Bineswar Brahma Engineering College

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ME181605: Heat Transfer – II

Syllabus

Module 1 - Fundamental of Convective Heat Transfer: Introduction, the basic equations, the convective heat transfer coefficient, forced convection over a flat plate (external flow), heat transfer and temperature distribution for flow between parallel plates, forced convection in circular tubes (internal flow).

Module 2 - Free convection: Laminar boundary layer equations of free convection on a vertical flat plate, concept of Grashoff number, empirical correlations for vertical plates, horizontal plates, inclined surface, vertical and horizontal cylinders, spheres.

Module 3 - Heat Exchanger Analysis and Design: Types, overall heat transfer coefficient, fouling factor, LMTD methods of analysis, effectiveness - NTU method, pressure drop and pumping power, aspects of design, double pipe heat exchanger, shell and tube heat exchanger, condensers, Optimization of heat exchangers.

Module 4 - Boiling and Condensation: Boiling heat transfer phenomena, boiling correlations, laminar film-wise condensation on a vertical plate.

Module 5 - Convective Mass Transfer: Convective mass transfer coefficient, the concentration boundary layer, analogy between momentum, heat and mass transfer, convective mass transfer correlation, evaporation of water into air.

Reference Books:

1. Heat transfer by P S Ghoshdastidar, Oxford University Press
2. Fundamentals for heat transfer by Sachdeva, Wiley Eastern
3. A basic approach to heat transfer by M N Ožišik, McGraw Hills

ME181605: Heat Transfer - II

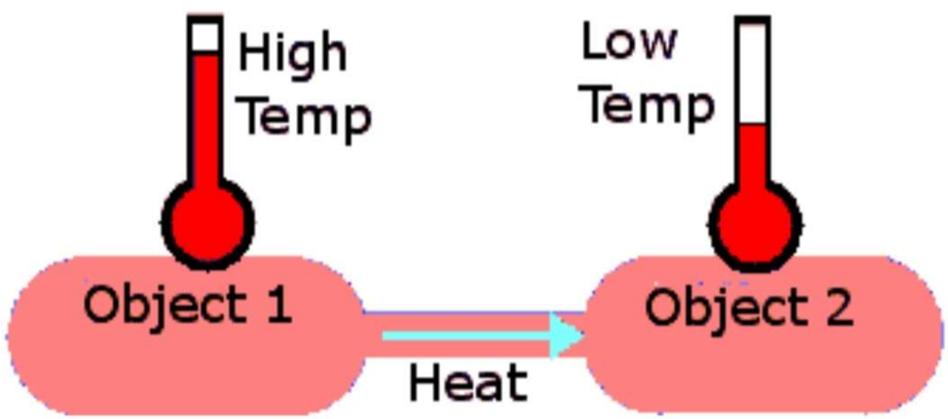
Module-1: Fundamentals of Convective Heat Transfer

❖ Introduction:

✓ Heat transfer is the branch of science/engineering which deals with the study of rate of heat transfer from one system to another due to temperature difference.

✓ Heat is the form of energy that can be transferred from one system to another system as a result of temperature difference.

✓ The *temperature difference* is the driving force for heat transfer, just as the *voltage difference* is the driving force for electric current flow and *pressure difference* is the driving force for fluid flow.



Heat always flows from high temperature to low temperature.

Introduction (Cont.)

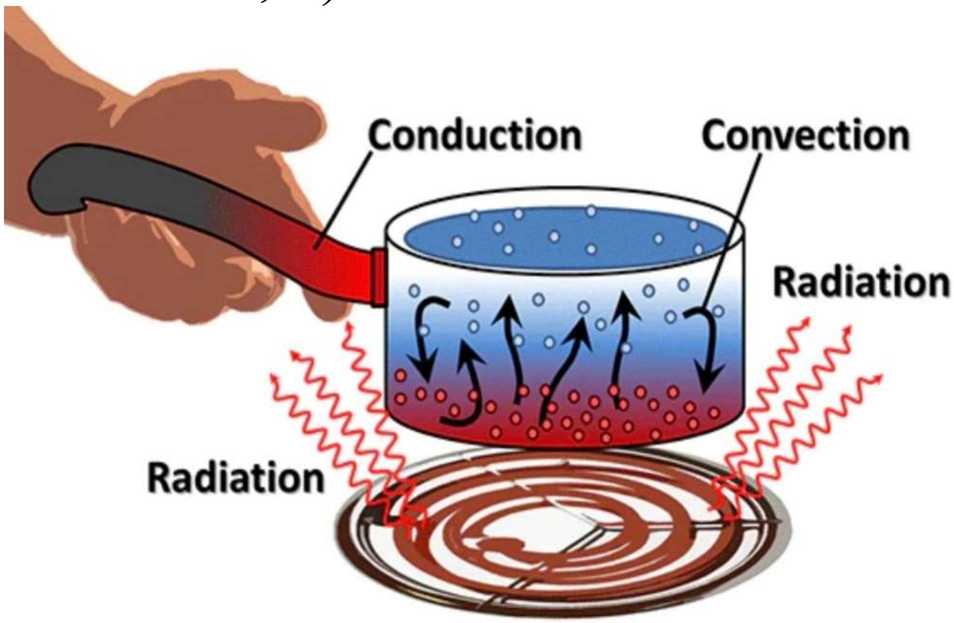
- Application of heat transfer: We can see application of heat transfer in day to day life appliances such as:

