MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS

L 1

MECH

III/V

Course Name with Code : 16MED13 & Heat and Mass Transfer

Course Faculty : Mr.R.Ramesh

Unit : **I - Conduction** **Date of Lecture:**

Topic of Lecture: Basic Concepts – Mechanism of Heat Transfer – Conduction, Convection and Radiation

Introduction : Heat Transfer

Heat can travel shift from one place to another in several ways. The different modes of heat transfer include:

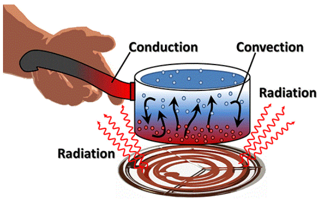
- Conduction
- Convection
- Radiation

Meanwhile, if the temperature difference exists between the two systems, heat will find a way to transfer from the higher to the lower system.

Prerequisite knowledge for Complete understanding and learning of Topic:

- (Max. Four important topics) : Ironing of clothes is an example of conduction where the heat is conducted from the iron to the clothes.
- Heat is transferred from hands to ice cube resulting in the melting of an ice cube when held in hands.
- Heat conduction through the sand at the beaches. This can be experienced during summers. Sand is a good conductor of heat.

Detailed content of the Lecture:



Convection

The movement of fluid molecules from higher temperature regions to lower temperature regions.

- Q is the heat transferred per unit time
- H_c is the coefficient of convective heat transfer
- A is the area of heat transfer
- T_s is the surface temperature
- T_f is the fluid temperature
- Convection Examples

Examples of convection include

- Boiling of water, that is molecules that are denser move at the bottom while the molecules which are less dense move upwards resulting in the circular motion of the molecules so that water gets heated.
- Warm water around the equator moves towards the poles while cooler water at the poles moves towards the equator.
- Blood circulation in warm-blooded animals takes place with the help of convection, thereby regulating the body temperature.

Radiation

- Thermal radiation is generated by the emission of electromagnetic waves. These waves carry away the energy from the emitting body. Radiation takes place through a vacuum or transparent medium which can be either solid or liquid. Thermal radiation is the result of the random motion of molecules in the matter. The movement of charged electrons and protons is responsible for the emission of electromagnetic radiation.
- Where,
- P is the net power of radiation
- A is the area of radiation
- Tr is the radiator temperature
- Tc is the surrounding temperature
- e is emissivity and σ is Stefan's constant

Radiation Example

Following are the examples of radiation:

- Microwave radiation emitted in the oven is an example of radiation.
- UV rays coming from the sun is an example of radiation.
- The release of alpha particles during the decaying of Uranium-238 into Thorium-234 is an example of radiation.

- Unit of Heat Transfer

SI system	Joule
MKS system	cal
Rate of transfer of heat	KW

Examples of Convection

- **boiling water** - When water boils, the heat passes from the burner into the pot, heating the water at the bottom. This hot water rises and cooler water moves down to replace it, causing a circular motion.
- **radiator** - A radiator puts warm air out at the top and draws in cooler air at the bottom.
- **steaming cup of hot tea** - The steam you see when drinking a cup of hot tea indicates that heat is being transferred into the air.
- **ice melting** - Ice melts because heat moves to the ice from the air. As a result, the ice melts from a solid to liquid.
- **frozen food thawing** - Frozen food thaws more quickly under cold running water than if it is placed in water. This is because the action of the running water transfers heat into the food faster than if the frozen item was placed in still water.
- **forced convection** - When a fan, pump or suction device is used to facilitate convection, the result is forced convection. Everyday examples of this can be seen with air conditioning, central heating, a car radiator using fluid, or a convection oven.

Video Content / Details of website for further learning (if any):

Can be added as link:https://www.youtube.com/watch?v=TiPzV15AIIs – heat conduction in a metal rod

Important Books/Journals for further learning including the page nos.:
Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 10

MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh.

Unit : 2- CONVECTION
Date of Lecture :

Topic of Lecture : Basic Concepts – Convective Heat Transfer Coefficients – Boundary Layer Concept

Introduction:

The heat transfer by convection requires a solid-fluid interface, a temperature difference between the solid surface and the surrounding fluid and a motion of the fluid. The process of heat transfer by convection would occur when there is a movement of macro-particles of the fluid in space from a region of higher temperature to lower temperature.

Prerequisite knowledge for Complete understanding and learning of Topic:

Convection Heat Transfer, Free and Forced Convection, Laminar and Turbulent Flow, Thermal Boundary Layer

Detailed content of the Lecture:

Convection Heat Transfer-Requirements

The heat transfer by convection requires a solid-fluid interface, a temperature difference between the solid surface and the surrounding fluid and a motion of the fluid. The process of heat transfer by convection would occur when there is a movement of macro-particles of the fluid in space from a region of higher temperature to lower temperature.

Convection Heat Transfer Mechanism

Let us imagine a heated solid surface, say a plane wall at a temperature T_W placed in an atmosphere at temperature T_∞, Fig. Since all real fluids are viscous, the fluid particles adjacent to the solid surface will stick to the surface. The fluid particle at A, which is at a lower temperature, will receive heat energy from the plate by conduction. The internal energy of the particle would Increase and when the particle moves away from the solid surface (wall or plate) and collides with another fluid particle at B which is at the ambient temperature, it will transfer a part of its stored energy to B. And, the temperature of the fluid particle at B would increase. This way the heat energy is transferred from the heated plate to the surrounding fluid. Therefore the process of heat transfer by convection involves a combined action of heat conduction, energy storage and transfer of energy by mixing motion of fluid particles.

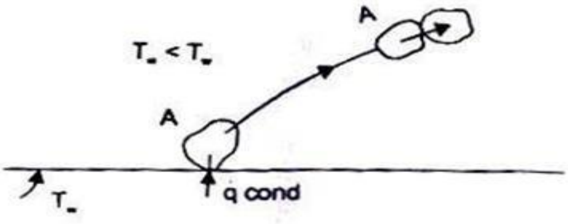


Fig. Principle of heat transfer by convection

Free and Forced Convection

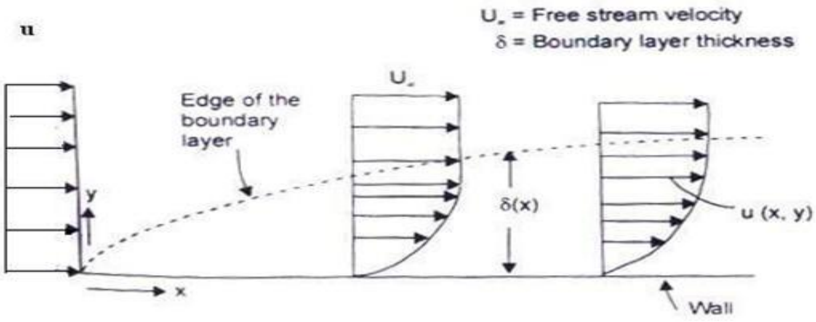
When the mixing motion of the fluid particles is the result of the density difference caused by a temperature gradient, the process of heat transfer is called natural or free convection. When the mixing motion is created by an artificial means (by some external agent), the process of heat transfer is called forced convection Since the effectiveness of heat transfer by convection depends largely on the mixing motion of the fluid particles, it is essential to have a knowledge of the characteristics of fluid flow.

Basic Difference between Laminar and Turbulent Flow

In laminar or streamline flow, the fluid particles move in layers such that each fluid particle follows a smooth and continuous path. There is no macroscopic mixing of fluid particles between successive layers, and the order is maintained even when there is a turn around a comer or an obstacle is to be crossed. If a lime dependent fluctuating motion is observed indirections which are parallel and transverse to the main flow, i.e., there is a radom macroscopic mixing of fluid particles across successive layers of fluid flow, the motion of the fluid is called' turbulent flow'. The path of a fluid particle would then be zigzag and irregular, but on a statistical basis, the overall motion of the macro particles would be regular and predictable.

Formation of a Boundary Layer

When a fluid flow, over a surface, irrespective of whether the flow is laminar or turbulent, the fluid particles adjacent to the solid surface will always stick to it and their velocity at the solid surface will be zero, because of the viscosity of the fluid. Due to the shearing action of one fluid layer over the adjacent layer moving at the faster rate, there would be a velocity gradient in a direction normal to the flow.



Let us consider a two-dimensional flow of a real fluid about a solid (slender in cross-section) as shown in Fig. Detailed investigations have revealed that the velocity of the fluid particles at the surface of the solid is zero. The transition from zero velocity at the surface of the solid to the free stream velocity at some distance away from the solid surface in the V-direction (normal to the direction of flow) takes place in a very thin layer called 'momentum or hydrodynamic boundary layer'. The flow field can thus be divided in two regions:

A very thin layer in the vicinity of the body where a velocity gradient normal to the direction of flow exists, the velocity gradient du/dy being large. In this thin region, even a very small Viscosity μ of the fluid exerts a substantial Influence and the shearing stress $\tau = \mu$ du/dy may assume large values. The thickness of the boundary layer is very small and decreases with decreasing viscosity.

Thermal Boundary Layer

Since the heat transfer by convection involves the motion of fluid particles, we must superimpose the temperature field on the physical motion of fluid and the two fields are bound to interact. It is intuitively evident that the temperature distribution around a hot body in a fluid stream will often have the same character as the velocity distribution in the boundary layer flow. When a heated solid body IS placed In a fluid stream, the temperature of the fluid stream will also vary within a thin layer In the immediate neighborhood of the solid body. The variation in temperature of the fluid stream also takes place in a thin layer in the neighborhood of the body and is termed 'thermal boundary layer'. Fig. shows the temperature profiles inside a thermal boundary layer.

Video Content / Details of website for further learning (if any): NIL

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 11

MECH

III/V

Course Name with Code : **HEAT & MASS TRANSFER &16 MED13**

Course Faculty : **MR.R.RAMESH**

Unit : **2 - CONVECTION**
Date of Lecture :

Topic of Lecture : Types of Convection – Forced Convection – Dimensional Analysis

Introduction:

When the mixing motion of the fluid particles is the result of the density difference Caused by a temperature gradient, the process of heat transfer is called natural or free convection. When the mixing motion is created by an artificial means (by some external agent), the process of heat transfer is called forced convection.

Prerequisite knowledge for Complete understanding and learning of Topic:

Free and Forced Convection, Dimensionless Parameters and their Significance

Detailed content of the Lecture:

Free and Forced Convection

When the mixing motion of the fluid particles is the result of the density difference Caused by a temperature gradient, the process of heat transfer is called natural or free convection. When the mixing motion is created by an artificial means (by some external agent), the process of heat transfer is called forced convection Since the effectiveness of heat transfer by convection depends largely on the mixing motion of the fluid particles, it is essential to have a knowledge of the characteristics of fluid flow.

