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Research Institute

INTRODUCTION TO HEAT TRANSFER
TUTORIAL SHEET 1

1. A $1m^2$ domestic hot water radiator acts approximately as vertical flat plate with an emissivity of 1. Calculate the ratio of convective to radiative heat transfer from the radiator when it is at 80°C. Why are the rear 'surface of such radiators sometimes covered in silver foil?

2. Explain in detail how a purely radiative heater, for example a peat fire, heats the air and the surfaces in a room.

3. Model a naked human being as a vertical flat plate and calculate the surface temperature necessary to dissipate 50W of heat in still air at 30°C. The emissivity of human skin is 0.95. Explain why evaporative heating is sometimes necessary.

4. Explain why ground frost sometimes forms where the air temperature is above freezing.

5. The radiator in question 1 is subjected to a draft of 2m/s parallel to its surface, calculate the new heat transfer rates if the surface temperature remains constant.

6. A 4.0cm diameter sphere is heated to a temperature of 150°C and is enclosed in a large room at 20°C. Calculate the radiant heat loss if the surface emissivity is 0.65.

7. If 3 kW is conducted through a section of insulating material $1.0m^{2\ in}$ cross section and 2.5cm thick and the thermal conductivity may be taken as 0.2W/mK. , compute the temperature difference across the material.

8. A woman informs an engineer that she frequently feels cooler in the summer when standing in front of an open refrigerator. The engineer tells her that is only "imagining things'' because there is no fan in the refrigerator to blow the cold air over her. A lively argument ensues. Whose side of the argument do you take? Why?

9. Two infinite black plates at 500 and 100°C exchange heat by radiation. Calculate the heat-transfer rate per unit area. If another perfectly black plate is placed between the 500 and 100°C plates, by how much is the heat transfer reduced? What is the temperature of the centre plate?

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10. Consider a wall heated by convection on one side and cooled by convection on the other side. Show that the heat-transfer rate through the wall

$$Q = \frac{T_1 - T_2}{\frac{1}{h_1 A} + \frac{\Delta x}{kA} + \frac{1}{h_2 A}}$$

Where T_1 and T_2 are the fluid temperatures on each side of the wall and h_1 and h_2 are the corresponding heat-transfer coefficients.

HEAT TRANSFER 2 (ID CONDUCTION)

1. A heat exchanger wall consists of a steel plate 2mm thick. One surface of the plate exposed to a fluid at 82°C, as a heat transfer coefficient of 2100W/m^2K and the other surface exposed to a fluid at 32°C has a heat transfer coefficient of 4500W/m^2K

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A) Draw the electrical analogue of the 'thermal circuit'
B) Calculate the surface temperature of the plate
C) Calculate the heat flux through the plate
D) Determine what % improvement would be obtained in the heat flux if the 2mm thick plate was made of aluminium.

Assume the thermal conductivities for the steel and aluminium are 55 and 202 W/mK respectively.

2. In order to bond a large sheet of plywood (thickness 22mm K=0.15W/mK) to a sheet of cork board (thickness 22mm K=0.043W/mK), the glue line must be maintained at 43°C for a long period. This is accomplished by a radiant heat source directed uniformly onto the surface of the wood. The heat transfer coefficients between the exposed surfaces of the wood and of the cork and the surrounding air at 21°C are each H=11.3 W $m^{-2}K^{-1.}$ Radiant heat losses from the sheets from the sheets are negligible.

A) Draw an electrical circuit which is analogue of the thermal system and calculate the thermal resistance.
B) Estimate the rate at which heat must be supplied to the surface of the wood to maintain the required temperature at the interface.
C) Without detailed calculation, decide whether it would be better to apply the heat source to the cork surface.

3. Show that an increase in the thickness of lagging surrounding a cylindrical pipe containing hot fluid will not reduce the heat loss, unless the outer radius exceeds a certain value. (Assume that the heat transfer coefficient between the surface of the lagging and the surrounding air is constant).

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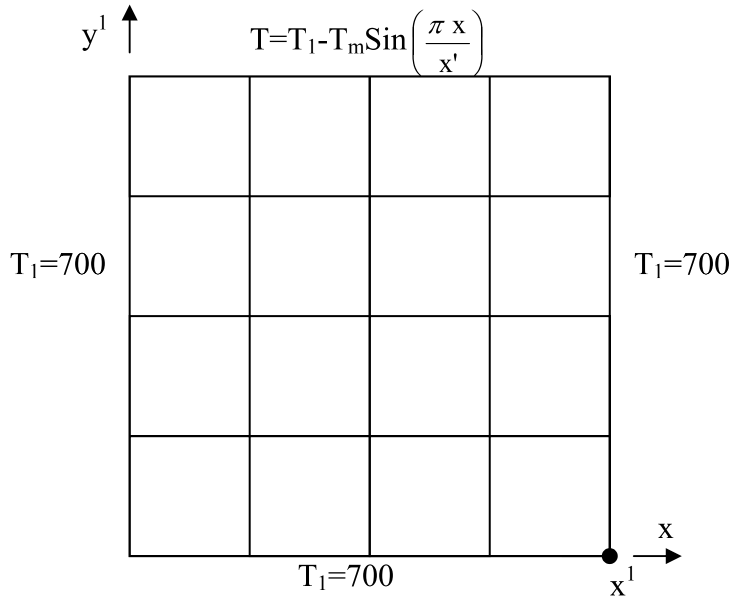
HEAT TRANSFER 3 (DIMENSIONAL CONDUCTION)

1. $x^1 = 10\text{mm}$
   $y^1 = 10\text{mm}$
   $T_m = 500$



Find the nodal temperatures analytically and numerically and compare the results. Find the heat flux in through the bottom face.

