GATE

2018

HEAT TRANSFER

MECHANICAL ENGINEERING

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GATE-2018: Heat Transfer| Detailed theory with GATE & ESE previous year papers and detailed solu ons.

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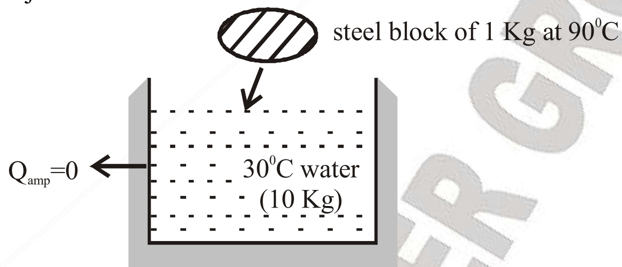
CONTENTS

CHAPTER - 1
BASIC CONCEPT

1.1 INTRODUCTION
The main difference between thermodynamic analysis and heat transfer analysis of a problem is that in thermodynamic we deal with system in equilibrium i.e., to bring a system from one equilibrium state how much heat is require is the main criteria in thermodynamic analysis.
But in heat transfer analysis we deal with how fast the change of state occurs by calculating the rate of heat transfer in joule/sec or watt.



In the above figure, a steel block which is at 90ºC is put in water at 30ºC.
Here we can use thermodynamic approach to find the equilibrium temperature T_e i.e.
Heat lost by steel = Heat gained by water

$$m_s \times c_{ps}(T_{si} - T_e) = m_w \times c_{pw}(T_e - T_{wi})$$

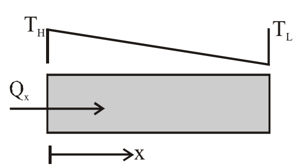
Where, m_s and m_w are mass of steel block and mass of water
c_{ps} and c_{pw} are specific heat of steel block and water
Tsi and Twi are initial temperature of steel block and water

$$1\times c_{ps}\times (90 - T_e) = 10\times c_{pw}\times (T_e - 30)$$

From the above equation T_e (equilibrium tamp.) can be easily found out with given value of specific heat of steel block and water.

1.2 MODES OF HEAT TRANSFER
The heat transfer generally takes place under three different controlling laws as Conduction, Convection and Radiation all three has been discusses below in detail.

1.3 CONDUCTION
In such case heat transfer takes place between the molecules of a stationery medium like solid, liquid and gas. The conduction phenomenon can be easily understand by Fourier law of conduction.



GATE QUESTIONS

1. As the temperature increases, the thermal conductivity of a gas

[GATE - 2014]

(a)Increases
(b)Decreases
(c)Remains constant
(d)Increases upto a certain temperature and then decreases

2. One dimensional unsteady state heat transfer equation doe a sphere with heat generation at the rate of 'q' can be written

[GATE - 2004]

(a) $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(b) $\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(c) $\frac{\partial^2 T}{\partial r^2}+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(d) $\frac{\partial^2}{\partial r^2}(rT)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

3. In descending order of magnitude, the thermal conductivity (a) Pure iron (b) Liquid water (c) saturated water vapour (d) Pure aluminium can be arranged as

[GATE - 2001]

(a) abcd (b) bcad
(c) dabc (d) dcba

4. For a given heat flow and for the same thickness, the temp, drop across the material will be maximum for

[GATE - 1996]

(a) Copper (b) Steel
(c) Glass wool (d) Refractory brick

5. Match the property with their units

Property
A. Bulk modulus
B. Thermal conductivity
C. Heat transfer coefficient
D. Heat flow rate

Units
(i) W/s
(ii) N/m^2
(iii) N/m^3
(iv) W
(v) W/mK
(vi) W/m^2K

[GATE - 1991]

Codes:
(a) A-i, B-ii, C-vi, D-v
(b) A-ii, B-v, C-vi, D-i
(c) A-ii, B-vi, C-iv, D-i
(d) A-i, B-v, C-ii, D-ii

6. Thermal conductivity is lower for

[GATE - 1990]

(a) Wood
(b) Air
(c) Water at 100°C
(d) Steam at 1 bar

ESE OBJ QUESTIONS

1. Consider the following statements about thermal conductivity:
1.Thermal conductivity decreases with increasing molecular weight.
2.Thermal conductivity of non-metallic liquids generally decreases with increasing temperature.
3.Thermal conductivity of gases and liquids is generally smaller than that of solids.
Which of the above statements are correct?
[ESE - 2016]
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2, and 3

2. The conduction heat diffuses in a material when the materials has :
1. High thermal conductivity
2. Low density
3. High specific heat
4. High viscosity
Which of the above are correct?
[ESE - 2014]
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 4 and 1

3. Hot air at 150°C flows over a flat plate maintained at 50°C .If the force convection heat transfer coefficient is 75 W/m^2K, the heat gain rate by the plate through an area of $2m^2$ will be
[ESE - 2013]
(a) 15kW
(b) 22.5kJ/s
(c) 7.5kJ/s
(d) None of the above

4. The poisson's equation of general conduction heat transfer applies to the case
[ESE - 2013]
(a)Steady state heat conduction with heat generation
(b)Steady state heat conduction without heat generation
(c)Unsteady state heat conduction without heat generation
(d)Unsteady state heat conduction with heat generation

5. Which of the following properties of air increase with rise in temperature?
1. Specific gravity
2. Specific heat
3. Thermal conductivity
4. Kinematic viscosity
[ESE - 2012]
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1 and 4 only

6. In unsteady-state conduction for bodies with negligible temperature gradients, the time temperature variation curve is
[ESE - 2012]
(a) Linear (b) Parabolic
(c) Sinusoidal (d) Exponential

7. A satellite floats in deep space with very high velocity. It will continuously lose heat by
[ESE - 2012]
(a) Convection
(b) Conduction and convection
(c) Radiation
(d) Radiation and convection

8. The unit of a following parameter is not m^2/s
[ESE - 2011]
(a) Thermal diffusivity
(b) Kinematic viscosity
(c) Mass diffusivity
(d) Dynamic viscosity

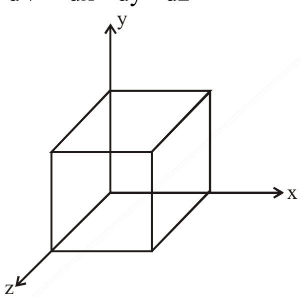
9. In the film established along a vertical plate during condensation of any vapour over the plates, the temperature distribution curve is
[ESE - 2011]
(a) Concave upwards
(b) Concave downwards

CHAPTER - 2
STEADY STATE CONDUCTION THROUGH A PLANE WALL

2.1 INTRODUCTION
The objective of conduction analysis is:
1. To calculate the temperature distribution and temperature gradient means variation of temperature with time and distance.
2. To calculate heat transfer rate through geometry.

