Department of Mechanical Engineering
MEL 802 Convection Heat and Mass Transfer
Major Examination

Max Marks : 70 May 3, 2007

Duration : 2 hours

Properties of air at 30^oC : ρ=1.165 kg/m^3, ν= 1.6 $\times$ 10^{-5} m^2/s, k= 0.02675 W/mK, Pr = 0.7

1. A wet carpet of size 6 m $\times$ 3 m, which has absorbed 10 kg of water, is hung outdoors from a line as shown in fig P1, such that vaporisation is possible from both the surfaces of the carpet. The carpet is exposed to a wind speed of 1 m/s. The dry bulb temperature of the air is 30 °C and its wet bulb temperature is 20 °C (under these conditions, the relative humidity of air is found to be about 40%). Assuming the boundary layer is laminar over the entire width W of the carpet, and the carpet surface is maintained at the wet bulb temperature of air throughout the drying process, estimate the total time required for drying the carpet. Assume the concentration of water vapour at the carpet surface remains unchanged throughout the drying process. The mass diffusivity of water vapour in air is known to be 0.288 $\times$ 10^{-4} m^2/s.
Comment whether it would have been better to dry the carpet with length L along the wind velocity and width W perpendicular to it.

(15)

2. (a) For a turbulent boundary layer over a flat surface, the boundary layer thickness δ can be determined by using the momentum integral equation for mean flow :

$$\frac{d}{dx}\int_o^\infty \overline{u}(U_\infty - \overline{u})dy = \frac{\tau_w}{\rho}$$

Assume the velocity profile in the entire boundary layer follows the 1/7th power law given by

$$\frac{\overline{u}}{u_\tau} = 8.75\left(\frac{yu_\tau}{\nu}\right)^{1/7}$$

show that

$$\frac{\delta}{x} = 0.37Re_x^{-1/5}$$

(b) The above leads to the following relation for the average friction coefficient over the flat surface

$$\overline{C_{f,L}} = 0.074Re_x^{-1/5}$$

Using Colburn's relation determine the average heat transfer coefficient in the carpet drying problem of Q 1, if U_∞ = 5 m/s and the boundary layer can be assumed to be turbulent throughout the width of the carpet. Also determine the rate of heat transfer between the carpet and the surroundings.

(20)

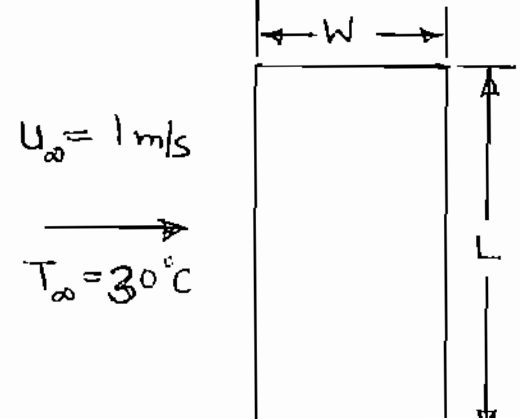

fig P1.

3. (a) What do you mean by Boussinesq approximations in the context of natural convection flow? (b)Consider a long channel, open at the top and bottom with its two walls maintained at a constant temperature of T_w, as shown in figure P3. Air flow is inducced through the chanuel due to natural convection effects. Assume the velocity as well as temperature profile to be fully developed throughout the length of the channel (neglect developing length), derive the simplified governing equations for the natural convection flow through the channel. Also give the boundary conditions. Assume that

$$P(x) = P_\infty(x)$$

where P is the pressure inside the channel. Using scale analysis of these equations, determine how the mean velocity of induced flow varies with the spacing W between the channel walls, their height H and the characteristic temperature difference $T_w - T_\infty$. Assume the flow is laminar. Hence determine the order of magnitude of average velocity through a channel of width 1 cm, and height 3 m, with $T_w = 30°C$ and $T_\infty = 20°C$.

(15)

4. Answer the following briefly : (20)

   (a) What do you understand by the term *energy cascade* in turbulent flows?

   (b) What is law of the wall and what is its significance?

   (c) What is Rayleigh Benard Convection and why does it start only after a critical Ra value?

   (d) If hot water at a given mass flow rate is to flow through a long pipe whose surfaces are maintained at constant temperature lower than that of hot water, what considerations you would use to decide the diameter of the pipe? If the pumping power required is not a constraint, would you recommend a large or a small diameter pipe?

   (e) A hot wire probe used for measuring the velocity in an air stream works on the principle of convective heat transfer from an electrically heated wire varying with the change in velocity. In certain designs of the anemometer, the wire temperature is maintained constant and the current through the wire is changed to balance the changed heat transfer due to change in velocity. Discuss the methodology for deriving the relationship between the change in the current through the wire and the change in velocity. Take the wire to be circular.(fig P4)

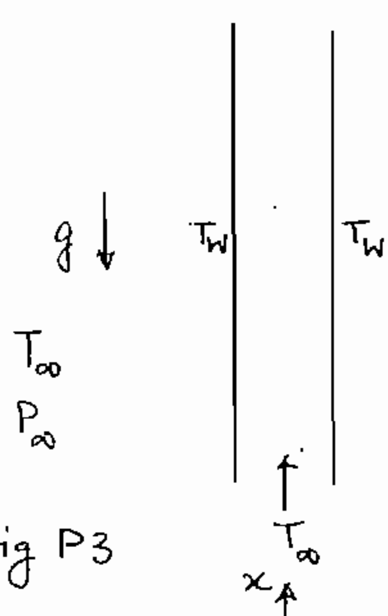

fig P3

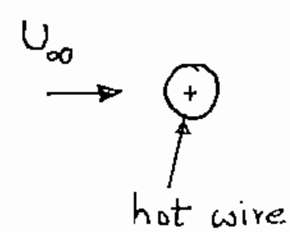

fig P4