FREE AND FORCED CONVECTION DURING EXTERNAL FLOW OVER PLATES:

Dimensionless Parameters and their Significance

The following dimensionless parameters are significent in evaluating the convection heat transfer coefficient: *The Nusselt Number (Nu)*-It is a dimensionless quantity defined as hL/ k, where h = convective heat transfer coefficient, L is the characteristic length and k is the thermal conductivity of the fluid The Nusselt number could be interpreted physically as the ratio of the temperature gradient in the fluid immediately in contact with the surface to a reference

Let us consider a hot flat plate (temperature T_W) placed in a free stream (temperature $T_\infty < T_W$). The temperature distribution is shown ill Fig. 2.4. Newton's Law of Cooling says that the rate of heat transfer per unit area by convection is given by

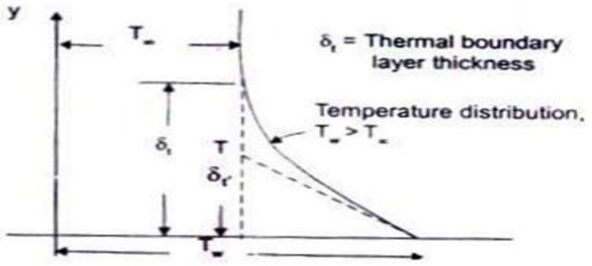

Fig. Temperature distribution in a boundary layer, Nusselt modulus

The heat transfer by convection involves conduction and mixing motion of fluid particles. At the solid fluid interface (y = 0),

Method of Dimensional Analysis

As pointed out in Chapter 5, dimensional analysis does not yield equations which can be solved. It simply combines the pertinent variables into non-dimensional numbers which facilitate the interpretation and extend the range of application of experimental data. The relevant variables for forced convection heat transfer phenomenon whether laminar or turbulent, are

the properties of the fluid – density p, specific heat capacity C_p, dynamic or absolute viscosity μ , thermal conductivity k.

The properties of flow – flow velocity Y, and the characteristic dimension of the system L. As such, the convective heat transfer coefficient, h, is written as h = f (ρ , V, L, μ , Cp, Since there are seven variables and four primary dimensions, we would expect three dimensionless numbers. As before, we choose four independent or core variables as ρ ,V, L, k, and calculate the dimensionless numbers by applying Buckingham π 's method:

Video Content / Details of website for further learning (if any): NIL

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 12

MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh.

Unit : 2 - CONVECTION
Date of Lecture :

Topic of Lecture : External Flow- Flow over Plates, Cylinders and Spheres

Introduction:

As pointed out earlier, when the motion of the fluid is caused by the imposition of external forces, such as pressure differences, and the fluid flows over a solid surface, at a temperature different from the temperature of the fluid, the mechanism of heat transfer is called 'forced convection'..

Prerequisite knowledge for Complete understanding and learning of Topic:

External Flow, Flow over Plates, Flow over Cylinders and Flow over Spheres.

Detailed content of the Lecture:

Flow over a Flat Plat:

As pointed out earlier, when the motion of the fluid is caused by the imposition of external forces, such as pressure differences, and the fluid flows over a solid surface, at a temperature different from the temperature of the fluid, the mechanism of heat transfer is called 'forced convection'. Therefore, any analytical approach to determine the convective heat transfer coefficient would require the temperature distribution in the flow field surrounding the body. That is, the theoretical analysis would require the use of the equation of motion of the viscous fluid flowing over the body along with the application of the principles of conservation of mass and energy in order to relate the heat energy that is convected away by the fluid from the solid surface.

For the sake of simplicity, we will consider the motion of the fluid in 2 space dimension, and a steady flow. Further, the fluid properties like viscosity, density, specific heat, etc are constant in the flow field, the viscous shear forces m the Y –direction is negligible and there are no variations in pressure also in the Y –direction.

FLOW OVER CYLINDERS:

Forced Convection Heat Transfer Principles

The mechanism of heat transfer by convection requires mixing of one portion of fluid with another portion due to gross movement of the mass of the fluid. The transfer of heat energy from one fluid particle or a molecule to another one is still by conduction but the energy is transported from one point in space to another by the displacement of fluid.

When the motion of fluid is created by the imposition of external forces in the form of pressure differences, the process of heat transfer is called ‘forced convection’. And, the motion of fluid particles may be either laminar or turbulent and that depends upon the relative magnitude of inertia and viscous forces, determined by the dimensionless parameter Reynolds number. In free convection, the velocity of fluid particle is very small in comparison with the velocity of fluid particles in forced convection, whether laminar or turbulent. In forced convection heat transfer, $Gr/Re^2 << 1$, in free convection heat transfer, $GrRe^2 >> 1$ and we have combined free and forced convection when $Gr/Re^2 \approx 1$.

Methods for Determining Heat Transfer Coefficient

The convective heat transfer coefficient in forced flow can be evaluated by:

(a) Dimensional Analysis combined with experiments;

(b) Reynolds Analogy – an analogy between heat and momentum transfer;

(c) Analytical Methods – exact and approximate analyses of boundary layer equations.

$$\pi_2 = \rho^a V^b L^c K^d \mu = \left(ML^{-3}\right)^a \left(LT^{-1}\right)^b (L)^c \left(MLT^{-3}\theta^{-1}\right)^d \left(ML^{-1}T^{-1}\right)$$

$$= M^o L^o T^o \theta^o$$

Equating the powers of M, L, T and on both sides, we get

$M : a + d + 1 = 0$

$L : - 3a + b + c + d = 1 = 0$

$T : - b - 3d - 1 = 0$

$\theta : - d = 0.$

By solving them, $d = 0$, $b = - 1$, $a = - 1$, $c = - 1$

and $\pi_2 = \mu / \rho VL$;or, $\pi_3 = \dfrac{1}{\pi_2} = \dfrac{\rho VL}{\mu}$

$M : a + d = 0;$ $\quad L : - 3a + b + c + d + 2 = 0$

$T : - b - 3d - 2 = 0;$ $\quad \theta : - d - 1 = 0$

By solving them,

$d =- 1, a = l, b = l, c = l,$

$$\pi_4 = \frac{\rho V L}{k} C_p \;;\; \pi_5 = \pi_4 \times \pi_2$$

$$= \frac{\rho V L}{k} C_p \times \frac{\mu}{\rho V L} = \frac{\mu C_p}{k}$$

$\therefore\ \pi_5$ is Prandtl number.

Therefore, the functional relationship is expressed as:

Nu = f (Re, Pr); or $Nu = C\,Re^{m}\,Pr^{n}$

where the values of c, m and n are determined experimentally.

Video Content / Details of website for further learning (if any): NIL

Important Books/Journals for further learning including the page nos.:

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LECTURE HANDOUTS

L 13

MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh.

Unit : 2 – CONVECTION

Date of Lecture :

Topic of Lecture : Internal Flow- Laminar and Turbulent Flow

Introduction:

The mechanism of heat transfer by convection requires mixing of one portion of fluid with another portion due to gross movement of the mass of the fluid. The transfer of heat energy from one fluid particle or a molecule to another one is still by conduction but the energy is transported from one point in space to another by the displacement of fluid

Prerequisite knowledge for Complete understanding and learning of Topic:

Internal Flow, Flow over Plates, Flow over Cylinders and Flow over Spheres.

Detailed content of the Lecture:

Internal Flow of a Flat Plat:

As pointed out earlier, when the motion of the fluid is caused by the imposition of external forces, such as pressure differences, and the fluid flows over a solid surface, at a temperature different from the temperature of the fluid, the mechanism of heat transfer is called ‘forced convection’. Therefore, any analytical approach to determine the convective heat transfer coefficient would require the temperature distribution in the flow field surrounding the body. That is, the theoretical analysis would require the use of the equation of motion of the viscous fluid flowing over the body along with the application of the principles of conservation of mass and energy in order to relate the heat energy that is convected away by the fluid from the solid surface.

For the sake of simplicity, we will consider the motion of the fluid in 2 space dimension, and a steady flow. Further, the fluid properties like viscosity, density, specific heat, etc are constant in the flow field, the viscous shear forces m the Y –direction is negligible and there are no variations in pressure also in the Y –direction.

INTERNAL FLOW OF CYLINDERS:

Laminar Flow Forced Convection Heat Transfer

Forced Convection Heat Transfer Principles

The mechanism of heat transfer by convection requires mixing of one portion of fluid with another portion due to gross movement of the mass of the fluid. The transfer of heat energy from one fluid particle or a molecule to another one is still by conduction but the energy is transported from one point in space to another by the displacement of fluid. Pressure differences, the process of heat transfer is called ‘forced convection’. And, the motion of fluid particles may be either laminar or turbulent and that depends upon the relative magnitude of inertia and viscous forces, determined by the dimensionless parameter Reynolds number. In free convection, the velocity of fluid particle is very small in comparison with the velocity of fluid particles in forced convection, whether laminar or turbulent. In forced convection heat transfer, $Gr/Re^2 << 1$, in free convection heat transfer, $GrRe^2 >> 1$ and we have combined free and forced convection when $Gr/Re^2 \approx 1$.

We choose a control volume ABCD, having a height H, length dx and unit thickness normal to the plane of paper, as shown in Fig. 25. We have:

(b) Conservation of Mass:
The external forces acting on the control volume are:

(a) Viscous force = $\mu \left.\frac{du}{dy}\right|_{y=0}$ dx acting in the –ve x-direction

(b) Buoyant force approximated as $\left[\int_0^H \rho g \beta \left(T - T_\infty\right) dy\right] dx$

From Newton’s law, the equation of motion can be written as:

$$\frac{d}{dx}\left[\int_0^\delta \rho u^2 dy\right] = -\mu \left.\frac{du}{dy}\right|_{y=0} + \int_0^\delta \rho g \beta \left(T - T_\infty\right) dy$$

because the value of the integrand between δ and H would be zero.

Video Content / Details of website for further learning (if any): NIL

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

Course Faculty

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LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **HEAT & MASS TRANSFER &16 MED13**

Course Faculty : **Mr.R.Ramesh.**

Unit : **2 - CONVECTION**
Date of Lecture :

Topic of Lecture : Combined Laminar and Turbulent Flow over Bank of tubes

Introduction:

As pointed out earlier, when the motion of the fluid is caused by the imposition of external forces, such as pressure differences, and the fluid flows over a solid surface, at a temperature different from the temperature of the fluid, the mechanism of heat transfer is called 'forced convection'..

Prerequisite knowledge for Complete understanding and learning of Topic:

External Flow, Flow over Plates, Flow over Cylinders and Flow over Spheres.

Detailed content of the Lecture:

Internal Flow of a Flat Plat:

As pointed out earlier, when the motion of the fluid is caused by the imposition of external forces, such as pressure differences, and the fluid flows over a solid surface, at a temperature different from the temperature of the fluid, the mechanism of heat transfer is called 'forced convection'. Therefore, any analytical approach to determine the convective heat transfer coefficient would require the temperature distribution in the flow field surrounding the body. That is, the theoretical analysis would require the use of the equation of motion of the viscous fluid flowing over the body along with the application of the principles of conservation of mass and energy in order to relate the heat energy that is convected away by the fluid from the solid surface.

For the sake of simplicity, we will consider the motion of the fluid in 2 space dimension, and a steady flow. Further, the fluid properties like viscosity, density, specific heat, etc are constant in the flow field, the viscous shear forces m the Y –direction is negligible and there are no variations in pressure also in the Y –direction.

INTERNAL FLOW OF CYLINDERS:

Laminar Flow Forced Convection Heat Transfer

Forced Convection Heat Transfer Principles

The mechanism of heat transfer by convection requires mixing of one portion of fluid with another portion due to gross movement of the mass of the fluid. The transfer of heat energy from one fluid particle or a molecule to another one is still by conduction but the energy is transported from one point in space to another by the displacement of fluid. pressure differences, the process of heat transfer is called 'forced convection'. And, the motion of fluid particles may be either laminar or turbulent and that depends upon the relative magnitude of inertia and viscous forces, determined by the dimensionless parameter Reynolds number. In free convection, the velocity of fluid particle is very small in comparison with the velocity of fluid particles in forced convection, whether laminar or turbulent. In forced convection heat transfer, $Gr/Re^2 << 1$, in free convection heat transfer, $GrRe^2 >> 1$ and we have combined free and forced convection when $Gr/Re^2 \approx 1$.