2.2 HEAT DIFFUSION EQUATION IN CARTESIAN COORDINATE SYSTEM
Consider an infinitesimal volume element through which heat flow rate exist and which is oriented in a three dimensional co-ordinate system. The sides dx, dy and dz have been taken parallel to the x, y and z respectively. The volume for element will be:

$$dV = dx \times dy \times dz$$



1. Accumulation of Heat in x-direction
By using Taylor series expansion we get,

$$Q_x - Q_{x+dx} = Q_x - \left[Q_x + \frac{-\partial}{\partial x}(Q_x)\,dx\right]$$

$$Q_x - Q_{x+dx} = -\frac{\partial}{\partial x}(Q_x)\,dx$$

$$Q_x - Q_{x+dx} = -\frac{\partial}{\partial x}\left(-k_x A_x \frac{dT}{dx}\right)dx$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x dydz \frac{dT}{dx}\right)dx$$

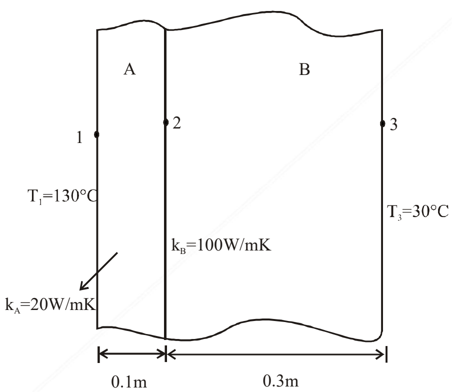
$$(\because A_x = dy \times dz)$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x \frac{dT}{dx}\right)dxdydz$$

$$Q_x - Q_{x+dx} = \frac{\partial}{\partial x}\left(k_x \frac{dT}{dx}\right)dV$$

GATE QUESTIONS

1. Steady one-dimensional heat conduction takes place across the faces 1 and 3 of a composite slab consisting of slabs of A and B in perfect as shown in figure , where k_A, k_b denote the respective thermal conductivities .Using the data as given in the figure, the interface temperature T_2 (in °C) is_______.

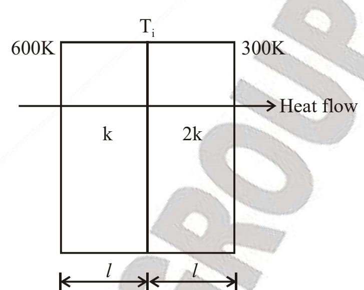


[GATE - 2016]

2. A plane wall has a thermal conductivity of 1.15W/mK. If the inner surface is at 1100°C and the outer surface is at 350°C, then the design thickness (in meter) of the wall to maintain a steady heat flux of 2500W/m^2 should be __________.

[GATE - 2014]

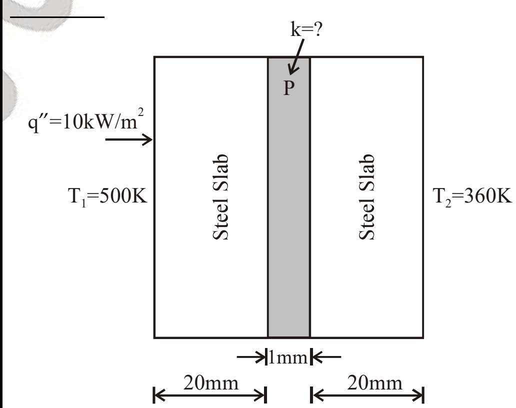
3. Heat transfer through a composite wall is shown in figure. Both the sections of the wall have equal thickness (l). The conductivity of one section is K and that of the other is 2k. The left face of the wall is at 600K and the right face is at 300K



The interface temperature T_i (in K) of the composite wall is ________.

[GATE - 2014]

4. A material P of thickness 1mm is sandwiched between two steel slabs, as shown in figure below. A heat flux 10 kW/m^2 is supplied to one of the steel slabs of shown. The boundary temperatures of the slabs are indicated in the figure. Assume thermal conductivity of this steel is 10W/m.K. Considering one-dimensional steady state heat conduction for the configuration, the thermal conductivity (k, in W.m.K) of material P is _______



[GATE - 2014]

5. Consider one dimensional steady state heat conduction across a wall (as shown in figure below) of thickness 30mm and thermal conductivity 15W/m.K. At x = 0, a constant

ESE OBJ QUESTIONS

1. A furnace is provided with an insulating refractory lining. The overall thermal conductivity of the material is 0.03 W/mK. The thickness of the lining is 100 mm. The inner and outer temperatures are 250°C and 50°C, respectively. The heat loss to the surroundings will be

[ESE - 2017]

(a) 30 $J/m^2/s$ (b) 60 $J/m^2/s$
(c) 60 J/s (d) 30 J/s

2. A wall of 0.6 m thickness has normal area of $1.5m^2$ and is made up of material of thermal conductivity 0.4 W/mK. If the temperatures on the two sides of the wall are 800°C and 1000°C, the thermal resistance of the wall is

[ESE - 2017]

(a) 1.8 K/W (b) 1.8 W/K
(c) 1 K/W (d) 1 W/K

3. In a furnace the heat loss through the 150mm thick refractory wall lining is estimated to be $50W/m^2$. If the average thermal conductivity of the refractory material is 0.05W/mK, the temperature drop across the wall will be

[ESE - 2016]

(a) 140°C (b) 150°C
(c) 160°C (d) 170°C

4. A plane wall is 20cm thick with an area of $1m^2$ and has a thermal conductivity of 0.5W/m.K. A temperature difference of 100°C is imposed across it .A heat flow is at

[ESE - 2016]

(a)150W (b) 180W
(c) 220W (d) 250W

5. In a wall of constant thermal conductivity , the temperature profile for heat conduction in the presence of a heat source inside the wall is

[ESE - 2015]

