University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER I EXAMINATIONS - 2013/2014

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* ***HB Pencil.***

50 Marks (out of 100) are allocated for Section B are based on any 2 Questions (25 marks each). Numbers in ( ) brackets indicate marks allocated to each part of a question.

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

Instructions for Invigilators

Candidates should be supplied with one MCQ Answer Sheet and One Answer Book.

Non-programmable calculators are permitted.

No rough-work paper is to be provided for candidates.

Section A Multiple Choice - (please use MCQ Answer Sheet)

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

Question A1.

Cooling of an electronic power transistor is assisted by attaching it to an aluminium heat sink. The electrical power to be dissipated is 0.3 watts, the exposed surface area of the heat sink is $0.002 m^2$, the convection heat transfer coefficient is $6.0 W.m^{-2}.K^{-1}$ and the ambient temperature is 20^oC. Assuming steady state conditions and ignoring radiation effects, the surface temperature of the heat sink will be

(A) 20^oC

(B) 25^oC

(C) 45^oC

(D) 70^oC

Question A2.

Which of the following statements about a material is true?

(A) A high U-value is a good insulator, and a high R-value is a good insulator.

(B) A high U-value is a good conductor, and a high R-value is a good conductor.

(C) A high U-value is a good insulator, and a high R-value is a good conductor.

(D) A high U-value is a good conductor, and a high R-value is a good insulator.

Question A3.

The units for heat flux are

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

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

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

(D) W

Question A4.

Steady state, one-dimensional, heat conduction occurs through a 100 mm thick concrete wall ($k = 0.8 W.m^{-1}.K^{-1}$) where the temperatures at the inner and outer faces are maintained at 17^oC and 7^oC respectively. The rate of heat transfer per m^2 of wall area will be

(A) $160 W.m^{-2}$

(B) $80 W.m^{-2}$

(C) $40 W.m^{-2}$

(D) $20 W.m^{-2}$

Question A5.

Considering the emissivity ε of a radiating heat transfer surface, which of the following expressions is correct?

(A) $0 \le \varepsilon \le 1.0$

(B) $\varepsilon < 0.0$

(C) $\varepsilon \propto \sigma.T^4$

(D) $\varepsilon > 1.0$

Question A6.

A 2.0 kW electric kettle has a heating element that consists of flat circular plate with a diameter of 150mm. When in operation, the heat flux at the interface between the plate and the water will be

(A) $113.2 kW.m^{-2}$

(B) $0.1414 m^2$

(C) $452.8 kW.m^{-1}$

(D) $452.8 kW.m^{-2}$

Question A7.

A well insulated external wall of a building has a U-value of $0.80 W•m^{-2}•K^{-1}$. The ambient air temperature is 0^oC and the room air temperature is 20^oC. The interior convection coefficient is $4 W•m^{-2}•K^{-1}$ and exterior convection coefficient is $16 W•m^{-2}•K^{-1}$. What is the temperature of the interior surface?

(A) 0^oC

(B) 10^oC

(C) 18^oC

(D) 20^oC

Question A8.

An engine crankshaft rotates at 3000 $rev.min^{-1}$ and transmits a torque of 30.0 N.m to its load. The engine power output is

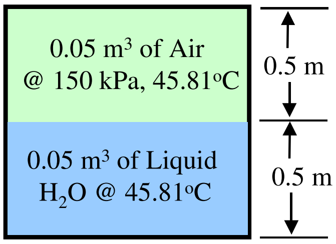
(A) 1.50 kW

(B) 90.0 kW

(C) 30 kW

(D) 9.42 kW

Question A9.



Air and liquid water (each at the same temperature of 45.81°C) are contained in a rigid circular cylinder, as shown. The air pressure is set at 150 kPa and the total internal volume is 0.10 m^3. The maximum pressure in the liquid water is

(A) 154.86 kPa

(B) 160 kPa

(C) 150 kPa

(D) 145.14 kPa

Question A10.

Air is trapped in a rigid vessel, the internal volume of which remains constant. The initial temperature and pressure are 300°C and 300 kPa respectively. Heat loss occurs such that the air temperature reduces to 150°C. The new air pressure in the vessel will be

(A) 150 kPa

(B) 221.5 kPa

(C) 300 kPa

(D) 406.5 kPa

Question A11.

The units of internal energy U are

(A) J

(B) $J.kg^{-1}$

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

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

Question A12.

0.1944 kg of H_2O is stored in a rigid vessel at 1.0 MPa, 200°C. Is this

(A) Saturated vapour?

(B) Saturated liquid?