We choose a control volume ABCD, having a height H, length dx and unit thickness normal to the plane of paper, as shown in Fig. 25. We have:

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The external forces acting on the control volume are:

(a) Viscous force = $\mu \left.\frac{du}{dy}\right|_{y=0} dx$ acting in the –ve x-direction

(b) Buoyant force approximated as $\left[\int_0^H \rho g\beta (T - T_\infty) dy\right] dx$

From Newton's law, the equation of motion can be written as:

$$\frac{d}{dx}\left[\int_0^\delta \rho u^2 dy\right] = -\mu \left.\frac{du}{dy}\right|_{y=0} + \int_0^\delta \rho g\beta (T - T_\infty) dy$$

because the value of the integrand between δ and H would be zero.

Video Content / Details of website for further learning (if any): NIL

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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L 15

LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **16MED13 - Heat and Mass Transfer**

Course Teacher : **Mr.R.Ramesh.**

Unit : **II - Convection**

Date of Lecture:

Topic of Lecture: Free Convection

Introduction :

- ✓ Free or Natural convection is the process of heat transfer which occurs due to movement of the fluid particles by density changes associated with temperature differential fluid.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Free convection
- ✓ Newton's law of cooling
- ✓ Grashoff Number
- ✓ Prandtl Number

Detailed content of the Lecture:

– The rate of heat transfer is calculated using the general convection equation given below:

$$Q = hA\,(t_s - t_\infty) \qquad \text{...(8.1)}$$

where,

Q = Heat transfer, ,

h = Convection coefficient, W/m^2°C,

A = Area, m^2, and

t_∞ = Temperature of fluid at distances well removed from the surface (here the stagnant fluid temperature).

– A property that comes into play in free or natural convection is the *coefficient of thermal expansion* of the fluid defined by

$$\beta = \frac{1}{\upsilon}\left(\frac{\partial \upsilon}{\partial T}\right)_p = -\frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_p \qquad \text{...(8.2)}$$

For an ideal gas $\upsilon = \dfrac{RT}{p}, \left(\dfrac{\partial \upsilon}{\partial T}\right)_p = \dfrac{R}{p}$

and, hence $\beta = \dfrac{1}{T}$

$Gr\,Pr > 10^9$ ... *for turbulent flow*

The values of Gr and Pr are *evaluated at the mean film temperature* $\left(t_f = \frac{t_w + t_\infty}{2}\right)$.

Since in free convection heat transfer coefficients are low and Reynolds number is not an independent parameter, a new dimensionless grouping plays the major role (in free convection) which incorporates the coefficient of thermal expansion β in the expression. This dimensionless grouping is called the **Grashoff number**, expressed as

$$Gr = \frac{L^3 g\beta\Delta t}{\nu^2} \qquad ...(8.3)$$

where, L = Characteristic length

$\Delta t = (t_s - t_\infty)$, where t_s and t_∞ are the surface temperature and temperature of the surrounding fluid respectively.

The role of Grashoff number is the same in free convection as that of Reynolds number in forced convection.

The *critical Grashoff number for the flow of air over a flat plate* has been observed to be 4×10^8 (approximately).

In general, $Nu = f(Gr, Pr) = C\,(Gr)^a\,(Pr)^b$ ...(8.4)

In several cases, the above relation simplifies to the form

$$Nu = C\,(Gr.\,Pr)^m \qquad ...(8.5)$$

Hence, a new dimensionless group is often used called *Rayleigh number* viz.,

$$Ra = Gr\,.\,Pr$$

The product is also a criterion of laminar or turbulent character of the flow as determined by its values. Thus

$10^4 < Gr\,Pr < 10^9$ ... *for laminar flow*

$Gr\,Pr > 10^9$ ... *for turbulent flow*

The values of Gr and Pr are *evaluated at the mean film temperature* $\left(t_f = \frac{t_w + t_\infty}{2}\right)$.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=CA3GnfImGmw

https://www.youtube.com/watch?v=BRkf-bi6_zM&list=PLajYbKcP5kMrwzHq5Z3dUjbRXt-bc3PAt

https://www.youtube.com/watch?v=yoUxqeAN0So

Important Books/Journals for further learning including the page nos.:

- **Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010**

Course Teacher

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L16

LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **16MED13 Heat and Mass Transfer**

Course Teacher : **Mr.R.Ramesh.**

Unit : **II - Convection** **Date of Lecture:**

Topic of Lecture: Dimensional Analysis- Flow over Vertical Plate

Introduction :

- ✓ It is a mathematical method which makes use of the study of dimensions for solving several engineering problems like heat flow problems in fluid mechanics and thermodynamics

Prerequisite knowledge for Complete understanding and learning of Topic:

- Dimensional Analysis
- Free convection
- Flow over plate

Detailed content of the Lecture:

Buckingham π theorem:

- ✓ If there are *n* variables in a dimensionally homogeneous equation and if these contain *m* fundamental dimensions, then the variables are arranged into (*n* – *m*)dimensionless terms.

Dimensionless Parameters and their Significance

- The following dimensionless parameters are significent in evaluating the convection heat transfer coefficient:
- *The Nusselt Number (Nu)*-It is a dimensionless quantity defined as hL/ k, where h = convective heat transfer coefficient, L is the characteristic length and k is the thermal conductivity of the fluid The Nusselt number could be interpreted physically as the ratio of the temperature gradient in the fluid immediately in contact with the surface to a reference temperature gradient (T_S - T_∞) /L. The convective heat transfer coefficient can easily be obtained if the Nusselt number, the thermal conductivity of the fluid in that temperature range and the characteristic dimension of the object is known.

8.4.1. VELOCITY AND TEMPERATURE PROFILES ON A VERTICAL FLAT PLATE

Assuming the velocity and temperature profiles to be similar at any x, the temperature profile may be taken as

$$\frac{t - t_\infty}{t_s - t_\infty} = C_1 + C_2\left(\frac{y}{\delta}\right) + C_3\left(\frac{y}{\delta}\right)^2$$

The following boundary conditions apply:

(*i*) At $y = 0$ $t = t_s$

(*ii*) At $y = \delta$ $t = t_\infty$

(*iii*) At $y = \delta$ $\dfrac{\partial t}{\partial y} = 0$

The *temperature distribution* is, therefore, obtained as

$$\frac{t - t_\infty}{t_s - t_\infty} = \left(1 - \frac{y}{\delta}\right)^2$$

The velocity profile may be similarly assumed.

$$\frac{u}{u_x} = a + b\left(\frac{y}{\delta}\right) + c\left(\frac{y}{\delta}\right)^2 + d\left(\frac{y}{\delta}\right)^3$$

where u_x is any arbitrary function with the dimension of velocity.

The boundary conditions, are:

(*i*) At $y = 0,$ $u = 0$

(*ii*) At $y = \delta,$ $u = 0$

(*iii*) At $y = \delta,$ $\dfrac{\partial u}{\partial y} = 0$

(*iv*) At $y = 0,$ $\dfrac{\partial^2 u}{\partial y^2} = -\, g\beta\,\dfrac{(t_s - t_\infty)}{\nu}$

The velocity distribution is, therefore, found to be

$$\frac{u}{u_x} = \left[\frac{g\beta\delta^2\,(t_s - t_\infty)}{4\nu}\right]\frac{y}{\delta}\left(1 - \frac{y}{\delta}\right)^2$$

or, $$u = u_1\frac{y}{\delta}\left(1 - \frac{y}{\delta}\right)^2$$

where, $$u_1 = \frac{u_x g\beta\delta^2\,(t_s - t_\infty)}{4\nu}$$

8.6.1. VERTICAL PLATES AND CYLINDERS

The commonly used correlations are:

Laminar flow: $\overline{Nu_L} = 0.59\,(Gr\,.\,Pr)^{1/4}$ for $(10^4 < Gr\,.\,Pr < 10^9)$

Turbulent flow: $\overline{Nu_L} = 0.10\,(Gr\,.\,Pr)^{1/3}$ for $(10^9 < Gr\,.\,Pr < 10^{12})$

All the fluid properties are evaluated at the mean film temperature $\left(t_f = \dfrac{t_s + t_\infty}{2}\right)$.

Churchill and Chu have recommended the following correlations:

$$\overline{Nu_L} = 0.68 + \frac{0.67\,(Gr\,.\,Pr)^{1/4}}{\left[1 + \left(\dfrac{0.492}{Pr}\right)^{9/16}\right]^{4/9}} \quad \text{for } (Gr\,.\,Pr < 10^9)$$

$$\overline{Nu_L} = \left[0.825 + \frac{0.387\,(Gr\,.\,Pr)^{1/6}}{\left[1 + \left(\dfrac{0.492}{Pr}\right)^{9/16}\right]^{8/27}}\right]^2 \quad \text{for } (Gr\,.\,Pr > 10^9)$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=CA3GnfImGmw

https://www.youtube.com/watch?v=BRkf-bi6_zM&list=PLajYbKcP5kMrwzHq5Z3dUjbRXt-bc3PAt

https://www.youtube.com/watch?v=yoUxqeAN0So

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **16MED13 Heat and Mass Transfer**

Course Teacher : **Mr.R.Ramesh.**

Unit : **II - Convection**

Date of Lecture:

Topic of Lecture: Horizontal Plate, Inclined Plate

Introduction : An experimental investigation has been conducted of the convective **heat transfer** of an **inclined** rectangular **plate** with blunt edges. A surface heating film provides a uniform wall flux boundary condition with temperature measurement by thermocouples.

Prerequisite knowledge for Complete understanding and learning of Topic: convection heat transfer for the problem, which is usually calculate with an equation of the form

q=hAsurface(Tsurface −Tfree stream)

Detailed content of the Lecture:

8.6.2. HORIZONTAL PLATES

In case of an irregular plate, the *characteristic length* is defined as the *surface area divided by the perimeter of the plate*.

(*i*) *The upper surface heated or the lower surface cooled*:

Laminar flow: $\overline{Nu}_L = 0.54\ (Gr\ .\ Pr)^{1/4}$ for $(10^5 < Gr\ .\ Pr \le 2 \times 10^7)$ ...(8.41)

Turbulent flow: $\overline{Nu}_L = 0.14\ (Gr\ .\ Pr)^{1/3}$ for $(2 \times 10^7 < Gr\ .\ Pr \le 3 \times 10^{10})$ ...(8.42)

8.6.4. INCLINED PLATES

For this case multiply Grashoff number by cos θ, where θ is the angle of inclination from the vertical and use vertical plate constants.

EXAMPLE 7-1 Constant Heat Flux from Vertical Plate

In a plant location near a furnace, a net radiant energy flux of 800 W/m^2 is incident on a vertical metal surface 3.5 m high and 2 m wide. The metal is insulated on the back side and painted black so that all the incoming radiation is lost by free convection to the surrounding air at 30°C. What average temperature will be attained by the plate?

