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NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2010-2011

MP2010/MP2310 – THERMODYNAMICS AND HEAT TRANSFER

December 2010 Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **THREE** (3) pages.
2. Answer **ALL FOUR** (4) questions.
3. All questions carry equal marks.
4. This is a CLOSED BOOK examination.

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1 (a) In a chemical process, a 10 kg/s of saturated vapour at 600 kPa is needed. However, the steam boiler could only supply 400^{0}C super-heated steam at 1000 kPa. The way to obtain the correct steam supply is to mix the boiler steam with water at 30^{0}C as shown in Figure 1. Calculate the mass flow rate of water and the boiler steam.

(9 marks)

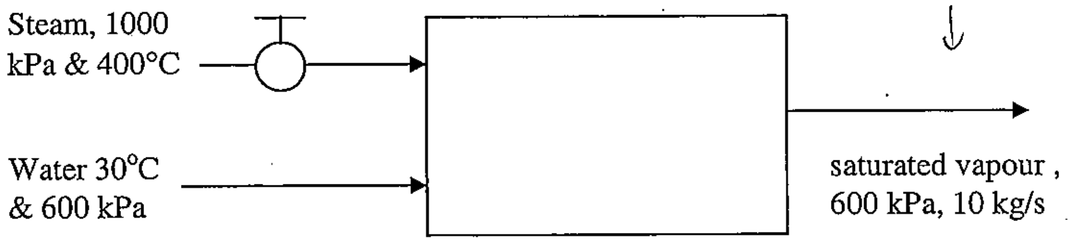


Figure 1

(b) The inner pressure of an automobile tyre depends on the air temperature inside the tyre. When the temperature of the air is 25°C, the guage pressure of the tyre is 210 kPa measured under an ambient pressure of 100 kPa. After a long distance trip up a hill of 90kPa ambient pressure, the tyre air temperature rises to 50°C. Assume the tyre has a constant volume of 0.025 m^3, calculate the measured gauge pressure of air inside the tyre.

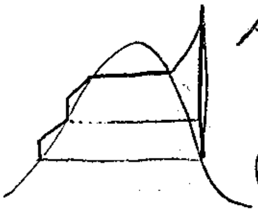
Determine the amount of air to be bled from the tyre to an inflatable rubber bag, which is completely evacuated initially, in order to reinstate the initial tyre gauge pressure if the process is isentropic. Assume that the air in the tyre and the bag is in equilibrium after the transfer process and the volume of the bag is of suitable size.

(16 marks)

Given: Gas constant for air, $R = 0.287$ kJ/kg K and isentropic index = 1.4.

$\frac{C_p}{C_v}$

2. An ideal regenerative Rankine cycle steam power plant uses an open feed water heater. Steam from the boiler at 1.6 MPa and 600°C enters a turbine and leaves the turbine at 10 kPa.



(a) If the regenerator pressure is 1.2 MPa, calculate the proportion of steam, y, that has to be tapped from the turbine and the cycle thermal efficiency.
(15 marks)

(b) If the regenerator pressure is reduced to 800 kPa, what are the values of y and the thermal efficiency? Explain why the thermal efficiency is improved by lowering the regenerator pressure.
(10 marks)

3. An egg was removed from boiling water at temperature T_i = 100°C and then was slowly cooling in an air environment with the ambient temperature T_∞ = 25°C [h = 5 W/(m^2·°C)]. The properties of the egg are as follows: thermal conductivity k = 0.5 W/(m·°C), density ρ = 1350 kg/m^3, and specific heat c = 3320 J/(kg·°C). For the purpose of considering its convective cooling, the egg can be modelled as a ball of mass m = 0.06 kg.

(a) Determine whether the lumped capacitance method can be used to model the egg's convective cooling.
(7 marks)

$V = \frac{m}{\rho}$ $\quad Bi = \frac{hL_c}{k}$ $\quad L_c = \frac{V}{A}$

(b) Using the conservation of energy principle, show that the egg's temperature T, as a function of time t, is given by $T(t) = T_\infty + (T_i - T_\infty)e^{-t/\tau}$, where $\tau = mc/(hA)$ and A is the egg's surface area.
(13 marks)

(c) Estimate the time required for the egg to cool down to T_e = 36°C.
(5 marks)

$T_i = T_0$

$$\frac{d\dot{Q}}{dt} = hA(T - T_\infty)$$

$$d\,kA\left(\frac{T-T_\infty}{l}\right) = hA$$

$$\ln\frac{T - T_\infty}{T_i - T_\infty} = \frac{hA}{mc}t + C_1$$

$$\ln\frac{T(t) - T_\infty}{T_i - T_\infty} = \frac{-t}{\tau} + C$$

4. A person with the skin temperature $T_s = 33°C$ is subjected to the wind velocity $W = 10$ km/h in an environment with the ambient temperature $T_\infty = 25°C$. For the purpose of considering convective heat transfer between such a person and the environment, the person can be modelled as a circular cross-section cylinder of height $H = 1.7$ m and the total surface area $A = 2$ m^2.

$Re_D = \frac{V_\infty D}{\nu}$ $Nu = \frac{hD}{k}$

(a) Determine the total convective heat transfer rate between the person and environment. The kinematic viscosity of air is $\nu = 1.57 \times 10^{-5}$ m^2/s, its thermal conductivity is $k = 0.026$ W/(m·°C), and its thermal diffusivity is $\alpha = 2.21 \times 10^{-5}$ m^2/s. The correlations for computing the Nusselt number, depending on the range of the Reynolds numbers, are as follows:

$Pr = \frac{\nu}{\alpha} = \frac{\mu}{\rho} \cdot \frac{\rho C_p}{k}$

0.1702

Range of Re_D	Nusselt number
0.4 – 4	$Nu_D = 0.989Re_D^{0.330}Pr^{1/3}$
4 – 40	$Nu_D = 0.911Re_D^{0.385}Pr^{1/3}$
40 – 4000	$Nu_D = 0.683Re_D^{0.466}Pr^{1/3}$
→ 4000 – 40000	$Nu_D = 0.193Re_D^{0.618}Pr^{1/3}$
→ 40000 - 400000	$Nu_D = 0.027Re_D^{0.805}Pr^{1/3}$

(17 marks)

(b) Determine the total convective heat transfer rate between the person and environment, if the wind velocity becomes $W = 1$ km/h and all the other conditions remain the same.

(3 marks)

(c) Compare the total convective heat transfer rate with the total amount of radiation emitted by the same person [The value of the Stephan-Boltzmann constant σ is 5.67×10^{-8} W/(m^2·K^4)]. Assume that the emissivity of an average human being is 0.75.

(5 marks)

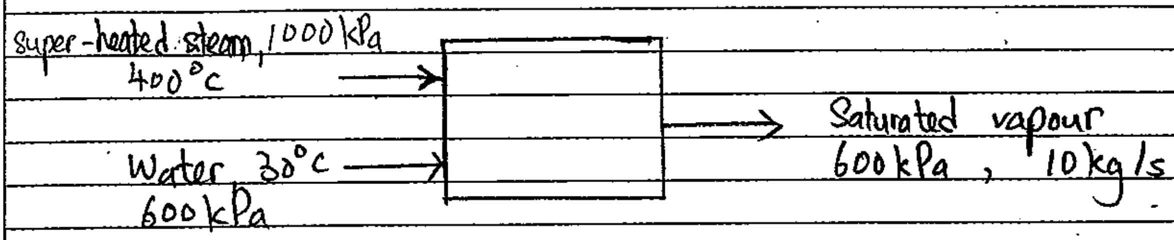
End of Paper

$2\pi r^2 + 3.4\pi r - 2 = 0$

December 2010

MP2310 Thermodynamic and Heat Transfer Pg ①

1 (a)



$m_{in} = m_{out}$ * Law of mass conservation

∵ There is any work done during the process and consider the process is adiabatic

∴ By first law of thermodynamic of open system

$h_{in} = h_{out}$

$(\dot{m}h)_{super\text{-}heated\ steam} + (\dot{m}h)_{water} = (\dot{m}h)_{sat}$

$h_{super\text{-}heated\ steam} = 3263.9$ $h_{sat} = 2756.8$

h_{water} (temp. depend.) $= 125.79$ (kJ/kg)

1 - superheated 2 - water

$\dot{m}_1 + \dot{m}_2 = m_{sat}$

$\dot{m}_1 + \dot{m}_2 = 10\,kg/s$

$\dot{m}_1 = 10 - \dot{m}_2$

$(3263.9)\dot{m}_1 + (125.79)(\dot{m}_2) = (2751.8)(\dot{m}_{sat})$ - ②

$(3263.9)(10 - \dot{m}_2) + (125.79)(\dot{m}_2) = (27518)$

$3138.11\,\dot{m}_2 = 5121$

$\dot{m}_2 = 1.632\,kg/s$

$\dot{m}_1 = 8.368\,kg\,s^{-1}$

b)

P_g - Gause Pressure

$P = P_g + P_{atm}$

At 25°C
$P_g = 210 kPa$ $P_{atm} = 100 kPa$

At 50°C

$P_{atm} = 90 kPa$

* Volume $= 0.025 \; m^3$
constant

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$(210 \times 10^3 + 100 \times 10^3)(50 + 273.15) = (P_2) \times (25 + 273.15)$$

$$P_2 = 335.99 \; kPa$$

$$P_{g_2} = 245.99 \; kPa$$

$\gamma = 1.4$

∵ It is an isentropic process

∵ Air is allow to move to the other vessel
∴ Pressure is constant

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

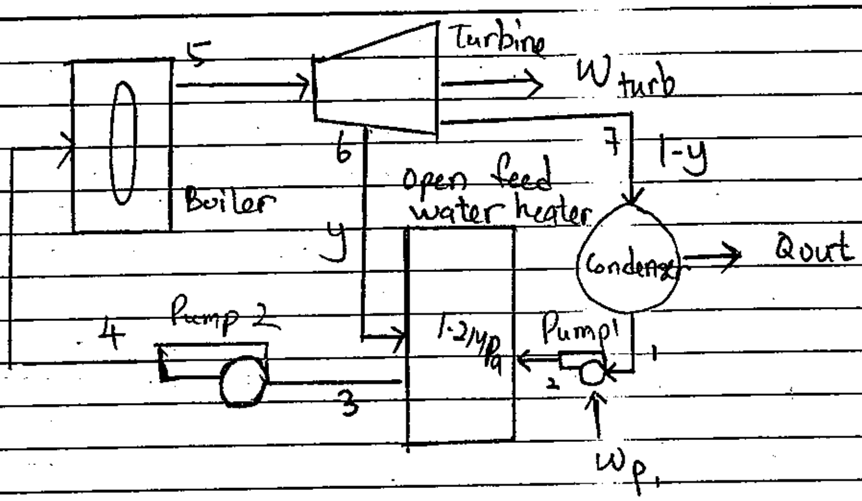
$$V_2 = 0.0271 \; m^3$$

∵ Tyre has fixed volume

∴ $V_{Balloon} = 2.096 \times 10^{-3} \; m^3$

* Comment: I am not able to find a way to solve it with the isentropic constant given. Sorry for that.

