UNIT- II

CONVECTION

PART-A

TWO MARKS QUESTIONS AND ANSWERS:

1. Define Critical Reynolds number. What is the typical value for flow over a flat plate and flow through a pipe? (May/June -2013)

The Reynold's number at which the flow changes from laminar to turbulent is called as critical reynold's number. For plate plate, it is 5 x 10^5 and for pipe 2300.

2. What is meant by laminar flow and turbulent flow? (May/June -2013)

Laminar flow: Laminar flow is sometimes called stream line flow. In this type of flow, the fluid moves in layers and each fluid particle follows a smooth continuous path. The fluid particles in each layer remain in an orderly sequence without mixing with each other.

Turbulent flow: In addition to the laminar type of flow, a distinct irregular flow is frequency observed in nature. This type of flow is called turbulent flow. The path of any individual particle is zig – zag and irregular. Fig. shows the instantaneous velocity in laminar and turbulent flow.

3. Define the term 'Boundary Layer' (Thermal). (Nov/ Dec 2013)

'Boundary Layer' (Thermal)

In thermal boundary layer, temperature of the fluid is less than 99% of free steam temperature.

4. In which mode of heat transfer is the convection heat transfer coefficient usually higher, natural or forced convection? (Nov/ Dec 2013)

Free convection is nothing but if the fluid motion is created due to the density difference resulting from temperature gradients are called as free or natural convection.

Forced convection is nothing but the fluid motion is produced by the help of some external force like a fan or blower.

Generally heat transfer coefficient is high in forced convection.

5. What are the dimensionless parameters used in forced and free convection heat transfer analysis? (May/June 2012)

Dimensional analysis is a mathematical technique which makes use of the study of the dimensions for solving several engineering problems.

It is used in forced convection heat transfer

$$N_u = C(R_e)^m (P_r)^n$$

It is used in free convection heat transfer

$$N_u = C(P_r)^n (G_r)^m$$

Where R_e = Reynolds number

P_r=Prandtl number

N_u = Nusselt number

G_r = Grashoff number

6. List the parameters that influence the heat transfer coefficient. (Nov/Dec 2011)

- Nusselt Number
- Thermal conductivity
- Length

7. Physically, what does the Grashoff number represent and how does it differ from Reynolds number? (Nov/Dec 2011)

Grashoff Number = $\frac{g\,\beta\,L^3\,\Delta T}{V^2}$

Reynolds Number, $R_e = \frac{UL}{v}$

Grashoff Number has a role in free convection similar to that played by Reynolds number in forced convection.

8. Define Bulk temperature. (April/May 2011)

The fluid properties involved in Nusselt number expressions are evaluated at film temperature which is called bulk temperature.

Bulk temperature = $\frac{T_w+T_\alpha}{2}$

9. Distinguish between free and forced convection. (Nov/Dec 2010)

Free convection	**Forced convection**
The fluid motion is produced due to change in density.	The fluid motion is artificially created by means of some external force like a blower.
If velocity (V) is not given, That is free convection problems.	If the velocity (V) is given, That is forced convection problems.
The heat transfer coefficient value is low.	The heat transfer coefficient Value is high as compared to free convection.

10. State Buckingham's π theorem. What is π – terms? (Nov/Dec 2010)

$f(\pi_1, \pi_2, \pi_3 \ldots\ldots \pi_{n-m}) = 0$

If there are n variables (dependent and independent variables) in a dimensionally homogeneous equation and if these contain m fundamental dimensions (such an M, L, T and Θ), then the variables are arranged in to (n - m) dimensionless terms are called π – term.

M – mass, L – length, T – term, Θ – temperature.

11. State Newton's law of cooling. (May/ June 2009)

The rate convective heat transfer between a surface and an adjacent fluid is prescribed by Newton's law of cooling.

$$Q = hA(t_s - t_f)$$

Where

Q = rate of convective heat transfer

A = area exposed to heat transfer

t_s = surface temperature

t_f = fluid temperature

h = convective heat transfer coefficient

12. What is over all heat transfer co-efficient? (May/June 2007)

The overall heat transfer co-efficient is a quality such that the rate of heat flow through a configuration is given by taking a product of U, the surface area and the overall temperature difference.

$$U = \frac{1}{\frac{1}{h_i} + \Sigma \frac{L}{k} + \frac{1}{k_o}}$$

13. What is the significance of dimensional number? (May/June 2007)

It is mathematical technique which makes use of study of the dimensions for solving convection problems.

It is used in forced convection heat transfer as

$$N_u = C(R_e)^m (P_r)^n$$

It is also used for free convection heat transfer

$$N_u = C(P_r)^n (G_r)^m$$

14. Define convection.

Convection is a process of heat transfer that will occur between a solid surface and a fluid medium when they are at different temperatures.

15. Define Reynolds number (Re) &Prandtl number (Pr).

Reynolds number is defined as the ratio of inertia force to viscous force.

$$Re = \frac{\text{Inertia force}}{\text{Viscous force}}$$

Prandtl number is the ratio of the momentum diffusivity of the thermal diffusivity.

$$Pr = \frac{\text{Momentum diffusivity}}{\text{Thermal diffusivity}}$$

16. Define Nusselt number (Nu).

It is defined as the ratio of the heat flow by convection process under an unit temperature gradient to the heat flow rate by conduction under an unit temperature gradient through a stationary thickness (L) of metre.

Nusselt number (Nu) = $\frac{Q_{conv}}{Q_{cond}}$.

17. Define Grashof number (Gr) & Stanton number (St).

It is defined as the ratio of product of inertia force and buoyancy force to the square of viscous force.

$$Gr = \frac{\text{Inertia force} \times \text{Buyoyancy force}}{(\text{Viscous force})^2}$$

18.Stanton number is the ratio of nusselt number to the product of Reynolds number and prandtl number.

$$St = \frac{Nu}{Re \times Pr}$$

19. What is meant by Newtonian and non – Newtonian fluids?

The fluids which obey the Newton's Law of viscosity are called Newtonian fluids and those which do not obey are called non – Newtonian fluids.

20. Define boundary layer thickness.

The thickness of the boundary layer has been defined as the distance from the surface at which the local velocity or temperature reaches 99% of the external velocity or temperature.

21. What is the form of equation used to calculate heat transfer for flow through cylindrical pipes?

$Nu = 0.023 (Re)^{0.8} (Pr)^n$

n = 0.4 for heating of fluids

n = 0.3 for cooling of fluids

22. What is dimensional analysis?

Dimensional analysis is a mathematical method which makes use of the study of the dimensions for solving several engineering problems. This method can be applied to all types of fluid resistances, heat flow problems in fluid mechanics and thermodynamics.

23. What are all the advantages of dimensional analysis?

1. It expresses the functional relationship between the variables in dimensional terms.

2. It enables getting up a theoretical solution in a simplified dimensionless form.

3. The results of one series of tests can be applied to a large number of other similarproblems with the help of dimensional analysis.

24. What are all the limitations of dimensiona1 analysis?

1. The complete information is not provided by dimensional analysis. It only indicates that there is some relationship between the parameters.
2. No information is given about the internal mechanism of physical phenomenon.
3. Dimensional analysis does not give any clue regarding the selection of variables.

25. What is hydrodynamic boundary layer?

In hydrodynamic boundary layer, velocity of the fluid is less than 99% of free stream velocity.

26. What are the dimensionless parameters used in forced convection?

1. Reynolds number (Re).2. Nusselt number (Nu).3. Prandtl number (Pr).

27. Define boundary layer thickness.

The thickness of the boundary layer has been defined as the distance from the surface at which the local velocity or temperature reaches 99% of the external velocity or temperature.

28. Indicate the concept or significance of boundary layer.

In the boundary layer concept the flow field over a body is divided into two regions:

1. A thin region near the body called the boundary layer where the velocity and the temperature gradients are large.
2. The region outside the boundary layer where the velocity and the temperature gradients are very nearly equal to their free stream values.

29. Define displacement thickness.

The displacement thickness is the distance, measured perpendicular to the boundary, by which the free stream is displaced on account of formation of boundary layer.

