**5. CONVECTION HEAT TRANSFER**

|  |  |
| --- | --- |
| **CONDUCTION** | **CONVECTION** |
| No bulk motion of particles (Stationary Fluid). | Bulk motion in fluid particles. |
|  |  |

Boiling & Condensation are convection heat transfer with phase change due to vapour bubble movement.

|  |  |  |  |
| --- | --- | --- | --- |
| **Free Convection** | **Forced Convection** | **Internal Flow** | **External Flow** |
| Flow due to | Flow due to | Flow inside the body | Flow over the body |

**NEWTON’S LAW OF COOLING:** The convective rate of heat transfer from a solid surface is directly proportional to temperature difference between solid surface and surrounding fluid and surface area.

**HEAT TRANSFER COEFFICIENT ():** is a quantity of rate of transfer convected from a unit surface area for a unit temperature difference. It’s not a property of fluid, it’s a experimental determined parameter.

|  |  |
| --- | --- |
| It depends on,   1. Thermophysical properties of fluid (). 2. Type of flow (Laminar or Turbulent). | 1. Type of surface (Smooth or Rough). 2. Position of Surface. 3. Geometry of Surface. |

|  |  |  |
| --- | --- | --- |
|  | For External Flow,  Free Stream Temp. | For Internal Flow,  Mean Flow Temp. |

In Some Cases, values vary.

**FORCED CONVECTION EXTERNAL FLOW:**

**CONCEPT OF BOUNDARY LAYER:**

**Assumption:**

|  |  |  |
| --- | --- | --- |
| Steady State | Incompressible Fluid Flow | Flow Parallel to Surface |

From FM:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | |  |  | |
| **Laminar Flow** | | | **Turbulent Flow** | |
|  | | |  | |
|  |  | |  |  |

**CONCEPT OF THERMAL BOUNDARY LAYER:**

The necessary condition to developed thermal boundary layer,

|  |  |  |
| --- | --- | --- |
| 3 |  | 1. (Cold Fluid Flow over a hot plate) OR 2. (Hot Fluid Flow over a Cold plate)   At the boundary layer,  Special Case, At |
| Conduction heat loss at S/c, | Convection above Surface, | Along the length direction, Temperature gradient decreasing at particular distance from the surface. |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **PRANDTL NUMBER:** It’s dimesionless number which represents ratio of momentum diffusivity (Kinematic Viscosity) to Thermal Diffusivity. | | |  | |
| **NOTE:** It’s property of fluid which indicates relation between velocity boundary layer and thermal boundary layer. | | | | |
| **RANGE OF PRANDTL NUMBER** | | **For Laminar Flow,** | | **For Turbulent Flow,**  Due to rapid mixing. |
| Liquid metal: | Gases: |
| Water: | Liquid organic fluids: |
| Oil: | Glycerine: |

**NUSSELT NUMBER: It’s** dimensionless number which represent ratio of convective flux to the conductive heat flux (Conductive heat flux) is calculated by assuming motionless fluid.

Higher the Nusselt number higher will be convective heat transfer.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | At Surface of Plate, | |  | | | |  |
|  |  | | | |  | | |  |
|  | | |  | | |  | Local Nusselt Number,  Local Nusselt Number, | |

**NOTE:** is same like but only change is .

**REYNOLD’S ANALOGY FOR LAMINAR FLOW OF GASES OVER A FLAT PLATE:**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | By integrating equation and substituting BCs & from Fluid Mechanics in Equation, | It’s valid for gases but we can also use for turbulent flow. |

|  |  |
| --- | --- |
| **STANTON NUMBER ():** It’s dimensionless number that measures ratio of heat transfer into a fluid to the thermal capacity of fluid. | **PECLET NUMBER ():** It’s ratio of rate of energy carried out due to fluid motion to rate of energy carried due to diffusion. |
|  |  |

**Note:** is used for liquid metals or low .

**BOUNDARY LAYER CONDITIONS USED IN CONVECTION:**

|  |  |
| --- | --- |
|  |  |

1. Dirichlet Boundary Condition: In this condition, surface maintained at constant temperature.

|  |  |  |
| --- | --- | --- |
|  |  | For , |

1. Neumann Boundary Condition: In this condition, Surface maintained at constant heat flux.

|  |  |
| --- | --- |
|  | Here, the question can be asked to find total heat transfer or temperature of the surface. |

**TO DEVELOP TEMPERATURE PROFILE IN FLUID FOLLOWING EQUATION USED:**

|  |  |
| --- | --- |
| 1. Navier Stoke’s Equation 2. Conservation of Mass (Continuity) | 1. Conservation of Momentum 2. Conservation of Energy |

**CORRELATION USED IN FORCED CONVECTION EXTERNAL FLOW:**

CASE-I: Laminar Flow over a flat plate and plate surface maintained at constant temperature.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | |  | |
|  | |  | |  | |
|  | | |  | |  |

CASE-II: Laminar Flow over a flat plate and plate surface maintained at constant Heat Flux.

|  |  |  |
| --- | --- | --- |
|  |  |  |

**Note:** For particular , Laminar Flow over a flat plate and plate surface maintained at constant Heat Flux boundary conditions is 36 % more than constant surface temperature boundary condition.

