CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF MARINE ENGINEERING TECHNOLOGY

FINAL EXAMINATION
SEPTEMBER 2016 SEMESTER

COURSE CODE	:	LGB 31503
COURSE NAME	:	THERMODYNAMICS
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	BACHELOR OF ENGINEERING TECHNOLOGY IN NAVAL ARCHITECTURE AND SHIPBUILDING
DATE	:	25 JANUARY 2017
TIME	:	09.00 AM – 11.30 AM
DURATION	:	2 ½ 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. Answers should be written in blue or black ink except for sketches, graphics and illustrations.
8. Thermodynamics Table of Properties and Formula has been appended for your reference.

THERE ARE 7 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 100 marks)

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

Question 1

0.05 m^3 of liquid water and 0.9 m^3 of water vapor in equilibrium are contained in a piston-cylinder device at 600 kPa as shown in Figure 1. The water is now heated at constant pressure until the temperature reaches 200 °C.

(a) Determine the initial temperature of the water, T_1 and explain.

(4 marks)

(b) Calculate the total mass of the water, m_t

(9 marks)

(c) Determine the final volume, V_2 and its phase.

(7 marks)

(d) Sketch the process on a $P-v$ diagram with respect to saturation lines.

(5 marks)

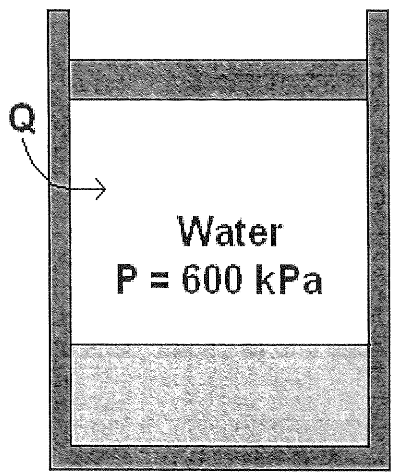

Figure 1: Piston cylinder containing water

Question 2

A rigid tank is divided into two equal parts by a partition. Initially, one side of the tank contains 5 kg of water at 200 kPa and 25 °C and the other side is evacuated as shown in Figure 2. The partition is then removed and the water expands into the entire tank. The water is allowed to exchange heat with its surrounding until the temperature in the tank returns to the initial value of 25 °C.

(a) Determine the volume of the tank, $V_{\tan k}$

(5 marks)

(b) Calculate the final pressure, P_2 and

(7 marks)

(c) Calculate the heat transfer for this process, Q_{in} .

(13 marks)

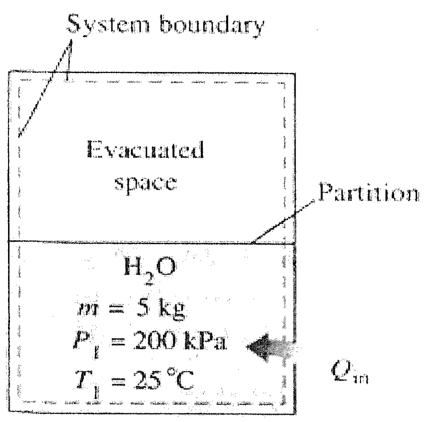

Figure 2: Tank divided into two equal parts by a partition

Question 3

The compressor in a refrigerator compresses saturated R-134a vapor at -18 °C to 1.4 MPa.

(a) State the assumptions and expressed the energy balance for this steady flow system in the rate form.

(8 marks)

(b) Calculate the work required, w_{in} by this compressor, in kJ/kg, when the compression process is isentropic.

(14 marks)

(c) Sketch the *T-s* diagram for this process.