(a) Linear (b) Logarithmic
(c) Parabolic (d) Hyperbolic

6. A plane wall is 20cm thick with an area perpendicular to heat flow of $1m^2$ and has a thermal conductivity of 0.5W/mK. A temperature difference of 100°C is imposed across it. The rate of heat flow is

[ESE - 2015]

(a) 0.10kW (b) 0.15kW
(c) 0.20kW (d) 0.25kW

7. There is a uniform distributed source of heat present in a plane wall whose one side (x =0) is insulated and other side (x = L) is exposed to ambient temperature (T_∞) with heat transfer coefficient (h) .Assuming constant thermal conductivity (k), steady state and one dimensional conduction , the temperature of the wall is maximum at x equal to

[ESE - 2015]

(a) 0 (b) L
(c) L/2 (d) L/4

8. There is a uniform distributed source of heat present in a plane wall whose one side (x = 0) is insulated and other side (x=L) is exposed to ambient temperature (T_∞), with heat transfer coefficient (h). Assuming constant thermal conductivity (k), steady state and one dimensional conduction, the temperature of the wall is maximum at x equal to

[ESE - 2015]

(a) 0 (b) L
(c) L/2 (d) L/4

9. A plane wall is 20cm thick with an area perpendicular to heat flow of $1m^2$ and has a thermal conductivity of 0.5W/mK. A temperature difference of 100° C is imposed across it. The rate of heat flow is

[ESE - 2015]

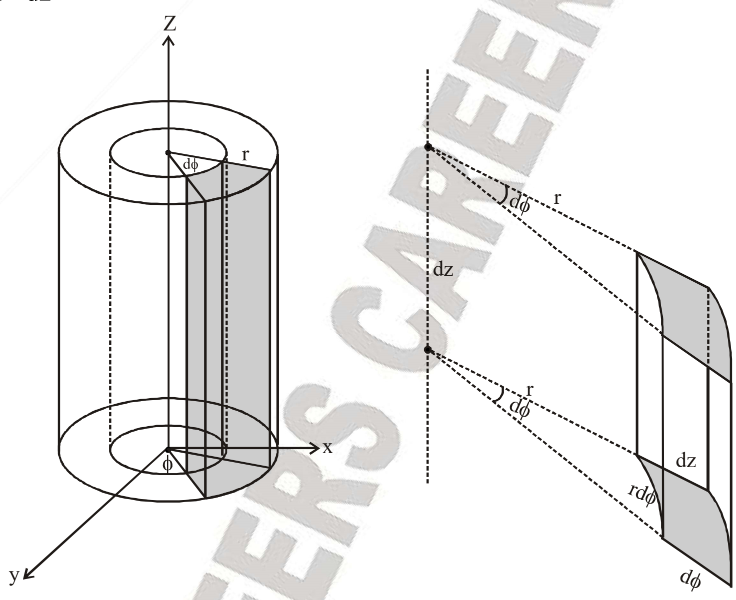
(a) 0.10kW (b) 0.15kW
(c) 0.20kW (d) 0.25kW

CHAPTER - 3
CONDUCTION ANALYSIS THROUGH A HOLLOW CYLINDER

3.1 INTRODUCTION
In power stations, process industries and oil refineries the cylindrical metal tubes are essential element. Almost in all thermodynamic applications the cylindrical tubes are used. Evidently, in tubes, pipes and insulation used to cover pipe has the radial heat transfer rate through is quite important.

3.2 HEAT DIFFUSION EQUATION IN CYLINDRICAL COORDINATE SYSTEM
As we know tubes and pipes have cylindrical geometry. Thus, it is more convenient to consider cylindrical co-ordinates. The general heat equation can be setup by considering an infinitesimal cylindrical volume element. The volume for element will be:

$dV = dr_o \times r_o d\phi \times dz$



1. Accumulation of Heat in Radial Direction (z – ϕ plane)

$$Q_{ro} - Q_{r_o + dr_o} = Q_{r_o} - \left[Q_{r_o} + \frac{\partial}{\partial r_o}\left(Q_{r_o}\right) dr_o \right]$$

$$Q_{r_o} - Q_{r_o + dr_o} = -\frac{\partial}{\partial r_o}\left(Q_{r_o}\right) dr_o$$

$$Q_{r_o} - Q_{r_o + dr_o} = -\frac{\partial}{\partial r_o}\left(-k_{r_o} A_{r_o} \frac{dT}{dr_o}\right) dr_o$$

GATE QUESTIONS

1. A plastic sleeve of outer radius r_0 = 1mm covers a wire (radius r = 0.5mm) carrying electric current .Thermal conductivity of the plastic is 0.15W/m–K. The heat transfer coefficient on the outer surface of the sleeve exposed to air is 25W/m^2–K. Due to the addition of the plastic cover, the heat transfer from the wise to the ambient will

[GATE - 2016]

(a) Increase (b) Remain the same
(c) Decrease (d) Be zero

2. Consider the radiation heat exchange inside an annulus between two very long concentric cylinders .The radius of the outer cylinder is R_0 and that of the inner cylinder is R_i. The radiation view factor of the outer cylinder into itself is

[GATE - 2016]

(a) $1-\sqrt{\frac{R_i}{R_0}}$ (b) $\sqrt{1-\frac{R_i}{R_0}}$

(c) $1-\left(\frac{R_i}{R_0}\right)$ (d) $1-\frac{R_i}{R_0}$

3. A hollow cylinder has length L, inner radius r_1, outer radius r_2, and thermal conductivity k. The thermal resistance of the cylinder for radial conduction is

[GATE - 2016]

(a) $\frac{In(r_2/r_1)}{2\pi kL}$ (b) $\frac{In(r_1/r_2)}{2\pi kL}$

(c) $\frac{2\pi kL}{In(r_2/r_1)}$ (d) $\frac{2\pi kL}{In(r_1/r_2)}$

4. Consider a long cylindrical tube of and outer radii, r_1 and r_0, respectively, length L and thermal conductivity k. Its inner and outer surfaces are maintained at T_1 and T_0, respectively ($T_1 > T_0$). Assuming one-dimensional steady state heat conduction in the radial direction , the thermal resistance in the wall of the tube is

[GATE - 2014]

