University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER I EXAMINATIONS - 2011/2012

School of Mechanical and Materials Engineering

MEEN10050 Energy Engineering

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Time Allowed: 2 Hours

Instructions for Candidates

50 Marks (out of 100) are allocated for Section A (MCQ), based on all 20 Questions.

- Questions A1 to A20 carry equal marks (+2.5 marks each).
- Negative marks apply for incorrect answers (-0.625 marks each)
- Zero mark applies for a blank answer on any question.

Please complete **MULTIPLE CHOICE "ANSWER SHEET"** *using* ***HP Pencil.***

50 Marks (out of 100) are allocated for Section B are based on any 2 Questions (25 marks each). The distribution of marks in the right margin give an approximate indication of the relative importance of each part of the question.

Fluid Property Data and Formulae are included at the end of this document.

Instructions for Invigilators

Please supply one Answer Book and one MULTIPLE CHOICE "ANSWER SHEET" to each Candidate.

Non-programmable calculators are permitted.
No rough-work paper is to be provided for candidates.

50 Marks are allocated for Section A (MCQ), based on all 20 Questions.

Question A1.
Consider a person standing in a well ventilated room where the air temperature is at 22°C and where the interior surfaces are each at a temperature of 18°C. The exposed surface area and temperature of the person are 1.6 m^2 and 29°C respectively. The emissivity ε of skin is 0.95 and the convection heat transfer coefficient is 4.0 $W.m^{-2}.K^{-1}$. The rate of heat loss from the person by convection will be?

(A) 44.8 W

(B) 42.6 W

(C) 70.4 W

(D) 115.9 W

Question A2.

Consider steady state heat conduction through the plane glass window of a building, where the thickness is 0.008 m, the height is 1.6 m and the width is 0.8 m. The heat transfer area for the window is?

(A) 0.000064 m^2

(B) 0.0128 m^2

(C) 1.28 m^2

(D) 2.0 m^2

Question A3.
The units for heat flux are

(A) $J.s^{-1}$

(B) $W.m^{-2}$

(C) $W.m^{-1}.K^{-1}$

(D) $W.m^{-2}.K^{-1}$

Question A4.
Consider a brick wall, 5.0 m high, 8.0 m wide and 180 mm thick, where the thermal conductivity of the brick is 0.8 $W.m^{-1}.K^{-1}$. During a particular one-hour period, the temperatures of the inner and outer surfaces were measured to be 15°C and 4°C respectively. The average rate of heat transfer by conduction through the wall during that hour is?

(A) 0.512 kW

(B) 7.2 kW

(C) 99.0 kW

(D) 1.96 kW

Question A5.
An engine crankshaft rotates at 2400 $rev.min^{-1}$ and transmits a torque of 24.0 N.m to its load. The engine power output is

(A) 57.6 kW

(B) 960 W

(C) 6.03 kW

(D) 10.0 kW

Question A6.

A 1.8 kW electric kettle has a heating element that consists of flat circular plate with a diameter of 180mm. When in operation, the heat flux at the interface between the plate and the water will be

(A) 70.3 $kW.m^{-2}$

(B) 0.0324 m^2

(C) 55.6 $kW.m^{-1}$

(D) 55.6 $kW.m^{-2}$

Question A7.

A liquid tank in the shape of a vertical circular cylinder contains water at 60°C. The tank diameter is 1.2 m and the depth of liquid is 3.16m. The upper surface of the liquid is exposed to an atmospheric pressure of 97.2 kPa. The pressure acting on the bottom surface of the tank will be

(A) 98.4 kPa

(B) 100.36 kPa

(C) 127.7 kPa

(D) 128.2 kPa

Question A8.

The State Postulate reads: "The state of a simple compressible substance is completely specified by two independent, intensive properties".

A pressure vessel contains a mixture of 0.20 kg of liquid and 0.80 kg of vapour H_2O in equilibrium at a Temperature T = 125°C. The state of this substance is completely specified by

(A) P = 232.1 kPa, T = 125°C

(B) m = 1.0 kg, H = 2275.8 kJ

(C) T = 125°C, H = 2275.8 kJ

(D) P = 232.1 kPa, h = 2275.8 kJ/kg

Question A9.