2



	P	T	h	s	v	
1	10		191.83		0.00101	
✓2	1200		193.02			
✓3	1200		798.65	2.2166	0.001139	Saturated liquid
4	1600		799.11			
5	1600	600	3693.2	7.8080	0.25	
✓6	1200	549.36	3584.9	7.8080		
7	10		2658.6	7.8080		
	kPa	°C	kJ/kg	kJ/kg.k	m³/kg	

$w_2 = v_3 (P_4 - P_3)$
$= 0.4556$ kJ/kg

$w_1 = v_1 (P_2 - P_1)$
$= 1.202$ kJ/kg

∵ It is an isentropic turbine

$\therefore \quad s_5 = s_6$

$s_5 = s_7$

$$\frac{T_6 - 500}{600 - 500} = \frac{7.8080 - 7.6759}{7.9435 - 7.6759}$$

$T_6 = 549.36$ °C

$s_7 = x s_{fg} + s_f$
$7.808 = 7.5009x + 0.6493$
$x = 0.9544$

$h_7 = 191.83 + 2584.7x$
$= 2658.6$

$$y = \frac{h_3 - h_2}{h_6 - h_2} = 0.1786$$

$W_{turb} = h_5 - y h_6 - (1-y) h_7$

$= 3693.2 - (0.1786)(3584.9) - (1-0.1786)(2658.6)$

$= 869.16$ kJ/kg

$W_{net} = W_{turb} - (1-y) W_{p_1} - W_{p_2}$

$= 869.16 - (1-0.1786)(1.202) - 0.4556$

$= 867.72$ kJ/kg

$\dot{q} = h_5 - h_4$
$= 2899.09$ kJ/kg

$\eta = \frac{W_{net}}{\dot{q}} = 0.30$

b) * repeat the same calculation

$P_3 = P_2 = P_6 = 800$ MPa

$W_{p_1} = 0.7979$

$* h_2 = 192.63$

$h_6 = 3437.78$

$y = 0.1629$

$* h_3 = 721.11$ $v_3 = 0.001115$

$W_{p_2} = 0.892$

$h_4 = 799.542$

$W_{turb} = 907.71$

$W_{net} = 906.15$

$\eta = 0.313$

* Less pump work for the pump 2 which consumed more energy.

3.

$T_i = 100°C \qquad T_\infty = 25°C$

Properties

$h = 5\ W/m^2 °C \qquad k = 0.5\ W/(m \cdot °C)$

$\rho = 1350\ kg/m^3 \qquad c = 3320\ J/kg\ °C$

* ball , $m = 0.06$

a) $\forall = \frac{m}{\rho}$

$= 4.44 \times 10^{-5}\ m^3$

$r = 0.022\ m$

$A = 6.068 \times 10^{-3}\ m^2$

$L_c = \forall / A$

$= 7.317 \times 10^{-3}\ m$

$Bi = \frac{h L_c}{k}$

$= \frac{(5)(7.317 \times 10^{-3})}{0.5}$

$= 0.0732 < 0.1$

∴ Lumped capacitance method is valid

b) $-E_{out} = \Delta E_{stored}$

$-hA_{surf}(T - T_\infty) = du/dt$

$= \rho c \forall\ dT/dt$

$T(0) = T_i$

$$\int \frac{d(T)}{T - T_\infty} = -\int \frac{hA_{surf}}{\rho c \forall}$$

$$\ln(T - T_\infty) = -\frac{hA_{surf}}{\rho c \forall} t + C_1$$

$$T = T_\infty + (T_i - T_\infty) e^{-t/\tau} \qquad \tau = \frac{\rho \forall c}{hA_{surf}}$$

c) $T_0 = 36°$

$36°C = 25°C + (75°C) e^{-t/\tau} \qquad \tau = 65.59 \times 10^3\ s$

$11°C = (75°C) e^{-t/\tau}$

$-1.92 = -t/\tau$

$t = 125.91 \times 10^3\ s$

4.

$T_s = 33°C$ $\quad$ $W = 10\ km/h$
$T_\infty = 25°C$ $\quad$ $= 2.7778\ ms^{-1}$

* circular cross-section cylinder, $H = 1.7m$, $A_{surf} = 2m^2$

a) $\nu = 1.57 \times 10^{-5}\ m^2/s$ $\quad$ $\alpha = 2.21 \times 10^{-5}\ m^2/s$
$k = 0.026\ W/(m \cdot °C)$

$A_{surf} = 2\pi r h + 2\pi r^2$
$0 = 2\pi r^2 + 3.4\pi r - 2$
$r = 0.1702$ or -1.8702

$r = 0.1702\ m$
$D = 0.3404\ m$

$$Re = \frac{(2.778)(0.3404)}{1.57 \times 10^{-5}} = 61404.6$$

$$Pr = \frac{\nu}{\alpha} = \frac{1.57 \times 10^{-5}}{2.21 \times 10^{-5}} = 0.7104$$

$$Nu_D = 0.027 Re_D^{0.805} Pr^{1/3}$$

$$h = (0.026)(0.027 \times 61404.6^{0.805} \times 0.7104^{1/3}) \div 0.3404$$
$$= 13.96\ W/m^2 °C$$

b) $W = 1\ km/h$
$= 0.2778\ ms^{-1}$

$Re = 6023.12$

$$Nu_D = 0.193 Re_D^{0.618} Pr^{1/3}$$

$$h = (0.026)(0.193 \times (6023.12)^{0.618} \times (0.7104)^{1/3}) \div 0.3404$$
$$= 2.857\ W/m^2 °C$$

c)

$\dot{q} = \varepsilon \sigma (T_1^4 - T_2^4)$

$\varepsilon = 0.75$

$\dot{q} = (0.75)(5.67 \times 10^{-8})[(33 + 273.15)^4 - (25 + 273.15)^4]$

$= 37.54 \ Js^{-1}$

Pg (5)

H$_2$O

TABLE A-4

Saturated water—Temperature table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6113	0.001000	206.14	0.0	2375.3	2375.3	0.01	2501.3	2501.4	0.000	9.1562	9.1562
5	0.8721	0.001000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008
15	1.7051	0.001001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	0.2245	8.5569	8.7814
20	2.339	0.001002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	0.2966	8.3706	8.6672
25	3.169	0.001003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	0.3674	8.1905	8.5580
30	4.246	0.001004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	0.4369	8.0164	8.4533
35	5.628	0.001006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	0.5053	7.8478	8.3531
40	7.384	0.001008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	0.5725	7.6845	8.2570
45	9.593	0.001010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	0.6387	7.5261	8.1648
50	12.349	0.001012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	0.7038	7.3725	8.0763
55	15.758	0.001015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	0.7679	7.2234	7.9913
60	19.940	0.001017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	0.8312	7.0784	7.9096
65	25.03	0.001020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	0.8935	6.9375	7.8310
70	31.19	0.001023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	0.9549	6.8004	7.7553
75	38.58	0.001026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001040	1.982	397.88	2102.7	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159
	Sat. press., MPa											
100	0.10135	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
105	0.12082	0.001048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8	1.3630	5.9328	7.2958
110	0.14327	0.001052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5	1.4185	5.8202	7.2387
115	0.16906	0.001056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0	1.4734	5.7100	7.1833
120	0.19853	0.001060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3	1.5276	5.6020	7.1296
125	0.2321	0.001065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
130	0.2701	0.001070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5	1.6344	5.3925	7.0269
135	0.3130	0.001075	0.5822	567.35	1977.7	2545.0	567.69	2159.6	2727.3	1.6870	5.2907	6.9777
140	0.3613	0.001080	0.5089	588.74	1961.3	2550.0	589.13	2144.7	2733.9	1.7391	5.1908	6.9299
145	0.4154	0.001085	0.4463	610.18	1944.7	2554.9	610.63	2129.6	2740.3	1.7907	5.0926	6.8833
150	0.4758	0.001091	0.3928	631.68	1927.9	2559.5	632.20	2114.3	2746.5	1.8418	4.9960	6.8379
155	0.5431	0.001096	0.3468	653.24	1910.8	2564.1	653.84	2098.6	2752.4	1.8925	4.9010	6.7935
160	0.6178	0.001102	0.3071	674.87	1893.5	2568.4	675.55	2082.6	2758.1	1.9427	4.8075	6.7502
165	0.7005	0.001108	0.2727	696.56	1876.0	2572.5	697.34	2066.2	2763.5	1.9925	4.7153	6.7078
170	0.7917	0.001114	0.2428	718.33	1858.1	2576.5	719.21	2049.5	2768.7	2.0419	4.6244	6.6663
175	0.8920	0.001121	0.2168	740.17	1840.0	2580.2	741.17	2032.4	2773.6	2.0909	4.5347	6.6256
180	1.0021	0.001127	0.19405	762.09	1821.6	2583.7	763.22	2015.0	2778.2	2.1396	4.4461	6.5857
185	1.1227	0.001134	0.17409	784.10	1802.9	2587.0	785.37	1997.1	2782.4	2.1879	4.3586	6.5465
190	1.2544	0.001141	0.15654	806.19	1783.8	2590.0	807.62	1978.8	2786.4	2.2359	4.2720	6.5079
195	1.3978	0.001149	0.14105	828.37	1764.4	2592.8	829.98	1960.0	2790.0	2.2835	4.1863	6.4698