(a) $\frac{1}{2\pi kL}\ln\left(\frac{r_1}{r_0}\right)$

(b) $\frac{L}{2\pi r_i k}$

(c) $\frac{1}{2\pi kL}\ln\left(\frac{r_0}{r_i}\right)$

(d) $\frac{L}{4\pi kL}\ln\left(\frac{r_0}{r_i}\right)$

5. If q_w = 5000 and the convection heat transfer coefficient at the pipe outlet is 1000W/m^{2}K , the temperature is °C at the inner surface of the pipe at the outlet is

[GATE - 2013]

(a) 71 (b) 76
(c) 79 (d) 81

6. If q_w = 2500 heat , c_p = 4.18kJ/kgK enters a pipe at rate 0.01kg/s and a temperature of 20°C , the pipe , of diameter 50mm and length 3m, is subjected to a wall heat flux q_w in W/m^2

[GATE - 2013]

(a) 42 (b) 62
(c) 74 (d) 104

7. A hollow enclosure is formed between two infinitely long concentric cylinders of radii 1m and 2m, respectively. Radiative heat exchange takes place between the inner surface of the larger cylinder (surface -2) and the outer surface of the smaller cylinder (surface-1). The radiating surface are diffuse and the medium in the enclosure is non-participating ,The fraction of the thermal radiation leaving the larger surface and striking itself is

ESE OBJ QUESTIONS

1. Consider the following statements.
1.The efficiency of heat transfer in a condenser will improve by increase of the overall heat transfer coefficient.
2.The efficiency of heat transfer in condenser will improve by increase of the velocity of flow of water in the tube.
3.The difference between the temperature of steam entering the condenser and the inlet water temperature should be maximum for maximum efficiency.
Which of the above statements are correct?

[ESE - 2017]

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

2. An insulating material with a thermal conductivity k= 0.12W/mK is used for a pipe carrying steam .The local coefficient of heat transfer (h) to the surroundings is $4 W/m^2K$.In order to provide insulation , the minimum outer diameter of the pipe should be

[ESE - 2015]

(a) 45mm (b) 60mm
(c) 75mm (d) 90mm

3. The fouling factor in heat exchanger is defined as

[ESE - 2012]

(a) $R_f = U_{dirty} - U_{Clean}$
(b) $R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{Clean}}$
(c) $\frac{1}{R_f} = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}}$
(d) $\frac{1}{R_f} = U_{dirty} - U_{clean}$

4. If the radius of any current carrying conductor is less than the critical radius, then the addition of electrical insulation will enable the wire to carry a higher current because

[ESE - 2011]

(a)The heat loss from the wire would decrease
(b)The heat loss from the wire would increase
(c)The thermal resistance of the insulation is reduced
(d)The thermal resistance of the conductor is increased

5. Upto the critical radius of insulation

[ESE - 2010]

(a)Convection heat loss will be less than conduction heat loss
(b)Heat flux will decrease
(c)Added insulation will increase heat loss
(d)Added insulation will decrease heat loss

6. 6.0 kJ of conduction heat transfer has to take place in 10 minutes from one end to other end of a metallic cylinder of 10 cm^2 cross-sectional area, length 1 meter and thermal conductivity as 100 W/mK. What is the temperature difference between the two ends of the cylindrical bar?

[ESE - 2005]

(a) 80°C (b) 100°C
(c) 120°C (d) 160°C

7. Upto the critical radius of insulation:

[ESE - 2005]

(a)Added insulation increases heat loss
(b)Added insulation decreases heat loss
(c)Convection heat loss is less than conduction heat loss
(d)Heat flux decreases

8. A hollow pipe of 1 cm outer diameter is to be insulated by thick cylindrical insulation having thermal conductivity 1 W/mK. The surface heat transfer coefficient on the insulation surface is 5 W/m^2K. What is the minimum effective thickness of insulation for causing the reduction in heat leakage from the insulated pipe?

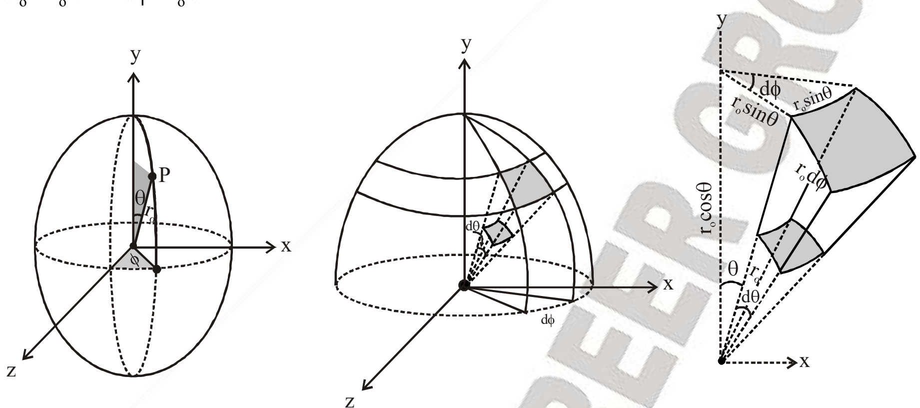
[ESE - 2004]

CHAPTER - 4
CONDUCTION ANALYSIS THROUGH A HOLLOW SPHERE

4.1 HEAT DIFFUSION EQUATION IN SPHERICAL COORDINATE SYSTEM

It is more convenient to consider spherical co-ordinates. The general heat equation can be setup by considering an infinitesimal Spherical volume element. The volume for element will be:

$$dV = dr_o \times r_o \sin\theta d\phi \times r_o d\theta$$



1. Accumulation of Heat in r_o direction ($\theta - \phi$ plane)

$$Q_{ro} - Q_{r_o+dr_o} = Q_{r_o} - \left[Q_{r_o} + \frac{\partial}{\partial r_o}\left(Q_{r_o}\right)dr_o\right]$$

$$Q_{r_o} - Q_{r_o+dr_o} = -\frac{\partial}{\partial r_o}\left(Q_{r_o}\right)dr_o$$

$$Q_{r_o} - Q_{r_o+dr_o} = -\frac{\partial}{\partial r_o}\left(-k_{r_o} A_{r_o} \frac{dT}{dr_o}\right)dr_o$$

$$Q_{r_o} - Q_{r_o+dr_o} = \frac{\partial}{\partial r_o}\left(k_\phi r_o^2 \sin\theta d\theta d\phi \frac{dT}{dr_o}\right)dr_o \quad \left(\because A_{r_o} = r_o \sin\theta d\phi \times r_o d\theta\right)$$

$$Q_{r_o} - Q_{r_o+dr_o} = \frac{\partial}{\partial r_o}\left(k_\phi r_o^2 \frac{dT}{dr_o}\right)\sin\theta d\theta d\phi dr_o$$

$$Q_{r_o} - Q_{r_o+dr_o} = \frac{1}{r_o^2}\frac{\partial}{\partial r_o}\left(k_\phi r_o^2 \frac{dT}{dr_o}\right)dV \quad \left(\because \frac{dV}{r_o^2} = \sin\theta\, d\theta\, dr_o\, d\phi\right)$$