  - ✓ Cooking food
  - ✓ Cooler
  - ✓ Refrigerator
  - ✓ Water heater
  - ✓ Iron
  - ✓ Computer
  - ✓ Car radiator
  - ✓ Solar collector
  - ✓ Dryer
  - ✓ Boiling water
  - ✓ Warm our body in a fireplace during winter

and so on.

Introduction (Cont.)

- Three modes of heat transfer: 1) Conduction, 2) convection and 3) radiation.



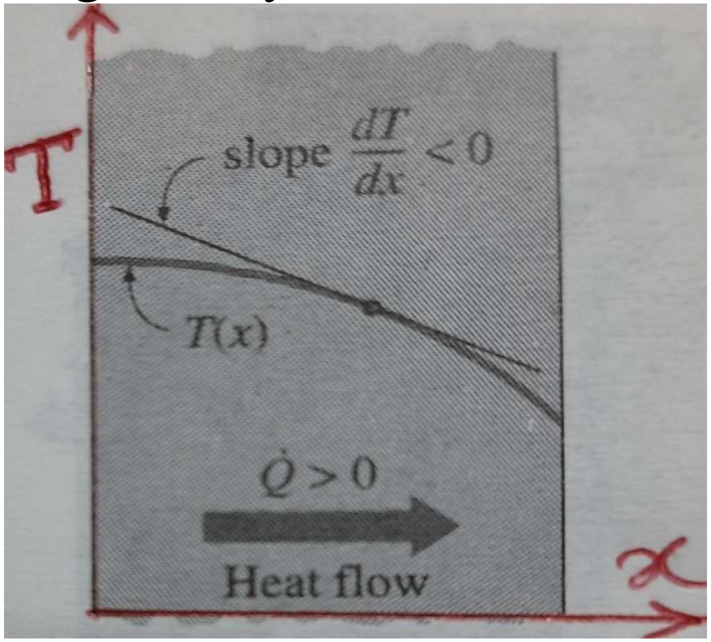
1) Conduction: is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic particles as a result of interactions between the particles.

2) Convection: is the mode of heat transfer between a solid surface and the adjacent liquid or gas which is in motion, and it involves the combined effects of conduction and fluid motion.

3) Radiation: is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

❖ The basic equations

- Fourier's law of conduction: For one-dimensional heat conduction through a material, the rate of heat transfer $\dot{Q}$ is given by the Fourier's law as follows:



$$\dot{Q} = -kA\frac{dT}{dx}$$

where,

k - thermal conductivity of the material

A - area of the material normal to the direction of heat transfer

$\frac{dT}{dx}$ - temperature gradient which is the slope of the temperature curve on a *T* vs *x* diagram and is negative because heat always transfers from high temperature to low temperature.

Note: The rate of heat transfer $\dot{Q}$ is a positive quantity (scalar) therefore in the RHS of above equation a negative sign is put to make it positive since $\frac{dT}{dx}$ is a negative quantity.

The basic equations (Cont.)

- Newton's law of cooling: The rate of convective heat transfer $\dot{Q}$ is observed proportional to the temperature difference from experimental studies and is conveniently expressed by Newton's law of cooling.