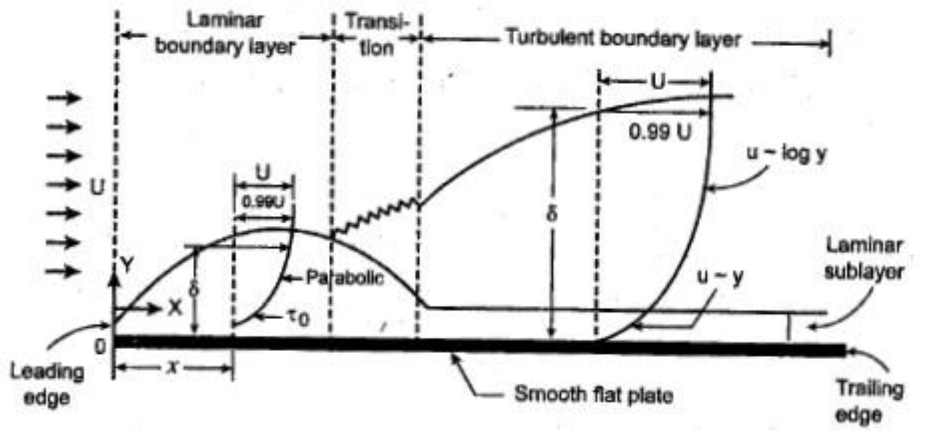
30. Define momentum thickness.

The momentum thickness is defined as the distance through which the total loss of momentum per second is equal to if it were passing a stationary plate.

31. Define energy thickness.

The energy thickness can be defined as the distance, measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in kinetic energy of the flowing fluid on account of boundary layer formation.

32. Sketch the boundary development of a flow.

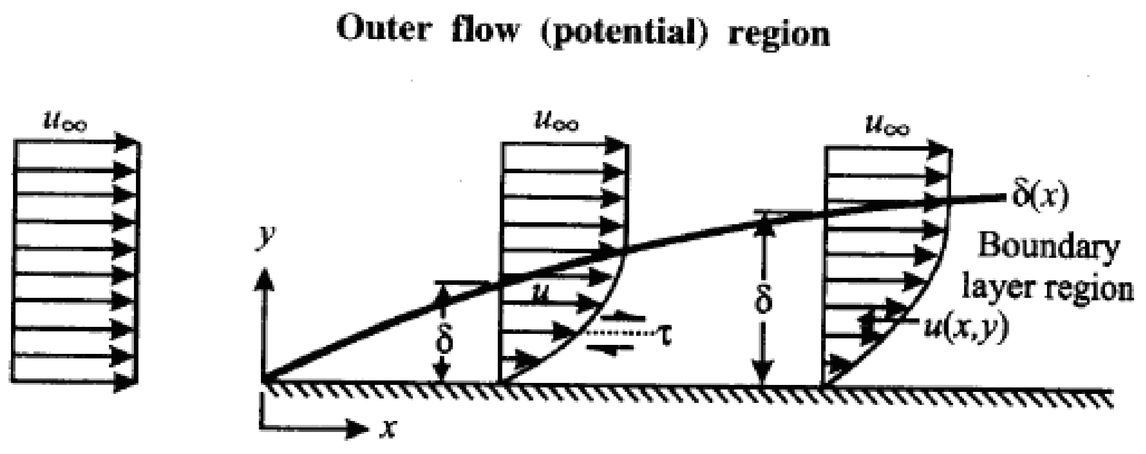


Part-B

1. Discuss briefly the development of velocity boundary layer for flow through a pipe. (May/June-2013)

Convection Boundary Layers:

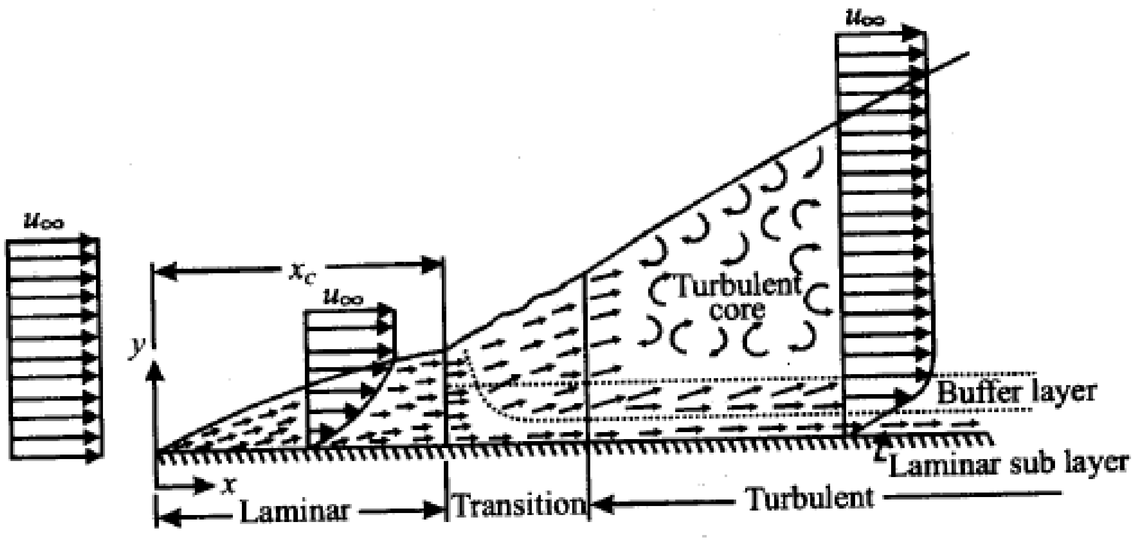
Velocity Boundary Layer: Consider the flow of fluid over a flat plate as shownin the figure. The fluid approaches the plate in x direction with uniform velocity u∞. The fluid particles in the fluid layer adjacent to the surface get zero velocity. This motionless layer acts to retart the motion of particles in the adjoining fluid layer as a result of friction between the particles of these two adjoining fluid layers at two different velocities. This fluid layer then acts to retart the motion of particles of next fluid layer and so on, until a distance
y =d from the surface reaches, where these effects become negligible and the fluid velocity u reaches the free stream velocity u∞. as a result of frictional effects between the fluid layers, the local fluid velocity u will vary from x =0, y = 0 to y =d .



Velocity Boundary Layer on a Flat Plate

The region of the flow over the surface bounded by din which the effects of viscous shearing forces caused by fluid viscosity are observed, is called velocity boundary layer or hydro dynamic boundary layer. The thickness of boundary layer d is generally defined as a distance from the surface at which local velocity u = 0.99 of free stream velocity u∞. The retardation of fluid motion in the boundary layer is due to the shear stresses acting in opposite direction with increasing the distance y from the surface shear stress decreases, the local velocity u increases until approaches u∞. With increasing the distance from the leading edge, the effect of viscosity penetrates further into the free stream and boundary layer thickness grows.

Thermal boundary Layer: If the fluid flowing on a surface has a different temperature than the surface, the thermal boundary layer developed is similar to the velocity boundary layer. Consider a fluid at a temperature T∞ flows over a surface at a constant temperature Ts. The fluid particles in adjacent layer to the plate get the same temperature that of surface. The particles exchange heat energy with particles in adjoining fluid layers and so on. As a result, the temperature gradients are developed in the fluid layers and a temperature profile is developed in the fluid flow, which ranges from Ts at the surface to fluid temperature T∞ sufficiently far from the surface in y direction.

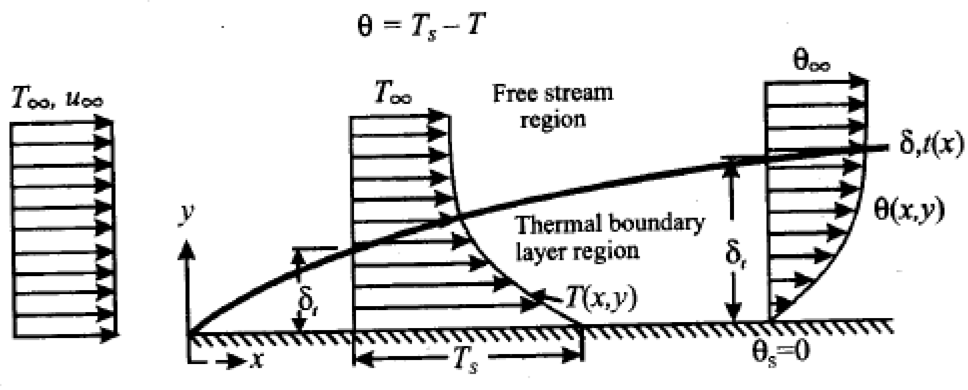


Development of Velocity Boundary Layer on a Flat Plate

The flow region over the surface in which the temperature variation in the direction normal to surface is observed is called thermal boundary layer. The thickness of thermalboundary layer d
th at any location along the length of flow is defined as a distance y from the surface at which the temperature difference (T-Ts) equal 0.99 of
(T∞ - Ts). With increasing the distance from leading edge the effect of heat transfer penetrates further into the free stream and the thermal boundary layer grows as shown in the figure. The convection heat transfer rate anywhere along the surface is directly related to the temperature gradient at that location. Therefore, the shape of the temperature profile in the thermal boundary layer leads to the local convection heat transfer between surface and flowing fluid.