GATE QUESTIONS

1. A spherical steel ball of 12mm diameter is initially at 1000K.It is slowly cooled in a surrounding of 300K.The heat transfer coefficient between the steel ball and the surroundings is $5W/m^2K$.The thermal conductivity of steel is 20W/mK. The temperature difference between the centre and the surface of the steel ball is

[GATE - 2011]

(a)Large because conduction resistance is far higher than the convective resistance
(b)Large because conduction resistance is far less than the convective resistance
(c)Small because conduction resistance is far higher than the convective resistance
(d) Small because conduction resistance is far less than the convective resistance

2. A small copper ball of 5mm diameter at 500K is dropped into an oil bath whose temperature is 300K.The thermal conductivity of copper is 400W/mK, its density $9000kg/m^3$ and its specific heat 385 J/kg .If the heat transfer coefficient is $250W/m^2$. K and lumped analysis is assumed to be valid, the rate of fall of the temperature of the ball at the beginning of cooling will be , in K/s

[GATE - 2005]

(a) 8.7 (b) 13.9
(c) 17.3 (d) 27.7

SOLUTIONS

Sol. 1.(d)

Biot number = $\frac{hL}{K}$

$= \frac{5\times12}{20\times1000\times2\times3} = 0.5\times10^{-3}$

Since value of biot number is very less hence conduction resistance is for less than convective resistance

Sol. 2.(c)

K = 400 $T_i = 500K$
ρ = 9000 $T_a = 300K$
$C_p = 385$
h = 250

$\frac{V}{A} = \frac{D}{6} = \frac{0.005}{6} = 8.33\times10^{-4}$

$T = T_\infty + (T_i - T_\infty)\ e^{\frac{-hAt}{\rho C_v}}$

$\frac{dT}{dt} = \frac{-hA}{\rho C_v}(T_i - T_\infty)$magnitude

$= \frac{250\times200}{9000\times385\times8.33\times10^{-4}}$

$\left.\frac{dT}{dt}\right|_{t=0} = 17.3160$

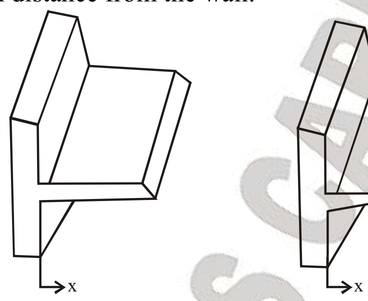
CHAPTER - 5
EXTENDED SURFACES (FINS)

5.1 INTRODUCTION

In many engineering applications the cooling of surface is mandatory to increase the working period of material whereas in compressors the surface cooling is required to reduce work input. It can be done by using suitable convective heat transfer coefficient (h) which leads to maximum heat transfer rate. The convective coefficient (h) is function of geometry, fluid properties and the flow rate. The optimum value of h can be determined from these parameters. As we know heat transfer rate is through convection is $Q = h\ A\ (T_s - T_a)$. In actual practice mostly engineering applications are in contact with atmospheric air only. In summer or hot weather conditions the temperature of hot gases will increase and temperature difference will starting decrease which leads to decrease in heat transfer rate due to convection. The possible effort to increase surface area will increase heat transfer rate. Thus, concept of fins introduced by the attachment of extended surfaces with surface area which is exposed to the surroundings.
The most commonly fins are discussed below

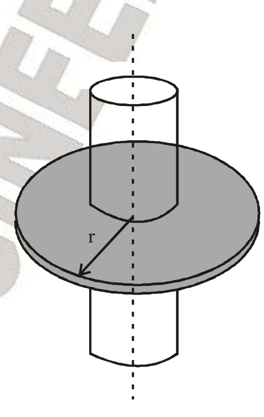
5.1.1 Straight Fin

It is an extended surface attached to the plane wall, the cross-sectional area of the fin may be uniform or it may vary with distance from the wall.



5.1.2 Annular Fins

These types of fins are usually attached circumferentially to a cylindrical surface and their cross-sectional area varies with radius from the centre line of the cylinder.



GATE QUESTIONS

1. Which one of the following configuration has the highest fin effectiveness?

[GATE - 2012]

(a) Thin, closely spaced fins
(b) Thin, widely spaced fins
(c) Thick, widely spaced fins
(d) Thick, closely spaced fins

2. A fin has 5mm diameter and 100mm length. The thermal conductivity of fin material is $400 Wm^{-1}K^{-1}$. One end of the fin is maintained at 130°C and its remaining surface is exposed to ambient air at 30°C .if the convective heat transfer coefficient is 40 $Wm^{-2}K^{-1}$, the heat loss (in W) from the fin is

[GATE - 2010]

(a) 0.08 (b) 5.0
(c) 7.0 (d) 7.8

SOLUTIONS

Sol. 1. (a)
Fin effectiveness,

$$\in = \frac{\text{heat transfer with fin}}{\text{heat transfer without fin}}$$

i.e., for so long fin

$$\in = \sqrt{\frac{Pk}{hA}} P\uparrow \& A\downarrow$$

And this is highest with thin closely spaced fins

Sol. 2. (b)

$$\sqrt{\frac{hP}{KA}}$$

$P = \pi d$

$A = \frac{\pi}{4}d^2$

$\frac{P}{A} = \frac{4}{d}$

$$m = \sqrt{\frac{4h}{Kd}} = \sqrt{\frac{4\times 40}{400\times 5\times 10^{-3}}} = 8.94$$

mL = 8.94×0.1 = 0.894

i.e., fin of so long

So the fin is insulated tip

$$Q_{f_{in}} = mAK(t_0 - t_a)\tan h(mL)$$

$$8.94\times \frac{\pi}{4}(5\times 10^{-3})^2 \times 400\times 100\times \tanh(8.94\times 0.1)$$

=5.008W

CHAPTER - 6
UNSTEADY STATE CONDUCTION HEAT TRANSFER

6.1 INTRODUCTION
Unsteady or transient means time dependent. Unsteady state conduction refers to the heat transfer and temperature distribution varies continuously with time at any point of the system. Undoubtedly, the heat transfer and temperature varies with time or we can say both are time dependent. In industries heating, Cooling and drying processes all are time dependent. For example: Quenching of steel, where temperature gradually decreases until rod and quenching medium attain the same temperature. An increase or decrease in temperature at any instant continues until steady state temperature distribution is attained.
Further, change in temperature during unsteady state may follow a periodic or non-periodic variation as discussed below in detail.

