9210-221
Level 7 Post Graduate Diploma in Engineering
Heat and mass transfer

Sample Paper

You should have the following for this examination
- one answer book
- non programmable calculator
- pen, pencil, drawing instruments

The following data is attached
- Table of thermodynamic and transport properties of fluids (steam tables)

General instructions
- Answer **five** questions selecting at least **two** questions from each section.
- Properties of air **c_p = 1.005 kJ/kg K, c_v = 0.718 kJ/kg K and γ = 1.4 and R = 0.287 kJ/kgK**

Section A

1 a) What is the critical Reynolds number for flow over a plate? On what does it depend? (6 marks)

b) A passenger car travels at a velocity of 100 km/h. The car engine can be approximated as a 0.5 m high, 0.45 m wide, and 0.75 m long rectangular block as shown in **Figure Q1**. The bottom surface of the block is at a temperature of 85°C and has an emissivity of 0.95. The ambient air is at 30°C and the road surface is at 35°C.

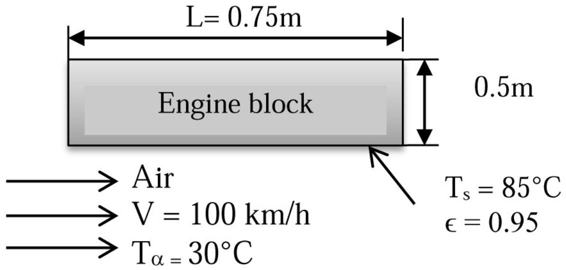

Figure Q1

Assume;

- The air flow to be turbulent over the entire surface because of the constant agitation of the engine block.
- steady operating conditions.
- air is an ideal gas with constant properties.

i) Calculate the Reynolds number and Prandtl number considering airflow parallel to the 0.75 m side. (4 marks)

ii) Determine the rate of heat transfer from the bottom surface of the engine block by convection and radiation. (10 marks)

Properties of air at 1 atm and at the mean film temperature of 57.5°C are,

$v = 1.9458 \times 10^{-5}$ m^2/s

k = 0.02844 W/mK

$\rho = 1.045$ kg/m^3

$C_p = 1.005$ kJ/kgK

Following data with usual notations can be used

$Nu = 0.037\ (Re)^{0.8}\ (Pr)^{0.3}$

Stefan-Boltzmann constant = 5.67×10^{-8} W/m^{2}K^4

2 a) Why are heat transfer coefficients for natural convection much less than those for forced convection? (2 marks)

b) Define Grashof number identifying each term? (4 marks)

c) What does the Grashof number represent Physically? (4 marks)

d) A nuclear reactor with its core constructed of parallel vertical plates 2.5 m high and 1.5 m wide, has been designed on free convection heating of liquid bismuth. The maximum temperature of the plate surfaces is limited to 970°C while the lowest allowable temperature of bismuth is 330°C.
Calculate the maximum possible heat dissipation from both sides of each plate. (10 marks)
For the convection coefficient the appropriate correlation is,

$$Nu = 0.13(Gr.Pr)^{1/3}$$

where the properties evaluated at the mean film temperature of 650°C for bismuth are,

$\rho = 10^4$ kg/m^3 $\mu = 8.66 \times 10^{-4}$ kg/ms
$C_p = 150.7$ J/kgK. $k = 13.02$ W/mK

3 a) What are the two modes in which condensation can take place on a cooling surface? (2 marks)

b) Briefly explain why the condenser tubes are usually horizontal. (3 marks)

c) Saturated steam at 110°C condenses on the outside of a bank of 100 horizontal tubes of 20 mm outer diameter, 1 m long, arranged in a 10 x 10 square array.

i) Calculate the rate of condensation if the surface is maintained at 100°C. (8 marks)

ii) What would be the rate of condensation if the condenser is in a vertical position? (7 marks)
Nusselt's equation for condensation on a bank of horizontal tubes is,

$$(h_m)horizontal = 0.725\left(\frac{k_l^3 \rho_l^2 g h_{fg}}{N \mu_l D_0 \theta}\right)^{1/4}$$

and for a vertical condenser, it is,

$$(h_m)vertical = 0.943\left(\frac{k_l^3 \rho_l^2 g h_{fg}}{\mu_l \theta L}\right)^{1/4}$$

where,

D_0 = outside diameter of the tube
N = Number of tubes in the tier
$\theta = T_{sat} - T_s$
Other notations have their usual meanings.

The properties of saturated water at 105°C are
□$\rho = 954.7$ kg/m^3
□$\mu = 271 \times 10^{-6}$ kg/ms
$k = 0.684$ W/mK
$h_{fg} = 2243.7$ kJ/kg

4 a) Define effectiveness (ε) of a heat exchanger. (2 marks)

b) What does NTU (Number of Transfer Units) in a heat exchanger mean? (2 marks)

c) A counter-flow double-pipe heat exchanger is to heat water from 20°C To 80°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal fluid available at 160°C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 15mm. Overall heat transfer coefficient (U_0) of the heat exchanger is 640 W/m2°C.