For Laminar Flow,

|  |  |  |
| --- | --- | --- |
|  | **Colburn Analogy Valid for Any Fluid.** | **Reynolds Analogy Valid for Gas** |

**TURBULENT FLOW OVER FLAT PLATE & PLATE SURFACE MAINTAINED AT CONSTANT TEMPERATURE:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | **From Colburn Analogy,** |  |  |

**TURBULENT FLOW OVER FLAT PLATE & PLATE SURFACE MAINTAINED AT CONSTANT HEAT FLUX:**

**Note:** For particular , Turbulent Flow over a flat plate and plate surface maintained at constant Heat Flux boundary conditions is 4 % more than constant surface temperature boundary condition.

**VARIATION OF HEAT TRANSFER COEFFICIENT OVER FLAT PLATE:**

|  |  |
| --- | --- |
| At surface,,  In External flow, all the thermophysical properties of fluid are assumed to be constant between they are calculated on mean film temperature,  is more in turbulent flow compare to laminar flow.  is more in turbulent flow compared to laminar flow. | Convection coefficient equations for forced air flow over flat surfaces -  ScienceDirect |

**ANALYSIS OF CROSS FLOW OVER SOLID CYLINDER:**

1. For laminar flow, Separation takes place at (Measured from Stagnation Point)
2. For Turbulent Flow, Separation takes place at (Measured from Stagnation Point)

is maximum at separation point hence at separation point is minimum.

**FORCED CONVECTION INTERNAL FLOW:**

Circular pipe geometry withstands high pressure without distortion compared to non-circular geometry.

**HYDRAULIC DIAMETER :** It’s used to analysing the thickness of boundary layer in internal flow.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Cross section Area,  Wetted perimeter | Pipe: Circular Cross Section | Duct: Non-Circular Cross Section |
|  | For Rectangular Duct, |

For Circular Concentric Annular Pipes,

|  |  |
| --- | --- |
| Nusselt Number, | **HYDRODYNAMIC BOUNDARY LAYER:** |
| For Laminar Flow, |
| For Turbulent Flow, |
| For Laminar Flow, |
| For Turbulent Flow, |

**THERMAL BOUNDARY LAYER:**

|  |  |  |
| --- | --- | --- |
| For Fully Developed Profile (Actual Profile),  Temperature Profiles, | From Energy Balance,  At ,  Hence, Within  Outside , | For constant cross section duct when, fluid properties are constant, then heat transfer coefficient along flow Direction remains constant.  Graph of |

In case of thermal fully developed flow, Temperature profile may vary with in the flow direction but dimensionless temperature profile remains unchanged. In the thermal fully developed region convection heat transfer coefficient is constant (Doesn’t vary with ).

Thermal Entrance Length **,**

|  |  |  |
| --- | --- | --- |
| For laminar Flow, | | For turbulent Flow, |
|  | In turbulent flow, the intense mixture due to random fluctuation of usually overshadows the effect of molecular diffusion. Therefore and is independent of Prandtl Number. is much shorter w.r.t. laminar Flow. | |

**GENERALISED THERMAL ANALYSIS OF FULLY DEVELOPED FLOW:**

|  |  |  |  |
| --- | --- | --- | --- |
| From the energy Balance,  Possibility,   |  |  | | --- | --- | |  |  | | Temperature Surface  Mean Temperature of flow at Inlet ()  Mean Temperature of flow at Outlet ()  Mean Temperature of flow at any Location ()  Parimeter |

**SURFACE MAINTAINED AT CONSTANT TEMPERATURE:**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |

By integration we can get,

|  |  |  |
| --- | --- | --- |
|  |  | Here, Varies exponentially with respect to . |

**NOTE:** For,

|  |  |  |
| --- | --- | --- |
|  | |  |
|  | Logarithmic Mean Temperature Difference  Arithmetic Mean Temperature Difference | |

**IMPORTANT POINTS:**

In Case of thermal fully developed flow for constant surface temperature boundary conditions ()

1. Temperature difference between surface and mean temperature of flow continuously varies w. r. t. location.
2. LMTD used as corrected temperature difference in Newton’s Law of cooling. AMTD Should not be used.
3. Mean Temperature of fluid varies exponentially with respect to location.
4. Shape of temperature profile varies with respect to location.