TABLE A–5

Saturated water—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.6113	0.01	0.001000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
1.0	6.98	0.001000	129.21	29.30	2355.7	2385.0	29.30	2484.9	2514.2	0.1059	8.8697	8.9756
1.5	13.03	0.001001	87.98	54.71	2338.6	2393.3	54.71	2470.6	2525.3	0.1957	8.6322	8.8279
2.0	17.50	0.001001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
2.5	21.08	0.001002	54.25	88.48	2315.9	2404.4	88.49	2451.6	2540.0	0.3120	8.3311	8.6432
3.0	24.08	0.001003	45.67	101.04	2307.5	2408.5	101.05	2444.5	2545.5	0.3545	8.2231	8.5776
4.0	28.96	0.001004	34.80	121.45	2293.7	2415.2	121.46	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001005	28.19	137.81	2282.7	2420.5	137.82	2423.7	2561.5	0.4764	7.9187	8.3951
7.5	40.29	0.001008	19.24	168.78	2261.7	2430.5	168.79	2406.0	2574.8	0.5764	7.6750	8.2515
10	45.81	0.001010	14.67	191.82	2246.1	2437.9	191.83	2392.8	2584.7	0.6493	7.5009	8.1502
15	53.97	0.001014	10.02	225.92	2222.8	2448.7	225.94	2373.1	2599.1	0.7549	7.2536	8.0085
20	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
25	64.97	0.001020	6.204	271.90	2191.2	2463.1	271.93	2346.3	2618.2	0.8931	6.9383	7.8314
30	69.10	0.001022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	0.9439	6.8247	7.7686
40	75.87	0.001027	3.993	317.53	2159.5	2477.0	317.58	2319.2	2636.8	1.0259	6.6441	7.6700
50	81.33	0.001030	3.240	340.44	2143.4	2483.9	340.49	2305.4	2645.9	1.0910	6.5029	7.5939
75	91.78	0.001037	2.217	384.31	2112.4	2496.7	384.39	2278.6	2663.0	1.2130	6.2434	7.4564
Press., MPa												
0.100	99.63	0.001043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
0.125	105.99	0.001048	1.3749	444.19	2069.3	2513.5	444.32	2241.0	2685.4	1.3740	5.9104	7.2844
0.150	111.37	0.001053	1.1593	466.94	2052.7	2519.7	467.11	2226.5	2693.6	1.4336	5.7897	7.2233
0.175	116.06	0.001057	1.0036	486.80	2038.1	2524.9	486.99	2213.6	2700.6	1.4849	5.6868	7.1717
0.200	120.23	0.001061	0.8857	504.49	2025.0	2529.5	504.70	2201.9	2706.7	1.5301	5.5970	7.1271
0.225	124.00	0.001064	0.7933	520.47	2013.1	2533.6	520.72	2191.3	2712.1	1.5706	5.5173	7.0878
0.250	127.44	0.001067	0.7187	535.10	2002.1	2537.2	535.37	2181.5	2716.9	1.6072	5.4455	7.0527
0.275	130.60	0.001070	0.6573	548.59	1991.9	2540.5	548.89	2172.4	2721.3	1.6408	5.3801	7.0209
0.300	133.55	0.001073	0.6058	561.15	1982.4	2543.6	561.47	2163.8	2725.3	1.6718	5.3201	6.9919
0.325	136.30	0.001076	0.5620	572.90	1973.5	2546.4	573.25	2155.8	2729.0	1.7006	5.2646	6.9652
0.350	138.88	0.001079	0.5243	583.95	1965.0	2548.9	584.33	2148.1	2732.4	1.7275	5.2130	6.9405
0.375	141.32	0.001081	0.4914	594.40	1956.9	2551.3	594.81	2140.8	2735.6	1.7528	5.1647	6.9175
0.40	143.63	0.001084	0.4625	604.31	1949.3	2553.6	604.74	2133.8	2738.6	1.7766	5.1193	6.8959
0.45	147.93	0.001088	0.4140	622.77	1934.9	2557.6	623.25	2120.7	2743.9	1.8207	5.0359	6.8565
0.50	151.86	0.001093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
0.55	155.48	0.001097	0.3427	655.32	1909.2	2564.5	665.93	2097.0	2753.0	1.8973	4.8920	6.7893
0.60	158.85	0.001101	0.3157	669.90	1897.5	2567.4	670.56	2086.3	2756.8	1.9312	4.8288	6.7600
0.65	162.01	0.001104	0.2927	683.56	1886.5	2570.1	684.28	2076.0	2760.3	1.9627	4.7703	6.7331
0.70	164.97	0.001108	0.2729	696.44	1876.1	2572.5	697.22	2066.3	2763.5	1.9922	4.7158	6.7080
0.75	167.78	0.001112	0.2556	708.64	1866.1	2574.7	709.47	2057.0	2766.4	2.0200	4.6647	6.6847
0.80	170.43	0.001115	0.2404	720.22	1856.6	2576.8	721.11	2048.0	2769.1	2.0462	4.6166	6.6628
0.85	172.96	0.001118	0.2270	731.27	1847.4	2578.7	732.22	2039.4	2771.6	2.0710	4.5711	6.6421
0.90	175.38	0.001121	0.2150	741.83	1838.6	2580.5	742.83	2031.1	2773.9	2.0946	4.5280	6.6226
0.95	177.69	0.001124	0.2042	751.95	1830.2	2582.1	753.02	2023.1	2776.1	2.1172	4.4869	6.6041
1.00	179.91	0.001127	0.19444	761.68	1822.0	2583.6	762.81	2015.3	2778.1	2.1387	4.4478	6.5865
1.10	184.09	0.001133	0.17753	780.09	1806.3	2586.4	781.34	2000.4	2871.7	2.1792	4.3744	6.5536
1.20	187.99	0.001139	0.16333	797.29	1791.5	2588.8	798.65	1986.2	2784.8	2.2166	4.3067	6.5233
1.30	191.64	0.001144	0.15125	813.44	1777.5	2591.0	814.93	1972.7	2787.6	2.2515	4.2438	6.4953

Pg ⑥

TABLE A–6

Superheated water

T °C	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	P = 0.01 MPa (45.81°C)[*]				*P* = 0.05 MPa (81.33°C)				*P* = 0.10 MPa (99.63°C)			
Sat.[†]	14.674	2437.9	2584.7	8.1502	3.240	2483.9	2645.9	7.5939	1.6940	2506.1	2675.5	7.3594
50	14.869	2443.9	2592.6	8.1749								
100	17.196	2515.5	2687.5	8.4479	3.418	2511.6	2682.5	7.6947	1.6958	2506.7	2676.2	7.3614
150	19.512	2587.9	2783.0	8.6882	3.889	2585.6	2780.1	7.9401	1.9364	2582.8	2776.4	7.6134
200	21.825	2661.3	2879.5	8.9038	4.356	2659.9	2877.7	8.1580	2.172	2658.1	2875.3	7.8343
250	24.136	2736.0	2977.3	9.1002	4.820	2735.0	2976.0	8.3556	2.406	2733.7	2974.3	8.0333
300	26.445	2812.1	3076.5	9.2813	5.284	2811.3	3075.5	8.5373	2.639	2810.4	3074.3	8.2158
400	31.063	2968.9	3279.6	9.6077	6.209	2968.5	3278.9	8.8642	3.103	2967.9	3278.2	8.5435
500	35.679	3132.3	3489.1	9.8978	7.134	3132.0	3488.7	9.1546	3.565	3131.6	3488.1	8.8342
600	40.295	3302.5	3705.4	10.1608	8.057	3302.2	3705.1	9.4178	4.028	3301.9	3704.4	9.0976
700	44.911	3479.6	3928.7	10.4028	8.981	3479.4	3928.5	9.6599	4.490	3479.2	3928.2	9.3398
800	49.526	3663.8	4159.0	10.6281	9.904	3663.6	4158.9	9.8852	4.952	3663.5	4158.6	9.5652
900	54.141	3855.0	4396.4	10.8396	10.828	3854.9	4396.3	10.0967	5.414	3854.8	4396.1	9.7767
1000	58.757	4053.0	4640.6	11.0393	11.751	4052.9	4640.5	10.2964	5.875	4052.8	4640.3	9.9764
1100	63.372	4257.5	4891.2	11.2287	12.674	4257.4	4891.1	10.4859	6.337	4257.3	4891.0	10.1659
1200	67.987	4467.9	5147.8	11.4091	13.597	4467.8	5147.7	10.6662	6.799	4467.7	5147.6	10.3463
1300	72.602	4683.7	5409.7	11.5811	14.521	4683.6	5409.6	10.8382	7.260	4683.5	5409.5	10.5183
	P = 0.20 MPa (120.23°C)				*P* = 0.30 MPa (133.55°C)				*P* = 0.40 MPa (143.63°C)			
Sat.	0.8857	2529.5	2706.7	7.1272	0.6058	2543.6	2725.3	6.9919	0.4625	2553.6	2738.6	6.8959
150	0.9596	2576.9	2768.8	7.2795	0.6339	2570.8	2761.0	7.0778	0.4708	2564.5	2752.8	6.9299
200	1.0803	2654.4	2870.5	7.5066	0.7163	2650.7	2865.6	7.3115	0.5342	2646.8	2860.5	7.1706
250	1.1988	2731.2	2971.0	7.7086	0.7964	2728.7	2967.6	7.5166	0.5951	2726.1	2964.2	7.3789
300	1.3162	2808.6	3071.8	7.8926	0.8753	2806.7	3069.3	7.7022	0.6548	2804.8	3066.8	7.5662
400	1.5493	2966.7	3276.6	8.2218	1.0315	2965.6	3275.0	8.0330	0.7726	2964.4	3273.4	7.8985
500	1.7814	3130.8	3487.1	8.5133	1.1867	3130.0	3486.0	8.3251	0.8893	3129.2	3484.9	8.1913
600	2.013	3301.4	3704.0	8.7770	1.3414	3300.8	3703.2	8.5892	1.0055	3300.2	3702.4	8.4558
700	2.244	3478.8	3927.6	9.0194	1.4957	3478.4	3927.1	8.8319	1.1215	3477.9	3926.5	8.6987
800	2.475	3663.1	4158.2	9.2449	1.6499	3662.9	4157.8	9.0576	1.2372	3662.4	4157.3	8.9244
900	2.705	3854.5	4395.8	9.4566	1.8041	3854.2	4395.4	9.2692	1.3529	3853.9	4395.1	9.1362
1000	2.937	4052.5	4640.0	9.6563	1.9581	4052.3	4639.7	9.4690	1.4685	4052.0	4639.4	9.3360
1100	3.168	4257.0	4890.7	9.8458	2.1121	4256.8	4890.4	9.6585	1.5840	4256.5	4890.2	9.5256
1200	3.399	4467.5	5147.5	10.0262	2.2661	4467.2	5147.1	9.8389	1.6996	4467.0	5146.8	9.7060
1300	3.630	4683.2	5409.3	10.1982	2.4201	4683.0	5409.0	10.0110	1.8151	4682.8	5408.8	9.8780
	P = 0.50 MPa (151.86°C)				*P* = 0.60 MPa (158.85°C)				* *P* = 0.80 MPa (170.43°C)			
Sat.	0.3749	2561.2	2748.7	6.8213	0.3157	2567.4	2756.8	6.7600	0.2404	2576.8	2769.1	6.6628
200	0.4249	2642.9	2855.4	7.0592	0.3520	2638.9	2850.1	6.9665	0.2608	2630.6	2839.3	6.8158
250	0.4744	2723.5	2960.7	7.2709	0.3938	2720.9	2957.2	7.1816	0.2931	2715.5	2950.0	7.0384
300	0.5226	2802.9	3064.2	7.4599	0.4344	2801.0	3061.6	7.3724	0.3241	2797.2	3056.5	7.2328
350	0.5701	2882.6	3167.7	7.6329	0.4742	2881.2	3165.7	7.5464	0.3544	2878.2	3161.7	7.4089
400	0.6173	2963.2	3271.9	7.7938	0.5137	2962.1	3270.3	7.7079	0.3843	2959.7	3267.1	7.5716
500	0.7109	3128.4	3483.9	8.0873	0.5920	3127.6	3482.8	8.0021	0.4433	3126.0	3480.6	7.8673
600	0.8041	3299.6	3701.7	7.3522	0.6697	3299.1	3700.9	8.2674	0.5018	3297.9	3699.4	8.1333
700	0.8969	3477.5	3925.9	8.5952	0.7472	3477.0	3925.3	8.5107	0.5601	3476.2	3924.2	8.3770
800	0.9896	3662.1	4156.9	8.8211	0.8245	3661.8	4156.5	8.7367	0.6181	3661.1	4155.6	8.6033
900	1.0822	3853.6	4394.7	9.0329	0.9017	3853.4	4394.4	8.9486	0.6761	3852.8	4393.7	8.8153
1000	1.1747	4051.8	4639.1	9.2328	0.9788	4051.5	4638.8	9.1485	0.7340	4051.0	4638.2	9.0153
1100	1.2672	4256.3	4889.9	9.4224	1.0559	4256.1	4889.6	9.3381	0.7919	4255.6	4889.1	9.2050
1200	1.3596	4466.8	5146.6	9.6029	1.1330	4466.5	5146.3	9.5185	0.8497	4466.1	5145.9	9.3855
1300	1.4521	4682.5	5408.6	9.7749	1.2101	4682.3	5408.3	9.6906	0.9076	4681.8	5407.9	9.5575

[*] The temperature in parentheses is the saturation temperature at the specified pressure.