Solution

We treat this problem as one with constant heat flux on the surface. Since we do not know the surface temperature, we must make an estimate for determining T_f and the air properties. An *approximate* value of h for free-convection problems is 10 W/m^2 · °C, and so, *approximately,*

$$\Delta T = \frac{q_w}{h} \approx \frac{800}{10} = 80°\text{C}$$

Then

$$T_f \approx \frac{80}{2} + 30 = 70°\text{C} = 343\ \text{K}$$

At 70°C the properties of air are

$$\nu = 2.043 \times 10^{-5}\ \text{m}^2/\text{s} \qquad \beta = \frac{1}{T_f} = 2.92 \times 10^{-3}\ \text{K}^{-1}$$

$$k = 0.0295\ \text{W/m} \cdot °\text{C} \qquad \text{Pr} = 0.7$$

From Equation (7-30), with $x = 3.5$ m,

$$\text{Gr}_x^* = \frac{g\beta q_w x^4}{k\nu^2} = \frac{(9.8)(2.92 \times 10^{-3})(800)(3.5)^4}{(0.0295)(2.043 \times 10^{-5})^2} = 2.79 \times 10^{14}$$

We may therefore use Equation (7-32) to evaluate h_x:

$$\begin{aligned} h_x &= \frac{k}{x}(0.17)(\text{Gr}_x^*\,\text{Pr})^{1/4} \\ &= \frac{0.0295}{3.5}(0.17)(2.79 \times 10^{14} \times 0.7)^{1/4} \\ &= 5.36\ \text{W/m}^2 \cdot °\text{C}\ [0.944\ \text{Btu/h} \cdot \text{ft}^2 \cdot °\text{F}] \end{aligned}$$

In the turbulent heat transfer governed by Equation (7-32), we note that

$$\text{Nu}_x = \frac{hx}{k} \sim (\text{Gr}_x^*)^{1/4} \sim (x^4)^{1/4}$$

or h_x does not vary with x, and we may take this as the average value. The value of $h = 5.41$ W/m^2 · °C is less than the approximate value we used to estimate T_f. Recalculating ΔT, we obtain

$$\Delta T = \frac{q_w}{h} = \frac{800}{5.36} = 149°\text{C}$$

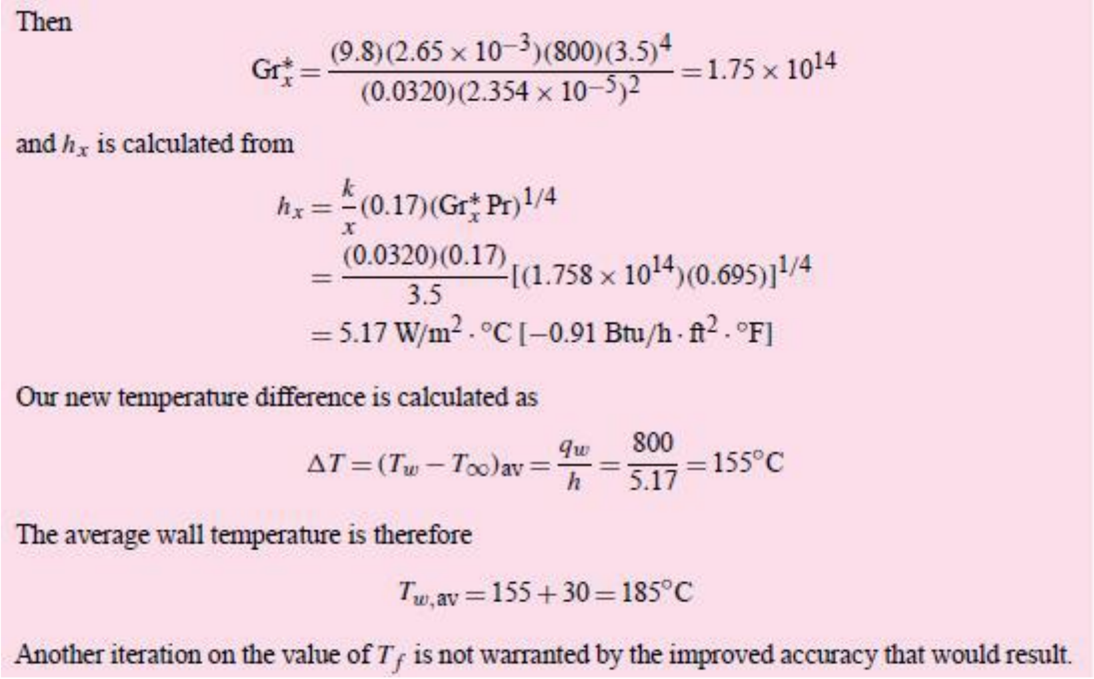
Our new film temperature would be

$$T_f = 30 + \frac{149}{2} = 104.5°\text{C}$$

At 104.5°C the properties of air are

$$\nu = 2.354 \times 10^{-5}\ \text{m}^2/\text{s} \qquad \beta = \frac{1}{T_f} = 2.65 \times 10^{-3}/\text{K}$$

$$k = 0.0320\ \text{W/m} \cdot °\text{C} \qquad \text{Pr} = 0.695$$



Then

$$\mathrm{Gr}_x^* = \frac{(9.8)(2.65\times10^{-3})(800)(3.5)^4}{(0.0320)(2.354\times10^{-5})^2} = 1.75\times10^{14}$$

and h_x is calculated from

$$h_x = \frac{k}{x}(0.17)(\mathrm{Gr}_x^*\,\mathrm{Pr})^{1/4}$$
$$= \frac{(0.0320)(0.17)}{3.5}[(1.758\times10^{14})(0.695)]^{1/4}$$
$$= 5.17\ \mathrm{W/m^2\cdot {}^\circ C}\ [-0.91\ \mathrm{Btu/h\cdot ft^2\cdot {}^\circ F}]$$

Our new temperature difference is calculated as

$$\Delta T = (T_w - T_\infty)_{\mathrm{av}} = \frac{q_w}{h} = \frac{800}{5.17} = 155^\circ\mathrm{C}$$

The average wall temperature is therefore

$$T_{w,\mathrm{av}} = 155 + 30 = 185^\circ\mathrm{C}$$

Another iteration on the value of T_f is not warranted by the improved accuracy that would result.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=CA3GnfImGmw
https://www.youtube.com/watch?v=BRkf-bi6_zM&list=PLajYbKcP5kMrwzHq5Z3dUjbRXt-bc3PAt
https://www.youtube.com/watch?v=yoUxqeAN0So

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LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **16MED13 Heat and Mass Transfer**

Course Teacher : **Mr.R.Ramesh.**

Unit : **II - Convection**

Date of Lecture:

Topic of Lecture: Cylinders and Spheres.

Introduction : The convection resistance remains the same in both cylindrical and spherical coordinates,
Rconv = 1/hA. However, note that the surface area *A = 2πrL* (cylindrical) and *A = 4πr2*
(spherical) are functions of radius.

Prerequisite knowledge for Complete understanding and learning of Topic:
To insulate a plane wall, the thicker the insulator, the lower the heat transfer rate (since the area is constant). However, for cylindrical pipes or spherical shells, adding insulation results in increasing the surface area which in turns results in increasing the convection heat transfer. As a result of these two competing trends the heat transfer may increase or decrease.

Detailed content of the Lecture:

8.6.3. HORIZONTAL CYLINDERS

For such a case, the *outside diameter is used as the characteristic dimension.*

Mc Adams has recommended the following correlations:

$$\text{Laminar flow: } \overline{Nu} = 0.53\,(Gr\,.\,Pr)^{1/4} \quad \text{for } (10^4\ Gr\,.\,Pr < 10^9) \qquad ...(8.45)$$

$$\text{Turbulent flow: } \overline{Nu} = 0.13\,(Gr\,.\,Pr)^{1/3} \quad \text{for } (10^9 < Gr\,.\,Pr < 10^{12}) \qquad ...(8.46)$$

The following general correlation has been suggested by Churchill and Chu for use over a wide range of $Gr\,.\,Pr$.

$$\overline{Nu} = \left[0.60 + \frac{0.387\,(Gr\,.\,Pr)^{1/6}}{\left\{1 + (0.559/Pr)^{9/16}\right\}^{8/27}}\right] \quad \text{for } (10^{-5} < Gr\,.\,Pr < 10^{12}) \quad ...(8.47)$$

The fluid properties, in all preceding equations, are determined at the mean film temperature

$$t_f = \left(\frac{t_s + t_\infty}{2}\right).$$

8.6.5. SPHERES

Yuge (1959) has recommended the following correlation for free convection from a sphere of diameter D :

$$\overline{Nu} = 2 + 0.43\,(Gr\,.\,Pr)^{1/4}$$

$$\text{for } (1 < Gr\,.\,Pr < 10^5) \text{ and } Pr = 1) \qquad ...(8.48)$$

8.6.7. CONCENTRIC CYLINDERS SPACES

Raithby and Hollands have recommended the following correlations for *long horizontal concentric cylinders*:

$$\frac{k_e}{k} = 0.386 \left(\frac{Pr}{0.861 + Pr} \right)^{1/4} (Ra_c)^{1/4}$$

$$\text{for } 10^2 \le Ra_c \le 10^7 \qquad \ldots(8.54)$$

where, $Ra_c = (Gr \,.\, Pr)_c = \dfrac{[\ln (D_o / D_i)]^4}{L^3 \left[D_i^{-3/5} + D_o^{-3/5} \right]} Ra_L$

and k_e is related as

$$Q = \frac{2\pi \, k_e}{\ln \, (D_o / D_i)} (t_i - t_o)$$

8.6.8. CONCENTRIC SPHERES SPACES

Refer Fig. 8.3. Raithby and Hollands have recommended the following correlations:

Fig. 8
cyli

$$Q = k_e \, \pi \, (D_i \, D_o / L) \, (t_i - t_o) \qquad \ldots(8.55)$$

and, k_e is expressed as

$$\frac{k_e}{k} = 0.74 \left[\frac{Pr}{0.861 + Pr} \right]^{1/4} (Ra_s)^{1/4}$$

where, $Ra_s = (Gr \,.\, Pr)_s = \left[\dfrac{L \, Ra_L}{(D_o \, D_i)^4 \, (D_1^{-7/15} + D_o^{-7/15})^5} \right]^{1/4}$

The above equations are valid for $(10^2 \le Ra_s \le 10^4)$.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=CA3GnfImGmw
https://www.youtube.com/watch?v=BRkf-bi6_zM&list=PLajYbKcP5kMrwzHq5Z3dUjbRXt-bc3PAt
https://www.youtube.com/watch?v=yoUxqeAN0So

Important Books/Journals for further learning including the page nos.:

- **Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010**

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III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : Nusselts theory of condensation

Introduction:

Condensation is a rather complicated process. It was Wilhelm Nusselt's idea to reduce the complexity of the real process to a rather simple model, namely that the only resistance for the removal of the heat released during condensation occurs in the condensate film.

Prerequisite knowledge for Complete understanding and learning of Topic:

Condensation and Boiling, Condensation-Film wise and Drop wise

Detailed content of the Lecture:

Condensation is a rather complicated process. It was Wilhelm Nusselt's idea to reduce the complexity of the real process to a rather simple model,namely that the only resistance for the removal of the heat released during condensation occurs in the condensate film. The following gives an explanation of the Nusselt theory at the example of condensation on avertical wall. Condensation occurs if a vapor is cooled below its (pressure dependent) saturation temperature. The heat of evaporation which is released during condensation must be removed by heat transfer, e.g. at a cooled wall. Figure shows how saturated vapor at temperature Ts is condensing on a vertical wall whose temperature Tw is constant and lower than the saturation temperature.

Condensation and Boiling

Heat energy is being converted into electrical energy with the help of water as a working fluid. Water is first converted into steam when heated in a heat exchanger and then the exhaust steam coming out of the steam turbine/engine is condensed in a condenser so that the condensate (water) is recycled again for power generation. Therefore, the condensation and boiling processes involve heat transfer with change of phase. When a fluid changes its phase, the magnitude of its properties like density, viscosity, thermal conductivity, specific heat capacity, etc., change appreciably and the processes taking place are greatly influenced by them. Thus, the condensation and boiling processes must be well understood for an effective design of different types of heat exchangers being used in thermal and nuclear power plants, and in process cooling and heating systems.

