Class Assignment-I

1. Calculate the rate at which heat is lost to the surroundings per unit length of an insulated steam pipe having the following dimensions and specifications:
   Inner diameter of pipe =3 cm; thickness of pipe = 0.2 cm; thickness of insulation = 1 cm heat transfer coefficient on inside surface =10 w/m^{2}K; heat transfer coefficient on outside surface =10 W/m^2-K temperature of steam =100^{0}C, temperature of surroundings =250 C thermal conductivity of pipe metal =15 W/m-K, thermal conductivity of insulation = 0.05 W/m-K.

2. 1m long steel plate(k=50 W/mK) is well insulated on its sides, while the top surface is at 100°C and the bottom surface is convectively cooled by a fluid at 20^0 C. Under steady state conditions with no generation, a thermocouple at the mid point of the plate reveals a temperature of 850C. What is the value of the convection heat transfer coefficient at the bottom surface.

3. An electrical wire having a radius of r= 5mm and a resistance per unit length of 10^{-4} ohm/m is coated with a plastic insulation of thermal conductivity k= 0.2W/mK. The insulation is exposed to ambient air for which T = 300 K and h = 10 W/m2 K. If the insulation has a maximum allowable temperature of 450K, what is the maximum possible current that may be passed by the wire.

4. The handle of a ladle used for pouring molten lead at 327^{0}C is 30cm long and is made of 2.5X1.5cm mild steel bar stock (k = 43 W/mK). In order to reduce the grip temperature, it is proposed to make a hollow handle of mild steel plate 1.5mm thick to the same rectangle shape. If the surface heat transfer coefficient is 14.5 W/m^{2}K and the ambient is at 27^{0}C, estimate the reduction in the temperature of the grip. Neglect heat transfer from the inner surface of the hollow shape.

<u>**End-Semester Exam (November 14, 2015)**</u>

ME-663 Advanced Heat Transfer

Max. Marks: 75

Note: **Exchange of notes is strictly not allowed.**

You are allowed to carry only the class notes, lecture material slides uploaded on the moodle and one (01) text book (Incropera DeWitt only). Any other material or text/reference book is not allowed.

Make any reasonable assumption in case you think any data is missing from any problem statement. Justify the assumption properly.

---

1. A homogeneous spherical piece of radioactive material of radius r_o=0.04 m is generating heat at a constant rate of 4×10^7 W/m^3. The heat generated is dissipated to the environment steadily. The outer surface of the sphere is maintained at a uniform temperature of 80^{o}C and the thermal conductivity of the sphere is k=15 W/m.K. Assuming steady one-dimensional heat transfer,
   a. Express the differential equation and boundary conditions for heat conduction through the sphere. (5)
   b. Obtain a relation for the variation of temperature in the sphere by solving the differential equation. (3)
   c. Determine the temperature at the center of the sphere. (2)

2. Thermometer is a frequently employed temperature measuring device. The speed with which the thermometer follows the fluid temperature becomes very important in the context of measurement of unsteady temperatures of a fluid. In one such application, a mercury bulb-based thermometer is to be employed for measuring the temperature of a fluid in which the temperature variations have a time period of about 11 seconds. The mercury bulb may be idealized as a sphere of 0.1 cm radius.
   a) Comment on the suitability of the proposed thermometer for this application. Take h as 50 W/m^{2}K. The values of thermal conductivity and thermal diffusivities may be taken as 8.54 W/m.K and 4.50×10^{-6} m^2/s. (5)
   b) How much time one would have to wait for if the acceptable error in temperature measurement is specified as 1%? Is the time interval thus obtained acceptable under the given conditions? (3)
   c) Determine the size of the mercury bulb if the response time of the thermometer is to be kept at 1 seconds. (2)

3. Sun has a diameter of 1.391×10^6 km. The earth has a mean diameter of 12740 km and lies at a mean distance of 1.496×10^8km from the center of sun.
   a) If earth is treated as a flat disk normal to the radius from sun to earth, determine the view factor $F_{sun-earth}$. (2)
   b) Use this view factor and the measured solar irradiation of $1.367\,kW/_{m^2}$ to show the effective black body temperature of sun is $5777K$. (3)

4. Water at 20^{o}C flows through a small-bore tube of 1 mm in diameter at a uniform speed of 0.2 m/s. The flow is fully developed at a point beyond which a constant heat flux of 6000 W/m^2 is imposed.
   a) Estimate the distance down the tube at which the water would reach 74^{o}C at its hottest point. (The thermophysical properties of water may be taken from Incropera Dewitt.) (5)
   b) Determine the heat transfer coefficient. Is the value ~~thus obtained as per~~ general expectations that you would have for water as the working fluid? If not, think of some possible physical

explanation of the result obtained and its plausible implication in effective heat removal techniques. (2+3)