$$\dot{Q} = hA_s(T_s - T_\propto)$$

where,

A_s - heat transfer surface area, m^2

h - convective heat transfer coefficient, $W/m^2 - {}^oC$

T_s - temperature of the surface or wall, ${}^oC$

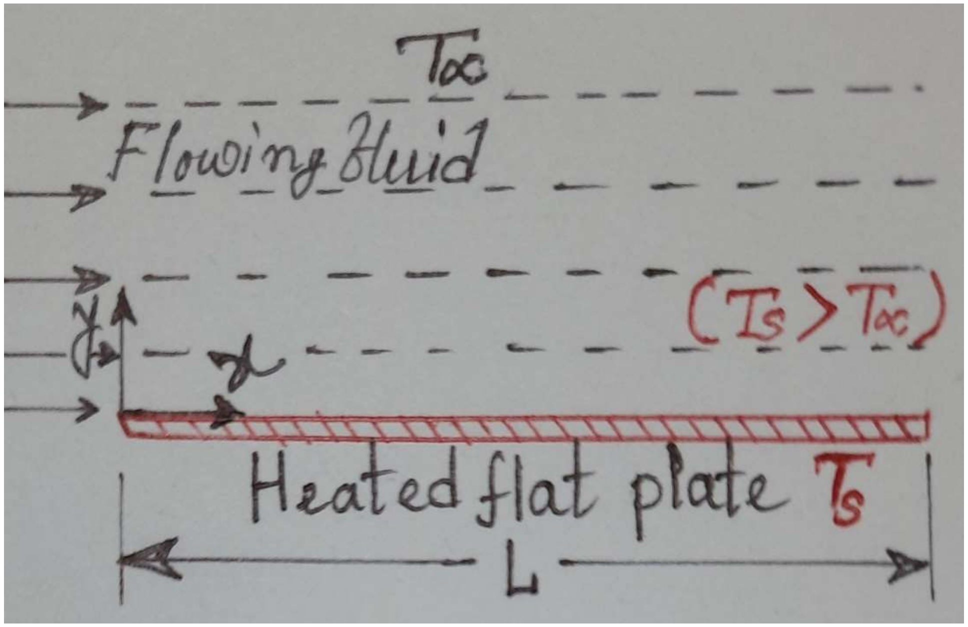
$T_\propto$ - temperature of the fluid sufficiently far from the surface, ${}^oC$

The term, $q'' = \dot{Q}/A_s$ is known as the heat flux and its unit is W/m^2.

Note: The convective heat transfer coefficient is not a property of the fluid. It is an experimentally determined parameter that depends upon the variables influencing the convection like surface geometry, nature of fluid motion and properties of fluid. In a nut shell, heat transfer coefficient is dependent on the physical properties of the fluid and the physical situation.

❖ Convective heat transfer coefficient

$h = f$ (fluid property, velocity, geometry.)



- Local heat transfer coefficient (h_x): It is the heat transfer coefficient at any point on an object/body. For example, h_x at any point on the heated flat plate as shown in the figure where a fluid flows having temperature T_∞ over the heated plate at temperature T_s.

- Average heat transfer coefficient (h_L): It is the heat transfer coefficient over the entire body/object. For example, in the above figure h_L over the entire plate is given by,

$$h_L = \frac{\int_0^L h_x dx}{L}$$

❖ Forced convection over a flat plate (external flow)

- Forced convection: When a fluid is forced to flow over a surface by some external means like a blower for a gas or a pump for a liquid is called forced convection.

- Free convection: When a fluid motion is caused by buoyancy forces that are induced by density differences due to variation of temperature in the fluid is called free or natural convection.

- External flow: The flow of an unbounded fluid over a surface is treated as external flow.

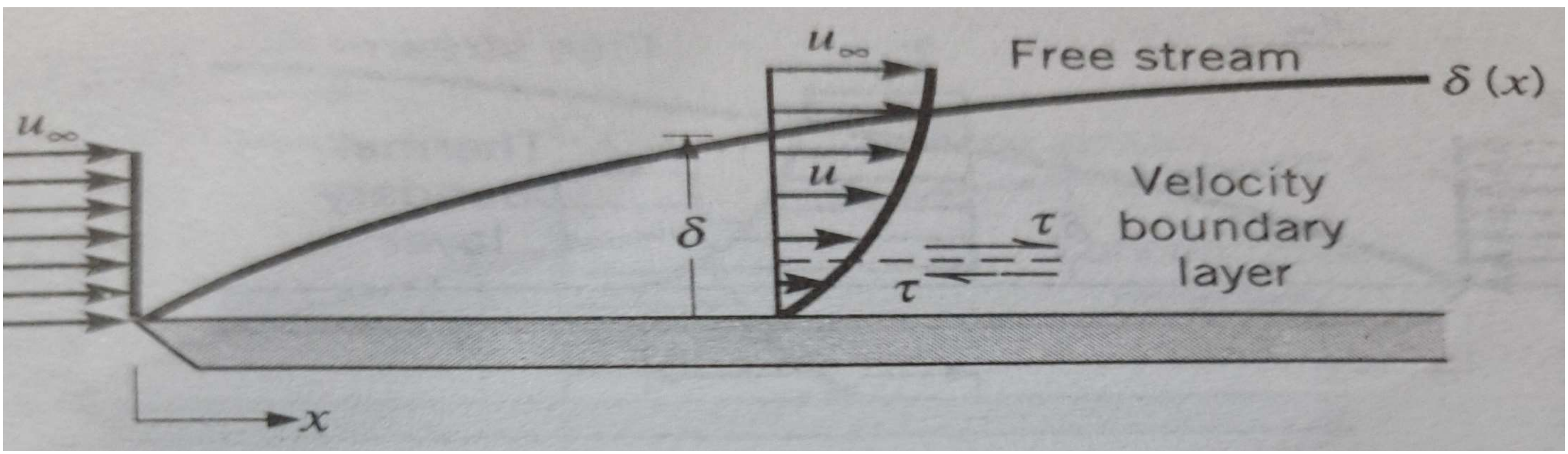
- Internal flows: When a fluid flow is completely bounded/ confined by surface, then it is treated as internal flow.