Condensation-Filmwise and Dropwise

Condensation is the process of transition from a vapour to the liquid or solid state. The process is accompanied by liberation of heat energy due to the change 10 phase. When a vapour comes 10 contact with a surface maintained at a temperature lower than the saturation temperature of the vapour corresponding to the pressure at which it exists, the vapour condenses on the surface and the heat energy thus released has to be removed. The efficiency of the condensing unit is determined by the mode of condensation that takes place:

Filmwise - the condensing vapour forms a continuous film covering the entire surface,

Dropwise - the vapour condenses into small liquid droplets of various sizes. The dropwise condensation has a much higher rate of heat transfer than filmwise condensation because the condensate in dropwise condensation gets removed at a faster rate leading to better heat transfer between the vapour and the bare surface. .

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:
Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3- PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : pool boiling, flow boiling

Introduction:

Pool boiling occurs only when the temperature of the heated surface exceeds the saturation temperature of the liquid. The liquid above the hot surface I s quiescent and its motion n ear the surface is due to free convection.

Prerequisite knowledge for Complete understanding and learning of Topic:

Pool boiling, Nucleate Pool Boiling, film boiling, Critical Heat Flux and Burnout Point

Detailed content of the Lecture:

REGIMES OF POOL BOILING AND FLOW BOILING ;

Regimes of Boiling

Let us consider a heating surface (a wire or a flat plate) submerged In a pool of water which is at its saturation temperature. If the temperature of the heated surface exceeds the temperature of the liquid, heat energy will be transferred from the solid surface to the liquid.

(i) Pool Boiling - Pool boiling occurs only when the temperature of the heated surface exceeds the saturation temperature of the liquid. The liquid above the hot surface I s quiescent and its motion n ear the surface is due to free convection.

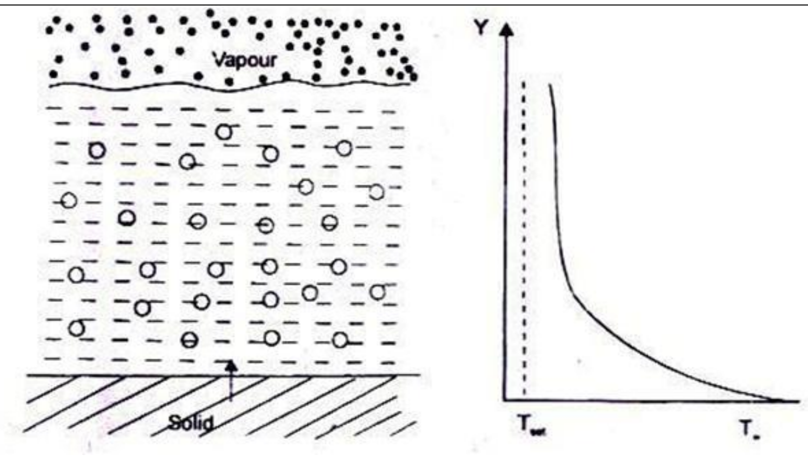

Fig. 1 Temperature distribution in pool boiling at liquid-vapour interface

Bubbles grow at the heated surface, get detached and move upward toward the free surface due to buoyancy effect. If the temperature of the liquid is lower than the saturation temperature, the process is called 'sub cooled or local boiling'. If the temperature of the liquid is equal to the saturation temperature, the process is known as 'saturated or bulk boiling'. The ($T_W – T_S$) increases beyond the

Temperature distribution in saturated pool boiling is shown in Fig.1. When T_W exceeds T_S by a few degrees, the convection currents circulate in the superheated liquid and the evaporation takes place at the free surface of the liquid.

(ii) Nucleate Pool Boiling - T_W increases a little more, vapour bubbles are formed at a number of favored spots on the heating surface. The vapour bubbles are initially small and condense before they reach the free surface. When the temperature is raised further, their number increases and they grow bigger and finally rise to the free surface. This phenomenon is called 'nucleate boiling'. It can be seen from the figure, that in nucleate boiling regime, the heat flux increases rapidly with increasing surface temperature. In the latter part of the nucleate boiling, (regime 3), heat transfer by evaporation is more important and predominating. The point A on the curve represents 'critical heat flux'.

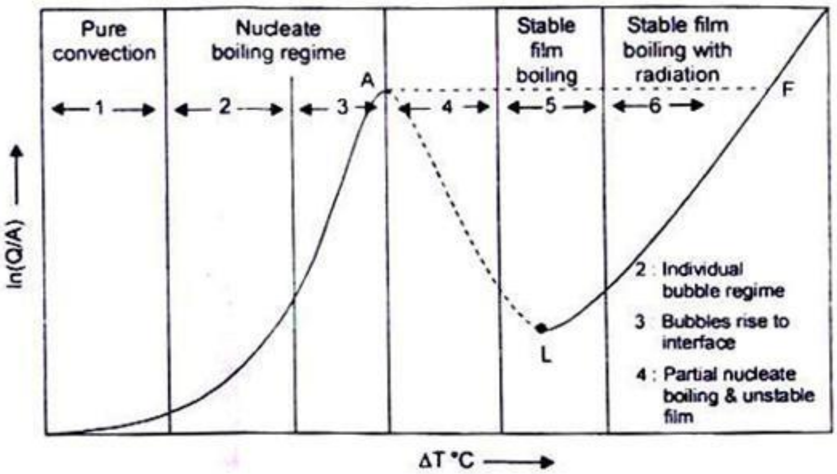

Fig.2 Heat Flux - Temperature difference curve for boiling water heated by a wire (Nukiyama's boiling curve for saturated water at atmospheric pressure)

(L is the Laidenfrost Point)

(iii) Film Bolling - point A, a vapour film forms and covers the entire heating surface. The heat transfer takes place through the vapour which is a poor conductor and this increased thermal resistance causes a drop in the heat flux. This phase is film boiling'. The transition from the nucleate boiling regime to the film boiling regime is not a sharp one and the vapour film under the action of circulating currents collapses and rapidly reforms. In regime 5, the film is stable and the heat flow rate is the lowest.

(iv) Critical Heat Flux and Burnout Point - temperature of the heating metallic surface is very high and the heat transfer occurs predominantly by radiation, thereby, increasing the heat flux. And finally, a point is reached at which the heating surface melts - point F in Fig.2. It can be observed from the boiling curve that the whole boiling process remains in the unstable state between A and F. Any increase in the heat flux beyond point A will cause a departure from the boiling curve and there would be a large increase in surface temperature.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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III/V

Course Name with Code : **HEAT & MASS TRANSFER &16 MED13**

Course Faculty : **Mr.R.Ramesh**

Unit : **3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS**
Date of Lecture :

Topic of Lecture : Correlations in boiling and condensation.

Introduction:

Pool boiling occurs only when the temperature of the heated surface exceeds the saturation temperature of the liquid. The liquid above the hot surface I s quiescent and its motion n ear the surface is due to free convection.

Prerequisite knowledge for Complete understanding and learning of Topic:

Pool boiling, Nucleate Pool Boiling, film boiling

Detailed content of the Lecture:

Condensation-Film wise and Drop wise

Condensation is the process of transition from a vapour to the liquid or solid state. The process is accompanied by liberation of heat energy due to the change 10 phase. When a vapour comes 10 contacts with a surface maintained at a temperature lower than the saturation temperature of the vapour corresponding to the pressure at which it exists, the vapour condenses on the surface and the heat energy thus released has to be removed. The efficiency of the condensing unit is determined by the mode of condensation that takes place:

An Expression for the Liquid Film Thickness and the Heat Transfer Coefficient Laminar Film wise Condensation on a Vertical Plate

liquid, Ii is the thickness of the liquid film at any x, and du/dy is the velocity gradient at x.

And the mass flow rate of condensate through any x position of the film would be

The rate of heat transfer at the wall in the area dx is, for unit width,

Since the thickness of the film increases in the positive X-direction, an additional mass of vapour will condense between x and x + dx, i.e.,

$$\frac{d}{dx}\left(\frac{\rho(\rho-\rho_v)g\delta^3}{3\mu}\right)dx = \frac{d}{d\delta}\left(\frac{\rho(\rho-\rho_v)g\delta^3}{3\mu}\right)\frac{d\delta}{dx}dx$$

$$= \frac{\rho(\rho-\rho_v)g\delta^2 d\delta}{\mu}$$

This additional mass of condensing vapour will release heat energy and that has to removed by conduction through the wall, or,

$$\therefore \quad \frac{\rho(\rho-\rho_v)g\delta^2 d\delta}{\mu}\times h_{fg} = k\,dx\left(T_g-T_s\right)/\,\delta \qquad (1)$$

We can, therefore, determine the thickness, δ, of the liquid film by integrating Eq.

We can, therefore, determine the thickness, δ, of the liquid film by integrating Eq. (11.4) with the boundary condition: at x = 0, δ = 0,

$$\text{or,} \quad \delta = \left(\frac{4\mu kx\left(T_g-T_s\right)}{gh_{fg}\,\rho(\rho-\rho_v)}\right)^{0.25} \qquad (2)$$

The rate of heat transfer is also related by the relation,

$$h\,dx\left(T_g-T_s\right) = k\,dx\left(T_g-T_s\right)/\,\delta;\ \text{or, } h = k/\delta$$

which can be expressed In dimensionless form in terms of Nusselt number,

$$Nu = hx/k = \left[\frac{\rho(\rho-\rho_v)gh_{fg}x^3}{4\mu k\left(T_g-T_s\right)}\right]^{0.25} \qquad (3)$$

The average value of the heat transfer coefficient is obtained by integrating over the length of the plate:

$$\bar{h} = (1/L)\int_0^L h_x\,dx = (4/3)h_x = L$$

$$Nu_L = 0.943\left[\frac{\rho(\rho-\rho_v)gh_{fg}L^3}{k\mu\left(T_g-T_s\right)}\right]^{0.25} \qquad (4)$$

The properties of the liquid in Eq. (5.50) and Eq. (5.49) should be evaluated at the mean temperature, T = $(T_g + T_s)/2$.

Thus:

Local $$Nu_x = 0.707\left[\frac{\rho(\rho-\rho_v)h_{fg}x^3 g\sin\theta}{\mu k\left(T_g-T_s\right)}\right]^{0.25}$$

and the average $$Nu_L = 0.943\left[\frac{\rho(\rho-\rho_v)h_{fg}L^3 g\sin\theta}{\mu k(T_g - T_s)}\right] \qquad (5)$$

zero, (a horizontal surface) we would get an absurd result. But these equations are valid for condensation on the outside surface of vertical tubes as long as the curvature of the tube surface is not too great.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

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III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : Types of Heat Exchangers

Introduction:

A heat exchanger is equipment where heat energy is transferred from a hot fluid to a colder fluid. The transfer of heat energy between the two fluids could be carried out (i) either by direct mixing of the two fluids and the mixed fluids leave at an intermediate temperature determined from the principles of conservation of energy, (ii) or by transmission through a wall separating the two fluids.

