CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF MARINE ENGINEERING TECHNOLOGY

FINAL EXAMINATION
SEPTEMBER 2016 SEMESTER

COURSE CODE	:	LGB11803
COURSE NAME	:	THERMODYNAMICS 1
PROGRAMME NAME	:	BET IN MARINE ENGINEERING
DATE	:	25 JANUARY 2017
TIME	:	9.00 A.M. – 11.30 A.M.
DURATION	:	2½ HOURS

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.
4. Answer FOUR (4) questions ONLY.
5. Please write your answers on the answer booklet provided.
6. Answer all questions in English language ONLY.
7. Thermodynamics Table of Properties and Formula have been appended for your reference.

THERE ARE 5 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 100 marks)

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

Question 1

A 0.9 m^3 rigid tank initially contains saturated refrigerant-134a vapor at 1200kPa. As a result of heat transfer from the refrigerant, the pressure drops to 400kPa. Determine:

(a) the final temperature, T_2

(6 marks)

(b) the amount of the refrigerant that has condensed

(10 marks)

(c) the amount of heat transfer, Q_{out}

(9 marks)

Question 2

Steam at 4MPa and 400°C enters a nozzle steadily with a velocity of 60m/s, and leaves at 2MPa and 300°C. The inlet area of the nozzles is 50cm², and heat is being lost at a rate of 75kJ/s. Calculate:

(a) the mass flow rate of the steam, $\dot{m}$ in *kg/s*

(9 marks)

(b) the exit velocity of the steam, V_2 in *m/s*

(12 marks)

(c) the exit area of the nozzle, A_2 in m^2

(4 marks)

Question 3

A Carnot heat engine receives heat from a reservoir at 900°C at a rate of 800kJ/min and rejects the waste heat to the ambient air at 27°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at - 5°C and transfer it to the same ambient air at 27°C as shown in Figure 1. Determine:

(a) the thermal efficiency for heat engine, $\eta_{th,rev}$,

(4 marks)

(b) the maximum power output of heat engine, $\dot{W}_{net,out}$,

(4 marks)

(c) the coefficient of performance, $COP_{R,rev}$ of Carnot refrigerator,

(4 marks)

(d) the maximum rate of heat removal from the refrigerated space, $\dot{Q}_{L,R}$ and

(4 marks)

(e) the total rate of heat rejection to the ambient air, ($\dot{Q}_{L,HE}$ and $\dot{Q}_{H,R}$)

(9 marks)

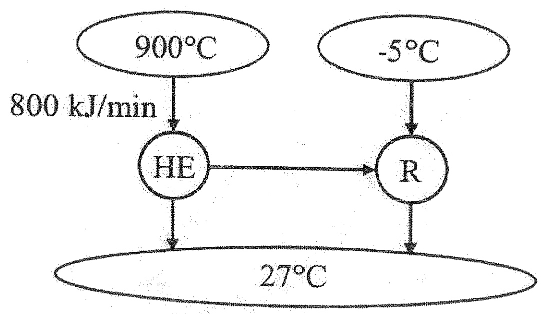

Figure 1: A refrigerator powered by a heat engine

Question 4

A rigid tank contains 5kg of saturated vapor steam at 100°C. The steam is cooled to the ambient temperature of 25°C.

(a) Determine the entropy change of the steam, in kJ/K.

(10 marks)

(b) For the steam and its surroundings, determine the total entropy change associated with this process, in kJ/K

(10 mark)

(c) Sketch the T-v diagram for this process

(5 marks)

Question 5

An air standard Diesel cycle has a compression ratio of 16 and cutoff ratio of 2. At the beginning of the compression process, air is at 95kPa and 27°C as shown in Figure 2. Accounting for the constant specific heats at room temperature, determine:

(a) the temperature after the heat addition process

(10 marks)

(b) the thermal efficiency, and

(10 marks)

(c) the mean effective pressure

(5 marks)

