First Semester Examination
2021/2022 Academic Session

February/March 2022

EMH 441 – Heat Transfer

Duration : 3 hours

Please ensure that this examination paper contains **SEVEN (7)** pages and **FOUR (4)** question before you begin the examination.

Instructions : Answer **ALL FOUR (4)** questions.

Answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.

Each question must begin from a new page.

1. a) A steel pipe (k = 45.0 W/mK) having a 0.05 m outer diameter is covered with a 0.05 m thick layer of magnesia (k = 0.07 W/mK) which in turn covered with a 0.02 m layer of fiberglass insulation (k = 0.048 W/mK). The pipe wall outside temperature is 95 °C and the outer surface temperature of the fiberglass is 30 °C. Calculate:

   (i) the interfacial temperature between the magnesia and fiberglass.
   (ii) the steady state heat transfer.

(40 marks)

   b) A large steel frying pan of thickness 0.5 cm, initially at 20 °C, is placed on a stove. The bottom of the pan is subjected to a uniform heat flux 300 W/m^2 and the top is exposed to cool ambient at 20 °C. The heat transfer coefficient between the pan and the ambient air is 30 W/m^{2}K. Calculate the temperature of the pan at 5 minutes and 10 minutes after the heating starts (For steel, thermal conductivity k = 70 W/mK, density ρ = 7840 kg/m^3 and heat capacity C_p = 450 J/kgK).

(60 marks)

2. Water enters a tube with diameter of 0.01 m. The velocity $(\mathrm{m/s})$ and temperature (K) can be expressed as

$$u(r) = 0.2[(1 - (r/R)^2]$$
$$T(r) = 280 + 100(r/R)^3$$

where r and R are radial position and the radius of the tube, respectively.

   a) Derive the average velocity and the mixed mean water temperature from the given velocity and temperature profiles.

(60 marks)

   b) Calculate the hydrodynamic and the thermal entrance length. The water properties can be taken to be density of $1000\ \mathrm{kg/m^3}$, dynamic viscosity of $1 \times 10^{-3}\ \mathrm{kg/ms}$ and thermal diffusivity to be $1.6 \times 10^{-7}\mathrm{m^2/s}$.

(40 marks)

3. Water is boiled at $100\ ^0\mathrm{C}$ at atmospheric pressure of $1\mathrm{atm}$ using a $25\ \mathrm{cm}$ long and $5\ \mathrm{cm}$ diameter electric heating element, as depicted in Figure 3. The cylindrical heating element is made of platinum. As indicated by the wattmeter, the electrical power consumed during the boiling process is $2\ \mathrm{kW}$.

...3/-

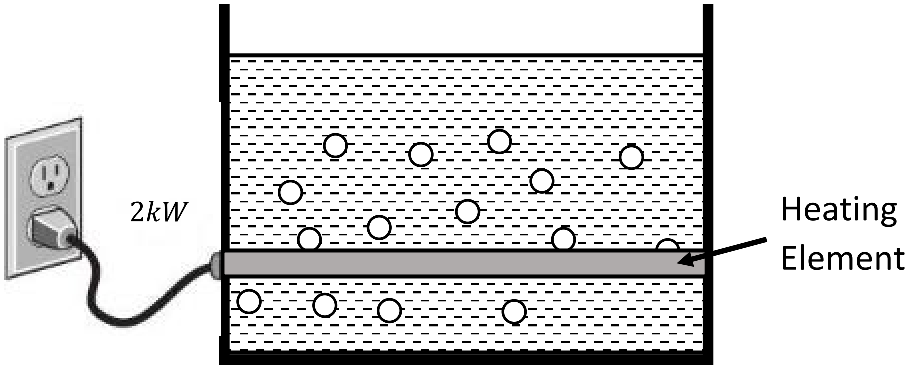

Figure 3

a) Assume that the efficiency of the electrical system is 100%, no loss of energy in the system and the electrical power is fully used to boil water in the pan, calculate the temperature on the surface of the heating element. Assume the boiling occurs in the nucleate boiling regime.

(60 marks)

b) Calculate the peak heat transfer rate.