6.1.1 Periodic Variation
In this case temperature changes in repeated cycles and condition repeated after some fixed time interval. In cylinder of I.C engine the temperature variations are considered to be periodic because during each cycle a definite variation temperature occurs with respect to the crank angle and its keeps on changing as long as engine is running. Temperature variation in building during full day period of 24 hrs can be also considered as period variations.

6.1.2 Non-Periodic Variation
In such case the temperature changes with time as non linear function. This variation is irregular and nor in repeated cycles. Heating of an ingot in a furnace is suitable example and here one medium is surrounded or influenced by another medium of given thermal state.

6.2 LUMPED PARAMETER ANALYSIS
It is the useful to many of the transient heat transfer problems which presumes that the solid posses very infinitely large thermal conductivity. The, internal conduction resistance is very small and heat transfer to or from the solid is mainly controlled by convective resistance. It means temperature gradient within the solid is negligible and varies with time only. T = f (t)
Consider a body of mass m, volume V, densityρ, specific heat C_p which is at an initial temperature of T_i is suddenly exposed to surrounding fluid (a thermal reservoir) which is at temperature of T_{sr}. The transient response of the solid can be determined by applying energy consevation:

$$\dot{E}_{in} - \dot{E}_{out} + \dot{Q}_{gen} = mc_p \frac{dT}{dt}$$

Here, $\dot{E}_{in} = \dot{Q}_{gen} = 0$

$$\dot{E}_{out} = -mc_p \frac{dT}{dt}$$

$$hA_s\left(T - T_{sr}\right) = -mc_p \frac{dT}{dt}$$

Upon rearranging, integrate above relation with temperature T and time t and we get,

$$\int_{T_s}^{T} \frac{dT}{\left(T - T_{sr}\right)} = -\frac{hA_s}{mc_p}\int_0^t dt$$

CHAPTER - 7
HEAT EXCHANGERS

7.1 INTRODUCTION

It is an effective equipment designed for heat transfer between two different or same fluid placed at different temperatures i.e. a hot fluid and coolant. It is a device which can be used for either heating or cooling of fluid. The heat exchanger may be used for boiling and condensation purposes where latent heat or phase change plays vital role. Some of the industrial applications of heat exchangers are:

1. Steam Power Plant

In power plants the heat exchangers are used in the form of:
(i) Boilers
(ii) Super heaters
(iii) Condensers
(iv) Economizer

2. Heat Engine

In heat engines the heat exchangers are used in the form of:
(i) Radiator
(ii) Oil coolers

3. Refrigerating Unit

In refrigerating unit the heat exchangers are used in the form of:
(i) Evaporator
(ii) Condenser

4. Gas Turbine Unit

In gas turbine units the heat exchangers are used in the form of:
(i) Intercooler
(ii) Regenerator

7.1.1 Nature of heat exchange process

The heat exchange between two fluids depends upon nature of heat exchange process. The commonly used processes are Direct Contact, Regeneration and Recuperation. Some of useful details for these processes are discussed below:

1. Direct Contact

The direct contact are also called as open heat exchangers where heat transfer takes place between hot and cold fluid due to physical mixing there is simultaneously transfer of heat and mass. Such units are limited to use where mixing is harmless and desired. Examples: Cooling Tower and jet condenser in steam power plants.

(i) Regeneration

In this method the hot fluid is passed through a certain medium called matrix and it accumulates the heat from hot fluid during heating period. The stored heat then subsequently passes to clod

GATE QUESTIONS

1. For a heat exchanger , ΔT_{max} is the maximum temperature difference and ΔT_{min} is the minimum temperature difference between the two fluids. LMTD is the log mean temperature difference. C_{min} and C_{max} are the minimum and the maximum heat capacity rates. The maximum possible heat transfer (Q_{max}) between the two fluids is

[GATE - 2016]

(a) C_{min}LMTD (b) $C_{min\Delta T}max$
(c) $C_{max}\Delta T_{max}$ (d) $C_{max}\Delta T_{min}$

2. Consider a parallel –flow heat exchanger with Area A_p and a counter flow heat exchanger with area A_c. In both the heat exchangers , the hot stream flowing at 1kg /s cools from 80°C to 50°C .For the cold stream in both the heat exchangers ,the flow rate and the inlet temperature are 2kg/s and 10°C , respectively .The hot and cold streams in both the heat exchangers are of the same fluid .Also, both the heat exchangers have the small overall heat transfer coefficient. The ratio A_c/A_p is ________.

[GATE - 2016]

3. In a counter flow heat exchanger , hot fluid enters at 60°C and cold fluid leaves at 30°C. Mass flow rate of the hot fluid is 1kg/s and that the cold fluid is 2kg/s. Specific heat of the hot fluid is 10kJ/kgK and that of the cold fluid is 5kJ/kgK.The log mean Temperature difference (LMTD) for the heat exchanger in °C is

[GATE - 2015]

(a) 15 (b) 30
(c) 35 (d) 45

4. Hot oil is cooled from 80 to 50°C in an oil cooler which uses air as the coolant .The air temperature rises from 30 to 40°C .The designer uses a LMTD value of 26°C .The type of heat exchanger is

[GATE - 2015]

(a) Parallel flow (b) Double pipe
(c) Counter flow (d) Cross flow

5. A double pipe counter flow heat exchanger transfers heat between two water streams .Tube side water at 19 litre/s is heated from 10°C to 38°C .Shell side water a at 25 litre/s is entering at 46°C .Assume constant properties of water , density is 1000 kg /m^3 and specific heat is 4186J/kg-K. The LMTD (in °C) is _______.