Development of velocity boundary layer on a flat plate:
It is most essential to distinguish between laminar and turbulent boundary layers.

Initially, the boundary layer development is laminar as shown in figure for the flow over a flat plate. Depending upon the flow field and fluid properties, at some critical distance.From the leading edge small disturbances in the flow begin to get amplified, a transition process takes place and the flow becomes turbulent. In laminar boundary layer, the fluid motion is highly ordered whereas the motion in the turbulent boundary layer is highly irregular with the fluid moving to and from in all directions. Due to fluid mixing resulting from these macroscopic motions, the turbulent boundary layer is thicker and the velocity profile in turbulent boundary layer is flatter than that in laminar flow.



Thermal Boundary Layer on a Flat Plate

The critical distance xc beyond which the flow cannot retain its laminar characteris usually specified in term of critical Reynolds number Re. Depending upon surface andturbulence level of free stream the critical Reynolds number varies between 105 and 3 X106. In the turbulent boundary layer, as seen three distinct regimes exist. A laminar sub-layer,existing next to the wall, has a nearly linear velocity profile. The convectivetransport in this layer is mainly molecular. In the buffer layer adjacent to the sub-layer,the turbulent mixing and diffusion effects are comparable. Then there is the turbulentcore with large scale turbulence.

2. Water at 60°c and a velocity of 2cm/s flow over a 5m long flat plate which is maintained at a temperature of 20°c. Determine the total drag force and the rate of heat transfer per unit width of the entire plate. (May/June-2013)

Given data:

T_∞= 60°c(fluid temperature)

Velocity,u = 2cm/s

X = 5m,Ts=20°c,L=5m.

To find:

Drag force,FD

Rate of heat transfer per unit width of the entire plate.

Solution: We know that

Film temperature, Tf=Tw+T∞/2

=60 + 20/2= 40

Properties of water @ 40

(Fromhmt data book, pg no. 33,6th edition)

P = 995 kg/m3

V= 0.657* 10^{-6}m2/s

Pr = 4.34

K = 0.628 W/mK

Reynold's number, Re_l =uL/v

=0.02*5/0.657*10-6

Since, Re<5*105, the flow is laminar.

Avg friction coefficient,C_{fl}= 1.328 * $Re_l^{-0.5}$

1.328*(1.522*10^{-5})

=1.328/390.128

=3.4*10^{-3}

Drag force,$F_{D\,=}$ area * avg shear stress

=1 *5 *C_{fL}*pu^2/2

=5* 995$(0.02)^2$/2 *3.4*10^{-3}

3.4*10^{-3}*1.99/2

F_D3.41*10^{-3}N

Local heat transfer co efficient,h_x:

Local nusselt number, Nu_x=0.322$(Re)^{0.5}(Pr)^{0.333}$

=0.322$(1.522*10^5)^{0.5}$*$4.34^{0.333}$

=0.332*390.128*1.6303

Nu_x = 211.168

$Nu_x = h_x L/K$

h_x=211.16*0.628/5

hx=26.52W/m^2K

h = 2*h_x=2*26.52=53.04W/m^2K

Rate of heat transfer

Q=hA(T_s-T∞)

Q=53.04*5*(333-293)

Q=10608W

3. A horizontal pipe of 6 m length and 8 cm diameter passes through a large room in which the air and walls are at 18°c. The pipe outer surface is at 70°c. Finds the rate of heat losses from the pipe by natural convection. (May/June-2013)

Given data:

Length of the pipe, L =- 6 m

Diameter of the pipe,d = 8 cm = 0.08 m

Surface temperature,T_s =70+273 =343K

Fluid temperature,T∞ = 18 +273 =291K

To find:Q/L

Solution

Film temperature, T_f =Ts + T∞/2

=70+18/2=44°c

The properties of air @ 40°c

P = 1.11Kg/m^3

V=17.45*$10^{-6}$$m^2$/s

The α = 25.014 *$10^{-6}$$m^2$/s

K = 0.02791 W/mK

Pr = 0.6985

$B= 1/T_f=1/317=0.00315K^{-1}$

$Gr = g\beta ДTd^3/v^2$

$=9.81*0.00315*(343-291)(0.08)^3/(17.455*10^{-6})^2$

$=8.229*10^{-4}-10^{-12}/304.677 = 2.7*10^6$

$Gr.Pr=2.7*10^{6=*0.6985}$

$Gr_DPr = 1.88*10^6$

For horizontal cylinder,

$Nu_D = (0.6+0.387(Gr_DPr/(1+(0.559/Pr)^{0.5625})^{0.296})^{0.167})^2$

$10^{-5}<Gr_DPr<10^{12}$

$=\{0.6+0.387[1.858*10^6/(1+(0.559/0.6985)^{0.}5625)0^{.2960})2$

$(0.6+0.387\ (1559130.86)^{0.167})^2$

$\{0.6+0.387(10.819)\}^2$

$\{0.6+4.186953\}^2$

$Nu_D= 22.916$

$=Nu_D= hd/k$

H = 22.916*0.02791/0.08=7.99

Q = hA(Ts-T∞)

=7.99*π*0.08*6*(343-291)

Q = 626.529W

4.Castor oil at 30°c flows over a flat plate at a velocity of 1.5 m/s. The length of the plate is 4 m. The plate is heated uniformly and maintained at 90°c. Calculate the following. Hydrodynamic boundary layer thicknesses, Thermal boundary layer thickness, Total drag force per unit width on one side of the plate, Heat transfer rate. (May/June-2012)

GIVEN:

Fluid temperature T∞=30°c

Velocity = 1.5m/s

Length l = 4m

Plate surface temp t_w= 90°c

Þ=956.8kg/m^2

K=0.213w/mk

V=$0.65*10^{-4}m^2/s$

TO FIND:

Hydrodynamic boundary layer thickness

Thermal boundary layer thickness

Total drag force per unit width on one side of the plate

Heat transfer

SOLUTION:

At the mean film temperature T_f =90+30/2=60°c, physical properties are taken as follows

P=956.8Kg/m^3; v = $0.65 * 10^{-4}m^2/s$

K = 0.213W/mK'; α= $7.2*10^{-8}m^2/s$.

We know that ,

Reynolds no.Re=UL/v

=1.5*4/0.65*10-4

=$9.23*10^4$

For flat plate laminar flow

From HMT dbpg: 112

HYDRODYNAMIC BOUNDARY LAYER THICKNESS:

$Д_{HXtr}=5*x*(re)^{-0.5}$

$=5*4*(9.23*10^4)^{-0.5}$

=0.065m

THERMAL BOUNDARY LAYER THICKNESS:

$Д=д*(pr)^{-0.333}$

$=0.065*(902.77)^{-0.333}$

$=6.74*10^{-3}$

TOTAL DRAG FORCE ON ONE SIDE OF THE PLATE

$C_{FL}=1.328(re)^{-0.5}$

$=1.328*(9.23*10^{4})^{-0.5}$

=4.37*10=-3

We know that

$C_{fL} = \tau/pU^2/2$

$4.37*10^{-3}= t/956.8*1.5^{2/2}$

$T= 4.70N/m^2$

$T = 4.70N/m^2$

Drag force,F_D= area * avg shear stress

= (L*W) * 4.70

= (4*1)*4.70

Drag force,F_D= 18.8N

Heat transfer rate:

We know that,

Local nusselt number

$Nu_x =0.332*(Re)^{0.5}(Pr)^{0.333}$

$Nu_x = h_xL/k$

$972.6 = h_x*4/0.213$

$h_x= 51.7W/m^2K$

Local heat transfer co-efficient,h_x= $51.7W/m^2k$

Avg heat transfer coefficient

$h = 2*h_x$

h = 2* 51.7

$h=103.58 W/m^2k$

heat transfer, $Q = hA (T_w-T\infty)$

$=h*L*W(Tw-T\infty)$

=103.58*4*1*(90-30)

Q = 24.859KW

5. Calculate the heat transfer from a 60W incandescent bulb at 115^{0}C to ambient air at 25^{o}C. Assume the bulb as a sphere of 50mm diameter .Also find the % of power lost by free convection. (May/June-2012)

GIVEN:

D=50mm

$T_{w=}$115 degcelusis +273=383k

$T\infty$=25 deg celusis+273=298k

TO FIND:

$T_{f=}t_w+t\infty/2$

=115+25/2=70 ^{o}**C**

The properties of air at 70 ^{o}**C**

K=0.02966w/mk

V=20.02*10$^{-6\ m2}$/s

Pr=0.694

B=1/t_f in k

=1/70+**273**

=2.915*10-3 k^{-1}

Grashof no, $gr=gD^3\beta(t_w - t\infty)$

$=9.81*(0.050)^3 *2.915*10^{-3}*(383-298)/(20.02*10^{-6})^2$

$=7.58*10^5$

Gr pr=7.58*10^{5*}0.694

$=5.26*10^5$

(hmtdb 137)

Nusselt no $nu=2+0.50(gr\ pr)^{0.25}$

$=15.46$

Hd/k= 15.46

$H=9.15w/m^{2\ n}kc$

Heat transfer $Q=h\ A\ (T_S-T_\infty)$

$=9.15*4\pi r^2\ (383-298)$

=6.10w

Percentage of power lost by free convection

=q/60*100

=6.10/60*100

=10.18%.