Prerequisite knowledge for Complete understanding and learning of Topic:

Parallel Flow and Counter Flow Heat exchangers, Cross-flow Heat exchangers, Compact Heat Exchangers and Condenser and Evaporator

Detailed content of the Lecture:

Classification of Heat Exchangers

Heat exchangers are generally classified according to the relative directions of hot and cold fluids:

(a) Parallel Flow – the hot and cold fluids flow in the same direction. Fig 1 depicts such a heat exchanger where one fluid (say hot) flows through the pipe and the other fluid (cold) flows through the annulus.

(b) Counter Flow – the two fluids flow through the pipe but in opposite directions. A common type of such a heat exchanger is shown in Fig. 2. By comparing the temperature distribution of the two types of heat exchanger.

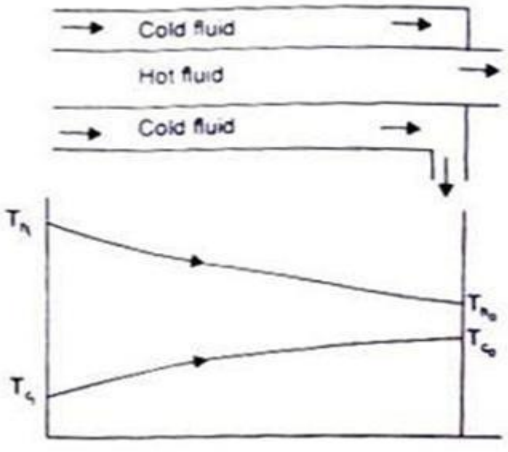

Fig 1 Parallel flow heat exchanger with temperature distribution

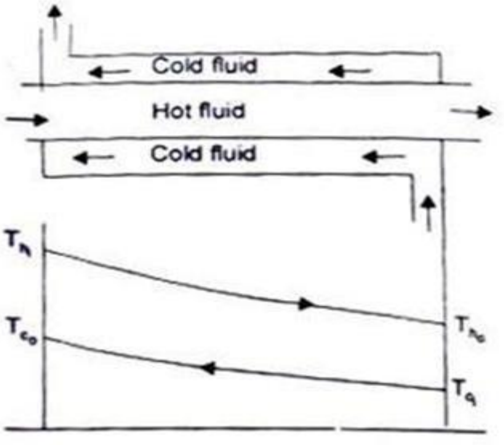

Fig 2 Counter-flow heat exchanger with temperature distribution

When the two fluids flow through the heat exchanger only once, it is called one-shell-pass and one-tube-pass as shown in Fig. 1 and 2. If the fluid flowing through the tube makes one pass through half of the tube, reverses its direction of flow, and makes a second pass through the remaining half of the tube, it is called 'one-shell-pass, two-tube-pass' heat exchanger, fig 3. Many other possible flow arrangements exist and are being used. Fig. 4 depicts a 'two-shell-pass, four-tube-pass' exchanger.

(c) Cross-flow - A cross-flow heat exchanger has the two fluid streams flowing at right angles to each other. Fig. 4. illustrates such an arrangement An automobile radiator is a good example of cross-flow exchanger. These exchangers are 'mixed' or 'unmixed' depending upon the mixing or not mixing of either fluid in the direction transverse to the direction of the flow stream and the analysis of this type of heat exchanger is extremely complex because of the variation in the temperature of the fluid in and normal to the direction of flow.

(d) Condenser and Evaporator - In a condenser, the condensing fluid temperature remains almost constant throughout the exchanger and temperature of the colder fluid gradually increases from the inlet to the exit. In an evaporator, the temperature of the hot fluid gradually decreases from the inlet to the outlet whereas the temperature of the colder fluid remains the same during the evaporation process. Since the temperature of one of the fluids can be treated as constant, it is immaterial whether the exchanger is parallel flow or counter flow.

(e) Compact Heat Exchangers - these devices have close arrays of finned tubes or plates and are typically used when atleast one of the fluids is a gas in fig 5. The tubes are either flat or circular as shown in Fig. 10.8 and the fins may be flat or circular. Such heat exchangers are used to a chieve a very large (≥ 700 m^2/mJ) heat transfer surface area per unit volume. Flow passages are typically small and the flow is usually laminar.

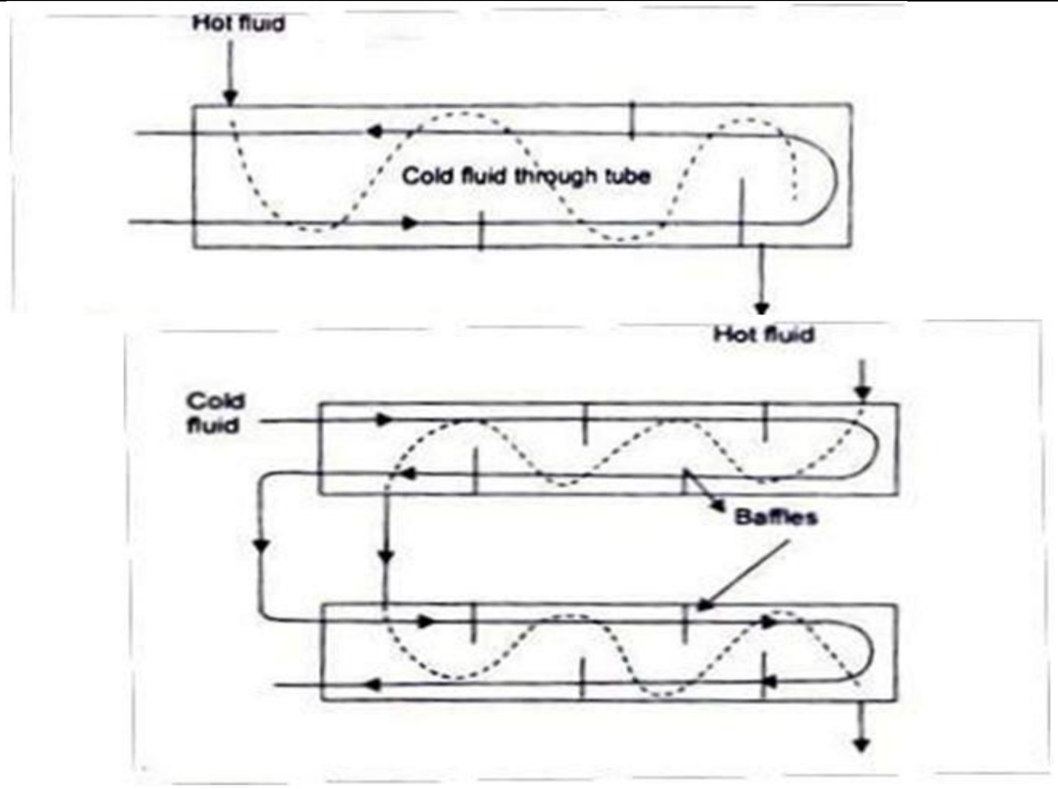

Fig 3 Two shell passes, four-tube passes heat exchanger (baffles increases the convection coefficient of the shell side fluid by inducing turbulance and a cross flow velocity component)

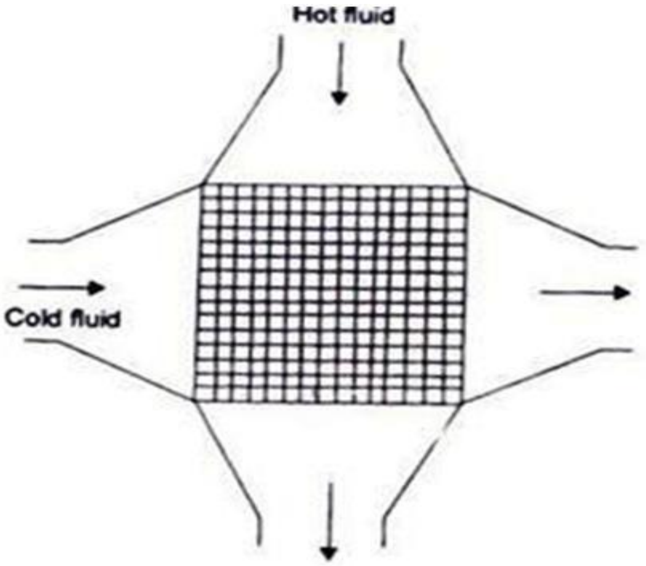

Fig 4 A cross-flow exchanger

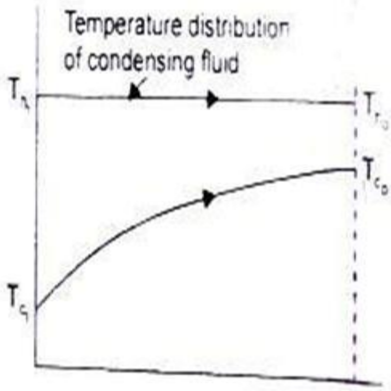

Fig. 10.7 (a) A condenser

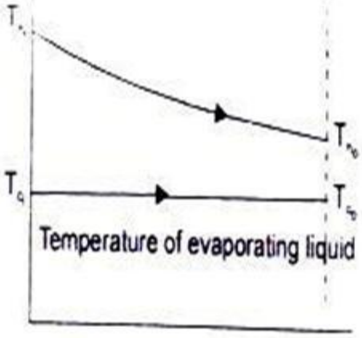

Fig. 10.7 (b) An evaporator

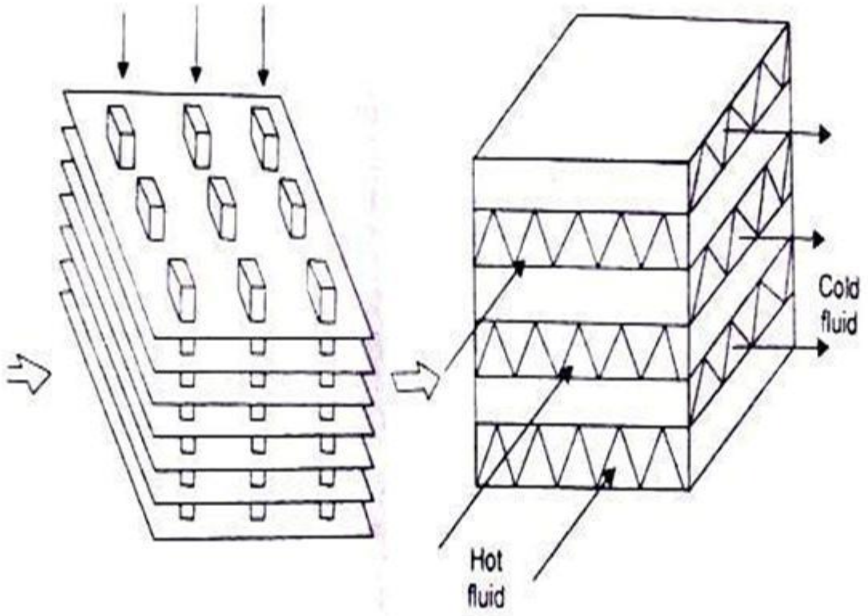

Fig. 5 Compact heat exchangers: (a) flat tubes, continuous plate fins, (b) plate fin (single pass)

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.: Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

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MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : LMTD Method of heat Exchanger Analysis

Introduction:

LMTD for a counter flow exchanger will be higher than for a given rate of mass flow of the two fluids and for given temperature changes, a counter flow exchanger will require less surface area

Prerequisite knowledge for Complete understanding and learning of Topic:

(i) Temperature distributions for a heat exchanger (condenser) where the hot fluid has a much larger heat capacity rate, $dT_h = -dQ/ C_h$

(ii) In a counter flow exchanger, when the heat capacity rate of uoth the fluids are equal,

Detailed content of the Lecture:

LMTD METHOD :

Expression for Log Mean Temperature Difference - Its Characteristics

Fig. 1 represents a typical temperature distribution which is obtained in heat exchangers. The rate of heat transfer through any short section of heat exchanger tube of surface area dA is: dQ = U dA(T_h – T_c cools and the cold fluid is heated in the direction of increasing area. therefore, we may write,

$dQ = -m_h\ c_h\ dT_h = m_c\ c_c\ dT_c$ and $dQ = -C_h\ dT_h = C_c\ dT_c$ where $C = m \times c$, and is called the 'heat capacity rate.'