[†] Properties of saturated vapor at the specified pressure.

8

TABLE A-6

Superheated water (*Continued*)

T °C	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	P = 1.00 MPa (179.91°C)				② *P* = 1.20 MPa (187.99°C) *				*P* = 1.40 MPa (195.07°C)			
Sat.	0.19444	2583.6	2778.1	6.5865	0.16333	2588.8	2784.8	6.5233	0.14084	2592.8	2790.0	6.4693
200	0.2060	2621.9	2827.9	6.6940	0.16930	2612.8	2815.9	6.5898	0.14302	2603.1	2803.3	6.4975
250	0.2327	2709.9	2942.6	6.9247	0.19234	2704.2	2935.0	6.8294	0.16350	2698.3	2927.2	6.7467
300	0.2579	2793.2	3051.2	7.1229	0.2138	2789.2	3045.8	7.0317	0.18228	2785.2	3040.4	6.9534
350	0.2825	2875.2	3157.7	7.3011	0.2345	2872.2	3153.6	7.2121	0.2003	2869.2	3149.5	7.1360
400	0.3066	2957.3	3263.9	7.4651	0.2548	2954.9	3260.7	7.3774	0.2178	2952.5	3257.5	7.3026
500	0.3541	3124.4	3478.5	7.7622	0.2946	3122.8	3476.3	7.6759 ←	0.2521	3121.1	3474.1	7.6027
600	0.4011	3296.8	3697.9	8.0290	0.3339	3295.6	3696.3	7.9435	0.2860	3294.4	3694.8	7.8710
700	0.4478	3475.3	3923.1	8.2731	0.3729	3474.4	3922.0	8.1881	0.3195	3473.6	3920.8	8.1160
800	0.4943	3660.4	4154.7	8.4996	0.4118	3659.7	4153.8	8.4148	0.3528	3659.0	4153.0	8.3431
900	0.5407	3852.2	4392.9	8.7118	0.4505	3851.6	4392.2	8.6272	0.3861	3851.1	4391.5	8.5556
1000	0.5871	4050.5	4637.6	8.9119	0.4892	4050.0	4637.0	8.8274	0.4192	4049.5	4636.4	8.7559
1100	0.6335	4255.1	4888.6	9.1017	0.5278	4254.6	4888.0	9.0172	0.4524	4254.1	4887.5	8.9457
1200	0.6798	4465.6	5145.4	9.2822	0.5665	4465.1	5144.9	9.1977	0.4855	4464.7	5144.4	9.1262
1300	0.7261	4681.3	5407.4	9.4543	0.6051	4680.9	5407.0	9.3698	0.5186	4680.4	5406.5	9.2984
	P = 1.60 MPa (201.41°C) ←				*P* = 1.80 MPa (207.15°C)				*P* = 2.00 MPa (212.42°C)			
Sat.	0.12380	2596.0	2794.0	6.4218	0.11042	2598.4	2797.1	6.3794	0.09963	2600.3	2799.5	6.3409
225	0.13287	2644.7	2857.3	6.5518	0.11673	2636.6	2846.7	6.4808	0.10377	2628.3	2835.8	6.4147
250	0.14184	2692.3	2919.2	6.6732	0.12497	2686.0	2911.0	6.6066	0.11144	2679.6	2902.5	6.5453
300	0.15862	2781.1	3034.8	6.8844	0.14021	2776.9	3029.2	6.8226	0.12547	2772.6	3023.5	6.7664
350	0.17456	2866.1	3145.4	7.0694	0.15457	2863.0	3141.2	7.0100	0.13857	2859.8	3137.0	6.9563
400	0.19005	2950.1	3254.2	7.2374	0.16847	2947.7	3250.9	7.1794	0.15120	2945.2	3247.6	7.1271
500	0.2203	3119.5	3472.0	7.5390	0.19550	3117.9	3469.8	7.4825	0.17568	3116.2	3467.6	7.4317
600	0.2500	3293.3	3693.2	7.8080	0.2220	3292.1	3691.7	7.7523	0.19960	3290.9	3690.1	7.7024
700	0.2794	3472.7	3919.7	8.0535	0.2482	3471.8	3918.5	7.9983	0.2232	3470.9	3917.4	7.9487
800	0.3086	3658.3	4152.1	8.2808	0.2742	3657.6	4151.2	8.2258	0.2467	3657.0	4150.3	8.1765
900	0.3377	3850.5	4390.8	8.4935	0.3001	3849.9	4390.1	8.4386	0.2700	3849.3	4389.4	8.3895
1000	0.3668	4049.0	4635.8	8.6938	0.3260	4048.5	4635.2	8.6391	0.2933	4048.0	4634.6	8.5901
1100	0.3958	4253.7	4887.0	8.8837	0.3518	4253.2	4886.4	8.8290	0.3166	4252.7	4885.9	8.7800
1200	0.4248	4464.2	5143.9	9.0643	0.3776	4463.7	5143.4	9.0096	0.3398	4463.3	5142.9	8.9607
1300	0.4538	4679.9	5406.0	9.2364	0.4034	4679.5	5405.6	9.1818	0.3631	4679.0	5405.1	9.1329
	P = 2.50 MPa (223.99°C)				*P* = 3.00 MPa (233.90°C)				*P* = 3.50 MPa (242.60°C)			
Sat.	0.07998	2603.1	2803.1	6.2575	0.06668	2604.1	2804.2	6.1869	0.05707	2603.7	2803.4	6.1253
225	0.08027	2605.6	2806.3	6.2639								
250	0.08700	2662.6	2880.1	6.4085	0.07058	2644.0	2855.8	6.2872	0.05872	2623.7	2829.2	6.1749
300	0.09890	2761.6	3008.8	6.6438	0.08114	2750.1	2993.5	6.5390	0.06842	2738.0	2977.5	6.4461
350	0.10976	2851.9	3126.3	6.8403	0.09053	2843.7	3115.3	6.7428	0.07678	2835.3	3104.0	6.6579
400	0.12010	2939.1	3239.3	7.0148	0.09936	2932.8	3230.9	6.9212	0.08453	2926.4	3222.3	6.8405
450	0.13014	3025.5	3350.8	7.1746	0.10787	3020.4	3344.0	7.0834	0.09196	3015.3	3337.2	7.0052
500	0.13993	3112.1	3462.1	7.3234	0.11619	3108.0	3456.5	7.2338	0.09918	3103.0	3450.9	7.1572
600	0.15930	3288.0	3686.3	7.5960	0.13243	3285.0	3682.3	7.5085	0.11324	3282.1	3678.4	7.4339
700	0.17832	3468.7	3914.5	7.8435	0.14838	3466.5	3911.7	7.7571	0.12699	3464.3	3908.8	7.6837
800	0.19716	3655.3	4148.2	8.0720	0.16414	3653.5	4145.9	7.9862	0.14056	3651.8	4143.7	7.9134
900	0.21590	3847.9	4387.6	8.2853	0.17980	3846.5	4385.9	8.1999	0.15402	3845.0	4384.1	8.1276
1000	0.2346	4046.7	4633.1	8.4861	0.19541	4045.4	4631.6	8.4009	0.16743	4044.1	4630.1	8.3288
1100	0.2532	4251.5	4884.6	8.6762	0.21098	4250.3	4883.3	8.5912	0.18080	4249.2	4881.9	8.5192
1200	0.2718	4462.1	5141.7	8.8569	0.22652	4460.9	5140.5	8.7720	0.19415	4459.8	5139.3	8.7000
1300	0.2905	4677.8	5404.0	9.0291	0.24206	4676.6	5402.8	8.9442	0.20749	4675.5	5401.7	8.8723

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2011-2012

MP2010/MP2310 – THERMODYNAMICS AND HEAT TRANSFER

November/December 2011 Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **SEVEN** (7) pages.
2. Answer **ALL FOUR** (4) questions.
3. All questions carry equal marks.
4. This is a CLOSED BOOK examination.

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1 (a) Liquid water can be considered as an incompressible fluid with a specific volume of 0.001 m^3/kg. Derive the equation for isentropic compression work of water from an initial pressure P_1 to a final pressure P_2. Hence or otherwise, calculate the power of a water pump that compresses 10 kg/sec of water from 100 kPa to 10 MPa.

(12 marks)

(b) An irreversible engine takes in heat from a 800 K source and rejects heat to a 400 K sink. The engine work is delivered through an irreversible gear box (with frictional losses) to drive an irreversible refrigerator. The refrigerator removes 240 kW of heat from a 240 K reservoir and reject heat to the same 400 K reservoir used by the engine. Given that the combined heat rejection to the 400 K reservoir is 800 kW and both the thermal efficiency of the engine and the COP of the refrigerator are only 80% of the respective Carnot cycle and reversed Carnot cycle operated between the same reservoirs

Calculate the thermal efficiency of the irreversible engine, the COP of the irreversible refrigerator and the power loss through the irreversible gear box.

(13 marks)

9

2 (a) The turbine cycle, shown in Figure 1, has a pressure ratio of 14 and isentropic efficiencies of both the compressor and turbine are 87%. Calculate the cycle thermal efficiency using $C_p = 1.005$ kJ/kg °C and $k = 1.4$.

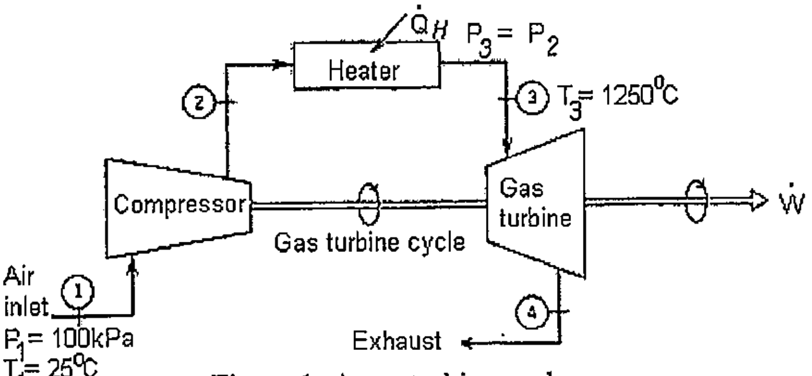

Figure 1: A gas turbine cycle

(7 marks)

(b) Saturated water of a steam power cycle, as shown in Figure 2, enters the pump at 10 kPa and leaves at 12.5 MPa. The pump isentropic efficiency is 85%. Steam enters the turbine at 500°C and the turbine isentropic efficiency is 87%. Calculate the thermal efficiency of the cycle.