Forced convection over a flat plate (Cont.)

- Hydrodynamic or velocity boundary layer: When fluid particles come into contact with a solid surface, their velocity becomes zero because of the no-slip condition. Then, the particles retard the motion of particles in the adjacent layer, which act to retard the motion of particles in the next layer and so on until at a distance ($y = \delta$) from the solid surface where the effect of the solid wall becomes negligible. That is how a boundary layer (BL) forms.

- Boundary layer thickness (δ): It is defined as the value of y at which u becomes equal to 99% of u_∞.

where, u_∞ and u are the velocities of fluid outside and inside the BL.

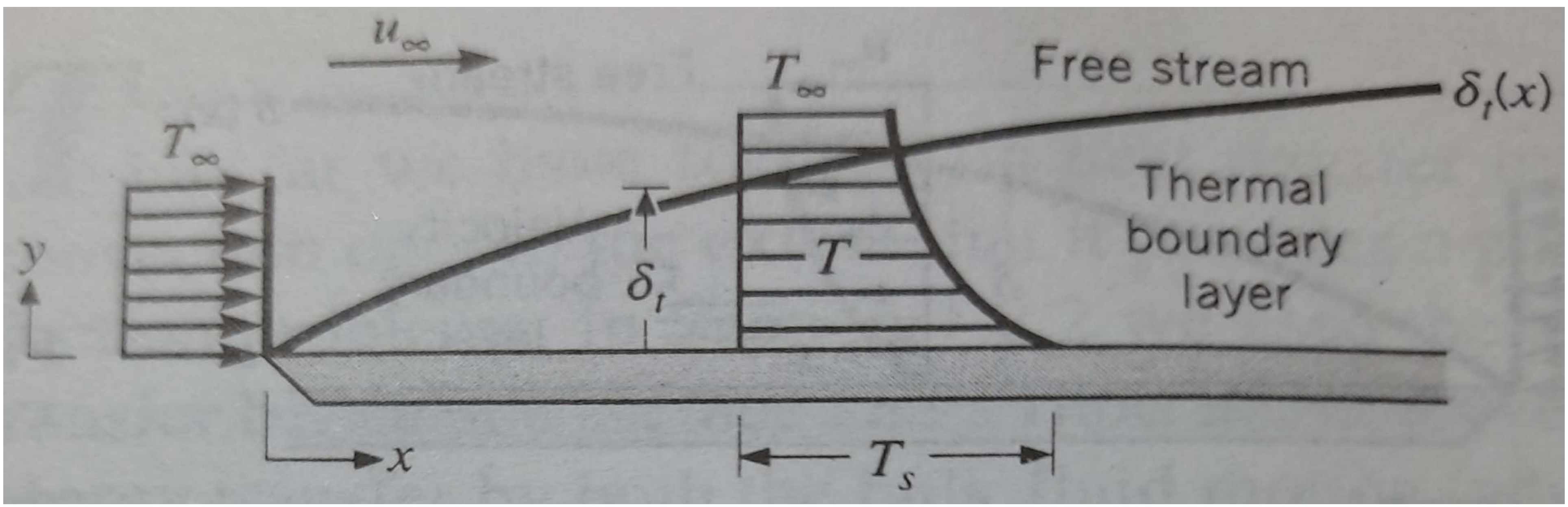


Forced convection over a flat plate (Cont.)

- Thermal or temperature boundary layer: Similar to the hydrodynamic boundary layer, a thermal boundary layer develops when there is temperature difference between a free stream fluid and the surface over which the fluid flows.

- Thermal boundary layer thickness (δ_t): It is defined as the value of y at which (T_s - T) becomes equal to 99% of (T_s - T_∞).

where, T denotes the temperature of fluid in the thermal boundary layer region, Ts is surface/wall temperature, T_∞ is the free stream temperature and $T_s > T_\infty$.



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