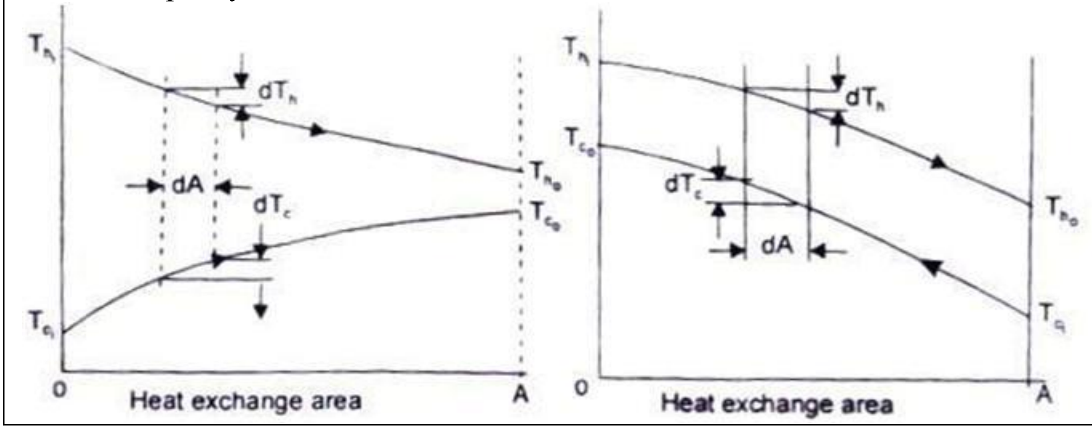

Fig. 1 Parallel flow and Counter flow heat exchangers and the temperature distribution with length,

Integrating equations (1.1) and (1.2) between the inlet and outlet. and assuming that the specific heats are constant, we get,

$$-(1/C_h \pm 1/C_c)Q = \Delta T_o - \Delta T_i \qquad (1.1)$$

The positive sign refers to parallel flow exchanger, and the negative sign to the counter flow type. Also, substituting for dQ in equations (1.1) and (1.2) we get

$$-(1/C_h \pm 1/C_c)UdA = d(\Delta T)/\Delta T \qquad (1.2)$$

Upon integration between inlet i and outlet 0 and assuming U as a constant,

We have $-(1/C_h \pm 1/C_c)U\,A = \ln(\Delta T_0/\Delta T_i)$

By dividing (1.3) by (1.4), we get

$$Q = UA\lceil(\Delta T_o - \Delta T_i)/\ln(\Delta T_o/\Delta T_i)\rceil \qquad (1.3)$$

Thus the mean temperature difference is written as

Log Mean Temperature Difference,

$$LMTD = (\Delta T_0 - \Delta T_i)/\ln(\Delta T_o/\Delta T_i) \qquad (1.4)$$

(The assumption that U is constant along the heat exchanger is never strictly true but it may be a good approximation if at least one of the fluids is a gas. For a gas, the physical properties do not vary appreciably over moderate range of temperature and the resistance of the gas film is considerably higher than that of the metal wall or the liquid film, and the value of the gas film resistance effectively determines the value of the overall heat transfer coefficient U.)

It is evident from Fig.1 shows that for parallel flow exchangers, the final temperature of fluids lies between the initial values of each fluid whereas m counter flow exchanger, the temperature of the colder fluid at exit is higher than the temperature of the hot fluid at exit. Therefore, a counter flow exchanger provides a greater temperature range, and the LMTD for a counter flow exchanger will be higher than for a given rate of mass flow of the two fluids and for given temperature changes, a counter flow exchanger will require less surface area.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 24

MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 -PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : Effectiveness of Heat Exchanger Analysis

Introduction:

For any heat exchanger, we can write: $\in = f\left(NTU, C_{min} / C_{max}\right)$. In order to determine a specific form of the effectiveness-NTU relation, let us consider a parallel flow heat exchanger for which $C_{min} = C_h$

Prerequisite knowledge for Complete understanding and learning of Topic:

(i) Temperature distributions for a heat exchanger (condenser) where the hot fluid has a much larger heat capacity rate, $dT_h = -dQ / C_h$

(ii) In a effectiveness of exchanger, when the heat capacity rate of both the fluids are equal,

Detailed content of the Lecture:

Effectiveness

For any heat exchanger, we can write: $\in = f\left(NTU, C_{min} / C_{max}\right)$. In order to determine a specific form of the effectiveness-NTU relation, let us consider a parallel flow heat exchanger for which $C_{min} = C_h$. From the definition of effectiveness , we get

$$\varepsilon = \left(T_{hi} - T_{h0}\right) / \left(T_{hi} - T_{ci}\right)$$

and, $C_{min} / C_{max} = C_h / C_c = \left(T_{c0} - T_{ci}\right) / \left(T_{hi} - T_{h0}\right)$ for a parallel flow heat exchanger, from Equation 10.4,

$$\ln\left(T_{h0} - T_{c0}\right) / \left(T_{hi} - T_{ci}\right) = -UA\left(1/C_h + 1/C_c\right) = \frac{-UA}{C_{min}}\left(1 + C_{min}/C_{max}\right)$$

or, $$\left(T_{h0} - T_{c0}\right) / \left(T_{hi} - T_{ci}\right) = \exp\left[-NTU\left(1 + C_{min}/C_{max}\right)\right]$$

But, $(T_{h0} - T_{c0})/(T_{hi} - T_{ci}) = (T_{h0} - T_{hi} + T_{hi} - T_{c0})/(T_{hi} - T_{ci})$

$$= \left[(T_{h0} - T_{hi}) + (T_{hi} - T_{ci}) - R\{(T_{hi} - T_{h0})\}\right]/(T_{hi} - T_{ci})$$

$$= \epsilon + 1 - R\,\epsilon = 1 - \epsilon(1 + R)$$

Therefore, $\epsilon = \left[1 - \exp\{-NTU(1 + R)\}\right]/(1 + R)$

$$NTU = -\ln\left[1 - \epsilon(1 + R)\right]/(1 + R)$$

Similarly, for a counter flow exchanger, $\varepsilon = \dfrac{\left[1 - \exp\{-NTU(1 - R)\}\right]}{\left[1 - R\exp\{-NTU(1 - R)\}\right]}$;

and, $NTU = \left[1/(R - 1)\right]\ln\left[(\epsilon - 1)/(\epsilon R - 1)\right]$

$$\epsilon = \frac{1 - \exp\left[-N(1 - R)\right]}{1 - R\exp\left[-N(1 - R)\right]};\ R < 1$$

$$\epsilon = N/(1 + N) \text{ for } R = 1$$

Kays and London have presented graphs of effectiveness against NTU for Various values of R applicable to different heat exchanger arrangements,.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 25

MECH

III/V

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : NTU method of Heat Exchanger Analysis

Introduction:

An useful parameter which also measures the efficiency of the heat exchanger is the 'Number of Transfer Units', NTU, defined as

NTU = Temperature change of one fluid/LMTD.

Prerequisite knowledge for Complete understanding and learning of Topic:

NTU = Number of Transfer Units.

Detailed content of the Lecture:

NTU METHOD:

Heat Exchangers Effectiveness - Useful Parameters

In the design of heat exchangers, the efficiency of the heat transfer process is very important. The method suggested by Nusselt and developed by Kays and London is now being extensively used. The effectiveness of a heat exchanger is defined as the ratio of the actual heat transferred to the maximum possible heat transfer.

It can be seen that the fluid with smaller thermal capacity, C, has the greater temperature change. Further, the maximum temperature change of any fluid would be

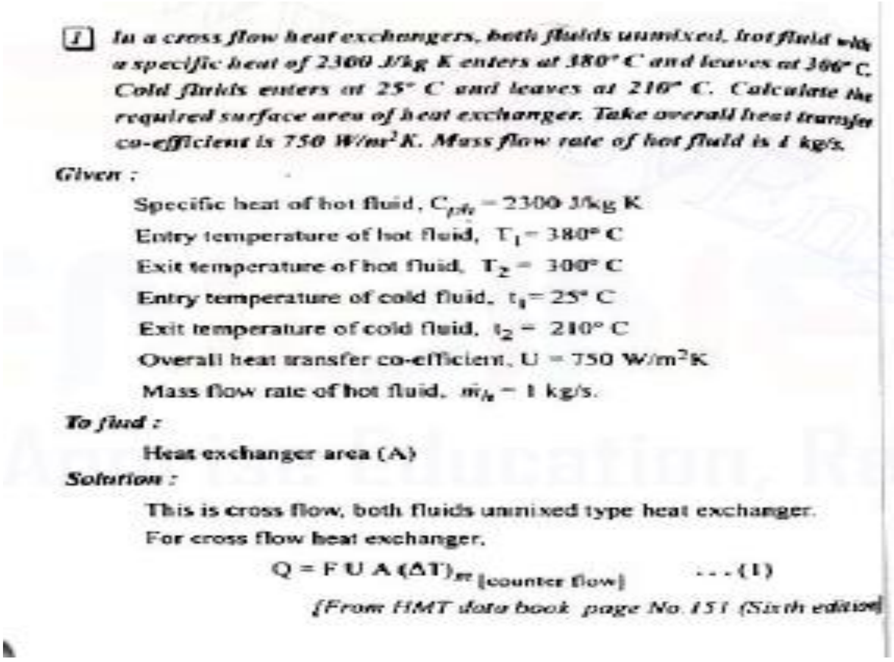
Or, the effectiveness compares the actual heat transfer rate to the maximum heat transfer rate whose only limit is the second law of thermodynamics. An useful parameter which also measures the efficiency of the heat exchanger is the 'Number of Transfer Units', NTU, defined as

NTU = Temperature change of one fluid/LMTD.

where R may vary between I (when both fluids have the same thermal capacity) and 0 (one of the fluids has infinite thermal capacity, e.g., a condensing vapour or a boiling liquid).

NTU Relations

For any heat exchanger, we can write: $\in = f\left(NTU, C_{min} / C_{max}\right)$. In order to determine a specific form of the effectiveness-NTU relation, let us consider a parallel flow heat exchanger for which $C_{min} = C_h$. From the definition of effectiveness (equation 10.14), we get



1 *In a cross flow heat exchangers, both fluids unmixed, hot fluid with a specific heat of 2300 J/kg K enters at 380° C and leaves at 300° C. Cold fluids enters at 25° C and leaves at 210° C. Calculate the required surface area of heat exchanger. Take overall heat transfer co-efficient is 750 W/m²K. Mass flow rate of hot fluid is 1 kg/s.*

Given :

Specific heat of hot fluid, $C_{ph} = 2300$ J/kg K

Entry temperature of hot fluid, $T_1 = 380°$ C

Exit temperature of hot fluid, $T_2 = 300°$ C

Entry temperature of cold fluid, $t_1 = 25°$ C

Exit temperature of cold fluid, $t_2 = 210°$ C

Overall heat transfer co-efficient, $U = 750$ W/m²K

Mass flow rate of hot fluid, $\dot{m}_h = 1$ kg/s.