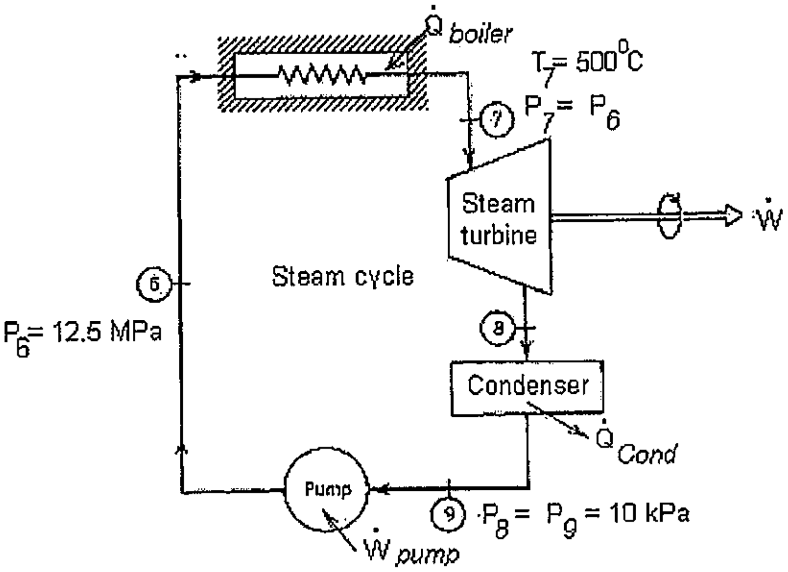

Figure 2: A steam power cycle

(7 marks)

Note: Question 2 continues on page 3.

(c) A combined cycle, as shown in Figure 3, can be arranged by making use of the exhaust gas energy from the gas turbine as heat source for the boiler in the steam power cycle. If the heat input rate to the burner of the gas turbine is 60MW, determine the mass flow rate of air in the gas turbine cycle, the mass flow rate of water in the steam power cycle and the overall thermal efficiency of the combined cycle.

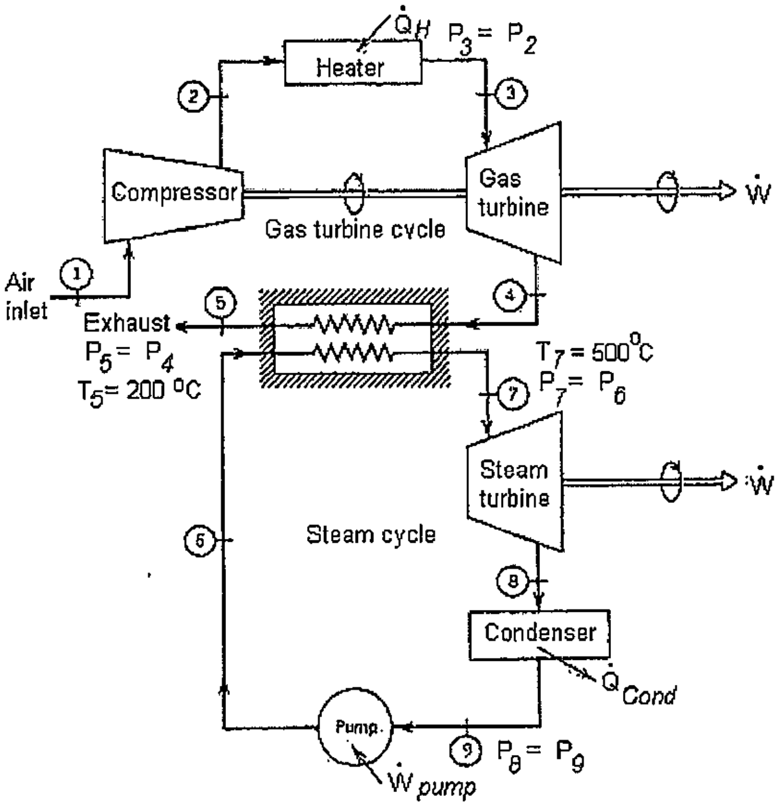

Figure 3: A combined cycle

(9 marks)

(d) Do you anticipate a higher thermal efficiency of the combined cycle than the two cycles operating alone? Please explain.

(2 marks)

Note: You may use Tables 1 and 2 on pages 6 and 7 for water properties.

3. One of the ways to enhance convective heat transfer from a solid surface is to cover this surface with semi-spherical cavities (dimples). As a fluid flow takes place over such a dimpled surface, tornado-like jets are formed inside the dimples. These tornado-like jets suck the near-wall viscous fluid layer out and deliver it to the main stream. Hence, the existence of tornado-like jets within the flow provides better mixing between fluid layers and therefore enhances heat transfer. The enhancement of heat transfer in such a case can be quantified by the Vicente correlation

$$\frac{\mathrm{Nu}}{\mathrm{Nu}_0} = 18.032\eta^{0.12}(\mathrm{Re}-1000)^{-0.21}$$

where Nu_0 is the Nusselt number for the corresponding smooth (without dimples) flat plate, η is the surface density of dimples and the Reynolds number, Re, is based on the diameter of dimples.

Consider a flat plate covered by semi-spherical dimples of diameter d = 1.5 mm with the dimple surface density η = 0.906. The total length of the plate is L = 0.4 m. The surface temperature of the plate is T_s = 60 °C. The plate is immersed in an air stream, the velocity of which is U_∞ = 16 m/s and temperature T_∞ = 20 °C. Calculate the total heat transfer rate per unit width of the plate.

The following properties of air are to be used: density ρ = 1.165 kg/m^3; specific heat c_p = 1006 J/(kg K); kinematic viscosity ν = 1.60 x 10^{-5} m^2/s; thermal conductivity k = 0.026 W/(m K).

The following correlations are available for the flat plate:

Re < 5 x 10^5 (laminar flow only)	$\mathrm{Nu}_0 = 0.664\mathrm{RE}_L^{1/2}\mathrm{Pr}^{1/3}$
Re > 5 x 10^5 (turbulent flow only)	$\mathrm{Nu}_0 = 0.037\mathrm{RE}_L^{4/5}\mathrm{Pr}^{1/3}$
Both laminar and turbulent flow regions exist	$\mathrm{Nu}_0 = 0.037\left(\mathrm{RE}_L^{4/5} - 871\right)\mathrm{Pr}^{1/3}$

(25 marks)

4. In 1862, the physicist William Thomson (who later became Lord Kelvin) of Glasgow published calculations, in which he made an attempt to estimate the age of Earth. He assumed that the Earth was formed as a completely molten object (the initial temperature of the molten rock is T_i = 2000 °C) and radiates into space, the temperature of which is 0 K. He then determined the amount of time it would take for the near-surface to cool to its present temperature, T_s = – 15 °C (the temperature of clouds). Assuming that the Earth is a sphere of diameter D = 12675 km with the mass $m = 5.98 \times 10^{24}$ kg and specific heat $c = 1.26 \times 10^3$ J/(kg K),

(a) start with the energy balance equation and show that the time span necessary for the Earth to cool down from T_i to T_s by radiation cooling is given by the formula

$$t = \frac{mc}{3\varepsilon\sigma A}\left(\frac{1}{T_s^3} - \frac{1}{T_i^3}\right)$$

where the Earth's emissivity $\varepsilon = 0.612$, the Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/(m^2 K^4), and A denotes the Earth's surface area;

(15 marks)

(b) compute the Kelvin cooling time for the Earth.

(5 marks)

(c) compare your answer with the real age of the Earth (4.54×10^9 years) and explain what was missing from Kelvin's model that led to such a huge difference.

(5 marks)

Table 1

Saturated water—Pressure table

		Specific volume, m³/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.6113	0.01	0.001000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
1.0	6.98	0.001000	129.21	29.30	2355.7	2385.0	29.30	2484.9	2514.2	0.1059	8.8697	8.9756
1.5	13.03	0.001001	87.98	54.71	2338.6	2393.3	54.71	2470.6	2525.3	0.1957	8.6322	8.8279
2.0	17.50	0.001001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
2.5	21.08	0.001002	54.25	88.48	2315.9	2404.4	88.49	2451.6	2540.0	0.3120	8.3311	8.6432
3.0	24.08	0.001003	45.67	101.04	2307.5	2408.5	101.05	2444.5	2545.5	0.3545	8.2231	8.5776
4.0	28.96	0.001004	34.80	121.45	2293.7	2415.2	121.46	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001005	28.19	137.81	2282.7	2420.5	137.82	2423.7	2561.5	0.4764	7.9187	8.3951
7.5	40.29	0.001008	19.24	168.78	2261.7	2430.5	168.79	2406.0	2574.8	0.5764	7.6750	8.2515
10	45.81	0.001010	14.67	191.82	2246.1	2437.9	191.83	2392.8	2584.7	0.6493	7.5009	8.1502
15	53.97	0.001014	10.02	225.92	2222.8	2448.7	225.94	2373.1	2599.1	0.7549	7.2536	8.0085
20	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
25	64.97	0.001020	6.204	271.90	2191.2	2463.1	271.93	2346.3	2618.2	0.8931	6.9383	7.8314
30	69.10	0.001022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	0.9439	6.8247	7.7686
40	75.87	0.001027	3.993	317.53	2159.5	2477.0	317.58	2319.2	2636.8	1.0259	6.6441	7.6700
50	81.33	0.001030	3.240	340.44	2143.4	2483.9	340.49	2305.4	2645.9	1.0910	6.5029	7.5939
75	91.78	0.001037	2.217	384.31	2112.4	2496.7	384.39	2278.6	2663.0	1.2130	6.2434	7.4564
Press., MPa												
0.100	99.63	0.001043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
0.125	105.99	0.001048	1.3749	444.19	2069.3	2513.5	444.32	2241.0	2685.4	1.3740	5.9104	7.2844
0.150	111.37	0.001053	1.1593	466.94	2052.7	2519.7	467.11	2226.5	2693.6	1.4336	5.7897	7.2233
0.175	116.06	0.001057	1.0036	486.80	2038.1	2524.9	486.99	2213.6	2700.6	1.4849	5.6868	7.1717
0.200	120.23	0.001061	0.8857	504.49	2025.0	2529.5	504.70	2201.9	2706.7	1.5301	5.5970	7.1271
0.225	124.00	0.001064	0.7933	520.47	2013.1	2533.6	520.72	2191.3	2712.1	1.5706	5.5173	7.0878
0.250	127.44	0.001067	0.7187	535.10	2002.1	2537.2	535.37	2181.5	2716.9	1.6072	5.4455	7.0527
0.275	130.60	0.001070	0.6573	548.59	1991.9	2540.5	548.89	2172.4	2721.3	1.6408	5.3801	7.0209
0.300	133.55	0.001073	0.6058	561.15	1982.4	2543.6	561.47	2163.8	2725.3	1.6718	5.3201	6.9919
0.325	136.30	0.001076	0.5620	572.90	1973.5	2546.4	573.25	2155.8	2729.0	1.7006	5.2646	6.9652
0.350	138.88	0.001079	0.5243	583.95	1965.0	2548.9	584.33	2148.1	2732.4	1.7275	5.2130	6.9405
0.375	141.32	0.001081	0.4914	594.40	1956.9	2551.3	594.81	2140.8	2735.6	1.7528	5.1647	6.9175
0.40	143.63	0.001084	0.4625	604.31	1949.3	2553.6	604.74	2133.8	2738.6	1.7766	5.1193	6.8959
0.45	147.93	0.001088	0.4140	622.77	1934.9	2557.6	623.25	2120.7	2743.9	1.8207	5.0359	6.8565
0.50	151.86	0.001093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
0.55	155.48	0.001097	0.3427	655.32	1909.2	2564.5	665.93	2097.0	2753.0	1.8973	4.8920	6.7893
0.60	158.85	0.001101	0.3157	669.90	1897.5	2567.4	670.56	2086.3	2756.8	1.9312	4.8288	6.7600
0.65	162.01	0.001104	0.2927	683.56	1886.5	2570.1	684.28	2076.0	2760.3	1.9627	4.7703	6.7331
0.70	164.97	0.001108	0.2729	696.44	1876.1	2572.5	697.22	2066.3	2763.5	1.9922	4.7158	6.7080
0.75	167.78	0.001112	0.2556	708.64	1866.1	2574.7	709.47	2057.0	2766.4	2.0200	4.6647	6.6847
0.80	170.43	0.001115	0.2404	720.22	1856.6	2576.8	721.11	2048.0	2769.1	2.0462	4.6166	6.6628
0.85	172.96	0.001118	0.2270	731.27	1847.4	2578.7	732.22	2039.4	2771.6	2.0710	4.5711	6.6421
0.90	175.38	0.001121	0.2150	741.83	1838.6	2580.5	742.83	2031.1	2773.9	2.0946	4.5280	6.6226
0.95	177.69	0.001124	0.2042	751.95	1830.2	2582.1	753.02	2023.1	2776.1	2.1172	4.4869	6.6041
1.00	179.91	0.001127	0.19444	761.68	1822.0	2583.6	762.81	2015.3	2778.1	2.1387	4.4478	6.5865
1.10	184.09	0.001133	0.17753	780.09	1806.3	2586.4	781.34	2000.4	2871.7	2.1792	4.3744	6.5536
1.20	187.99	0.001139	0.16333	797.29	1791.5	2588.8	798.65	1986.2	2784.8	2.2166	4.3067	6.5233
1.30	191.64	0.001144	0.15125	813.44	1777.5	2591.0	814.93	1972.7	2787.6	2.2515	4.2438	6.4953