5. Two large porous plates are separated by a distance H. An incompressible fluid fills the channel formed by the plates. The lower plate is maintained at temperature T_1 and the upper plate at T_2. An axial pressure gradient dp/dx is applied to the fluid to set it in motion. A fluid at temperature T_1 is injected through the lower plate at velocity v_o and leave through the upper plate with same velocity. The injected fluid is identical to the channel fluid. Neglect gravity, viscous dissipation and axial variation of temperature. Determine the axial velocity and surface heat flux at each plates. (10)

6. Fourier law of heat conduction fails to predict the thermal response of the given sample for the cases that deal with very small length scales (of the order of microns to sub microns) and/or ultra fast heating rates (e.g. manufacturing applications wherein ultra fast pulsed lasers are employed as heating sources). For such applications, the generalized non-Fourier heat conduction models have been proposed in the literature. This generalized non-Fourier heat conduction model may be expressed as follows:

$$\tau \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}$$

Here τ represents the thermal relaxation time and α is the thermal diffusivity of the material. The thermal relaxation time can vary between very low values (≈ 0, representing Fourier model) to considerably larger values, which eventually lead to non-Fourier models. With this background, attempt the following:

a) Express the above equation for the cases for which the thermal relaxation time is significantly high ($\tau >> t$). (2)

b) Now you are given a material which is characterized by a very high thermal relaxation time. Consider a one-dimensional slab of this material with thickness "L". Initial, the slab is maintained at a temperature of T_c. The side walls of the slab are suddenly raised to a temperature of T_h. You may assume the initial heating rate i.e. $\partial T/\partial t = 0$. Write down the governing equation, initial conditions and the necessary boundary conditions. (5)

c) Determine the time-dependent temperature distribution i.e. $T(x,t)$ within the body of the one-dimensional slab, as given in part (b) above. (10)

d) Determine the thermal wave speed for one such material for which the thermal diffusivity is 1.37×10^{-7} m^2/s and the thermal relaxation time is 10 s. Compare the thermal wave speed thus obtained with that of some common engineering material e.g. mild steel which has thermal relaxation time of the order of few picoseconds. Comment. (3)

7. The clearance space between the shaft and the bearing surface in a lubricated bearing is somehow maintained at a constant value of 0.005 cm (though this clearance does actually change around the circumference giving rise to severe pressure gradients!). In one such configuration, the surface velocity of the shaft is 30 m/s (this actually corresponds to an RPM of 6,000 for a 10 cm shaft). The bearing surface is maintained at a constant temperature of 35^{o}C. Find the steady state temperature of the shaft and calculate the heat removed per unit time at the bearing surface. Attempt the above for the case when there is no provision for cooling the shaft. Take k = 1 W/mK and μ = 0.012 Ns/m^2. Explicitly mention any assumptions made. (10)

Mid-Semester Exam (September 10, 2015)

ME-663 Advanced Heat Transfer

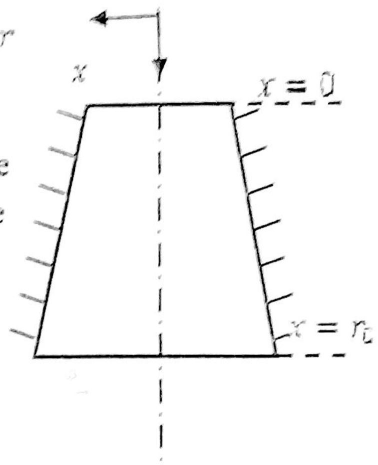
Max. Marks: 60

- Note: Exchange of notes is strictly not allowed.
  You are allowed to carry only the class notes, lecture material slides uploaded on the moodle and one (01) text book (Incropera DeWitt only). Any other material or text/reference book is not allowed.
  Make any reasonable assumption in case you think any data is missing from any problem statement. Justify the assumption properly.

---

1. (a) A solid truncated cone serves as a support for the system which helps to maintain the top surface of the cone at constant temperature 'T_1' while the base of the cone is at 'T_2' ($T_2 < T_1$). The thermal conductivity of the solid depends on temperature according to the relation $k = k_0 - aT$ where 'a' is a positive constant, and the sides of the cone are well insulated. Do the following quantities increase, decrease, or remain the same with increasing x:

