAY 2016
TIME	:	09.00 AM – 11.30 AM
DURATION	:	2 HOURS 30 MINUTES

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) sections; Section A and Section B.
4. Answer ALL questions in Section A. For Section B, answer TWO (2) questions only.
5. Please write your answers on the answer booklet provided.
6. Answer all questions in English language ONLY.

THERE ARE 7 PAGES OF QUESTIONS, EXCLUDING THIS PAGE.

SECTION A (Total: 60 Markah)

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

Question 1

(a) Convert :

i. Pressure of 20 N/cm^2 into Pa

(3 Marks)

ii. Density of 5.5 g/l into kg/m^3

(3 Marks)

iii. Temperature of 36^0C into ^0F

(3 Marks)

(b) The mass of a copper cube of sides 2.5cm is 240g. Calculate the density of copper to the correct number of significant figures in SI units.

(5 Marks)

(c) Distinguish between heat and temperature, and state the Zeroth Law of Thermodynamics.

(6 Marks)

Question 2

(a) Define *path functions* and *point functions*. Give one example for each type of functions.

(5 Marks)

(b) The force F required to compress a spring a distance x is given by $F - F_0 = kx$ (Figure 1) where k is the spring constant and F_0 is the preload. Determine the work required to compress a spring whose spring constant is $k = 4kN/cm$ a distance of one cm starting from its free length where $F_0 = 0kN$. Express your answer in both kN.m and kJ.

(5 Marks)

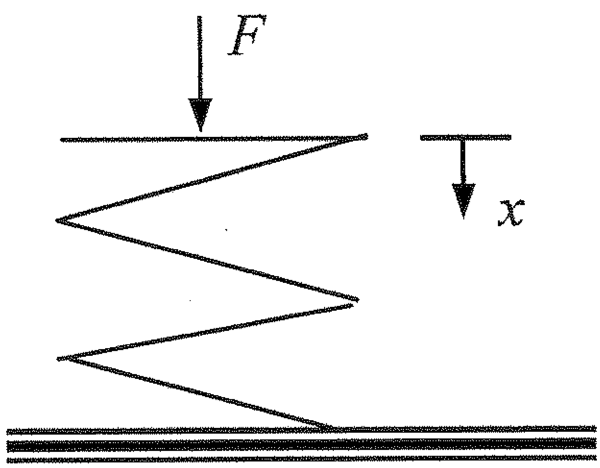

Figure 1: Compression of spring

(c) A 7 hp (shaft) pump is used to raise water to an elevation of 15m. If the mechanical efficiency of the pump is 82 percent:

i. calculate the maximum power for this pump, then

(4 Marks)

ii. determine the maximum volume flow rate of water.

(6 Marks)

Question 3

(a) Define the phases below:

i. Compressed liquid
ii. Saturated liquid
iii. Saturated vapor
iv. Superheated vapor

(4 Marks)

(b) One kilogram of water fills a 0.1546 m^3 weighted piston-cylinder device at a temperature of 350^0C. The piston-cylinder device is now cooled until its temperature is 100^0C. Determine:

i. the final pressure of water, in Mpa

(3 Marks)

ii. the final volume, in m^3

(3 Marks)

(c) Complete this table for refrigerant-134a: (*show all the calculations involved*)

(10 Marks)

Table 1: Refrigerant-134a Properties

T (^0C)	P (kPa)	h (kJ/kg)	X	Phase Description
(a)	600	180	(b)	(c)
-10	(d)	(e)	0.6	(f)
-14	500	(g)	(h)	(i)
(j)	1200	300.63	(k)	(l)

SECTION B (Total: 40 M).

INSTRUCTION: Answer only TWO (2) questions.
Please use the answer booklet provided.

Question 4

(a) Complete Table 2 below on the basis of the conservation of energy principle for a closed system. Show all the calculations involved.

(10 Marks)

Table 2: Conservation of energy principle

Q_{in}, (kJ)	W_{out}, (kJ)	E_1, (kJ)	E_2, kJ	m, kg	e_2-e_1, kJ/kg
280	(i)	1020	860	3	(ii)
-350	130	550	(iii)	5	(iv)
(v)	260	300	(vi)	2	-150
300	(vii)	750	500	1	(viii)

(b) A 3 m^3 rigid tank contains hydrogen at 250 kPa and 500K. The gas is now cooled until its temperature drops to 350K. Determine the:

i. final pressure in the tank and

(3 Marks)

ii. amount of heat transfer.

(7 Marks)

Question 5

(a) Distinguish between nozzle and diffuser in terms of it functions, velocity of fluid flow, fluid pressure and cross section area for inlet and outlet. You may sketch a cross-section illustration for each device.

(8 Marks)

(b) Steam enters a nozzle at 400°C and 800 kPa with a velocity of 10 m/s, and leaves at 300°C and 200 kPa while losing heat at a rate of 25kW as shown in Figure 2. For an inlet area of 800 cm², determine the :

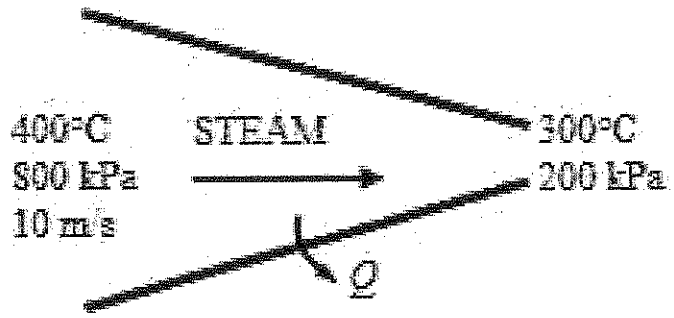

Figure 2: Nozzle

i. velocity at the nozzle exit, $V_2 (m/s)$

(9 Marks)

ii. volume flowrate of the steam at the nozzle exit, $\dot{V} (m^3/s)$

(3 Marks)

Question 6

(a) Draw with a label the basic components of a refrigeration system and typical operating conditions.