Table 2

H_2O

Superheated water (*Continued*)

T °C	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	P = 4.0 MPa (250.40°C)				*P* = 4.5 MPa (257.49°C)				*P* = 5.0 MPa (263.99°C)			
Sat.	0.04978	2602.3	2801.4	6.0701	0.04406	2600.1	2798.3	6.0198	0.03944	2597.1	2794.3	5.9734
275	0.05457	2667.9	2886.2	6.2285	0.04730	2650.3	2863.2	6.1401	0.04141	2631.3	2838.3	6.0544
300	0.05884	2725.3	2960.7	6.3615	0.05135	2712.0	2943.1	6.2828	0.04532	2698.0	2924.5	6.2084
350	0.06645	2826.7	3092.5	6.5821	0.05840	2817.8	3080.6	6.5131	0.05194	2808.7	3068.4	6.4493
400	0.07341	2919.9	3213.6	6.7690	0.06475	2913.3	3204.7	6.7047	0.05781	2906.6	3195.7	6.6459
450	0.08002	3010.2	3330.3	6.9363	0.07074	3005.0	3323.3	6.8746	0.06330	2999.7	3316.2	6.8186
500	0.08643	3099.5	3445.3	7.0901	0.07651	3095.3	3439.6	7.0301	0.06857	3091.0	3433.8	6.9759
600	0.09885	3279.1	3674.4	7.3688	0.08765	3276.0	3670.5	7.3110	0.07869	3273.0	3666.5	7.2589
700	0.11095	3462.1	3905.9	7.6198	0.09847	3459.9	3903.0	7.5631	0.08849	3457.6	3900.1	7.5122
800	0.12287	3650.0	4141.5	7.8502	0.10911	3648.3	4139.3	7.7942	0.09811	3646.6	4137.1	7.7440
900	0.13469	3843.6	4382.3	8.0647	0.11965	3842.2	4380.6	8.0091	0.10762	3840.7	4378.8	7.9593
1000	0.14645	4042.9	4628.7	8.2662	0.13013	4041.6	4627.2	8.2108	0.11707	4040.4	4625.7	8.1612
1100	0.15817	4248.0	4880.6	8.4567	0.14056	4246.8	4879.3	8.4015	0.12648	4245.6	4878.0	8.3520
1200	0.16987	4458.6	5138.1	8.6376	0.15098	4457.5	5136.9	8.5825	0.13587	4456.3	5135.7	8.5331
1300	0.18156	4674.3	5400.5	8.8100	0.16139	4673.1	5399.4	8.7549	0.14526	4672.0	5398.2	8.7055
	P = 6.0 MPa (275.64°C)				*P* = 7.0 MPa (285.88°C)				*P* = 8.0 MPa (295.06°C)			
Sat.	0.03244	2589.7	2784.3	5.8892	0.02737	2580.5	2772.1	5.8133	0.02352	2569.8	2758.0	5.7432
300	0.03616	2667.2	2884.2	6.0674	0.02947	2632.2	2838.4	5.9305	0.02426	2590.9	2785.0	5.7906
350	0.04223	2789.6	3043.0	6.3335	0.03524	2769.4	3016.0	6.2283	0.02995	2747.7	2987.3	6.1301
400	0.04739	2892.9	3177.2	6.5408	0.03993	2878.6	3158.1	6.4478	0.03432	2863.8	3138.3	6.3634
450	0.05214	2988.9	3301.8	6.7193	0.04416	2978.0	3287.1	6.6327	0.03817	2966.7	3272.0	6.5551
500	0.05665	3082.2	3422.2	6.8803	0.04814	3073.4	3410.3	6.7975	0.04175	3064.3	3398.3	6.7240
550	0.06101	3174.6	3540.6	7.0288	0.05195	3167.2	3530.9	6.9486	0.04516	3159.8	3521.0	6.8778
600	0.06525	3266.9	3658.4	7.1677	0.05565	3260.7	3650.3	7.0894	0.04845	3254.4	3642.0	7.0206
700	0.07352	3453.1	3894.2	7.4234	0.06283	3448.5	3888.3	7.3476	0.05481	3443.9	3882.4	7.2812
800	0.08160	3643.1	4132.7	7.6566	0.06981	3639.5	4128.2	7.5822	0.06097	3636.0	4123.8	7.5173
900	0.08958	3837.8	4375.3	7.8727	0.07669	3835.0	4371.8	7.7991	0.06702	3832.1	4368.3	7.7351
1000	0.09749	4037.8	4622.7	8.0751	0.08350	4035.3	4619.8	8.0020	0.07301	4032.8	4616.9	7.9384
1100	0.10536	4243.3	4875.4	8.2661	0.09027	4240.9	4872.8	8.1933	0.07896	4238.6	4870.3	8.1300
1200	0.11321	4454.0	5133.3	8.4474	0.09703	4451.7	5130.9	8.3747	0.08489	4449.5	5128.5	8.3115
1300	0.12106	4669.6	5396.0	8.6199	0.10377	4667.3	5393.7	8.5475	0.09080	4665.0	5391.6	8.4842
	P = 9.0 MPa (303.40°C)				*P* = 10.0 MPa (318351.06°C)				*P* = 12.5 MPa (327.89°C)			
Sat.	0.02048	2557.8	2742.1	5.6772	0.018026	2544.4	2724.7	5.6141	0.013495	2505.1	2673.8	5.4624
325	0.02327	2646.6	2856.0	5.8712	0.019861	2610.4	2809.1	5.7568				
350	0.02580	2724.4	2956.6	6.0361	0.02242	2699.2	2923.4	5.9443	0.016126	2624.6	2826.2	5.7118
400	0.02993	2848.4	3117.8	6.2854	0.02641	2832.4	3096.5	6.2120	0.02000	2789.3	3039.3	6.0417
450	0.03350	2955.2	3256.6	6.4844	0.02975	2943.4	3240.9	6.4190	0.02299	2912.5	3199.8	6.2719
500	0.03677	3055.2	3386.1	6.6576	0.03279	3045.8	3373.7	6.5966	0.02560	3021.7	3341.8	6.4618
550	0.03987	3152.2	3511.0	6.8142	0.03564	3144.6	3500.9	6.7561	0.02801	3125.0	3475.2	6.6290
600	0.04285	3248.1	3633.7	6.9589	0.03837	3241.7	3625.3	6.9029	0.03029	3225.4	3604.0	6.7810
650	0.04574	3343.6	3755.3	7.0943	0.04101	3338.2	3748.2	7.0398	0.03248	3324.4	3730.4	6.9218
700	0.04857	3439.3	3876.5	7.2221	0.04358	3434.7	3870.5	7.1687	0.03460	3422.9	3855.3	7.0536
800	0.05409	3632.5	4119.3	7.4596	0.04859	3628.9	4114.8	7.4077	0.03869	3620.0	4103.6	7.2965
900	0.05950	3829.2	4364.8	7.6783	0.05349	3826.3	4361.2	7.6272	0.04267	3819.1	4352.5	7.5182
1000	0.06485	4030.3	4614.0	7.8821	0.05832	4027.8	4611.0	7.8315	0.04658	4021.6	4603.8	7.7237
1100	0.07016	4236.3	4867.7	8.0740	0.06312	4234.0	4865.1	8.0237	0.05045	4228.2	4858.8	7.9165
1200	0.07544	4447.2	5126.2	8.2556	0.06789	4444.9	5123.8	8.2055	0.05430	4439.3	5118.0	8.0937
1300	0.08072	4662.7	5389.2	8.4284	0.07265	4460.5	5387.0	8.3783	0.05813	4654.8	5381.4	8.2717

End of Paper

November/December 2011

MP2310 / MP2010

1. (a)

$$\begin{cases} dq = du + pdv \\ h = u + pv \end{cases}$$

$$dh = du + pdv + vdp$$

$$du = dh - Pdv - vdp$$

$$dq = dh - Pdv - vdp + Pdv = dh - vdp = Tds$$

For isentropic compression $Tds = 0$

So $dh - vdp = 0$

$$dh = vdp$$

Because Liquid is compressed $v \cong v_1 = \text{Const}$.