A vehicle with a mass of 15000 kg travels along a horizontal road and decelerates from 80 km.h^{-1} to 50 km.h^{-1} over a distance of 150m. The change in potential energy is;

(A) 45.0 MJ

(B) 30 MJ

(C) 2.26 MJ

(D) 0.0 MJ

Question A10.

H_2O is stored in a rigid vessel at 200 kPa, 120.0^{o}C. Is this

(A) Superheated vapour ?

(B) Sub-cooled liquid ?

(C) Saturated vapour ?

(D) Saturated liquid ?

Question A11.

The specific enthalpy of a mixture of liquid and vapour (in equilibrium) is given by

(A) $\boxed{h_{mixture} = h_g + (x).(h_f)}$

(B) $\boxed{h_{mixture} = h_f + (x).(h_g)}$

(C) $\boxed{h_{mixture} = h_f - (x).(h_{fg})}$

(D) $\boxed{h_{mixture} = (1-x).h_f + (x).h_g}$

Question A12.

Heat is added to a closed vessel of constant pressure containing 0.1 kg of carbon dioxide (CO_2) gas. The heat input needed to increase the temperature of the gas from 20^{o}C to 80^{o}C is

(A) 2.000 kJ

(B) 3.942 kJ

(C) 5.076 kJ

(D) 6.030 kJ

Question A13.

An adiabatic process involving an ideal gas in a closed system is one in which

(A) No heat is transferred

(B) Temperature remains constant

(C) Pressure remains constant

(D) No work is done

Question A14.

1.2 kg of liquid water at atmospheric pressure is heated electrically in an insulated kettle from 17.5 to 60.06^{o}C over a time period of 106.7 seconds. The average electric power is?

(A) 1.0 kW

(B) 2.0 kW

(C) 3.0 kW

(D) 4.0 kW

Question A15.

The units of enthalpy H are

(A) J

(B) J.kg^{-1}

(C) J.kg^{-1}.K^{-1}

(D) J.m^{-3}

Question A16.

The quality of a liquid-vapour mixture in equilibrium is

(A) The volume fraction in vapour form (%)

(B) The volume fraction in liquid form (%)

(C) The mass fraction in liquid form (%)

(D) The mass fraction in vapour form (%)

Question A17.

Air is trapped in a closed cylinder at an initial temperature of 76.85^{o}C. The pressure is held constant whilst the volume is doubled. The final temperature of the gas is

(A) 153.7^{o}C

(B) 38.425^{o}C

(C) 76.85^{o}C

(D) 426.85^{o}C

Question A18.

The correct sequence of processes occurring in a vapour compression refrigeration cycle is

(A) Throttling, Evaporation, Compression, Condensation

(B) Compression, Expansion, Throttling, Evaporation

(C) Compression, Evaporation, Throttling, Condensation

(D) Intake, Compression, Evaporation, Expansion, Condensation

Question A19.

The amount of an ideal gas contained in vessel at a pressure P and a temperature T is given by

(A) $\boxed{m = \frac{R.T}{P.V}}$

(B) $\boxed{n = \frac{P.V}{R.T}}$

(C) $\boxed{n = \frac{P.v}{R_u.T}}$

(D) $\boxed{m = \frac{P.V}{R.T}}$

Question A20.

A gas expands in a closed container during a polytropic process where the index n = 1.3416. The initial pressure is 1.8 MPa. If the volume trebles during the process will the final pressure be

(A) 1.800 MPa

(B) 1.3416 MPa

(C) 0.600 MPa

(D) 0.412 MPa

SECTION B (50 Marks) (please use an Answer Book)

Marks for Section B are based on any two Questions (25 marks each)

Question B1

Consider a 1.2 m high and 1.2 m wide single-layer of glass window whose thickness is 8 mm and which has a thermal conductivity k_{glass} = 1.1 $W.m^{-1}.K^{-1}$. The room is maintained at 20°C and the outside air is at minus 3 °C. Determine;

(a) the steady state rate of heat transfer through this glass window, (10 marks)
(b) the overall heat transfer coefficient, and (8 marks)
(c) the temperature of its outer surface for a time during the day (7 marks)

Assume that the heat transfer coefficients at the inner and outer surfaces of the window to be h_i = 6 $W.m^{-2}.K^{-1}$ and h_o = 18 $W.m^{-2}.K^{-1}$ respectively and disregard any heat transfer by radiation.