6. Find the convective heat loss from a radiator 0.6 m wide and 1.2 m high maintained at a temp of 90°c in a room at 14° c consider the radiator as a vertical plate. (May/June-2012)

Given data:

Wide , W = 0.6 m

Height or length,L = 1.2 m

Wall temperature, T_w= 90°c

Room temperasture,T_∞= 30°c

To find: convective heat loss(Q).

Solution: velocity (U)is not ghiven. So, this is natural convection type problem.

We know that,

Film temperature,$T_f = T_w + T_\infty/2$

=90+30/2

T_f = 60°c

Properties of air at 60°c:

(fromhmt data book, pg no. 33)

$P = 1.060 Kg/m^3$

$V = 18.97 * 10^{-6} m^2/s$

Pr = 0.696

K = 0.023896 W/mK

We know that,

Coefficient of thermal expansion, $\beta = 1/T_f$ in K

=1/(60+273)

$=3 * 10^{-3} K^{-1}$

Grashof number, $Gr = g*\beta*L^3*дT/v^2$

$=9.81*3*10^{-3}*1.2^3*(90-30)/(18.97*10^{-*6})^2$

$Gr = 8.4 * 10^9$

$GrPr = 8.4 * 10^9 * 0.696$

$Gr\ Pr = 5.9 * 10^9$

Since Gr Pr> 10^9,flow is trurbulant.

For turbulent flow,

Nusse3lt number, $Nu = 0.10(Gr\ Pr)^{0.333}$

From hmt data book, pg no 135

$Nu = 0.10[5.9 * 10^9\}^{0.333}$

Nu = 179.3

We know that,

Nusselt number, Nu = hL/K

179.3 = h * 1.2/0.02896

Convective heat transfer co efficient, h =- 4.32 W/m^2k

Heat loss, Q = hA(ДT)

$=hWL(T_w - T\infty)$

=4.32*0.7*1.2*(90-30)

Q= 228.16 W

7. A steam pipe 80mm in diameter is covered with 30mm thick layer of insulation which has a surface emissivity of 0.94.the insulation surface temperature is 85°C and the pipe is placed in atmospheric air at 15°C. If the heat is lost both by radiation and free convection find the following: The heat loss from 5m length of the pipe, the overall heat transfer coefficient, Heat transfer co-efficient due to radiation. (April/May-2011)

GIVEN:

D=80mm=0.080m

Thickness=30mm=0.030m

Actual diameter =0.080+2*0.030

=0.14m

Emissivity €=0.94

Surface temp t_w=85 °C

Air temperature t∞=15 °C

TO FIND:

Heat loss from 5m length of pipe, q

Overall heat transfer co-efficient, ht

Heat transfer co-efficient due to radiation, hr

SOLUTION:

Film temperature t_f=t $_w$+t_∞

=85+15/2

=50 °C

Prop of air @50°C

(hmtdb 33)

Þ=1.093 kg/m^3

V=17.95*10^{-6} m2/s

Pr=0.698

K=0.0286 w/mk

Co-efficient of thermal expansion=1/$t_{f\ in}$ k

=1/50+273

=$3.095*10^{-3}k^{-1}$

Grashof no gr=$g*\beta*d^3*$delta t/v^2

=$9.81*3.095*10^{-3}*(0.14)^3*(85-15)/(17.95*10^{-6})^2$

=$18.10*10^6$

Gr pr =$18.10*10^6$

Gr pr =$1.263*10^7$

Nu=c[gr pr]^m

Gr pr=$1.263*10^7$ [c=0.125,m=0.333)

Nu=0.125[$1.263*10^7)^{0.033}$

Nu=28.952

Nu=hd/k

28.952=h*0.14/0.02826

H=5.84 W/m^2 k

Heat lost by convection

$Q_{conv=}$h a (delta T)

=h*π*d*l*(t_w-$t_{\infty)}$

$_=$5.84*π*0.14*5*(85-15)

=898.99 W

Heat lost by radiation

Q=€(sigma)A[T^4_w–$T^4_{\infty]}$

=85+273

=358k

$Q_{rad=}0.94*5.67*10^{-8}*\pi*0.14*5*[358^4-288^{4]}$

=1118.90W

Total heat loss=$q_{conv\ +}\ q_{rad}$

=898.99+1118.90

=2017.89W

Total heat transfer q_t=h AДt

2017.89=h_t(πdl)д t

2017.89=h_t*π*d*l

H_t=13.108 W/m^2

Overall heat transfer coeffiecient =13.108 W/m^2k(h_t)

Radiative heat transfer coeffiecient

$H_{r=}h_t-h_c$

=13.108-5.84

=7.268W/m^2k1`

8. Air at 30^{o}C flows over a plate at a velocity of 2m/s The plate is 2m long and 1.5m wide. calculate the following; Hydrodynamic and thermal boundary layer thickness at the trailing edge of the plate , Total drag force , Total mass flow rate through the boundary layer between x=40cm , x=85cm. (April/May-2010)

GIVEN;

T∞=30 DEG CELUSIS

U=2m/s

L=2m

W=1.5m

Solution:

Properties of air at 30 degcelusis

P=1.165 kg/m^3

V=16*10^{-6} m^2/s

Pr=0.701

K=0.02675W/mk

Re=UL/V

$=4/16*10^{-6}$

$=2.5*10^{5}$ $5*10^{5}$

The flow is laminar

For fl;at plate laminar flow

$Delta_{hx}=5*x*(r_{e)})^{-0.5}$

$=5*2*(2.5*10^{5})^{-0.5}$

=0.02m

Thermal boundary l;ayer thickness

Delta $tx=delta_{hx*}pr^{-0.333}$

$=0.02*(0.701)^{-0.333}$

=0.0225m

$c_{fl}=1.328(re)^{-0.5}$

$=1.328*(2.5*10^{5})^{-0.5}$

$=2.65*10^{-3}$

We know c_{fl} $=\ell/pU^{2/2}$

$2.65*10^{-3}$ $=\ell/(1.165*2^{2})/2$

$=6.1*10^{-3}$ N/m^{2}

Drag force =area *average shear stress

$=2*1.5*6.1*10^{-3}$

=0.018 N

Drag force on two sides of the plate

0.018*2=0.036 N

Total mass flow rate x=40Cm ,x=85cm

Delta m =(5/8) pU

$=5*x*(r_e)^{-0.5}$

$=5*0.85*(U*x/v)^{-0.5}$

$=5*0.85*(2*0.85/16*10^{-6})^{-0.5}$

=0.0130m

Delta hx $=5*x*(r_{ex})^{-0.5}$

$=5*0.40*(2*0.40/16*10^{-6})^{-0.5}$

$=8.9*10^{-3\ m}$

Delta m $=(5/8)*1.165*2\{0.0130-8.9*10^{-3)}$

$=5.97*10^{-3\ kg/s}$

9. Air at 20°C at atmospheric pressure flows over a flat plate at a velocity of 3 m/s. if the plate is 1 m wide and 80°C, calculate the following at x = 300 mm.