$$w = h_2 - h_1 \cong v_1 (P_2 - P_1)$$

$$W = \dot{m}\, w = 10 \times 0.01 \times (10000 - 100)$$

$$= 990 \text{ kW} \;,,$$

(b) For carnot cycles

$$\eta' = \frac{T_H - T_L}{T_H} = \frac{400}{800} = 0.5$$

$$COP' = \frac{T_L}{T_H - T_L} = \frac{240}{400 - 240} = 1.5$$

For the real situation

$$\eta = 0.8 \times \eta' = 0.4 \;,,$$

$$COP = 0.8 \times 1.5 = 1.2 \;,,$$

$$COP = \frac{Q_{L\,ref}}{Q_{H\,ref} - Q_{L\,ref}} \quad \text{and} \quad Q_{L\,ref} = 240 \text{ kW}$$

So $Q_{H\,ref} = 440 \text{ kW}$

$$W_{ref} = Q_{H\,ref} - Q_{L\,ref} = 200 \text{ kW}$$

Because $Q_{H\,ref} + Q_{L\,eng} = 800 \text{ kW}$

So $Q_{L\,eng} = 360 \text{ kW}$

$$\cancel{\eta = \frac{W_{eng}}{Q}} \qquad \eta = \frac{Q_{H\,eng} - Q_{L\,eng}}{Q_{H\,eng}}$$

So $Q_{H\,eng} = 600 \text{ kW}$

$$W_{eng} = Q_{H\,eng} - Q_{L\,eng} = 240 \text{ kW}$$

So Power Loss through gear box $= W_{eng} - W_{ref}$

$= 40\,KW$ //

2 (a) at point ① $P_1 = 100kPa$ $T_1 = 25°C = 298\,K$

at point ② $P_2 = 14 \times P_1 = 1400kPa$

$$\left(\frac{P_1}{P_2}\right)^{1-k}\left(\frac{T_1}{T_{2s}}\right)^{k} = 1 \quad \text{So } T_{2s} = 633\,K$$

$$\eta = \frac{T_{2s}-T_1}{T_{2a}-T_1} = 0.87 \quad \text{So } T_{2a} = 683\,K$$

So $w_{comp} = C_p(T_{2a} - T_1) = 387\,kJ/kg$

From ② to ③

~~Q_H~~ $q_H = C_p(T_3 - T_{2a}) = 844.2\,kJ/kg$

at point ③ $P_3 = P_2 = 1400\,kPa$ $T_3 = 1523\,K$

at point ④ $P_4 = P_1 = 100\,kPa$

$$\left(\frac{P_3}{P_4}\right)^{1-k}\left(\frac{T_3}{T_{4s}}\right)^{k} = 1 \quad \text{So } T_{4s} = 716.5\,K$$

$$\eta = \frac{\cancel{T_{4a}}\ T_3 - T_{4a}}{T_3 - T_{4s}} = 0.87 \quad \text{So } T_{4a} = 820.9\,K$$

So $w_{turb} = C_p(T_3 - T_{4a}) = 705.6\,kJ/kg$

Therefore $\eta_{thermal} = \dfrac{w_{turb} - w_{comp}}{q_H} = 0.377$ //

(b) at point ⑨ $P_9 = 10kPa$ So $v_9 = 0.001010\,m^3/kg$

So $w_{pump} = v_9(P_6 - P_9)/\eta$

$= 0.001010\,(12500 - 10)/0.85 = 14.84\,kJ/kg$

$h_9 = 191.83\,kJ/kg$

$h_6 = h_9 + w_{pump} = 206.67\,kJ/kg$

at ⑦ $P_7 = 12.5 MPa$ $T_7 = 500°C$

So $h_7 = 3341.8$ kJ / kg

$q_{boiler} = h_7 - h_6 = 3133.13$ kJ / kg

$S_7 = 6.4618$ ~~kJ kg/K~~ kJ/kg.K

$= S_{8\,isentropic} = S_f + x_{8\,isentropic} S_{fg}$

$= 0.6493 + x_8 \cdot 7.3009$

So $x_8 = 0.775$

So $h_{8\,isentropic} = h_f + x_8 h_{fg}$

$= 2046$ kJ/kg

So $W_{turb} = \eta\,(h_7 - h_{8\,isentropic})$

$= 947.5$ kJ / kg

So $\eta_{cycle} = \dfrac{W_{turb} - W_{pump}}{q}$ = ~~29~~ 0.297 //

(c) From ④ to ⑤

$q_{out} = C_P (T_4 - T_5) = 349.6$ kJ / kg

$\dot{Q}_H = \dot{m}\, q_{②-③}$ So $\dot{m} = 71.07$ kg / s

So $\dot{Q}_{out} = \dot{m}\, q_{out} = 24874$ kW $= \dot{Q}_{in\text{-}steam\,cycle}$

$\dot{Q}_{in\text{-}steam\,cycle} = \dot{m}_{steam} \cdot q_{boiler}$

$\dot{m}_{steam} = 7.93$ kg / s

$\eta_{overall} = \dfrac{\cancel{\dot{Q}_H \cdot \eta_{gas} + \ominus}\;\; \dot{Q}_H \cdot \eta_{gas} + \dot{Q}_{in\text{-}steam\,cycle} \cdot \eta_{steam}}{\dot{Q}_H}$

$= \dfrac{60\,000 \times 0.377 + 24874 \times 0.297}{60\,000} = 0.5$ //

(d) Yes. For Gas turbine cycle, the exhaust still carry certain amout of energy. With Combined cycle, this energy is used to generate more work, So the efficiency should be higher.

3. $P_r = \frac{\mu C_p}{k} = \frac{\rho \nu C_p}{k} = 0.72$

$Re_L = \frac{VL}{\nu} = \frac{16 \times 0.4}{1.6 \times 10^{-5}} = 4 \times 10^5 < 5 \times 10^3$

So $Nu_0 = 0.664 Re_L^{1/2} P_r^{1/3}$

$= 376.4$

$Re = \frac{Vd}{\nu} = \frac{16 \times 1.5 \times 10^{-3}}{1.6 \times 10^{-5}} = 1500$

So $Nu = Nu_0 \times 18.032 \, \eta^{0.12} (Re - 1000)^{-0.21}$

$= 1818.71$

$Nu = \frac{h\delta}{k}$ So $h = 118.2 \ W/(m^2 \cdot k)$

So $\dot{Q} = hL(T_\infty - T_s)$

$= 1891.47 \ W/m$ //

4. (a) ~~$mc(T_s - T_i) = \int \dot{Q} \, dt$~~

~~$mc(T_s - T_i) = \int A\varepsilon\sigma T^4 \, dt$~~

~~$mc(T_s - T_i)$~~

$\int mc \, dT = -\int A\varepsilon\sigma T^4 \, dt$

$mc \, dT = -A\varepsilon\sigma T^4 \, dt$

$\frac{1}{T^4} dT = -\frac{A\varepsilon\sigma}{mc} dt$

$$\int_i^s \frac{1}{T^4}\, dT = -\int_i^s \frac{A\varepsilon\sigma}{mc}\, dt$$

$$-\frac{1}{3}\left[\frac{1}{T_s^3} - \frac{1}{T_i^3}\right] = -\frac{A\varepsilon\sigma}{mc}(t_s - T_i) = -\frac{A\varepsilon\sigma}{mc}\, t$$

$$\text{So } t = \frac{mc}{3\varepsilon\sigma A}\left(\frac{1}{T_s^3} - \frac{1}{T_i^3}\right) \quad //$$

(b) use formula above $A = 4\pi\left(\frac{D}{2}\right)^{2\cancel{3}} = 5.04\times10^{4}\ m^2$

$$t = \frac{5.98\times10^{24}\times1.26\times10^{3}\left(\frac{1}{238^3} - \frac{1}{2273^3}\right)}{3\times0.612\times5.67\times10^{-8}\times\cancel{1.066\times10^{21}}\ 5.04\times10^{14}} \ \cancel{= 1.066\times10^{21}}$$

$$\cancel{= 3947881\ s = 8} = 8.35\times10^{12}\ s$$
$$= 2.64779\times10^{5}\ \text{years}$$

(c) The calculated value is much smaller.

The reason is that temp. of earth is not uniform. inside is much hotter that surface and it is the temp. of surface ~~de~~ that determine how fast it radiates the heat. As a result, earth emit heat much slower than Kelvin's prediction and takes much longer to reach the current temp. //

15

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2015-2016

MA3010 – THERMODYNAMICS AND HEAT TRANSFER

November/December 2015 Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR** (4) questions and comprises **THREE** (3) pages.
2. Answer **ALL FOUR** (4) questions.
3. All questions carry equal marks.
4. This is a **CLOSED BOOK** examination.

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1 (a) What is the difference and similarity between work and heat?

(7 marks)

(b) State the Second Law of thermodynamics. Provide ONLY ONE of many possible equivalent formulations of the Second Law.

(6 marks)

(c) A large piece of meat is taken from a refrigerator and is left to warm up in a kitchen. If the piece of meat warms from its initial temperature T_i = 4 °C to the room temperature T_∞ = 18 °C, what is the net entropy change associated with this process? The piece of meat can be treated as a homogeneous spherical object of diameter D = 0.2 m with the density ρ = 1200 kg/m^3 and specific heat c_p = 4.1 kJ/kg·K.

(12 marks)

/6

2. At 20°C and 101 kPa pressure, a mixture of gases has been made by mixing 1.0 kg of oxygen, O_2, 100 moles of nitrogen, N_2, and 1.0 m^3 of carbon dioxide, CO_2. This mixture is then heated from 20°C to 120°C in a container which is maintained at a constant pressure of 101 kPa throughout the mixing and heating processes.

The universal gas constant is 8.314 kJ/kmol·K. The specific heats at constant pressure of O_2, N_2 and CO_2 are 0.918 kJ/kg·K, 1.039 kJ/kg·K and 0.846 kJ/kg·K, respectively, and the molar masses of O_2, N_2 and CO_2 are 32 kg/kmol, 28 kg/kmol and 44 kg/kmol, respectively. For ideal gases with constant specific heats undergoing a process from 1 to 2, the change in specific entropy can be determined from

$$\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

(a) What are the mass fractions of oxygen, nitrogen and carbon dioxide in the mixture?

(10 marks)

(b) What are the mole fractions of oxygen, nitrogen and carbon dioxide in the mixture?

(5 marks)

(c) Determine the average specific heat of the mixture.

(5 marks)

(d) Determine the entropy change in the mixture due to heating.

(5 marks)

3. Cold air feels much colder in windy weather than what the thermometer reading indicates, because of the "chilling effect" of the wind. This effect is due to the increase in the convection heat transfer coefficient with increasing air velocities. The equivalent wind chill temperature, T_{eqv}, is given by

$$T_{eqv} = T_{skin} - (T_{skin} - T_{amb})(0.475 - 0.0126w + 0.240\sqrt{w})$$

where w is the wind velocity in km/h, T_{amb} is the ambient air temperature, and T_{skin} denotes the mean skin temperature. All the temperatures are in °C. The equation above is valid for winds up to 70 km/h.