(40 marks)

4. a) As shown in Figure 4(a), two large spheres (D1 and D2) have a diameter of 5 m and 2 m, respectively. Calculate:

(i) The view factor from surface D1 to surface D1.

(20 marks)

(ii) Radiation heat transfer for D1 to D2, assume all sphere are black body condition. Take Stefan Boltzmann coefficient = 5.67×10^{-8} W/m^2K^4.

(20 marks)

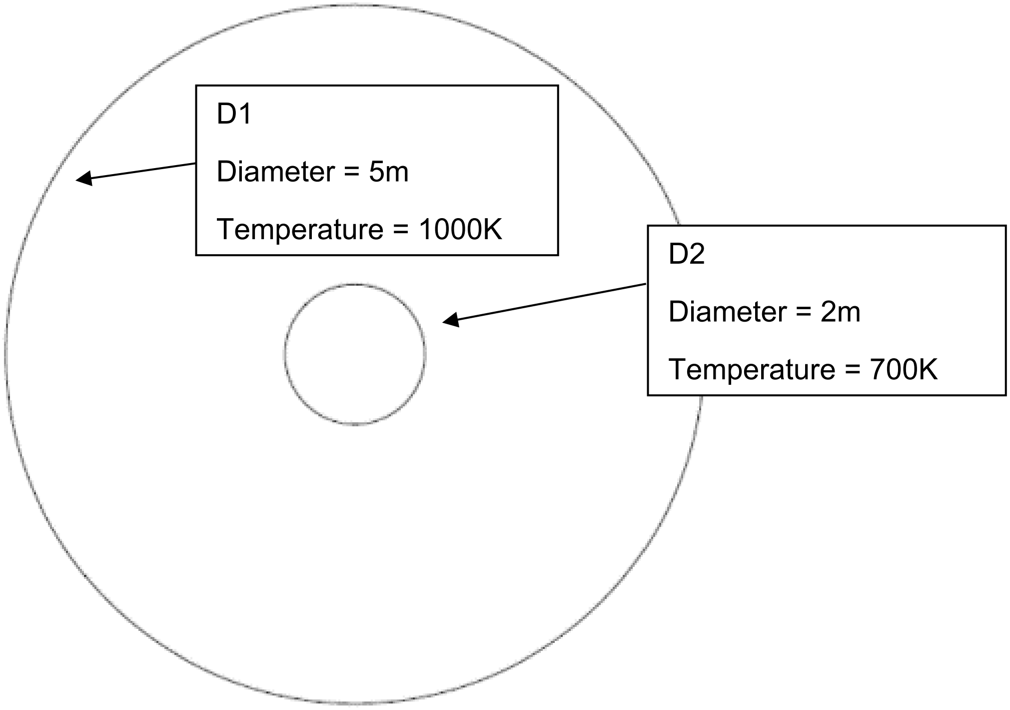

Figure 4 (a)

b) As shown in the Figure 4(b), the effective surface area = 20 m^2. Calculate overall heat transfer coefficient. Take c_P for air and oil are 1000 J/kg.K and 2100 J/kg.K. The overall heat transfer coefficient = 350 W/m^{2}K. Calculate outlet temperatures of air and oil.

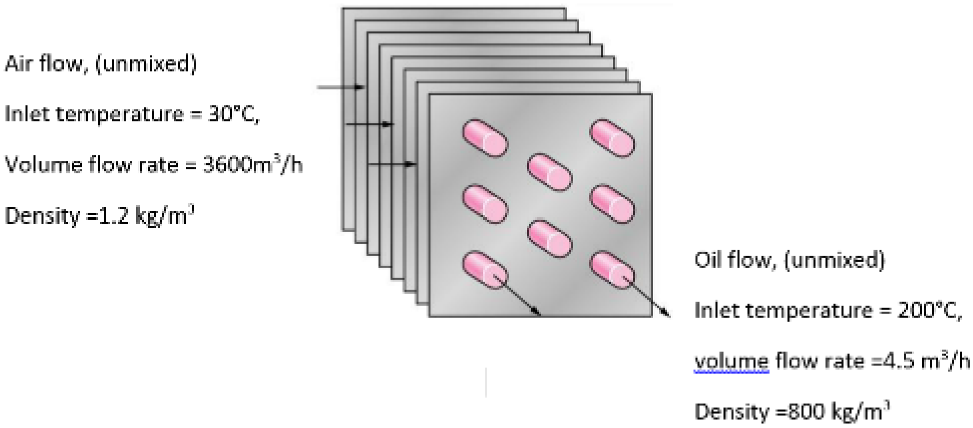

Figure 4 (b)