1. Hydrodynamic boundary layer thickness,
2. Thermal boundary layer thickness,
3. Local friction coefficient,
4. Average friction coefficient,
5. Local heat transfer coefficient
6. Average heat transfer coefficient,
7. Heat transfer.(Nov/Dec-2008)

Given: Fluid temperature T_∞ = 20°C Velocity U = 3 m/s

Wide W = 1 m Surface temperature Tw = 80°C

Distance x = 300 mm = 0.3 m

Solution: We know, Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$= \frac{80 + 20}{2}$

$T_f = 50°C$

Properties of air at 50°C

Density $\rho = 1.093\ kg/m^3$

Kinematic viscosity $v = 17.95 \times 10^{-6} m^2/s$

Prandtl number $Pr = 0.698$

Thermal conductivity $K = 28.26 \times 10^{-3} W/mK$

We know,

Reynolds number $Re = \frac{UL}{v}$

$= \frac{3 \times 0.3}{17.95 \times 10^{-6}}$

$Re = 5.01 \times 10^4 < 5 \times 10^5$

Since $Re < 5 \times 10^5$, flow is laminar

For Flat plate, laminar flow,

1. Hydrodynamic boundary layer thickness:

$\delta_{hx} = 5 \times x \times (Re)^{-0.5}$

$= 5 \times 0.3 \times (5.01 \times 10^4)^{-0.5}$

$\delta_{hx} = 6.7 \times 10^{-3} m$

2. Thermal boundary layer thickness:

$\delta_{TX} = \delta_{hx} (Pr)^{-0.333}$

$\Rightarrow \delta_{TX} = \left(6.7 \times 10^{-3}\right)(0.698)^{-0.333}$

$\delta_{TX} = 7.5 \times 10^{-3} m$

3. Local Friction coefficient:

$C_{fx} = 0.664 (Re)^{-0.5}$

$= 0.664\ (5.01 \times 10^4)^{-0.5}$

$C_{fx} = 2.96 \times 10^{-3}$

4. Average friction coefficient:

$$\overline{C_{fL}} = 1.328\ (Re)^{-0.5}$$
$$= 1.328\ (5.01 \times 10^4)^{-0.5}$$
$$= 5.9 \times 10^{-3}$$
$$\overline{C_{fL}} = 5.9 \times 10^{-3}$$

5. Local heat transfer coefficient (h_x):

Local Nusselt Number $Nu_x = 0.332\ (Re)^{0.5}\ (Pr)^{0.333}$

$$= 0.332\ (5.01 \times 10^4)\ (0.698)^{0.333}$$
$$Nu_x = 65.9$$

We know

Local Nusselt Number

$$Nu_x = \frac{h_x \times L}{K}$$
$$65.9 = \frac{h_x \times 0.3}{23.26 \times 10^{-3}} \quad [\because\ x = L = 0.3m]$$
$$\Rightarrow\ h_x = 6.20\ W/m^2K$$

Local heat transfer coefficient $h_x = 6.20\ W/m^2K$

6. Average heat transfer coefficient (h):

$$h = 2 \times h_x$$
$$= 2 \times 6.20$$
$$h = 12.41\ W/m^2K$$

7. Heat transfer:

We know that,

$$Q = h\ A (T_w - T_\infty)$$
$$= 12.41 \times (1 \times 0.3)\ (80\text{-}20)$$
$$Q = 23.38\ Watts$$

10. A vertical plate of 0.7m wide and 1.2m height maintained at a temperature of 90°C in a room at 30 °C. Calculate the convective heat loss:

Given:

W=0.7m

L=1.2m

T_w=90 degcelusis

$t\infty$=30 degcelusis

To find: convective heat loss (q)

Solution:

$t_f=t_w+t_\infty/2$

=90+30/2

=60 **°C**

Properties of air at 60 degcelusis

P=1.061 kg/m^3

V=18.97*10^{-6} m^2/s

Pr=0.696

K=0.02896 w/mk

B=1/t_f in k

=1/(60+273)

=3*10^{-3} k^{-1}

Gr= $g*\beta*l^3*$delta t

$=9.81*3*10^{-3}*(1.2)^3*(90-30)/(18.97*10^{-6})^2$

=8.4*10^9

Nu=0.10(gr pr $)^{0.333}$

$=0.10(5.96*10^9)^{0.333}$

=179.3

Nu =hl/k

179.3=h*1.2/0.02896

H=4.32 W/m^2k

Heat loss q=h A (delta T)

=4.32*0.7*1.2*(90-30)

=218.16w

11. **Air at 20°C, at a pressure of 1 bar is flowing over a flat plate at a velocity of 3 m/s. if the plate maintained at 60°C, calculate the heat transfer per unit width of the plate. Assuming the length of the plate along the flow of air is 2m.**

Given: Fluid temperature T_∞ = 20°C, Pressure p = 1 bar,

Velocity U = 3 m/s, Plate surface temperature T_w = 60°C,

Width W = 1 m, Length L = 2m.

Solution: We know,

Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$= \frac{60 + 20}{2}$

$T_f = 40°C$

Properties of air at 40°C:

Density ρ = 1.129 Kg/m^3 Thermal conductivity K = $26.56 \times 10^{-3} W/mK$,

Kinematic viscosity v = $16.96 \times 10^{-6} m^2/s$. Prandtl number Pr = 0.699

We know, Reynolds number Re = $\frac{UL}{v} = \frac{3 \times 2}{16.96 \times 10^{-6}}$

$= 35.377 \times 10^4$

$Re = 35.377 \times 10^4 < 5 \times 10^5$

Reynolds number value is less than 5×10^5, so this is laminar flow.

For flat plate, Laminar flow,

Local Nusselt Number $Nu_x = 0.332 (Re)^{0.5} (Pr)^{0.333}$

$Nu_x = 0.332 (35.377 \times 10^4)^{0.5} \times (0.699)^{0.333}$

$Nu_x = 175.27$

We know that,

Local Nusselt Number $Nu_x = \frac{h_s \times L}{K}$

$\Rightarrow 175.27 = \frac{h_s \times 2}{26.56 \times 10^{-3}}$

Local heat transfer coefficient $h_x = 2.327\ W/m^2K$ We know,

Average heat transfer coefficient $h = 2 \times h_x$ $h = 2 \times 2.327$

$h = 4.65\ W/m^2K$

Heat transfer $Q = h A (T_w - T_\infty)$

$= 4.65 \times 2\ (60 - 20)$

$[\therefore \text{Area} = \text{width} \times \text{length} = 1 \times 2 = 2]$

$Q = 372$ Watts.

12.Air at 30°C flows over a flat plate at a velocity of 2 m/s. The plate is 2 m long and 1.5 m wide. Calculate the following:

1. **Boundary layer thickness at the trailing edge of the plate,**
2. **Total drag force,**
3. **Total mass flow rate through the boundary layer between x = 40 cm and x = 85 cm.**

Given: Fluid temperature $T_\infty = 30°C$

Velocity $U = 2\ m/s$

Length $L = 2\ m$

Wide W $W = 1.5\ m$

To find:

1. **Boundary layer thickness**
2. **Total drag force.**
3. **Total mass flow rate through the boundary layer between x = 40 cm and x = 85 cm.**

Solution: Properties of air at 30°C

$\rho = 1.165\ kg/m^3$

$v = 16 \times 10^{-6}\ m^2/s$

$Pr = 0.701$

$K = 26.75 \times 10 - 3\ W/mK$

We know,

Reynolds number $Re = \frac{UL}{v}$

$$= \frac{2 \times 2}{16 \times 10^{-6}}$$

$$Re = 2.5 \times 10^{5} < 5 \times 10^{5}$$

Since $Re < 5 \times 10^{5}$, flow is laminar

For flat plate, laminar flow, [from HMT data book, Page No.99]

Hydrodynamic boundary layer thickness

$$\delta_{hx} = 5 \times x \times (Re)^{-0.5}$$

$$= 5 \times 2 \times (2.5 \times 10^{5})^{-0.5}$$

$$\delta_{hx} = 0.02 \text{ m}$$

Thermal boundary layer thickness,

$$\delta_{tx} \delta_{hx} \times (Pr)^{-0.333}$$

$$= 0.02 \times (0.701)^{-0.333}$$

$$\delta_{TX} = 0.0225 \text{ m}$$

We know,

Average friction coefficient,

$$\overline{C_{fL}} = 1.328 \, (Re)^{-0.5}$$

$$= 1.328 \times (2.5 \times 10^{5})^{-0.5}$$

$$\overline{C_{fL}} = 2.65 \times 10^{-3}$$

$$\overline{C_{fL}} = \frac{t}{\frac{\rho U^2}{2}}$$

$$\Rightarrow \quad 2.65 \times 10^{-3} = \frac{t}{\frac{1.165 \times (2)^2}{2}}$$

