UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: August 2015

Module Number: ME7321 **Module Name: Heat Transfer**

[Three Hours]

[Steam Tables are provided. **Answer all questions.** Your drawings should be neat, clear and precise. State all assumptions]

Q1. a) What does the Grashof number represent? How does the Grashof number differ from Reynolds number?

[2 marks]

b) Solar radiation is incident on the glass cover of a solar collector at a rate of 1000W/m^2. The glass transmits 90 percent of the incident radiation and has an emissivity of 0.90. The hot water needs of a family can be met completely by a collector 1.5 m high and 2 m wide, and tilted 40° from the horizontal. The temperature of the glass cover is measured to be 40°C on a calm day when the surrounding air temperature is 30°C. The effective sky temperature for radiation exchange between the glass cover and the open sky is -30°C. Water enters the tubes attached to the absorber plate at a rate of 1 kg/min. Assuming the back surface of the absorber plate to be heavily insulated and the only heat loss occurs through the glass cover, determine

I. the total rate of heat loss from the collector

[6 marks]

II. the collector efficiency, which is the ratio of the amount of heat transferred to the water to the solar energy incident on the collector

[2 marks]

III. the temperature rise of water as it flows through the collector

[2 marks]

$Ra = \frac{g\beta(T_\infty - T_s)L_c^3}{\upsilon^2}Pr$, $Nu = 0.15(Ra\cos\gamma)^{1/3}$, $L_c = \frac{A_s}{p}$, C_p of water = 4180 J/kg/K

Q2. a) Define view factor.

[1 marks]

b) State the *reciprocity rule* and show how it can be used to determine the view factor of two plain parallel walls of areas A_i and A_j facing each other.

[2 marks]

c) A 2-m-internal-diameter double-walled spherical tank is used to store iced water at 0°C. Each wall is 0.5 cm thick, and the 1.5-cm-thick air space between the two walls of the tank is evacuated in order to minimize heat transfer. The surfaces surrounding the evacuated space are polished so that each surface has an emissivity of 0.10. The temperature of the outer wall of the tank is measured to be 25°C. Assuming the inner wall of the steel tank to be at 0°C, determine

I. the rate of heat transfer to the iced water in the tank

[5 marks]

II. the amount of ice at 0°C that melts during a 24-h period

[2 marks]

$\sigma = 5.67 \times 10^{-8} W/m^2K^4$, latent heat of ice melting =333.7kJ/kg

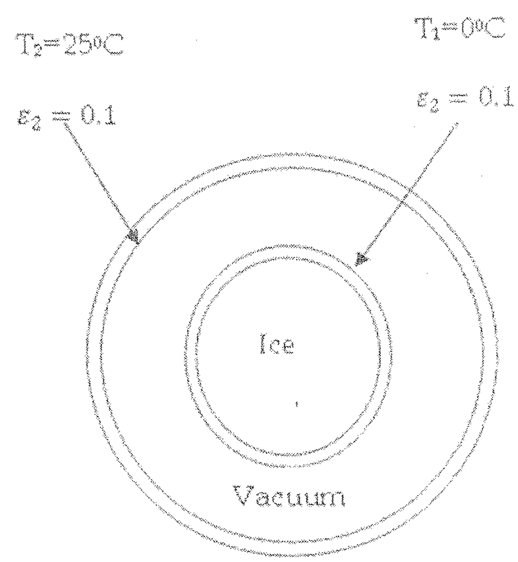

Figure Q2

Q3. a) What are the 3 basic steps of CFD simulation for a heat transfer problem?

[2 marks]

b) How would you test the accuracy of outputs you generated from CFD simulation?

[2 marks]

c) How can you achieve more accurate results from a CFD simulation?

[2 marks]

Q4. a) What causes the deterioration of overall heat transfer coefficient of a heat exchanger with passage of time?

[2 marks]

b) What are the factors to consider in selecting a heat exchanger other than the quantity of heat to be transfered?

[2 marks]

c) In a Rankine power system, 1.5 kg/s of steam leaves the turbine as saturated vapor at 0.51 bar. The steam is condensed to saturated liquid by passing it over the tubes of a shell-and-tube heat exchanger, while liquid water, having an inlet temperature of Tc,i = 280 K, is passed through the tubes. The condenser contains 100 thin walled tubes, each of 10-mm diameter, and the total water flow rate through the tubes is 15 kg/s.

I. What is the water outlet temperature?

[5 marks]

II. What is the required tube length (per tube)?

[3 marks]

The average convection coefficient associated with condensation on the outer surface of the tubes may be approximated as $h_o = 5000\ W/m^2K$.

Appropriate property values for the liquid water are C_p=4178 J/kgK, $\mu = 700 \times 10^{-6}$ kg/s.m, k =0.628 W/mK, and Pr = 4.6.

$Nu_D = 0.023 Re_D^{0.8} Pr^{0.4}$

Q5. a) Draw the typical pool boiling curve for water at 1atm pressure, indicating boiling regimes on the curve.

[3 marks]

b) In film boiling, the heater is surrounded by vapour. If the heat supply is continued, the heater will eventually fail. What is the reason for the heater to fail?

[3 marks]

c) A large horizontal cylinder is immersed in a pool of water which is at 100°C. Calculate the critical heat flux. You may use the following equation and tables.

[4 marks]

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

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

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

Properties of saturated water

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