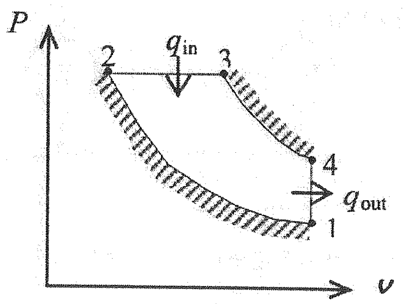

Figure 2: Diesel cycle

Question 6

An ideal vapor-compression refrigeration cycle that uses refrigerant-134a as its working fluid maintains a condenser at 800kPa and the evaporator at -12°C as shown in Figure 3. Determine:

(a) the mass flow rate of the refrigerant, $\dot{m}$ in kg/s

(10 marks)

(b) the amount of power required to service a 150kW cooling load, $\dot{W}_{in}$

(4 marks)

(c) The coefficient of performance, COP_R of the refrigerator

(4 marks)

(d) Sketch the cycle on a *T-s* diagram with respect to saturation lines.

(7 marks)

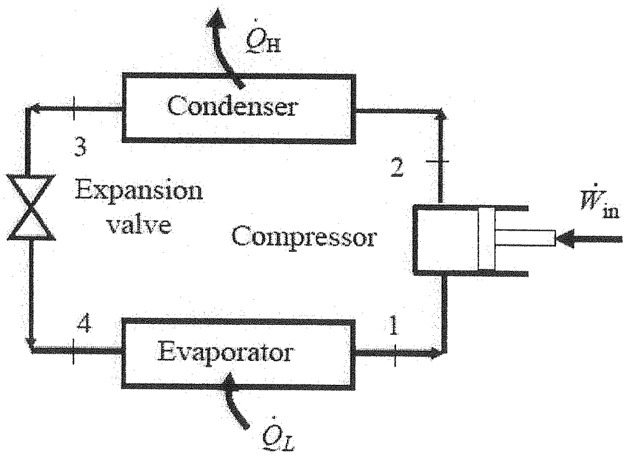

Figure 3: Ideal Vapor-Compression Refrigeration Cycle

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, $\eta_{th,Otto} = \dfrac{W_{net}}{Q_{in}} = 1 - \dfrac{q_{out}}{q_{in}}$
$\eta_{th,Otto} = 1 - \dfrac{1}{r^{k-1}}$
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, $r_c = \dfrac{V_3}{V_2} = \dfrac{v_3}{v_2}$
$\eta_{th,Diesel} = 1 - \dfrac{1}{r^{k-1}}\left[\dfrac{r_c^k - 1}{k(r_c - 1)}\right]$
Rankine Cycle
$w_{pump,in} = h_2 - h_1 = v(P_2 - P_1)$
$q_{in} = h_3 - h_2$
$w_{turb,out} = h_3 - h_4$
$q_{out} = h_4 - h_1$
$\eta_{th} = \dfrac{w_{net}}{q_{in}} = 1 - \dfrac{q_{out}}{q_{in}}$
$w_{net} = q_{in} - q_{out} = w_{turb,in} - w_{pump,in}$
$x_4 = \dfrac{s_4 - s_f}{s_{fg}}$
$h_4 = h_f + x_4 h_{fg}$
Refrigeration Cycle
$W_{net,out} = Q_H - Q_L$
$\eta_{th} = \dfrac{W_{net,out}}{Q_H} = 1 - \dfrac{Q_L}{Q_H}$
$COP_R = \dfrac{Q_L}{W_{net,in}} = \dfrac{q_L}{w_{net,in}} = \dfrac{Q_L}{Q_H - Q_L} = \dfrac{h_1 - h_4}{h_2 - h_1}$
$COP_{HP} = \dfrac{Q_H}{W_{net,in}} = \dfrac{q_H}{w_{net,in}} = \dfrac{Q_H}{Q_H - Q_L} = \dfrac{h_2 - h_3}{h_2 - h_1}$
$COP_{HP} = COP_R + 1$

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 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 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 m³ = 1000 L = 10⁶ cm³ (cc)	1 m³ = 6.1024 × 10⁴ 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 = 10⁶ cm³/s	1 m³/s = 15,850 gal/min (gpm) = 35.315 ft³/s = 2118.9 ft³/min (cfm)

[1]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 × 10⁸ m/s = 9.836 × 10⁸ 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