$\Rightarrow$ Average shear stress $t = 6.1 \times 10^{-3} \, N/m^2$

We know

Drag force = Area × Average shear stress

$$= 2 \times 1.5 \times 6.1 \times 10^{-3}$$

Drag force = 0.018 N

Drag force on two sides of the plate

$$= 0.018 \times 2$$

$$= 0.036 \text{ N}$$

Total mass flow rate between x = 40 cm and x= 85 cm.

$$\Delta m = \frac{5}{8}\rho\ U\ [\delta_{hx} = 85 - \delta_{hx} = 40]$$

Hydrodynamic boundary layer thickness

$$= 5 \times 0.85 \times \left[\frac{2 \times 0.85}{16 \times 10^{6}}\right]^{-0.5}$$

$$\delta_{HX=0.85} = 0.0130\ m$$

$$\delta_{hx=0.5} = 5 \times x \times (Re)^{-0.5}$$

$$= 5 \times 0.85 \times \left[\frac{U \times x}{v}\right]^{-0.5}$$

$$\delta_{hx=0.40} = 5 \times x \times (Re)^{-0.5}$$

$$= 5 \times 0.40 \times \left(\frac{U \times x}{v}\right)^{-0.5}$$

$$= 5 \times 0.40 \times \left(\frac{2 \times 0.40}{16 \times 10^{-6}}\right)^{-0.5}$$

$$\delta_{HX=0.40} = 8.9 \times 10^{-3}\ m$$

$$(1) \Rightarrow \Delta m = \frac{5}{8} \times 1.165 \times 2\ \left[0.0130 - 8.9 \times 10^{-3}\right]$$

$$\Delta m = 5.97 \times 10^{-3} Kg/s,$$

13.Air at 290°C flows over a flat plate at a velocity of 6 m/s. The plate is 1m long and 0.5 m wide. The pressure of the air is 6 kN/^{2}. If the plate is maintained at a temperature of 70°C, estimate the rate of heat removed form the plate.

Given : Fluid temperature T_∞ = 290°C Velocity U = 6 m/s. Length L = 1 m

Wide W = 0.5 m Pressure of air P = 6 kN/m^2 $= 6 \times 10^3 N/m^2$

Plate surface temperature T_w = 70°C

To find: Heat removed from the plate

Solution: We know, Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$$= \frac{70 + 290}{2}$$

$$T_f = 180°C$$

Properties of air at 180°C (At atmospheric pressure)

$$\rho = 0.799\ Kg/m^3$$

$$\nu = 32.49 \times 10^{-6}\ m^2/s$$

$$Pr = 0.681$$

$$K = 37.80 \times 10^{-3}\ W/mK$$

Note: Pressure other than atmospheric pressure is given, so kinematic viscosity will vary with pressure. Pr, K, C_p are same for all pressures.

Kinematic viscosity $\nu = \nu_{atm} \times \frac{P_{atm}}{P_{given}}$

$$\Rightarrow \nu = 32.49 \times 10^{-6} \frac{1\ bar}{6 \times 10^3 N/m^2}$$

[∵ Atmospheric pressure = 1 bar]

$$= 32.49 \times 10^{-6} \times \frac{10^5 N/m^2}{6 \times 10^3 N/m^3}$$

$[\because\ 1\ bar = 1 \times 10^5 N/m^2]$

Kinematic viscosity $v = 5.145 \times 10^{-4} m^2/s.$

We know, Reynolds number $Re = \frac{UL}{v}$

$$= \frac{6 \times 1}{5.145 \times 10^{-4}}$$

$Re = 1.10 \times 10^4 - 5 \times 10^5$

Since $Re < 5 \times 10^5$, flow is laminar

For plate, laminar flow,

Local nusselt number

$NU_x = 0.332\ (Re)^{0.5} (Pr)^{0.333}$

$= 0.332\ (1.10 \times 10^4)^{0.5}\ (0.681)^{0.333}$

$NU_x = 30.63$

We know $NU_x = \frac{h_x L}{K}$

$30.63 = \frac{h_x \times 1}{37.80 \times 10^{-3}}$ [∵ L = 1 m]

Local heat transfer coefficient $h_x = 1.15\ W/m^2K$

We know

Average heat transfer coefficient $h = 2 \times h_x$

$h = 2 \times 1.15$

$h = 2.31\ W/m^2K$

We know

Heat transferred $Q = h\,A\,(T_\infty - T_w)$

$= 2.31 \times (1 \times 0.5) \times (563 - 343)$

$Q = 254.1\ W$

Heat transfer from both side of the plate = 2 × 254.1

= 508.2 W.

15. Air at 40°C flows over a flat plate, 0.8 m long at a velocity of 50 m/s. The plate surface is maintained at 300°C. Determine the heat transferred from the entire plate length to air taking into consideration both laminar and turbulent portion of the boundary layer. Also calculate the percentage error if the boundary layer is assumed to be turbulent nature from the very leading edge of the plate.

Given : Fluid temperature T_∞ = 40°C, Length L = 0.8 m, Velocity U = 50 m/s , Plate surface temperature T_w = 300°C

To find :

1. Heat transferred for:

   i. Entire plate is considered as combination of both laminar and turbulent flow.
   ii. Entire plate is considered as turbulent flow.

2. Percentage error.

Solution: We know Film temperature $T_f = \frac{T_w - T_\infty}{2}$ T

$= \frac{300 + 40}{2} = 443\ K$

$T_f = 170°C$

Properties of air at 170°C:

$\rho = 0.790\ Kg/m^3$

$\nu = 31.10 \times 10^{-6}\ m^2/s$

$Pr = 0.6815$

$K = 37 \times 10^{-3}\ W/mK$

We know

$$\text{Reynolds number } Re = \frac{UL}{v}$$

$$= \frac{50 \times 0.8}{31.10 \times 10^{-6}} = 1.26 \times 10^{6}$$

$$Re = 1.26 \times 10^{6} > 5 \times 10^{5}$$

$Re > 5 \times 10^{5}$, so this is turbulent flow

Case (i): Laminar – turbulent combined. [It means, flow is laminar upto Reynolds number value is 5×10^5, after that flow is turbulent]

Average nusselt number = Nu = $(Pr)^{0.333}$ $(Re)^{0.8}$ – 871

Nu = $(0.6815)^{0.333}$ [0.037 $(1.26 \times 10^6)^{0.8}$ – 871

Average nusselt number Nu = 1705.3

$$\text{We know } Nu = \frac{hL}{K}$$

$$1705.3 = \frac{h \times 0.8}{37 \times 10^{-3}}$$

$h = 78.8 \ W/m^2K$

Average heat transfer coefficient

$h = 78.8 \ W/m^2K$

$$\text{Head transfer } Q_1 = h \times A \times (T_w + T_\infty)$$

$$= h \times L \times W \times (T_w + T_\infty)$$

$$= 78.8 \times 0.8 \times 1 \times (300 - 40)$$

$$Q_1 = 16390.4 \ W$$

Case (ii) : Entire plate is turbulent flow:

Local nusselt number} Nux = 0.0296 × $(Re)^{0.8}$× $(Pr)^{0.333}$

NU_x = 0.0296 × $(1.26 \times 10^6)^{0.8}$× $(0.6815)^{0.333}$

NU_x = 1977.57

We know $NU_x = \frac{h_x \times L}{K}$

$$1977.57 = \frac{h_x \times 0.8}{37 \times 10^{-3}}$$

$h_x = 91.46 \ W/m^2K$

Local heat transfer coefficient h_x = 91.46 W/m^2K

Average heat transfer coefficient (for turbulent flow)

$h = 1.24 \times h_x$

$= 1.24 \times 91.46$

Average heat transfer coefficient} $h = 113.41\ W/m^2K$

We know Heat transfer $Q_2 = h \times A \times (T_w + T_\infty)$

$= h \times L \times W \times (T_w + T_\infty)$

$= 113.41 \times 0.8 \times 1\ (300 - 40)$

Q_2 = 23589.2 W

2. Percentage error = $\dfrac{Q_2 - Q_1}{Q_1}$

$= \dfrac{23589.2 - 16390.4}{16390.4} \times 100$

$= 43.9\%$

16.250 Kg/hr of air are cooled from 100°C to 30°C by flowing through a 3.5 cm inner diameter pipe coil bent in to a helix of 0.6 m diameter. Calculate the value of air side heat transfer coefficient if the properties of air at 65°C are