Determine the area of the heat exchanger required to achieve the desired heating,

i) using the LMTD method (8 marks)

ii) Using the effectiveness–NTU method (8 marks)

NTU relations for counter flow double pipe heat exchanger are:

$$NTU = \frac{1}{R-1} \ln\left(\frac{\varepsilon-1}{\varepsilon R-1}\right)$$

$$NTU = U_0 A_s / C_{\min} \quad , \qquad R = \frac{C_{min}}{C_{max}}$$

where R = heat capacity ratio

A_s = heat transfer surface area of the heat exchanger

$C_{\min}$ and $C_{\max}$ are heat capacity rates

Take specific heat of water and geothermal fluid to be 4.18 kJ/kgK and 4.31 kJ/kgK respectively.

Section B

5 a) Explain what is meant by 'Stefan flow'. (5 marks)

b) A 10 mm diameter Stefan tube is used to measure diffusion coefficient of carbon tetrachloride (CCl_4) into Oxygen at 0°C and 760 mmHg pressure

Following data are recorded.
Length of tube above liquid surface = 150 mm
Vapour pressure of CCL_4 at 0°C = 33 mmHg
Evaporation of CCL_4 = 0.03 g
Time of evaporation = 10 hrs

Estimate the diffusion coefficient (D) of CCl_4 into Oxygen.
The following relationship with usual notation may be used, if necessary, for steady state unidirectional diffusion of arbitrary component A through stationary arbitrary component B along a distance y.

$$\frac{N_A}{A} = \frac{DP}{RT}\frac{1}{(y_2 - y_1)} ln \frac{P_{B2}}{P_{B1}}$$

where
N_A/A = total flux of A (kmol/m^3)
R = 8.3143 x 10^3(J/kmol K)
P_{B2} and P_{B2} are partial pressure of component B (15 marks)

6 a) State Fick's law of diffusion. (4 marks)

b) How does the mass diffusivity of a gas mixture change with temperature and pressure? (4 marks)

c) Helium diffuses through a plane plastic membrane 1mm thick. The concentration of helium in the membrane is 0.02 kmol/m^3 at the inner surface and 0.005 kmol/m^3 at the outer surface.
If the binary diffusion coefficient of helium with respect to the plastic is 10^{-9} m^2/s, what is the diffusion flux of helium through the plastic?. (12 marks)

7 a) Define Schmidt number and Lewis number with their usual notations. (04 marks)

b) i) Dry air at 1atm blows across a thermometer enclosed in a dampened cover. The wet bulb temperature recorded is 18.3 °C.
Calculate the temperature of dry air. (6 marks)

ii) If the air stream is at 32.9°C, while the wet bulb temperature remains at 18.3°C, Calculate the relative humidity of the air stream.
Given that,
Mass diffusivity D = 0.26 x 10^{-4} m^2/s (for air- water system)
Thermal diffusivity α = 0.221 x 10^{-4} m^2/s (for air)
Cp = 1.005 kJ/kgK for air
Saturated water pressure at 18.3°C = 2.107 kPa
h_{fg} at 18.3°C = 2456 kJ/kg
specific volume ν = 28.2 m^3/kg for saturated water at 32.9°C
You may use the following relationship with usual notations

$$\frac{h_m}{k_m} = \rho Cp \left(\frac{\alpha}{D}\right)^{2/3}$$

where
h_m/k_m ratio of heat and mass transfer coefficient. (10 marks)

8 a) During evaporation from a water body to air, under what conditions will the latent heat of vaporization be equal to convection heat transfer from the air? (5 marks)

b) In the past, it was very popular to use jugs made of porous clay to make cool water. A small amount of water that leaks out keeps the outer surface of the jug wet at all times, and hot and relatively dry air flowing over the jug causes this water to evaporate. Part of the latent heat of evaporation comes from the water in the jug, and the water is cooled as a result.
A porous clay jug is kept in the environment of 1 atm pressure , 30°C temperature, and 35 percent relative humidity. Determine the temperature of the water when steady conditions are reached.
Since dry air properties for the mixture at the average temperature cannot be determined, assume properties of water and dry air as given below.

Water properties at 20°C:
P_{vs} = 2.34 kPa h_{fg} = 2454 kJ/kgK

Dry air properties at 1 atm and 25°C:
Cp = 1.007 kJ/kgK $\alpha = 2.141 \times 10^{-5}$ m²/s

Saturated water pressure at 30°C = 4.25 kPa

You may use rearranged Chilton-Colburn equation with usual notations.

$$T_s = T_\alpha - \frac{h_{fg}}{Cp(Le)^{\frac{2}{3}}} \frac{M_v}{M} \frac{(P_{vs} - P_{v\alpha})}{P}$$

where
T_s – surface temperature P_{vs} – vapour pressure of water
T_α – dry air temperature $P_{v\alpha}$ – vapour pressure of air
M_v and M are molecular weight of water and dry air in kg/kmol respectively (15 marks)