(C) Superheated vapour?

(D) Sub-cooled liquid?

Question A13.

A rigid tank contains a saturated mixture of liquid and vapour water at 500 kPa. The dryness fraction *x* is 0.10. What is the specific volume of the mixture?

(A) 0.03749 $m^3 \bullet kg^{-1}$

(B) 0.03847 $m^3 \bullet kg^{-1}$

(C) 0.3541 $kg \bullet m^{-3}$

(D) 3.565 $m^3 \bullet kg^{-1}$

Question A14.

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) 0.412 MPa

(B) 0.600 MPa

(C) 1.3416 MPa

(D) 1.800 MPa

Question A15.

0.5 kg of water is contained in a rigid vessel at a temperature of 125°C and a pressure of 232.1 kPa. The specific enthalpy is 1619.2 $kJ \bullet kg^{-1}$. Which of the following could also be correct?

(A) v = 0.001065 m^3/kg

(B) v = 0.7706 m^3/kg

(C) x = 0.5

(D) x = 0.24

Question A16.

A closed Thermodynamic System

(A) Always contains heat

(B) Always contains work

(C) Always has a constant volume

(D) Always has a constant mass

Question A17.

Heat is added to a closed cylinder 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°C to 80°C is

(A) 5.076 kJ

(B) 2.000 kJ

(C) 3.942 kJ

(D) 6.030 kJ

Question A18.

0.8 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 142.3 seconds. What average electric power is required?

(A) 1.0 kW

(B) 1.8 kW

(C) 2.0 kW

(D) 3.0 kW

Question A19.

The pressure of an ideal gas drops significantly as it flows under steady state conditions through an insulated throttle valve. Which of the following does not remain constant?

(A) Temperature

(B) Specific internal energy

(C) Specific enthalpy

(D) Specific entropy

Question A20.

Compression of a refrigerant in the ideal vapour compression refrigeration cycle occurs at constant

(A) Specific entropy

(B) Specific internal energy

(C) Specific enthalpy

(D) Temperature

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

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

Question B1 (25 Marks)

Consider a 1.2 m high and 1.2 m wide single-layer of glass window whose thickness is 10 mm and which has a thermal conductivity $k_{glass} = 0.8$ W.m^{-1}.K^{-1}.
The room is maintained at 22^{o}C and the outside air is minus 1 ^{o}C.

Determine;

(a) the steady state rate of heat transfer through this glass window, (10 marks)
(b) the overall heat transfer coefficient, and (10 marks)
(c) the temperature of its inner surface. (5 marks)

Assume that the heat transfer coefficients at the inner and outer surfaces of the window to be h_i = 3 W.m^{-2}.K^{-1} and h_o = 15 W.m^{-2}.K^{-1} respectively and disregard any heat transfer by radiation.

Question B2 (25 Marks)

During some actual expansion and compression processes in piston-cylinder devices, the gases have been observed to satisfy the relationship $P.V^n = \text{constant}$, where the polytropic index n is also constant.
Assuming such a process to be internally reversible, show that the work done (during a change of state from initial state *1* to final state *2*) is given by;

$$\boxed{{}_1W_2 = \frac{P_2.V_2 - P_1V_1}{1-n}} \quad n \neq 1$$

(10 marks)

A mass of 0.10 kg of air undergoes a polytropic compression in a piston–cylinder assembly from an initial P_1 = 100 kPa and temperature T_1 = 27^{o}C to a final pressure P_2 = 500 kPa. Assuming ideal gas behaviour and a polytropic index n = 1.35, determine;

(1) the final volume, and (8 marks)
(2) the final temperature (^{o}C) (7 marks)

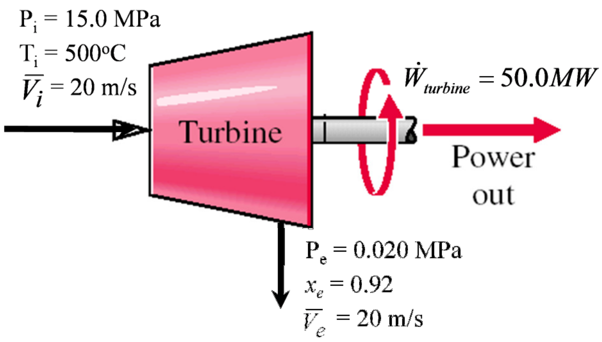
Question B3 (25 Marks)

List the conditions to be met for a thermodynamic process to be accurately described as a steady state, steady flow process. Write down a mathematical expression for the First Law of Thermodynamics as applied to such a process, explaining clearly the notation and sign conventions used.