K = 0.0298 W/mK

μ = 0.003 Kg/hr – m

Pr = 0.7

ρ = 1.044 Kg/m^3

Given : Mass flow rate in = 205 kg/hr

$= \dfrac{205}{3600} Kg/s\ in = 0.056\ Kg/s$

Inlet temperature of air T_{mi} = 100°C

Outlet temperature of air T_{mo} = 30°C

Diameter D = 3.5 cm = 0.035 m

Mean temperature $T_m = \dfrac{T_{mi} + T_{mo}}{2} = 65°C$

To find: Heat transfer coefficient (h)

Solution:

Reynolds Number Re = $\frac{UD}{\nu}$

Kinematic viscosity $\nu = \frac{\mu}{\rho}$

$$\frac{\frac{0.003}{3600} Kg/s-m}{1.044\ Kg/m^3}$$

$v = 7.98 \times 10^{-7}\ m^2/s$

Mass flow rate in = ρ A U

$$0.056 = 1.044 \times \frac{\pi}{4} \times D^2 \times U$$

$$0.056 = 1.044 \times \frac{\pi}{4} \times (0.035)^2 \times U$$

$\Rightarrow$ U = 55.7 m/s

$(1) \Rightarrow \quad Re = \frac{UD}{\nu}$

$= \frac{55.7 \times 0.035}{7.98 \times 10^{-7}}$

$Re = 2.44 \times 10^6$

Since Re > 2300, flow is turbulent

For turbulent flow, general equation is (Re > 10000)

$Nu = 0.023 \times (Re)^{0.8} \times (Pr)^{0.3}$

This is cooling process, so n = 0.3

$\Rightarrow \quad Nu = 0.023 \times (2.44 \times 10^6)^{0.8} \times (0.7)^{0.3}$

Nu = 2661.7

We know that, $Nu = \frac{hD}{K}$

$$2661.7 = \frac{h \times 0.035}{0.0298}$$

Heat transfer coefficient h = 2266.2 W/m^2K

17. **In a long annulus (3.125 cm ID and 5 cm OD) the air is heated by maintaining the temperature of the outer surface of inner tube at 50°C. The air enters at 16°C and leaves at 32°C. Its flow rate is 30 m/s. Estimate the heat transfer coefficient between air and the inner tube.**

Given :

Inner diameter D_i = 3.125 cm = 0.03125 m

Outer diameter D_o = 5 cm = 0.05 m

Tube wall temperature T_w = 50°C

Inner temperature of air T_{mi} = 16°C

Outer temperature of air t_{mo} = 32°C

Flow rate U = 30 m/s

To find: Heat transfer coefficient (h)

Solution:

Mean temperature $T_m = \frac{T_{mi} + T_{mo}}{2}$

$$= \frac{16 + 32}{2}$$

$$T_m = 24°C$$

Properties of air at 24°C:

$\rho = 1.614\ Kg/m^3$

$\nu = 15.9 \times 10^{-6}\ m^2/s$

$Pr = 0.707$

$K = 26.3 \times 10^{-3} W/mK$

We know,

Hydraulic or equivalent diameter

$$D_h = \frac{4A}{P} = \frac{4 \times \frac{\pi}{4}\left[D^2 - D_i^2\right]}{\pi\left[D_o + D_i\right]}$$

$$= \frac{\left(D_o + -D_i\right)\ \left(D_o - D_i\right)}{\left(D_o + D_i\right)}$$

$$= D_o - D_i$$

= 0.05 – 0.03125

D_h= 0.01875 m

$$\text{Reynolds number Re} = \frac{UD_h}{\nu}$$

$$= \frac{30 \times 0.01875}{15.9 \times 10^6}$$

Re = 35.3 $\times$ 10^{-6}

Since Re > 2300, flow is turbulent

For turbulent flow, general equation is (Re > 10000)

Nu = 0.023 $(Re)^{0.8}$ $(Pr)^n$

This is heating process. So n = 0.4

$$\Rightarrow \quad Nu = 0.023 \times (35.3 \times 10^3)^{0.8} (0.707)^{0.4}$$

$$Nu = 87.19$$

$$\text{We know } Nu = \frac{hD_h}{K}$$

$$\Rightarrow \quad 87.19 = \frac{h \times 0.01875}{26.3 \times 10_{-3}}$$

$$\Rightarrow \quad h = 122.3\ W/m^2K$$

18.Engine oil flows through a 50 mm diameter tube at an average temperature of 147°C. The flow velocity is 80 cm/s. Calculate the average heat transfer coefficient if the tube wall is maintained at a temperature of 200°C and it is 2 m long.

Given : Diameter D = 50 mm = 0.050 m

Average temperature T_m = 147°C

Velocity U = 80 cm/s = 0.80 m/s

Tube wall temperature T_w = 200°C

Length L = 2m

To find: Average heat transfer coefficient (h)

Solution : Properties of engine oil at 147°C

$\rho = 816\ Kg/m^3$

$\nu = 7 \times 10^{-6}\ m^2/s$

$Pr = 116$

$K = 133.8 \times 10^{-3}\ W/mK$

We know

$$\text{Reynolds number } Re = \frac{UD}{\nu}$$

$$= \frac{0.8 \times 0.05}{7 \times 10^{-6}}$$

$$Re = 5714.2$$

Since Re < 2300 flow is turbulent

$$\frac{L}{D} = \frac{2}{0.050} = 40$$

$$10 < \frac{L}{D} < 400$$

For turbulent flow, (Re < 10000)

$$\text{Nusselt number } Nu = 0.036\ (Re)^{0.8} (Pr)^{0.33} \left(\frac{D}{L}\right)^{0.055}$$

$$Nu = 0.036\ (5714.2)^{0.8} \times (116)^{0.33} \times \left(\frac{0.050}{2}\right)^{0.055}$$

$$Nu = 142.8$$

$$\text{We know } Nu = \frac{hD}{K}$$

$$\Rightarrow\ 142.8 = \frac{h \times 0.050}{133.8 \times 10^{-3}}$$

$$\Rightarrow\ h = 382.3\ W/m^2K$$

19.A large vertical plate 4 m height is maintained at 606°C and exposed to atmospheric air at 106°C. Calculate the heat transfer is the plate is 10 m wide.

Given :

Vertical plate length (or) Height L = 4 m

Wall temperature T_w = 606°C

Air temperature T_∞ = 106°C

Wide W = 10 m

To find: Heat transfer (Q)

Solution:

Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$= \frac{606 + 106}{2}$

$T_f = 356°C$

Properties of air at 356°C = 350°C

$\rho = 0.566\ Kg/m^3$

$\nu = 55.46 \times 10^{-6}\ m^2/s$

$Pr = 0.676$

$K = 49.08 \times 10^{-3}\ W/mK$

Coefficient of thermal expansion} $\beta = \frac{1}{T_f \text{ in } K}$

$= \frac{1}{356 + 273} = \frac{1}{629}$

$\beta = 1.58 \times 10^{-3} K^{-1}$

Grashof number $Gr = \frac{g \times \beta \times L^3 \times \Delta T}{v^2}$

$\Rightarrow \quad Gr = \frac{9.81 \times 2.4 \times 10^{-3} \times (4)^3 \times (606 - 106)}{(55.46 \times 10^{-6})^2}$

$Gr = 1.61 \times 10^{11}$

$Gr\ Pr = 1.61 \times 10^{11} \times 0.676$

$Gr\ Pr = 1.08 \times 10^{11}$

Since $Gr\ Pr > 10^9$, flow is turbulent

For turbulent flow,

Nusselt number $Nu = 0.10\ [Gr\ Pr]^{0.333}$

$\Rightarrow \quad Nu = 0.10\ [1.08 \times 10^{11}]^{0.333}$

$Nu = 471.20$

We know that,

Nusselt number $Nu = \frac{hL}{K}$

$\Rightarrow \quad 472.20 = \frac{h \times 4}{49.08 \times 10^{-3}}$

Heat transfer coefficient h = 5.78 W/m^{2}K

Heat transfer Q = h A ΔT

$= h \times W \times L \times (T_w - T_\infty)$

$= 5.78 \times 10 \times 4 \times (606 - 106)$

$Q = 115600\ W$

$Q = 115.6 \times 10^3\ W$

20. A thin 100 cm long and 10 cm wide horizontal plate is maintained at a uniform temperature of 150°C in a large tank full of water at 75°C. Estimate the rate of heat to be supplied to the plate to maintain constant plate temperature as heat is dissipated from either side of plate.