[GATE - 2014]

6. In a concentric counter flow heat exchanger , water flows through the inner tube at 25°C and leaves at 42°C .The engine oil enters at 100°C and flows in the annular flow passage .The exit temperature of the engine oil is 50°C .Mass flow rate of water and the engine oil are 1.5kg/s and 1kg/s , respectively .The specific heat of water and oil are 4178 J/kg. K and 2130 J/kg .K, respectively .The effectiveness of this heat exchanger is _______.

[GATE - 2014]

7. In a heat exchanger , it is observed that $\Delta T_1 = \Delta T_2$, where ΔT_1 is the temperature difference between the two single phase fluid streams at one end and ΔT_2 is the temperature difference at the other end .This heat exchanger is

[GATE - 2014]

(a) A condenser
(b) An evaporator
(c) A counter flow heat exchanger
(d) A parallel flow heat exchanger

8. Water (Cp = 4.18kJ/kg.K) at 80°C enters a counter flow heat exchanger with a mass flow rate of 0.5kg/s.Air (Cp = 1kJ/kg.K)enters at 30°C with a mass flow rate of 2.09kg/s .if the effectiveness of the heat exchanger is 0.8, the LMTD (in °C) is

CHAPTER - 8
THERMAL RADIATION

8.1 INTRODUCTION

In Thermal radiation the heat transfer takes place between two bodies without any medium or physical contact between them unlike conduction and convection. Thermal radiations occur most effectively in the vacuum because energy released by radiating surface is not continuous but in the form of discrete packets of energy called photons. These photons are propaGATEd through space as rays and the movement of set of photons can be described as electromagnetic waves and travels with speed of light (c = 3 × 10^8m/sec) without changing their frequency in straight paths. When these photons reach at receiving body then reconverts into thermal energy and it may partly absorb, reflect and transmit as per condition receiving body. The magnitude of absorption, transmission and reflection purely depends upon the nature of surface of the receiving body only.

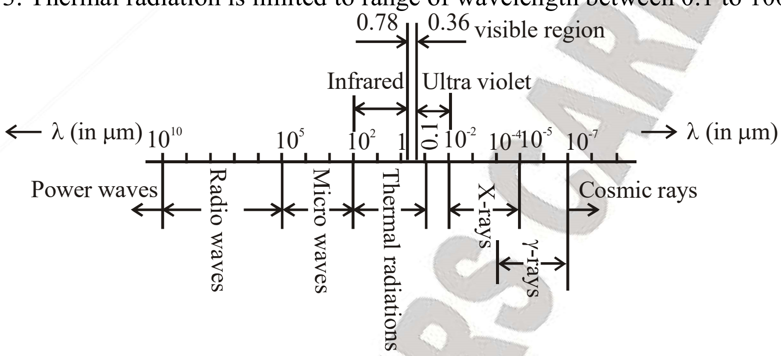
8.2 CHARACTERISTICS OF THERMAL RADIATION

Some of the characteristics of thermal radiations are discussed below:

1. The amount of emit of thermal radiations (energy) completely depends upon the nature of surface and its absolute temperature. Each surface emits radiations above 0 K temperatures.
2. A high temperature body will have high frequency photons which lead to shorter wavelength.

Speed of light (c) = wavelength (λ) × Frequency (f)

3. Thermal radiation is limited to range of wavelength between 0.1 to 100 micron (μm).



Electromagnetic wave spectrum

Thermal radiation consists of entire visible and infrared and some part of ultraviolet from spectrum of electromagnetic waves.

4. Thermal radiation shows characteristics similar to the visible light and also follows the optical laws.
5. The heat exchange by radiation gets enhanced at elevated temperatures of the source and the surrounding unlike conduction and convection in which heat transfer primarily on the basis of temperature gradient only within the same body.
6. Thermal radiation is a volume phenomenon because all solid, liquid and gases emit, absorb and transmitted though entire volume due to continuous motion electron, atom and molecules above absolute zero temperature.
7. Thermal radiation for opaque objects like: metals, wood and rock is considered as surface (phenomenon because radiation emitted by interior region can never reach the surface and radiation incident on such bodies is usually absorbed within few microns from the surface.

GATE QUESTIONS

1. Consider the radiation heat exchange inside an annulus between two very long concentric cylinders .The radius of the outer cylinder is R_0 and that of the inner cylinder is R_{21} .The radiation view factor of the outer cylinder onto itself is

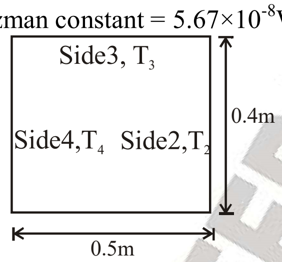
[GATE - 2016]

(a) $1-\sqrt{\frac{R_1}{R_0}}$ (b) $\sqrt{1-\frac{R_1}{R_0}}$

(c) $1-\left(\frac{R_1}{R_0}\right)^{1/3}$ (d) $1-\frac{R_1}{R_0}$

2. An infinitely long furnace of 0.5m ×0.4m cross-section is shown in the figure below .Consider all surfaces of the furnace to be black.The top and bottom walls are maintained at temperature $T_1 = T_3 = 927°C$ while the side walls are at temperature $T_2 = T_4 = 527°$ .The view factor , F_{1-2} is 0.26 .The net radiation heat loss or gain on side 1 is W/m

Stefan –Boltzman constant = $5.67\times10^{-8} W/m^2\text{-}K^4$



[GATE - 2016]

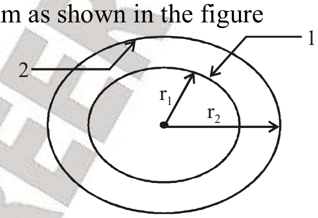
3. Two large parallel plates having a gap of 10mm in between them are maintained at temperatures T_1=1000K and T_2 = 400K.Given emissivity values , $\varepsilon_1 = 0.5$, $\varepsilon_2 = 0.25$ and Stefan –Boltzmann constant $\sigma = 5.67\times10^{-8} W/m^2\text{-}K$.the heat transfer between the plates (in kW/m^2) is __________ **[GATE - 2016]**

4. Two infinite parallel plates are place at a certain distance apart .An infinite radiation shield is inserted between the plates without touching any of them to reduce heat exchange between the plates .Assume that the emissivities of plates and radiation shield are equal .The ratio of the net heat exchange between the plates with and without the shield is

[GATE - 2014]

(a) 1/2 (b) 1/3
(c) 1/ 4 (d) 1/8

5. A solid sphere of radius r1 = 20mm is placed concentrically inside a hollow sphere of radius r_2 = 30mm as shown in the figure



The view factor F_{21} for radiation heat transfer

[GATE - 2014]

(a) $\frac{2}{3}$ (b) $\frac{4}{9}$

(c) $\frac{8}{27}$ (d) $\frac{9}{4}$

6. A hemispherical furnace of 1m radius has the inner surface (emissivity , ε =1) of its roof maintained at 800K, while its floor (ε =0.5) is kept at 600K.Stefan –Boltzmann constant is $5.668\times10^{-8} W/m^2.K^4$ .The net radiative heat transfer (in kW) from the roof to the floor is ________.