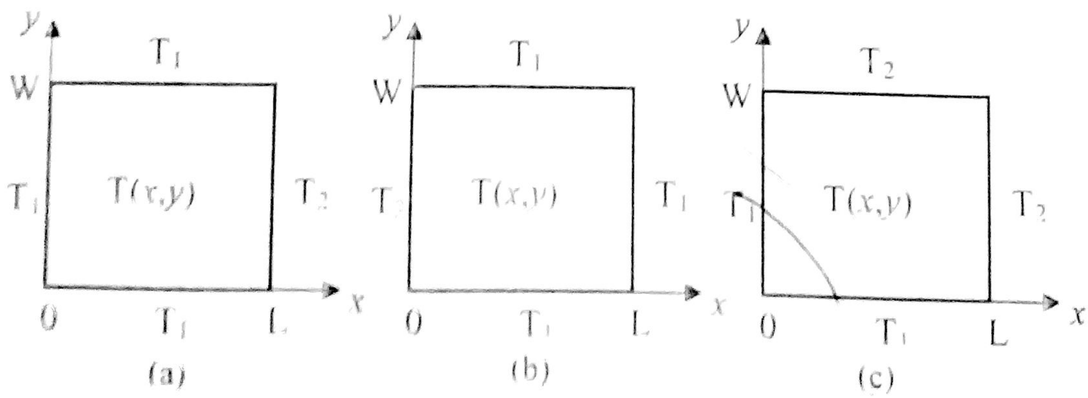
   a) heat transfer rate,
   b) heat flux,
   c) thermal conductivity k,
   d) and the temperature gradient



   (b) Solve for the steady state temperature profile if the thermal conductivity is assumed to be constant and the radius varies as $r = \sqrt{r_0^2 - x^2}$, where r_0 is a positive constant. (10)

2. Consider a fin 2L long. The half of the fin is peripherally insulated and the fin base temperature on this half is specified to be T_w. The other half transfers the heat into the surrounding medium with heat transfer coefficient h and the ambient temperature of T_∞. The end of this half is insulated. Find the temperature of the middle vertical plane and that of the insulated end of the fin. (10)

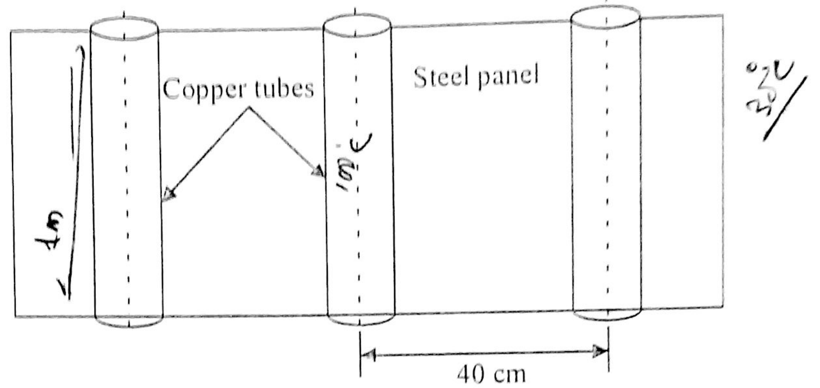
3. Application of the methodology of Separation of Variables (SOV) to solve steady state 2-dimensional heat conduction equation was demonstrated in the class for a thin rectangular plate subjected to the specified boundary conditions. Now consider a similar thin rectangular plate whose boundaries are subjected to the set of boundary conditions shown in each cases below:



$\theta = \frac{T - T_1}{T_2 - T_1}$

Determine expressions for the two-dimensional temperature distributions for the cases (a), (b) and (c) shown in the above figure. Illustrate each step in clear terms. (15)

4. Consider a 1 mm thick steel panel (of 1 mm length) on which copper tubes are soldered parallel to each other 40 cm apart. Steam at 100°C passes through these and condenses into water at 100°C so that the tube temperature is maintained effectively at 100°C. The atmospheric temperature is 30°C. Find the rate of heat loss per meter run of one tube, given that the h for the geometry is 20 W/m^2-K. Thermal conductivity of the steel may be taken to be equal to 60 W/m-K. Think of an approach through which the problem definition may be simplified and you may make use of some of the standard concepts that have already been discussed in the class. Explicitly mention any assumption made by you for solving the problem with proper justification. Comment on the final answer that you may get with such assumptions, if any. (15)



5. Consider 1-D unsteady heat conduction in a slab of length L which is initially at a temperature T_2. The left face of the slab is suddenly raised to temperature T_1. The steady state temperature (after the initial transients die out) is linear, varying from T_1 on the left face to T_2 on the right. Obtain an expression for the temperature distribution inside the slab. (10)

$C_1 = C_3 e^{-\lambda^2 \alpha t}$

At $t = 0$

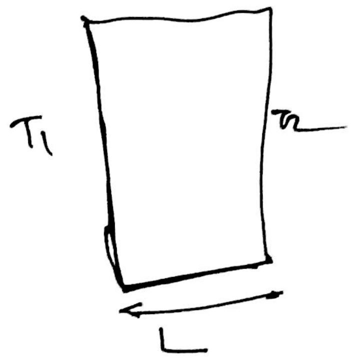
$\theta_2 = C_3 e$

$C_1 = \theta_2 e^{-\lambda^2 \alpha t}$

$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} = -\lambda^2$

$\cos\lambda x + C_2 \sin\lambda x$

$C_2 \sin\lambda x$



At $t = 0$, $T = T_2$

At $x = 0$, $T = T_1$

At x, $t \to \infty$: $T = T_1 + \left(\frac{T_2 - T_1}{L}\right) x$

Scanned by CamScanner