Given :

Length of horizontal plate L = 100 cm = 1m

Wide W = 10 cm = 0.10 m

Plate temperature T_w = 150°C

Fluid temperature T_∞ = 75°C

To find: Heat loss (Q) from either side of plate

Solution:

Film temperature $T_f = \frac{T_w - T_\infty}{2}$

$= \frac{150 + 75}{2}$

$T_f = 112.5°C$

Properties of water at 112.5°C

$\rho = 951\ Kg/m^3$

$\nu = 0.264 \times 10^{-6}\ m^2/s$

$Pr = 1.55$

$K = 683 \times 10^{-3}\ W/mK$

Coefficient of thermal expansion} $\beta = \frac{1}{T_f \text{ in } K} = \frac{1}{112.5 + 273}$

$\beta = 2.59 \times 10^{-3} K^{-1}$

Grashof Number $Gr = \frac{g \times \beta \times L^3 \times \Delta T}{v^2}$

For horizontal plate,

Characteristic length $L_c = \frac{W}{2} = \frac{0.10}{2}$

$L_c = 0.05$ m

(1) $\Rightarrow$ $Gr = \frac{9.81 \times 2.59 \times 10^{-3} \times (0.05)^3 \times (150 - 75)}{(0.264 \times 10^{-6})^2}$

$Gr = 3.41 \times 10^9$

$Gr\ Pr = 3.41 \times 10^9 \times 1.55$

$Gr\ Pr = 5.29 \times 10^9$

Gr Pr value is in between 8×10^6 and 10^{11}

i.e., $8 \times 10^6 < Gr\ Pr < 10^{11}$

For horizontal plate, upper surface heated:

Nusselt number $Nu = 0.15\ (Gr\ Pr)^{0.333}$

$\Rightarrow$ $Nu = 0.15\ [5.29 \times 10^9]^{0.333+}$

$\Rightarrow$ $Nu = 259.41$

We know that,

$$\text{Nusselt number } Nu = \frac{h_u L_c}{K}$$

$$259.41 = \frac{h_u \times 0.05}{683 \times 10^{-3}}$$

$$h_u = 3543.6 \ W/m^2K$$

Upper surface heated, heat transfer coefficient h_u = 3543.6 W/m^{2}K

For horizontal plate, lower surface heated:

Nusselt number Nu = 0.27 [Gr Pr]$^{0.25}$

$$\Rightarrow \quad Nu = 0.27 \ [5.29 \times 10^9]^{0.25}$$

$$Nu = 72.8$$

We know that,

$$\text{Nusselt number } Nu = \frac{h_1 L_c}{K}$$

$$72.8 = \frac{h_1 L_c}{K}$$

$$72.8 = \frac{h_1 \times 0.05}{683 \times 10^{-3}}$$

$$h_1 = 994.6 \ W/m^2K$$

Lower surface heated, heat transfer coefficient h_1 = 994.6 W/m^{2}K

Total heat transfer Q = $(h_u + h_1) \times A \times \Delta T$

= $(h_u + h_1) \times W \times L \times (T_w - T_\infty)$

= $(3543.6 + 994.6) \times 0.10 \times (150 - 75)$**Q = 34036.5 W**

<u>Review questions:</u>

Part-A:

1. Define Critical Reynolds number. What is the typical value for flow over a flat plate and flow through a pipe? **(May/June -2013) (Ref.pg. 2, Qn.no:1)**

2. What is meant by laminar flow and turbulent flow? **(May/June -2013) (Ref.pg. 2, Qn.no:2)**

3. Define the term 'Boundary Layer' (Thermal). **(Nov/ Dec 2013) (Ref.pg. 2, Qn.no:3)**

4. In which mode of heat transfer is the convection heat transfer coefficient usually higher, natural or forced convection? **(Nov/ Dec 2013) (Ref.pg. 2, Qn.no:4)**

5. What are the dimensionless parameters used in forced and free convection heat transfer analysis? **(May/June 2012) (Ref.pg. 2, Qn.no:5)**

6. List the parameters that influence the heat transfer coefficient. **(Nov/Dec 2011)**

(Ref.pg. 3, Qn.no:6)

7 Physically, what does the Grashoff number represent and how does it differ from Reynolds number? **(Nov/Dec 2011) (Ref.pg. 3, Qn.no:7)**

8. Define Bulk temperature. **(April/May 2011)(Ref.pg. 3, Qn.no:8)**

9. Distinguish between free and forced convection. **(Nov/Dec 2010) (Ref.pg. 3, Qn.no:9)**

10. State Buckingham's π theorem. What is π – terms? **(Nov/Dec 2010)(Ref.pg. 4, Qn.no:10)**

11. State Newton's law of cooling. **(May/ June 2009) (Ref.pg. 4, Qn.no:11)**

12. Draw the velocity and temperature profiles for free convection on a hot vertical plate. **(May/June 2009) (Ref.pg. 5 Qn.no:12)**

13. What is over all heat transfer co-efficient? **(May/June 2007) (Ref.pg. 5, Qn.no:13)**

14. What is the significance of dimensional number? **(May/June 2007) (Ref.pg. 5, Qn.no:14)**

15.Define grashoff number and prandtl number. **(May/June 2014) (Nov/Dec 2014) (Ref.pg. 3, Qn.no:7)**

16. Name four dimensions used for dimensional analysis **(Nov/Dec 2014)**

Mass (M), Length (L), Time (T), Temperature (θ)

17. Differentiate viscous sublayer and buffer layer. **(May/June 2014)**

Part-B:

1. Discuss briefly the development of velocity boundary layer for flow through a pipe. **(May/June-2013)(Nov/Dec 2014)((Refer pg No: 9, Q. No: 1)**

2. Water at 60°c and a velocity of 2cm/s flow over a 5m long flat plate which is maintained at a temperature of 20°c. Determine the total drag force and the rate of heat transfer per unit width of the entire plate**. (May/June-2013)(Refer pg No: 11, Q. No: 2)**

3. A horizontal pipe of 6 m length and 8 cm diameter passes through a large room in which the air and walls are at 18°c. The pipe outer surface is at 70°c. Finds the rate of heat losses from the pipe by natural convection**. (May/June-2013)(Refer pg No: 13, Q. No: 3)**

4. Castor oil at 30°c flows over a flat plate at a velocity of 1.5 m/s. The length of the plate is 4 m. The plate is heated uniformly and maintained at 90°c. Calculate the following.

Hydrodynamic boundary layer thicknesses, Thermal boundary layer thickness, Total drag force per unit width on one side of the plate, Heat transfer rate. **(May/June-2012)(Refer pg No: 14, Q. No: 4)**

5. Calculate the heat transfer from a 60W incandescent bulb at 115^{0}C to ambient air at 25^{o}C. Assume the bulb as a sphere of 50mm diameter .Also find the % of power lost by free convection. **(May/June-2012)(Refer pg No: 17, Q. No: 5)**

6. Find the convective heat loss from a radiator 0.6 m wide and 1.2 m high maintained at a temp of 90°c in a room at 14° c consider the radiator as a vertical plate. **(May/June-2012)(Refer pg No:18, Q. No: 6)**

7. A steam pipe 80mm in diameter is covered with 30mm thick layer of insulation which has a surface emissivity of 0.94.the insulation surface temperature is 85^{o}C and the pipe is placed in atmospheric air at 15^{o}C. If the heat is lost both by radiation and free convection find the following: The heat loss from 5m length of the pipe, the overall heat transfer coefficient, Heat transfer co-efficient due to radiation. **(April/May-2011)(Refer pg No: 19, Q. No: 7)**

8. Air at 30^{o}C flows over a plate at a velocity of 2m/s .The plate is 2m long and 1.5m wide. calculate the following; Hydrodynamic and thermal boundary layer thickness at the trailing edge of the plate , Total drag force , Total mass flow rate through the boundary layer between x=40cm , x=85cm. **(April/May-2010)(Refer pg No:22, Q. No: 8)**

9. Air at 20°C at atmospheric pressure flows over a flat plate at a velocity of 3 m/s. if the plate is 1 m wide and 80°C, calculate the following at x = 300 mm.

1. Hydrodynamic boundary layer thickness,
2. Thermal boundary layer thickness,
3. Local friction coefficient,
4. Average friction coefficient,
5. Local heat transfer coefficient
6. Average heat transfer coefficient,
7. Heat transfer. **(Nov/Dec-2008) (Refer pg No:24, Q. No: 9)**