Question B2

A pneumatic tyre fitted to the wheel of a racing car has an internal volume of 0.01 m^3 and is filled with compressed air. The pressure is 300 kPa (absolute) when the tyre is at an ambient temperature of 20°C. Determine;

(i) the pressure rise (in kPa) if the air temperature in the tyre rises to 80°C under racing conditions, neglecting any changes in the internal volume, (10 marks)
(ii) the mass of air in the tyre, (8 marks)
(iii) the mass of air which must be bled off to restore the pressure to 300 kPa, at 80°C. (7 marks)

Question B3

Write down a mathematical expression for the First Law of Thermodynamics as applied to a steady state, steady flow process, explaining clearly the notation and sign conventions used. (10 marks)

Air at an inlet temperature of 18°C and at a pressure of 100.0 kPa flows at 0.15 kg/s through an insulated circular duct, where the internal diameter is constant throughout at 200 mm. A 2.0 kW electrical resistance element is installed and transfers energy to the flowing air within the duct. Compute;

(i) The air temperature at exit from the duct (°C). (8 marks)
(ii) The air velocity at exit from the duct (m/s). (7 marks)

Properties of H_2O

Table 1: Saturated Water & Steam (extract from Table A-5)

Pressure	Saturation Temp. (°C)	Specific Volume (m^3/kg)		Specific Internal Energy (kJ/kg)			Specific Enthalpy (kJ/kg)			Specific Entropy (kJ/kgK)		
P	T	v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
2 kPa	17.50	0.001001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
10 kPa	45.81	0.001010	14.67	191.8	2246.1	2437.9	191.8	2392.8	2584.7	0.6493	7.5009	8.1502
20 kPa	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
100 kPa	99.63	0.001043	1.6940	417.4	2088.7	2506.1	417.5	2258.0	2675.5	1.3026	6.0568	7.7394
101.325 kPa	100	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
200 kPa	120.23	0.001061	0.8857	504.49	2025.0	2529.5	504.7	2201.9	2706.7	1.5301	5.5970	7.1271
232.1 kPa	125.00	0.001065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
500 kPa	151.86	0.001093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
1.0 MPa	179.91	0.001127	0.19444	761.7	1822.0	2583.6	762.8	2015.3	2778.1	2.1387	4.4478	6.5865
10 MPa	311.06	0.001452	0.018026	1393.0	1151.4	2544.4	1407.7	1317.1	2724.7	3.3596	2.2544	5.6141
14 MPa	336.75	0.001611	0.011485	1548.6	928.2	2476.8	1571.1	1066.5	2637.6	3.6232	1.7485	5.3717
15 MPa	342.24	0.001658	0.010337	1585.6	869.8	2455.5	1610.5	1000.0	2610.5	3.6848	1.6249	5.3098

Table 2: Superheated Steam (extract from Table A-6)

Pressure	Temp. (°C)	Specific Volume (m^3/kg)	Specific Internal Energy (kJ/kg)	Specific Enthalpy (kJ/kg)	Specific Entropy (kJ/kgK)
P	T	v	u	h	s
10 kPa	500	35.679	3132.3	3489.1	9.8978
100 kPa	500	3.565	3131.6	3488.1	8.8342
200 kPa	500	1.7814	3130.8	3487.1	8.5133
1.0 MPa	500	0.3541	3124.4	3478.5	7.7622
10 MPa	500	0.03279	3045.8	3373.7	6.5966
15.0 MPa	500	0.02080	2996.6	3308.6	6.3443

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MEEN 10050 - Energy Engineering Formulae

Heat Transfer

Conduction: $\boxed{\dot{Q}_{\text{conduction}} = -k.A.\dfrac{dT}{dX}}$ Convection: $\boxed{\dot{Q}_{conv} = h.A.(T_{surface} - T_{fluid})}$