(3 marks)

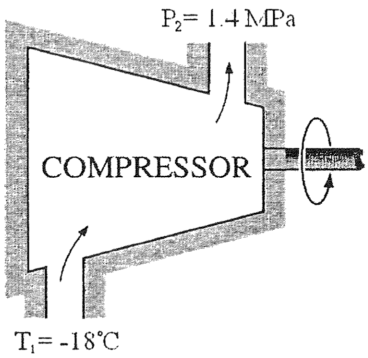

Figure 3: Compressor compresses saturated R-134a vapor

Question 4

A four-cylinder spark ignition engine that operates on ideal Otto cycle has a compression ratio of 10.5. At the beginning of the compression process, the air is at 98 kPa and 310 K and the temperature at the end of constant-volume heat addition process is 1827 °C as shown in Figure 4. Accounting for the variation of specific heats with temperature, determine the followings;

(a) The amount of heat supplied to the air, Q_{in}

(15 marks)

(b) The thermal efficiency, η_{th}

(10 marks)

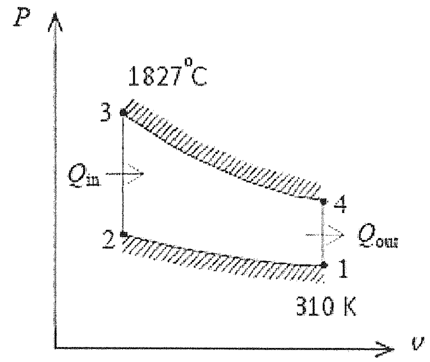

Figure 4: Otto cycle

Question 5

A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.14 MPa and 0.8 MPa as shown in Figure 5. If the mass flow rate of the refrigerant is 0.05 kg/s.

(a) The rate of heat removal, $\dot{Q}_L$ from the refrigerated space and

(16 marks)

(b) The rate of power input, $\dot{W}_{in}$ to the compressor,

(4 marks)

(c) The rate of heat rejection, $\dot{Q}_H$ to the environment, and

(3 marks)

(d) The coefficient of performance, COP of the refrigerator

(2 marks)

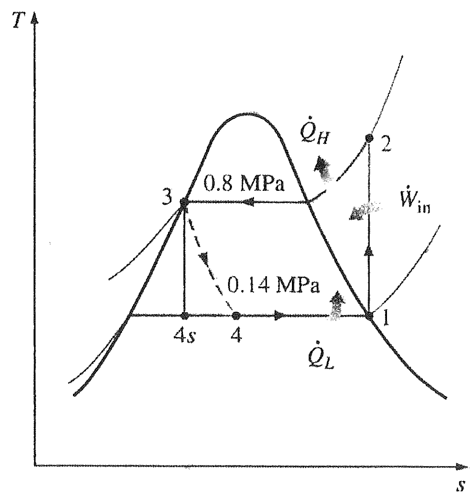

Figure 5: Ideal Vapor-Compression Refrigeration Cycle

Question 6

Saturated humid air at 200 kPa and 15°C is heated to 30°C as it flows through a 2 cm radius pipe at a velocity of 1200 m/min as shown in Figure 6. Disregarding pressure losses, determine

(a) The relative humidity at the pipe outlet, ϕ_2

(4 marks)

(b) The volume flow rate at the pipe inlet, $\dot{V}_1$

(3 marks)

(c) The mass flow rate of dry air, $\dot{m}_a$, and

(7 marks)

(d) The rate of heat transfer, in kW, to the air.

(11 marks)

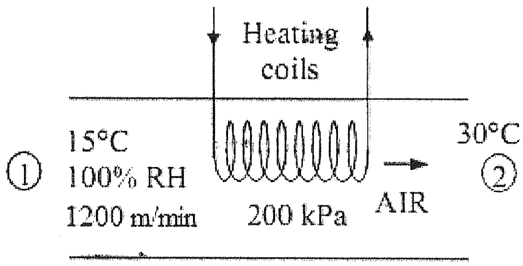

Figure 6: Air flows through heating coil

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULA

First Law of Thermodynamics
$KE = \frac{mV^2}{2}$
$PE = mgz$
$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out})$
$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
$Q = \dot{Q}\Delta t$
$Electrical\ power,\ \dot{W}_e = VI\ (kW)$
$Electrical\ work,\ W_e = VI\Delta t\ (kJ)$
$W = Fs$
$Shaft\ work,\ W_{sh} = 2\pi nt$
$F = kx$
$F = PA$
$Spring\ work,\ W_{spring} = \frac{1}{2}k(x_2{}^2 - x_1{}^2)$
$H = U + PV$
$Quality,\ x = \frac{m_g}{m_{total}}$
$m_{total} = m_f + m_g$
$v_{fg} = v_g - v_f$
$v_1 = v_f + x_1 v_{fg}$
$u_1 = u_f + x_1 u_{fg}$
$Pv = RT$
$PV = mRT$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$Pv = ZRT$