2. Derive the following equation for the temperature of an internal corner node with convection

$$T_{m,n} = \frac{\left(\frac{h\Delta x}{K}\right)T_{\infty} + T_{m,n+1} + T_{m-1,n} + \left(T_{m+1,n} + T_{m,n-1}\right)/2}{3 + \frac{h\Delta x}{K}}$$

3. Derive the following equation for the temperature distribution in a cylinder when there is temperature symmetry about the cylinders axis.

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = 0$$

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HEAT TRANSFER 4 (EMPERICAL CONVECTION)

1. A vertical square plate 300mm on a side, is maintained at 50°C and exposed to room air at 20°C. The surface emissivity is 0.8. Calculate the total heat loss by both sides of the plate.

2.

(a) A 2kw immersion heater consists of an electrical heating element contained in a 50mm diameter sealed horizontal tube, and is used to heat water at 60°. If the surface temperature of the tube is not to exceed 95°C, calculate the length of tube required. The coefficient of cubical expansion of water may be taken as 6.21 X 10^4 /K

(b) A tube of 2.5 cm diameter and surface temperature of 34°C, is losing heat by free convection to air at 20°C and 1 bar pressure. In order to estimate the heat loss, model tests with a wire heated electrically to 284°C are to be carried out in compressed air at 20°C. The wire is to be 0.25cm diameter. Calculate the air pressure that would be required, assuming that

Nu = f (Gr. Pr) with the properties evaluated at the film temperature.

3. A 2m X 2m flat plate is required to dissipate 5 kw of heat at 100°C in still air. Find the maximum air temperature at which this can be achieved.

4. A ballast resistor in the form of a long circular cylinder dissipates heat uniformly along its length by a stream of air flowing perpendicular to the axis of the cylinder. When the resistor is dissipating 100W its surface temperature is 50K above the approaching air temperature for a flow felocity of 5m/s and at greater velocities the temperature difference is found to vary inversely as the square root of the velocity.

The resistor is replaced be a second resistor of the same length but twice the diameter. The surface temperature of this resistor is 80K above the approaching air temperature at a flow velocity of 7m/s.

i. State the non-dimensional relationship between heat transfer coefficient, diameter, velocity and fluid properties. (The numerical constant need not be evaluated).
ii. Calculate the power dissipated in the second resistor. (Neglect the variation of the properties of air with temperature).

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HEAT TRANSFER 5 (CONVECTION)

1. Explain the assumptions leading to the derivation of the equation

$$\frac{K}{\rho C_p}\frac{\partial^2 T}{\partial y^2} = u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}$$

What is the physical mechanism behind each of these terms?

2. Making the appropriate non-dimensional assumptions show that:

$$\frac{1}{R_e P_r}\frac{\partial^2 T^*}{\partial x^{*2}} = u^*\frac{\partial T^*}{\partial x^*} + v^*\frac{\partial T^*}{\partial y^*}$$

If we have two different fluids with the same product of R_e and P_r how will their dimensionless temperature boundary layers, $T^* = f(y^*, x^*)$, compare when u^* and v^* are the same for each fluid.

3. Write a short description of how heat transfer is enhanced when laminar flow becomes turbulent.

4. Find the heat transfer rate in W/m^2 from a plate with the following temperature distribution at a point:

$$T = 10^3 y^3 + 500y + T_p$$

The thermal conductivity is 2×10^{-3} W/mK. If $T_p - T_\infty = 200K$ find the heat transfer coefficient.

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HEAT TRANSFER 6

1.An opaque surface has a reflectively of 0.2 Calculate the amount of heat it radiates at 300k.

2. Describe the spectral distribution of radiant black body energy at various temperatures. If the emissivity of white paint is low for low wavelengths and high for high wavelengths explain why it is advisable to paint buildings white in the tropics.

3. A gas fire radiates black body heat at 800k, its surface area is 0.04m^{2,} and it is vertically mounted. What is the heat flux for the fire? What percentage of the maximum heat available would I feel if I was sat at an angle of 20° to the plane of the fire?

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HEAT TRANSFER 7 (REVISION)

1. It is better to lag a copper hot water pipe of 10mm outside diameter with 50 mm of lagging with a conductivity of 0.04W/mk or with 25mm of lagging of conductivity 0.01W/MK. Assume the outside surface heat transfer coefficient if constant at 12W/mk.

2. A 2kW immersion heater is required to heat water to 60°C without the surface temperature of the heater exceeding 95°C. Assuming that this heating surface is a horizontal cylinder Z and diameter d, find a numerical formula relating these two dimensions. Hence determine the length of heating element required when the diameter is (a) 10mm and (b) 50mm. Properties of water are given in Engineering tables (Use the diameter d as the characteristic length in the Nusselt and Grashof numbers).

3.Write an essay describing what effect changes in the mainstream flow has on the heat transfer to a flat plate.

4.Prove that in a counter-current heat exchanger the total heat transferred Q is given by

$$Q = UA\ T_{LM}$$

Where u is the overall heat transfer coefficient, A is the total heat transfer area and T_{LM} is the logarithmic mean temperature difference between the two fluid streams.

5. Describe how the Relaxation Method is used to solve two dimensional conduction problems.

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