Radiation: $\boxed{\dot{Q}_{\text{radiation-net}} = \varepsilon_s.\sigma.A_s.\left(T_s^{\ 4} - T_{\text{surr}}^{\ 4}\right)}$ Stefan-Boltzmann Const. σ = $5.67\text{X}10^{-8}$ W.m^{-2}K^{-4}

Thermal Resistances: $\boxed{R_{cond} = \dfrac{L}{k.A}}$ $\boxed{R_{conv} = \dfrac{1}{h.A}}$

Resistances in Series: $\boxed{R_{total} = R_1 + R_2 = \sum R}$ In Parallel: $\boxed{\dfrac{1}{R_{total}} = \left(\dfrac{1}{R_1} + \dfrac{1}{R_2}\right) = \dfrac{R_1.R_2}{R_1 + R_2}}$

Overall: $\boxed{\dot{Q} = U.A.\Delta T_{overall}}$ $\boxed{\dot{Q} = \dfrac{\Delta T_{overall}}{R_{total}}}$ $\boxed{U.A = 1/R_{total}}$

Single-Layer Plane Wall: $\boxed{\dot{Q} = \dfrac{(T_i - T_o)}{\left(\dfrac{1}{h_i.A} + \dfrac{\Delta x}{k_w.A} + \dfrac{1}{h_o.A}\right)}}$ $\boxed{\dfrac{1}{U_A} = \dfrac{1}{h_i} + \dfrac{\Delta x}{k_w} + \dfrac{1}{h_o}}$

Multi-Layered Plane Wall: $\boxed{R_{total} = R_{conv,1} + R_{wall,1} + R_{wall,2} + R_{conv,2} = \dfrac{1}{h_1.A} + \dfrac{L_1}{k_1.A} + \dfrac{L_2}{k_2.A} + \dfrac{1}{h_2.A}}$

Thermal Contact Resistance $\boxed{R_c = \dfrac{1}{h_c} = \dfrac{\Delta T_{\text{interface}}}{\dot{Q}/A} \quad (m^2.K.W^{-1})}$

Ideal Gases: $\boxed{P.v = R.T}$ $\boxed{P.V = m.R.T}$ $\boxed{C_{P_0} = C_{v_0} + R}$ $\boxed{du = C_{v_0}.dT}$ $\boxed{dh = C_{P_0}.dT}$ $\boxed{u = \int_0^T C_{v_o}\,dT = C_{v_o}.T}$

Specific Heats: $\boxed{C_{v_0} = \left(\dfrac{\partial u}{\partial T}\right)_{v=\text{const}}}$ $\boxed{C_{P_0} = \left(\dfrac{\partial h}{\partial T}\right)_{P=\text{const}}}$

Mixtures of Liquid & Vapour:

Specific Volume $\boxed{v_{mix} = v_f + x.v_{fg}}$ $\boxed{v_{fg} = v_g - v_f}$ $\boxed{V = m.v}$

Specific Internal Energy $\boxed{u_{mix} = u_f + x.u_{fg}}$ $\boxed{u_{fg} = u_g - u_f}$ $\boxed{U = m.u}$

Specific Enthalpy $h = u + P.v$ $\boxed{h_{mix} = h_f + x.h_{fg}}$ $\boxed{h_{fg} = h_g - h_f}$ $\boxed{H = m.h}$

Specific Entropy $\boxed{s_{mix} = s_f + x.s_{fg}}$ $\boxed{s_{fg} = s_g - s_f}$ $\boxed{S = m.s}$ $\boxed{dS = \left(\dfrac{\delta Q}{T}\right)_{\text{int. rev}}}$