(60 marks)

-oooOooo-

...5/-

APPENDIX 1

Formulation

1. General properties

Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³		Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg·K		Thermal Conductivity k, W/m·K		Dynamic Viscosity μ, kg/m·s		Prandtl Number Pr	
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255×10^{-3}	1.261×10^{-5}	1.58	1.00

2. External forced convection heat transfer formulations:

Flow in a tube

Average velocity

$$V_{avg} = \frac{2}{R^2}\int_0^R u(r)rdr$$

Mixed mean temperature

$$T_m = \frac{2}{V_{avg}R^2}\int_0^R T(r)u(r)rdr$$

Hydrodynamic entrance length

$$L_{h,laminar} = 0.05ReD$$

Thermal entrance length

$$L_{t,laminar} = 0.05RePrD$$

3. Natural convection:

Grashof number: $Gr_L = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2}$

4. Boiling and condensation:

$$\dot{q}_{nucleate} = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left[\frac{C_{pl}(T_s - T_{sat})}{C_{sf} h_{fg} Pr_l^n}\right]^3$$

$$\dot{q}_{max} = C_{cr} h_{fg} [\sigma g \rho_v^2 (\rho_l - \rho_v)]^{1/4}$$

$$\dot{q}_{min} = 0.09 \rho_v h_{fg} \left[\frac{\sigma g (\rho_l - \rho_v)}{(\rho_l + \rho_v)^2}\right]^{1/4}$$

Surface tension of liquid–vapor interface for water

T, °C	σ, N/m*
0	0.0757
20	0.0727
40	0.0696
60	0.0662
80	0.0627
100	0.0589
120	0.0550
140	0.0509
160	0.0466
180	0.0422
200	0,0377
220	0.0331
240	0.0284
260	0.0237
280	0.0190
300	0.0144
320	0.0099
340	0.0056
360	0.0019
374	0.0

*Multiply by 0.06852 to convert to lbf/ft or by 2.2046 to convert to lbm/s^2.

Values of the coefficient C_{sf} and n for various fluid–surface combinations

Fluid-Heating Surface Combination	C_{sf}	n
Water–copper (polished)	0.0130	1.0
Water–copper (scored)	0.0068	1.0
Water–stainless steel (mechanically polished)	0.0130	1.0
Water–stainless steel (ground and polished)	0.0060	1.0
Water–stainless steel (teflon pitted)	0.0058	1.0
Water–stainless steel (chemically etched)	0.0130	1.0
Water–brass	0.0060	1.0
Water–nickel	0.0060	1.0
Water–platinum	0.0130	1.0
n-Pentane–copper (polished)	0.0154	1.7
n-Pentane–chromium	0.0150	1.7
Benzene–chromium	0.1010	1.7
Ethyl alcohol–chromium	0.0027	1.7
Carbon tetrachloride–copper	0.0130	1.7
Isopropanol–copper	0.0025	1.7

Values of the coefficient C_{cr} for use in Eq. 10–3 for maximum heat flux (dimensionless parameter $L^* = L[g(\rho_l - \rho_v)/\sigma]^{1/2}$)

Heater Geometry	C_{cr}	Charac. Dimension of Heater, L	Range of L^*
Large horizontal flat heater	0.149	Width or diameter	$L^* > 27$
Small horizontal flat heater[1]	$18.9K_1$	Width or diameter	$9 < L^* < 20$
Large horizontal cylinder	0.12	Radius	$L^* > 1.2$
Small horizontal cylinder	$0.12L^{*-0.25}$	Radius	$0.15 < L^* < 1.2$
Large sphere	0.11	Radius	$L^* > 4.26$
Small sphere	$0.227L^{*-0.5}$	Radius	$0.15 < L^* < 4.26$

[1] $K_1 = \sigma/[g(\rho_l - \rho_v)A_{heater}]$