(a) The given equation has two possible solutions for the case of no "chilling effect". Find these solutions. Comment on the values you found.

(18 marks)

(b) Assuming that a person with the mean skin temperature of 33 °C closely approximates a grey body with emissivity $\varepsilon = 0.8$, determine the total emissive power of such a person [$\sigma = 5.67 \times 10^{-8}$ W/$m^2 \cdot K^4$]. Then determine the total amount of radiation emitted by this person, assuming that the person's surface area is 1.8 m^2. Comment on your result.

(7 marks)

4. Consider a plane composite wall composed of two materials of thermal conductivities $k_A = 0.4$ W/m·K and $k_B = 1.0$ W/m·K, with thicknesses $L_A = 10$ mm and $L_B = 20$ mm. Material A adjoins a fluid at $T_1 = 200°\text{C}$ with the convective heat transfer coefficient $h_1 = 40$ W/m^2·K, and material B adjoins a fluid $T_2 = 20°\text{C}$ with the convective heat transfer coefficient $h_2 = 10$ W/m^2·K. In addition to being adjoined with the fluid, material B is also exposed to large surroundings at $T_{sur} = 20°\text{C}$ with the effective radiation heat transfer coefficient $h_{rad} = 5$ W/m^2·K.

(a) Draw a schematic diagram describing this problem and the corresponding thermal resistance circuit. Using their respective notations, indicate clearly in your circuit all the component resistances and temperature nodes.

(10 marks)

(b) Determine the total thermal resistance of unit area of the wall.

(5 marks)

(c) Determine the rate of heat transfer per unit area of this wall.

(5 marks)

(d) What is the temperature at the interface of the two materials?

(5 marks)

End of Paper

17

1. ⓐ

$Q = W + \Delta U$

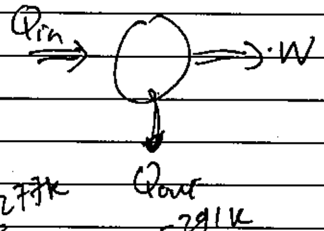
Heat work change in internal erg
by system

Differences between heat & work :
- Heat is a form of energy that is due to the temperature.
  Naturally heat flows from higher temperature to lower temperature.
- Work is usually related with e.g. mechanical work
  e.g. Work done by gas $= \int p dV$
  Work done by shaft.

Similarities :
- Both are 'form' of energy & have the same units : joule.
- They can be converted from one to another.
  $Q = W + \Delta U$

ⓑ 2nd Law of Thermodynamics :
For any irreversible process, the sum of entropy always increases.
$\Delta S > 0$
↳ there is a maximum performance / efficiency for a process / cycle.
⇒ Carnot cycle $\eta = 1 - \frac{T_{LOW}}{T_{HIGH}}$

You cannot convert all the input heat to Work.



ⓒ $T_i = 4°C$ = 277K, $T_\infty = 18°C$ = 291K

$D = 0.2m$, $\rho = 1200 kg/m^3$ → $m = \rho \frac{4\pi}{3}\left(\frac{D}{2}\right)^3 = 1200 \times \frac{4\pi}{3}(0.1)^3 = 5.03 kg$

$C_p = 4.1 kJ/kgK$

$\Delta Q = mC_p\Delta T = 5.03 \times 4.1 \times 14 = 288.52 kJ$

$$\Delta S_{net} = \Delta S_{meat} + \Delta S_{environment} = \int_{T_i}^{T_\infty} \frac{mC_p dT}{T} - \frac{\Delta Q}{T_\infty} = 5.03 \times 4.1 \ln\frac{291}{277} - \frac{288.52}{291} = \boxed{0.025 \ kJ/K}$$

② $T = 20°C = 293K$ $20°C \rightarrow 120°C$

$P = 101kPa \rightarrow$ constant

$Mr = 32$ kg/kmol	$Mr = 28$ kg/kmol	$Mr = 44$ kg/kmol
O_2 $c_p = 0.918$ kJ/kgK	N_2 $c_p = 1.039$ kJ/kgK	CO_2 $c_p = 0.846$ kJ/kgK
$n = 31.25$mol +	$n = 100$moles +	$n = 41.46$moles
$m = 1kg$	$m = 2.8kg$	$m = 1.82kg$
		$V = 1m^3$

$$n_{O_2} = \frac{1kg}{32 kg/kmol} = 31.25 mol$$

$$m_{N_2} = 0.1 \times 28 = 2.8kg$$

$$PV = nRT$$

$$n_{CO_2} = \frac{101000 \times 1}{8.314 \times 293} = 41.46 mol$$

$$m_{CO_2} = \frac{41.46 \times 44}{1000} = 1.82kg$$

$$n_{TOTAL} = 31.25 + 100 + 41.46 = 172.71 moles$$

$$m_{TOTAL} = 1 + 2.8 + 1.82 = 5.62kg$$

ⓐ

$$X_{O_2} = \frac{m_{O_2}}{m_{TOT}} = \frac{1}{5.62} = 0.178$$

$$X_{N_2} = \frac{2.8}{5.62} = 0.498$$

$$X_{CO_2} = \frac{1.82}{5.62} = 0.324$$

ⓑ

$$y_{O_2} = \frac{n_{O_2}}{n_{TOTAL}} = \frac{31.25}{172.71} = 0.181$$

$$y_{N_2} = \frac{100}{172.71} = 0.579$$

$$y_{CO_2} = \frac{41.46}{172.71} = 0.240$$

ⓒ

$$\bar{C_p} = X_{O_2}C_{P_{O_2}} + X_{N_2}C_{P_{N_2}} + X_{PCO_2}C_{P_{CO_2}} = 0.178 \times 0.918 + 0.498 \times 1.039 + 0.324 \times 0.846$$

$$= \boxed{0.955 \text{ kJ/kgK}}$$

ⓓ Due to Heating:

$$\Delta S = m_{TOTAL}\bar{C_p}\ln\left(\frac{T_2}{T_1}\right) - n_{TOTAL}\hat{R}\ln\frac{P_2}{P_1}$$

$$= 5.62 \times 0.955 \ln\frac{393}{293} - \cancel{\frac{172.71 \times 8.314}{1000}\ln\frac{P_2}{P_1}}$$ $P_2 = P_1$

$$= \boxed{1.58 \text{ kJ/k}}$$

③

ⓐ $T_{eqv} = T_{skin} - (T_{skin} - T_{amb})\ (0.475 - 0.0126W + 0.240\sqrt{W})$

No chilling effect $\Rightarrow$ $T_{eqv} = T_{amb}$

$T_{amb} - T_{skin} = -(T_{skin} - T_{amb})\ (0.475 - 0.0126W + 0.240\sqrt{W})$

$1 = 0.475 - 0.0126W + 0.240\sqrt{W}$

$0 = -0.0126W + 0.24\sqrt{W} - 0.525$ → Solve this quadratic eq

$W = \boxed{6.357 \text{ km/hr}}$ → valid solution

273.122 km/hr ✗ → invalid since the eq only valid for speed < 70 km/h

ⓑ $T = 33°C = 306k$, $\varepsilon = 0.8$, $\sigma = 5.67\ 10^{-8}\ W/m^2k^4$

$\varepsilon \sigma T^4 = 0.8 \times 5.67\ 10^{-8} \times 306^4 = 397.70\ W/m^2$

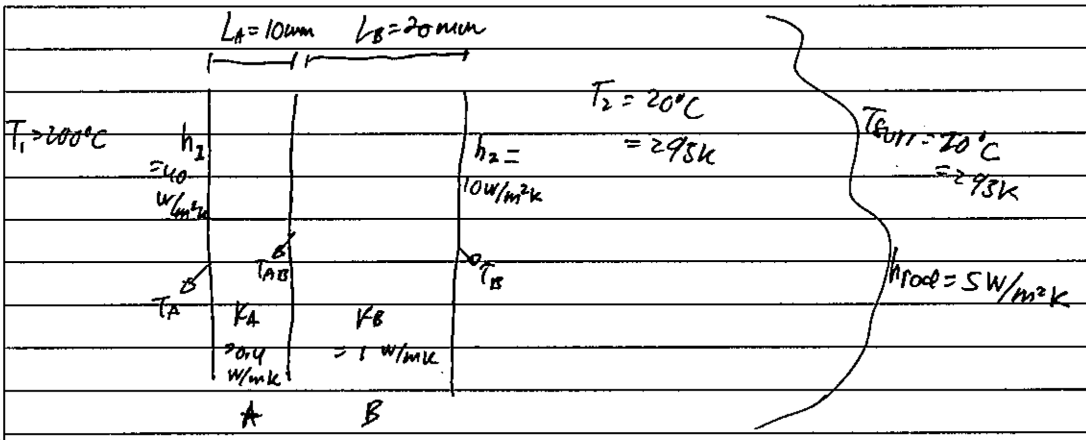
if $A = 1.8 m^2$

$\varepsilon \sigma A T^4 = 397.7 \times 1.8 = 715.87\ W$

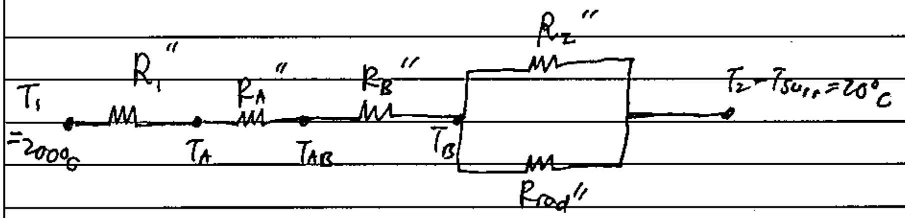
Total amount of radiation

for relatively low temperature stuffs (e.g. human), heat transfer by radiation is usually less significant compared to by convection.

(4)



(a)



$R_1'' = \frac{1}{h_1} = \frac{1}{40} = 0.025 \frac{m^2K}{W}$ $R_2'' = \frac{1}{h_2} = \frac{1}{10} = 0.1 m^2K/W$

$R_A'' = \frac{L}{k_A} = \frac{0.01}{0.4} = 0.025 \frac{m^2K}{W}$ $R_{rad}'' = \frac{1}{h_{rad}} = \frac{1}{5} = 0.2 m^2K/W$

$R_B'' = \frac{L_B}{k_B} = \frac{0.02}{1} = 0.02 \frac{m^2K}{W}$

(b) [illegible]

$\frac{\text{Total thermal resistance}}{\text{Area}} = 0.025 + 0.025 + 0.02 + \overbrace{\frac{0.1 \times 0.2}{0.1 + 0.2}}^{0.067} = 0.137 m^2K/W$

(c) $\frac{\Delta Q}{A} = \frac{\Delta T}{R''} = \frac{200 - 20}{0.137} = \boxed{1313.87 W/m^2}$

(d) $\frac{\Delta Q}{A} = \frac{T_1 - T_{AB}}{R_1'' + R_A''} \rightarrow 1313.87 = \frac{200 - T_{AB}}{0.05}$

$\boxed{T_{AB} = 134.3°C}$

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*