(8 marks)

Consider steady state, steady flow of steam through a turbine used for electricity generation. You may assume that the process is adiabatic. The steam inlet and exit conditions are listed below;

	Inlet	Exit
Pressure (MPa)	15.0	0.020
Temperature (°C)	500	
Velocity (m/s)	20	20
Dryness Fraction		0.92



Making use of the Data Tables given at the end of this paper, determine;

(i) The outlet temperature of the steam (°C), (5 marks)

(ii) The change in specific enthalpy of the steam (kJ/kg), (5 marks)

(iii) The mass flow rate of steam required to yield a turbine mechanical power output of 50.0 MW (Neglecting potential energy changes and any mechanical friction losses in the turbine).

(7 marks)

oOo

Properties of H_2O

Table 1: Saturated Water & Steam

Pressure	Saturation Temp. (°C)	Specific Volume ($m^3 \cdot kg^{-1}$)		Specific Internal Energy ($kJ \cdot kg^{-1}$)			Specific Enthalpy ($kJ \cdot kg^{-1}$)			Specific Entropy ($kJ \cdot kg^{-1} \cdot K^{-1}$)		
P	$T_{sat.}$	v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.87 kPa	5.00	0.001000	147.01	21.0	2360.8	2381.8	21.02	2489.1	2510.1	0.0763	8.9585	9.0248
2.0 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
12.35 kPa	50.0	0.001012	12.03	209.3	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
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	100.00	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

Pressure	Temp. (°C)	Specific Volume ($m^3 \cdot kg^{-1}$)	Specific Internal Energy ($kJ \cdot kg^{-1}$)	Specific Enthalpy ($kJ \cdot kg^{-1}$)	Specific Entropy ($kJ \cdot kg^{-1} \cdot K^{-1}$)
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

MEEN 10050 - Energy Engineering Formulae

Heat Transfer

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

Radiation: $\dot{Q}_{\text{radiation-net}} = \varepsilon_s.\sigma.A_s.\left(T_s^{\,4} - T_{surr}^{\,4}\right)$ Stefan-Boltzmann Const. σ □□= 5.67X10^{-8} W.m^{-2}K^{-4}

Thermal Resistances (K•W^{-1}): $R_{cond} = \dfrac{L}{k.A}$ $R_{conv} = \dfrac{1}{h.A}$

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

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

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

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

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

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

Mixtures of Liquid & Vapour:

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

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

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

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

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

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}

${}_1W_2 = \dfrac{P_2.V_2 - P_1V_1}{1-n}$ {polytropic: $P.V^n = \text{constant}\ ,\ n \neq 1.0$ } $\quad {}_1\mathrm{W}_2 = \mathrm{P}_1\mathrm{V}_1 \cdot \ln\left(\dfrac{\mathrm{V}_2}{\mathrm{V}_1}\right)$ {P.V=constant}

$\mathrm{W}_{\text{net cycle}} = \oint_{cycle} P.dV$ $\quad P = \omega.T = 2.\pi.N.T$

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

First Law - System: ${}_1Q_2 = U_2 - U_1 + \dfrac{m(\overline{V}_2^2 - \overline{V}_1^2)}{2} + m.g.(Z_2 - Z_1) + {}_1W_2$ $\quad \dot{Q} = \dfrac{dE}{dt} + \dot{W}$

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

$\dot{m} = \rho.A.\overline{V}_{average}$ $\quad$ **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: $W_{net,out} = Q_{in} - Q_{out}$ $\quad$ Efficiency: $\eta_{th} = \dfrac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \dfrac{W_{net,out}}{Q_{in}} = \dfrac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \dfrac{Q_{out}}{Q_{in}}$

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

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

***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}
$R_{water\ vapour}$	= 461.9 J•kg^{-1}•K^{-1}
$R_{carbon\ dioxide\ (CO2)}$	= 189 J•kg^{-1}•K^{-1}
M_{air}	= 28.96 kg•kmol^{-1}
$M_{oxygen\ (O2)}$	= 32.0 kg•kmol^{-1}
$M_{nitrogen\ (N2)}$	= 28.0 kg•kmol^{-1}
$M_{carbon\ dioxide\ (CO2)}$	= 44.0 kg•kmol^{-1}
$M_{water\ vapour\ (H2O)}$	= 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}

Acceleration due to gravity g = 9.81 m.s^{-2}

Standard Atmospheric Press.
= 101.325 kPa (760 mm Hg)

Approx. composition of air:
3.76 kmol N_2 : 1 kmol O_2