[GATE - 2014]

7. Two large diffuse gray parallel plates , separated by a small distance , have surface temperature of 400K and 300K .If the emissivities of the surfaces are 0.8 and the Stefan –Boltzmann constant is $5.67\times^{10\text{-}}8$ W/m^3K^4 , the net radiation the two plates is

[GATE - 2013]

(a) 0.66 (b) 0.79

CHAPTER - 9
CONVENTION HEAT TRANSFER

9.1 INTRODUCTION

In any convection heat transfer problem it is required to obtain, the convection heat transfer coefficient h for a given boundary conditions prevailing between the solid surface and the surrounding moving fluid. And hence to obtain the convention heat transfer rate between solid and fluid from Newton's low of cooling.

i.e. $q_{conv} = hA\,\Delta T \rightarrow (T_{\omega} - T_{\infty})$

Wall/surface temperature free stream

Two types

Forced convection
(Velocity of fluid is evident)

Free convection
No velocity is evident but the flow of fluid occurs naturally due to buoughly forces arising out of desity charges of fluid

9.1.1 Force Convection

Forced convection

Flow over flat plates

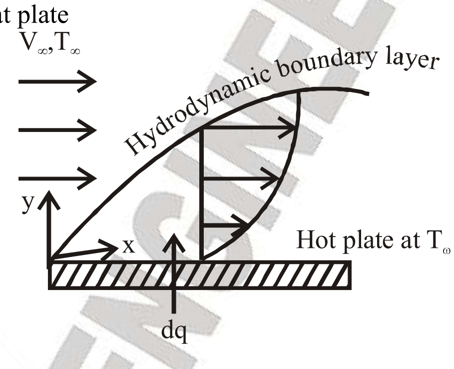
Flow through pipes or ditcts (internal flow)

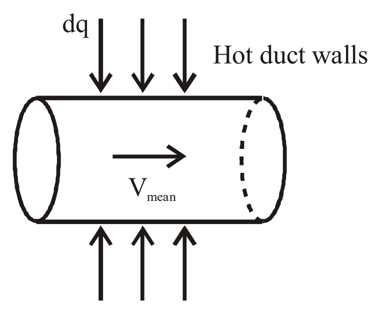
In any forced convection heat transfer,

$$h = f\,(\vec{V}, D, \rho, \mu, C_p, k)$$

$$\vec{D} = \text{Charactersitic dimension of body}$$

For flat plate





GATE QUESTIONS

1. Grash of number signifies the ratio of **[GATE - 2016]**

(a) Inertia force to viscous force
(b) Buoyancy force to viscous force
(c) Buoyancy force to inertia force
(d) Inertial force to surface tension force

2. Match List-I with List-II

List-I

A. Biot number
B. Grash of number
C. Prandtl number
D. Reynold's number

List-B

(i) Ratio of buoyancy to viscous force
(ii) Rate of inertia force to viscous force
(iii) Ratio of momentum to thermal diffusivities
(iv) Ratio of internal thermal resistance to boundary layer thermal resistances

[GATE - 2014]

Codes :

(a) A-iv, B-i, C-iii, D-ii
(b) A-iv, B-iii, C-i, D-ii
(c) A-iii, B-ii, C-i, D-iv
(d) A-ii, B-i, C-iii, D-iv

3. For laminar force convection over a flat plate if the free stream velocity increases by a factor of 2, the average heat transfer coefficient **[GATE - 2014]**

(a) Remains same
(b) Decreases by a factor of $\sqrt{2}$
(c) Rises by a factor of $\sqrt{2}$
(d) Rises by a factor of 4

4. Water flows through a tube of diameter 25mm at an average velocity of 1.0m/s. The properties of water are ρ = 1000kg/m^3, μ=7.25×10^{-4}N.s/m^2 , k = 0.625W/m, K, Pr = 4.85. Using Nu = 0.023Re$^{0.8}$ Pr$^{0.4,}$ the convective heat transfer coefficient (in W/m^2.K) is ______ **[GATE - 2014]**

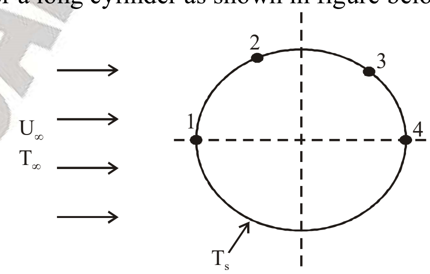
5. The non-dimensional fluid temperature profile near the surface of a convectively cooled flat plate is given by

$$\frac{T_w - T}{T_w - T_\infty} = a + b\frac{y}{L} + c\left(\frac{y}{L}\right)^2,$$

where y is measured perpendicular to the plate, L is the plate length , and a , b and c are arbitrary constants .T_w and T_∞ are wall and ambient temperatures ,respectively .if the thermal conductivity of the fluid is k and the wall heat flux is q" , the Nusselt number Nu = $\frac{q''}{T_w - T_\infty}\frac{L}{K}$ is equal to **[GATE - 2014]**

(a) a (b) b
(c) 2c (d) (b+2c)

6. Consider a two dimensional laminar flow over a long cylinder as shown in figure below



The free stream velocity is U_∞ and the free stream temperature T_∞ is lower than the cylinder surface temperature T_s .The local heat transfer coefficient is minimum at point **[GATE - 2014]**

(a)1 (b) 2
(c) 3 (d) 4

7. The ratios of the laminar hydrodynamic boundary layer thickness to thermal boundary layer thickness of flows of two fluids P and Q on a flat plate are ½ and 2 respectively .The Reynolds number based on the plate length for both the flows is 10^4 .The Prandtl and Nusselt