**SURFACE MAINTAINED AT CONSTANT HEAT FLUX BOUNDARY CONDITION:**

|  |  |  |
| --- | --- | --- |
|  | Constant. |  |
|  |  |  |

For fully developed flow,

|  |  |
| --- | --- |
|  |  |
|  | Here,  Initially  After Some Time,  For Fully Developed Flow,  Imp Points for fully developed flow for constant heat flux,   1. Temperature difference between surface and mean temperature of fluid remain constant. 2. Mean temperature of fluid varies linearly with respect to location. 3. Shape of the temperature profile remains unchanged. Just the temperature increases but shape remains same. |

**CORRELATIONS USED IN FORCED CONVECTION (INTERNAL FLOW):**

**CASE-I:** Laminar Flow through a pipe and pipe surface maintained at Constant Temperature.

|  |  |  |
| --- | --- | --- |
|  |  |  |

**CASE-II:** Laminar Flow through a pipe & pipe surface maintained at Constant heat Flux.

|  |  |  |
| --- | --- | --- |
|  |  |  |

For fully developed laminar flow constant Heat Flux gives 19% more Nusselt number than constant surface temperature.

For Laminar/ Fully Developed Flow,

For fully developed laminar flow Heat loss is independent of diameter due to constant Nusselt number.

**CASE-III:** Turbulent Flow Through A Pipe.

|  |  |
| --- | --- |
| **DITTUS BOILTER EQUATION:**  From Colburn Analogy, | For Cooling of Fluid,  For Heating of Fluid, |

For particular in turbulent flow as (From above Equation & )

1. DITTUS BOILTER EQUATION valid for both the boundary condition.
2. In turbulent flow Nusselt number is much higher than laminar flow.
3. In turbulent flow entry length is much shorter than laminar flow.
4. In general, constant heat flux boundary condition gives more Nusselt number than constant surface temperature conation.
5. In Internal flow, all the thermophysical properties of fluid are assumed to be constant between they are calculated on mean film temperature,

**FREE OR NATURAL CONVECTION:** Convection process takes place due to density difference and Gravity Force.

|  |  |  |
| --- | --- | --- |
| **Conduction** | **Free Convection** | Free Convection takes place where gravity is present. And it has less heat transfer rate and No maintenance cost. |
| situated above | situated above |
|  |  |
| Stable Heat Transfer | Unstable Heat Transfer |

**CHARACTERISTIC LENGTH ():**

|  |  |  |
| --- | --- | --- |
| Vertical Plate: | Vertical Cylinder: | Chap09 HT 3e Natural Convection |
| Sphere: | Horizontal Cylinder: |
| Hot Face Upward:  Takes Less time for Colling. | Hot Face Downward:  Takes Long time for Colling. |
| Horizontal Plate: | Horizontal Circular Plate: |
| For Free convection flow within boundary layer, there are majorly Buoyancy force and Viscous forces which plays major role. | |
| **COEFFICIENT OF VOLUME EXPANSION ():**   |  |  | | --- | --- | | Same line coefficient of linear expansion, | For linear Variation of density with temp.  Large Value gives higher free convection. | | For ideal Gas, | | | |

**GRASHOF NUMBER ():** It represents ratioof buoyancy force to the viscous force acting on fluid. Grashof Number provide the main criteria to determining whether the fluid flow is laminar or turbulent in natural convection.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |

is not suitable for constant heat flux because the surface temperature continuously increases and also changes.

**RAYLEIGH NUMBER ():**

It viewed a ratio of buoyancy force and product of thermal and momentum diffusivities.

For Vertical Plate & Vertical Cylinder,

|  |  |
| --- | --- |
| For laminar Flow, | For Turbulent Flow, |

**MODIFIED GRASHOF NUMBER ():** It’s suitable for constant heat flux boundary condition.

**RICHARDSON NUMBER ():**

|  |  |  |
| --- | --- | --- |
| For Free Convection, | For Forced Convection, | For Mixed Convection, |

**CORRELATION USED IN FREE CONVECTION:**

**VERTICAL PLATE:**

**CASE-I:** Surface Maintained at constant temperature.

|  |  |  |
| --- | --- | --- |
| Const. (Generally, < 1) | For Laminar Flow, | For Turbulent Flow, |

**CASE-II:** Surface Maintained at constant Heat Flux.

|  |  |  |
| --- | --- | --- |
| Const. (Generally, < 1) | For Laminar Flow, | For Turbulent Flow, |

**GENERAL THERMAL ANALYSIS OF LAMINAR FREE CONVECTION OVER A VERTICAL PLATE OR CYLINDER:**

**CASE-I:** Surface Maintained at constant temperature.

For Laminar Flow,

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |

For Turbulent Flow,

is independent of

**CASE-II:** Surface Maintained at constant Heat Flux.

For Laminar Flow,

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |

For Turbulent Flow,

is independent of

**NOTE:** In Turbulent Flow, Free Convection is independent of characteristic length.