$\boxed{x = (m_{vapour})/(m_{total})}$

Work: $\delta W = \int P.dV \quad _{(rev)}$ $\quad {}_1W_2 = \int_1^2 \delta W = \int_1^2 P.dV$ $\quad {}_1W_2 = P(V_2 - V_1)$ {constant P}

$${}_1W_2 = \frac{P_2.V_2 - P_1V_1}{1-n}$$ {polytropic: $P.V^n = \text{constant}$, $n \neq 1.0$ }

$${}_1W_2 = P_1V_1 \cdot \ln\left(\frac{V_2}{V_1}\right)$$ {P.V=constant}

$$W_{\text{net cycle}} = \oint_{cycle} P.dV$$

First Law: $\oint \delta Q = \oint \delta W$ (cycle) $\quad \delta Q = dE + \delta W$ (process)

First Law - System:

$${}_1Q_2 = U_2 - U_1 + \frac{m(\overline{V}_2^2 - \overline{V}_1^2)}{2} + m.g.(Z_2 - Z_1) + {}_1W_2 \qquad \dot{Q} = \frac{dE}{dt} + \dot{W}$$

First Law - Control Volume:

$$\dot{Q}_{cv} + \sum \dot{m}_i (h_i + \overline{V_i^2}/2 + gZ_i) = \sum \dot{m}_e (h_e + \overline{V_e^2}/2 + gZ_e) + \dot{W}_{cv} + \frac{d}{dt}\left(U + m.\overline{V}^2/2 + m.g.Z\right)$$

SSSF: $$\dot{Q}_{cv} + \sum \dot{m}_i (h_i + \overline{V_i^2}/2 + gZ_i) = \sum \dot{m}_e (h_e + \overline{V_e^2}/2 + gZ_e) + \dot{W}_{cv}$$

$\dot{m} = \rho.A.\overline{V}_{average}$ **SSSF** $\quad q_{cv} + h_i + \overline{V_i^2}/2 + gZ_i = h_e + \overline{V_e^2}/2 + gZ_e + w_{cv}$

Heat Engines: 1st Law: $W_{net,out} = Q_{in} - Q_{out}$ Efficiency: $\eta_{th} = \frac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \frac{W_{net,out}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$

I.C. Engine $\quad i.m.e.p = \frac{\oint_{cycle} P.dV}{V_d} \quad i.m.e.p = \frac{P_i}{\left(N/n_r\right)V_d} \quad \dot{W} = \omega.T = 2.\pi.N.T \ \{N \, in \ rev.s^{-1}\}$

Refrigeration: $C.O.P._R = \frac{\dot{Q}_L}{\dot{W}_{in}}$ **Heat Pump**: $C.O.P._{HP} = \frac{\dot{Q}_H}{\dot{W}_{in}}$

***Additional Data** which may or may not be required.* (Sections A and B)

0^oC = 273.15 K
R_u = 8314.5 J.kg^{-1}.K^{-1}
R_{air} = 287.0 J.kg^{-1}.K^{-1}
$R_{nitrogen}$ = 296.8 J.kg^{-1}.K^{-1}
$R_{\text{water vapour}}$ = 461.9 J.kg^{-1}.K^{-1}
$R_{\text{carbon dioxide (CO2)}}$ = 189 J.kg^{-1}.K^{-1}
M_{air} = 28.96 kg.kmol^{-1}
$M_{\text{oxygen (O2)}}$ = 32.0 kg.kmol^{-1}
$M_{\text{nitrogen (N2)}}$ = 28.0 kg.kmol^{-1}
$M_{\text{carbon dioxide (CO2)}}$ = 44.0 kg.kmol^{-1}
$M_{\text{water vapour (H2O)}}$ = 18.0 kg.kmol^{-1}

C_p for air = 1005 J.kg^{-1}.K^{-1}
C_v for air = 718 J.kg^{-1}.K^{-1}
C_p for liquid water = 4180 J.kg^{-1}.K^{-1}
C_p for nitrogen = 1039 J.kg^{-1}.K^{-1}
C_v for nitrogen = 743 J.kg^{-1}.K^{-1}
C_p for carbon dioxide = 846 J.kg^{-1}.K^{-1}
C_v for carbon dioxide = 657 J.kg^{-1}.K^{-1}
Approx. composition of air:
3.76 kmol N_2 : 1 kmol O_2
Acceleration due to gravity g = 9.81 m.s^{-2}
Standard Atmospheric Press.
= 101.325 kPa (760 mm Hg)