$W = W_b = \int_1^2 P dV$
$w = Pv$
Entropy
$dS = \left(\frac{dQ}{T}\right)_{\text{int } rev}$
$\Delta S = \frac{Q}{T_o}$
$S_{gen} \geq 0$
$s_2 - s_1 = c_{avg} \ln \frac{T_2}{T_1}$
$s_2 - s_1 = c_{v,avg} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$
$s_2 - s_1 = c_{p,avg} \ln \frac{T_2}{T_1} - R \ln \frac{v_2}{v_1}$
$s_2 - s_1 = s^o{}_2 - s^o{}_1 - R \ln \frac{P_2}{P_1}$
$w_{rev} = -\int_1^2 v dP - \Delta ke - \Delta pe$
$w_{rev} = -v(P_2 - P_1) - \Delta ke - \Delta pe$
(isentropic) $w_{comp,in} = \frac{kR(T_2 - T_1)}{k-1} = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$
(polytropic) $w_{comp,in} = \frac{nR(T_2 - T_1)}{n-1} = \frac{nRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$
(isothermal) $w_{comp,in} = RT \ln \frac{P_2}{P_1}$
$\eta_T = \frac{w_a}{w_s} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
$\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$

$$\eta_P = \frac{w_s}{w_a} = \frac{v(P_2 - P_1)}{h_{2a} - h_1}$$
Carnot Heat Engine
$$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$$
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
$$r = \frac{V_{\max}}{V_{\min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$$
$$MEP = \frac{W_{net}}{V_{\max} - V_{\min}} = \frac{w_{net}}{v_{\max} - v_{\min}}$$
Otto Cycle
$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$
$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$
$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$
$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = \left(\frac{v_3}{v_4}\right)^{k-1} = \frac{T_4}{T_3}$$
$$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

Diesel Cycle

$$q_{in} = u_3 - u_2 = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

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

$$\dot{Q}_L = \dot{m}(h_1 - h_4)$$

$$\dot{Q}_H = \dot{m}(h_2 - h_3)$$

$$\dot{W}_{in} = \dot{m}(h_2 - h_1)$$

$$W_{in} = Q_H - Q_L$$

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

Heat Pump

$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$
$COP_{HP} = COP_R + 1$
Total Pressure
$P = P_a + P_v$ (kPa)
Partial Pressure of Water Vapor
$P_v = \phi P_g = \phi P_{sat@T}$
Specific Humidity of Air
$\omega = \frac{m_v}{m_a} = \frac{P_v V / R_v T}{P_a V / R_a T} = \frac{P_v / R_v}{P_a / R_a} = 0.622 \frac{P_v}{P_a}$
$\omega_2 = \frac{0.622 P_{g_2}}{P - P_{g_2}}$ (kg water vapor/kg dry air)
$\omega_1 = \frac{c_p (T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1 - h_{f_2}}}$
Relative Humidity of Air
$\phi_1 = \frac{m_v}{m_a} = \frac{P_v V / R_v T}{P_g V / R_v T} = \frac{P_v}{P_g}$ where $P_g = P_{sat@T}$
$\phi_1 = \frac{\omega_1 P_1}{(0.622 + \omega_1) P_{g_1}}$
Enthalpy of Air
$H = H_a + H_v = m_a h_a + m_v h_v$
$h = h_a + \omega h_g \cong c_p T + \omega h_g$ (kJ/kg dry air)

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	$T(K) = T(°C) + 273.15$ $\Delta T(K) = \Delta T(°C)$	$T(R) = T(°F) + 459.67 = 1.8T(K)$ $T(°F) = 1.8\ T(°C) + 32$ $\Delta T(°F) = \Delta T(R) = 1.8\ \Delta T(K)$
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 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

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).