(8 Marks)

(b) A heat engine is operating on a Carnot cycle and has a thermal efficiency of 55 percent. The waste heat from this engine is rejected to a nearby lake at 15^{0}C at a rate of 800kJ/min as shown in Figure 3. Determine the :

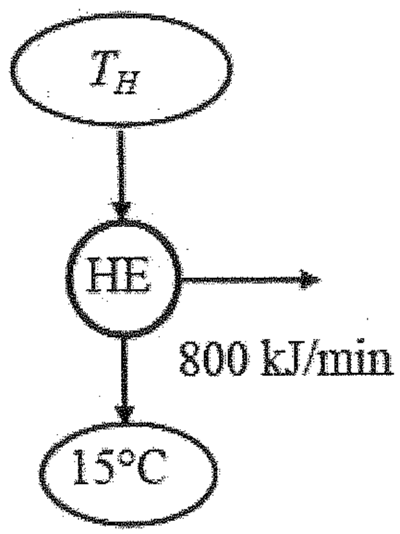

Figure 3: Heat Engine

i. power output of the engine (kW), and

(4 Marks)

ii. temperature of the source.

(3 Marks)

(c) During the isothermal heat rejection process of a Carnot cycle, the working fluid experiences an entropy change of -1.3 kJ/K as shown in Figure 4. If the temperature of the heat sink is 35^{0}C, determine the:

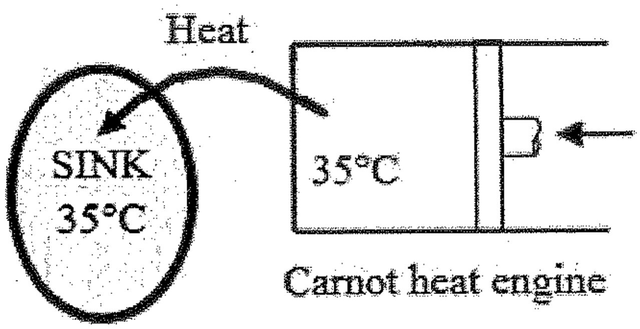

Figure 4: Carnot Heat Engine

i. the amount of heat transfer (kJ),

(3 Marks)

ii. the entropy change of the sink, (ΔS_{sink}).

(3 Marks)

iii. the total entropy change for this process (ΔS_{total}).

(1 Mark)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULA

First Law of Thermodynamics
Kinetic Energy, $KE = \frac{mV^2}{2}$
Potential Energy, $PE = mgz$
Total energy, $E = U + KE + PE$
Heat transfer, $Q = \dot{Q}\Delta t$
$W = Fs$
Force, $F = PA$
Spring Force, $F = kx$
Electrical work, $W_e = VI\Delta t$
Shaft work $W_{sh} = 2\pi nt$
Spring Work, $W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$
Enthalpy, $H = U + PV$
Quality, $x = \frac{m_g}{m_{total}}$
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 $Q - W = \Delta U + \Delta KE + \Delta PE$
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 $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m}[h + V^2/2 + gz] - \sum_{in} \dot{m}[h + V^2/2 + gz]$
Boundary work (P = constant), $W_b = mP_0(v_2 - v_1)$
Boundary work (T = constant), $W_b = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
Mass flow rate $\dot{m} = \rho AV = \rho\dot{V} = \dot{V}/v$
Volume flow rate $\dot{V} = VA = \dot{m}/\rho$

Thermal efficiency of a Heat Engine
$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$
Coefficient of performance
$COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L}$ $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L}$
Carnot Heat Engine
$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$
Carnot Refrigerators and Heat Pumps
$COP_R, carnot = \frac{1}{T_H / T_L - 1}$
$COP_R, carnot = \frac{1}{1 - T_L / T_H}$
Isentropic Process
$s_2 = s_1$
$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$
$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$
$\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_2}{v_1}\right)^{k}$
$\left(\frac{P_2}{P_1}\right)_{s=const.} = \frac{P_{r2}}{P_{r1}}$
$\left(\frac{v_2}{v_1}\right)_{s=const.} = \frac{v_{r2}}{v_{r1}}$
Power Cycles
Compression ratio, $r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$
$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} = \frac{w_{net}}{v_{\max} - v_{\min}}$
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, $\eta_{th,Otto} = \frac{W_{net}}{Q_{in}} = 1 - \frac{q_{out}}{q_{in}}$
$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$
Diesel Cycle
$q_{in} = u_3 - u_2 = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
Cutoff ratio, $r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$
$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$
Rankine Cycle
$w_{pump,in} = h_2 - h_1 = v(P_2 - P_1)$
$q_{in} = h_3 - h_2$
$w_{turb,out} = h_3 - h_4$
$q_{out} = h_4 - h_1$
$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$
$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$
$x_4 = \frac{s_4 - s_f}{s_{fg}}$
$h_4 = h_f + x_4 h_{fg}$
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(K) = T(°C) + 273.15 ΔT(K) = ΔT(°C)	T(R) = T(°F) + 459.67 = 1.8T(K) T(°F) = 1.8 T(°C) + 32 ΔT(°F) = ΔT(R) = 1.8 ΔT(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)

[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	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