To find :

Heat exchanger area (A)

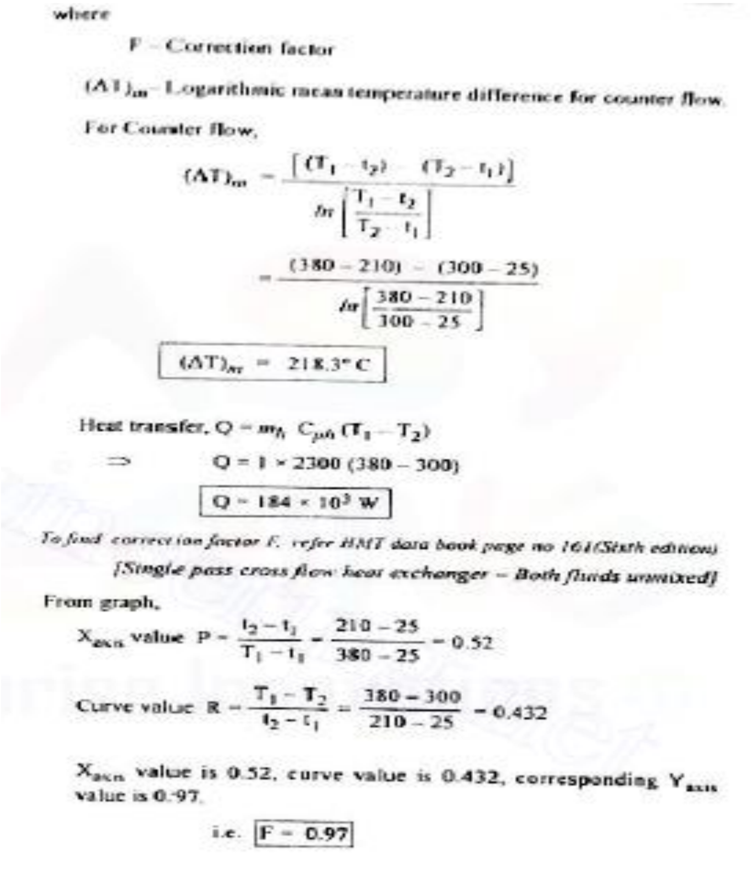
Solution :

This is cross flow, both fluids unmixed type heat exchanger.

For cross flow heat exchanger,

$$Q = F\,U\,A\,(\Delta T)_{m\ [\text{counter flow}]} \qquad \ldots (1)$$

[From HMT data book page No. 151 (Sixth edition)



where

F – Correction factor

$(\Delta T)_m$ – Logarithmic mean temperature difference for counter flow.

For Counter flow,

$$(\Delta T)_m = \frac{[(T_1 - t_2) - (T_2 - t_1)]}{ln\left[\frac{T_1 - t_2}{T_2 - t_1}\right]}$$

$$= \frac{(380 - 210) - (300 - 25)}{ln\left[\frac{380 - 210}{300 - 25}\right]}$$

$$\boxed{(\Delta T)_m = 218.3° C}$$

Heat transfer, $Q = m_h\ C_{ph}\ (T_1 - T_2)$

$$\Rightarrow \qquad Q = 1 \times 2300\ (380 - 300)$$

$$\boxed{Q = 184 \times 10^3\ W}$$

To find correction factor F, refer HMT data book page no 161(Sixth edition)

[Single pass cross flow heat exchanger – Both fluids unmixed]

From graph,

$$X_{axis} \text{ value } P = \frac{t_2 - t_1}{T_1 - t_1} = \frac{210 - 25}{380 - 25} = 0.52$$

$$\text{Curve value } R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{380 - 300}{210 - 25} = 0.432$$

X_{axis} value is 0.52, curve value is 0.432, corresponding Y_{axis} value is 0.97.

i.e. $\boxed{F = 0.97}$

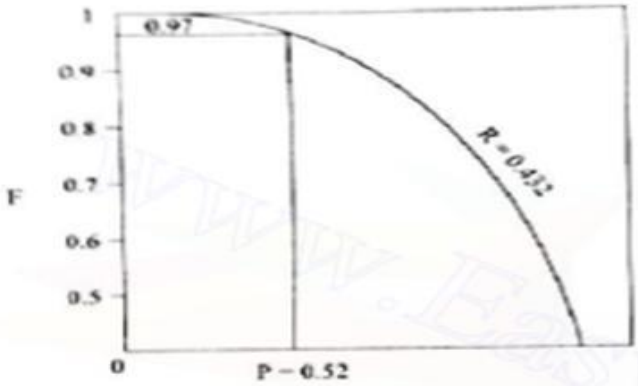


Fig. 3.15

Substitute Q, F, $(\Delta T)_m$ and U value in Equn (1)

$$(1) \Rightarrow \quad Q = F\,U\,A\,(\Delta T)_m$$

$$184 \times 10^3 = 0.97 \times 750 \times A \times 218.3$$

$$\Rightarrow \quad \boxed{A = 1.15\ m^2}$$

Result :

Surface area, $A = 1.15\ m^2$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:
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MECH

III/V

Course Name with Code : **HEAT & MASS TRANSFER &16 MED13**

Course Faculty : **Mr.R.Ramesh**

Unit : **3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS**
Date of Lecture :

Topic of Lecture : Overall Heat Transfer Coefficient – Fouling Factors

Introduction:

The determination of the overall heat transfer coefficient is an essential, and often the most uncertain, part of any heat exchanger analysis. The deposition of a film or scale on the surface greatly increases the resistance to heat transfer between the hot and cold fluids.

Prerequisite knowledge for Complete understanding and learning of Topic:

(i) The overall heat transfer coefficient
(ii) Fouling factors analysis

Detailed content of the Lecture:

The Overall Heat Transfer Coefficient

The determination of the overall heat transfer coefficient is an essential, and often the most uncertain, part of any heat exchanger analysis. We have seen that if the two fluids are separated by a plane composite wall the overall heat transfer coefficient is given by:

$$1/U = 1/(h_i) + (L_1/k_1) + (L_2/k_2) + 1/(h_o) \qquad (3.8)$$

If the two fluids are separated by a cylindrical tube (inner radius r_i, outer radius r_0), the overall heat transfer coefficient is obtained as:

$$1/U_i = (1 + h_i) + (r_i/k)\ln(r_o/r_i) + (r_i/r_o)(1/h_o) \qquad (3.9)$$

where h_i, and h_o are the convective heat transfer coefficients at the inside and outside surfaces and V, is the overall heat transfer coefficient based on the inside surface area. Similarly, for the outer surface area, we have:

$$1/U_o = 1/(h_o) + (r_o/k)\ln(r_o/r_i) + (r_o/r_i)(1/h_i) \qquad (3.10)$$

and $U_i A_i$ will be equal to $U_o A_o$; or, $U_i r_i = U_o r_o$.

The effect of scale formation on the inside and outside surfaces of the tubes of a heat exchanger would be to introduce two additional thermal resistances to the heat flow path. If h_{si} and h_{so} are the two heat transfer coefficients due to scale formation on the inside and outside surface of the inner pipe, the rate of heat transfer is given by

$$Q = (T_i - T_o) / \left[1/(h_i A_i) + 1/(h_{si} A_i) + \ln(r_o / r_i) / 2\pi L k + 1/(h_{so} A_o) + 1/(h_o A_o) \right] \qquad (3.11)$$

where T_i, and T_o are the temperature of the fluid at the inside and outside of the tube. Thus, the overall heat transfer coeffiCIent based on the inside and outside surface area of the tube would be:

$$1/U_i = 1/h_i + 1/h_{si} + (r_i / k)\ln(r_o / r_i) + (r_i / r_o)(1/h_{so}) + (r_i / r_o)(1/h_o); \qquad (3.12)$$

and

$$1/U_o = (r_o / r_i)(1/h_i) + (r_o / r_i)(1/h_{si}) + \ln(r_o / r_i)(r_0 / k) + 1/h_{so} + 1/h_o K$$

FOULING FACTORS ANALYSIS :

Heat exchanger walls are usually made of single materials. Sometimes the walls are bimettalic (steel with aluminum cladding) or coated with a plastic as a protection against corrosion, because, during normal operation surfaces are subjected to fouling by fluid impurities, rust formation, or other reactions between the fluid and the wall material. The deposition of a film or scale on the surface greatly increases the resistance to heat transfer between the hot and cold fluids. And, a scale coefficient of heat transfer h, is defined as:

$R_s = 1/h_s A$, $^oC/W$ or K/W

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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LECTURE HANDOUTS

L 27

MECH

III/VI

Course Name with Code : HEAT & MASS TRANSFER &16 MED13

Course Faculty : Mr.R.Ramesh

Unit : 3 - PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS
Date of Lecture :

Topic of Lecture : Solved Problems

Introduction:

The determination of the overall heat transfer coefficient is an essential, and often the most uncertain, part of any heat exchanger analysis. The deposition of a film or scale on the surface greatly increases the resistance to heat transfer between the hot and cold fluids.

Prerequisite knowledge for Complete understanding and learning of Topic:

(i) The overall heat transfer coefficient
(ii) Fouling factors analysis

Detailed content of the Lecture:

Another source of heat generation in a medium is exothermic chemical reactions that may occur throughout the medium. The chemical reaction in this case serves as a *heat source* for the medium. In the case of endothermic reactions , however, heat is absorbed instead of being released during reaction, and thus the chemical reaction serves as a *heat sink.* The heat generation term becomes.

Often it is also convenient to model the absorption of radiation such as solar energy or gamma rays as heat generation when these rays penetrate deep into the body while being absorbed gradually. For example, the absorption of solar energy in large bodies of water can be treated as heat generation

The rate of heat generation in a medium may vary with time as well as position within the medium. When the variation of heat generation with position is known, the *total* rate of heat generation in a medium of volume V can be determined from In the special case of *uniform* heat generation, as in the case of electric resistance heating throughout a homogeneous material, the relation in

The fin efficiency is defined as the ratio of the energy transferred through a real fin to that transferred through an ideal fin. An ideal fin is thought to be one made of a perfect or infinite conductor material. A perfect conductor has an infinite thermal conductivity so that the entire fin is at the base material temperature

1 ***An aluminium pan of 15cm diameter is used to boil water and the water depth at the time of boiling is 2.5 cm. The pan is placed on an electric stove and the heating element raises the temperature of the pan to 110°C. Calculate the power input for boiling and the rate of evaporation. Take C_{sf} = 0.0132.***

[Dec.2005, Anna Univ]

Given :

Diameter, d = 15 cm = 0.15 m

Distance, x = 2.5 cm = 0.025 m

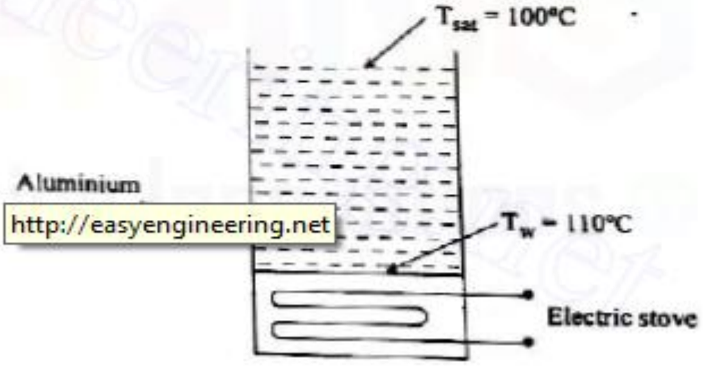
Surface temperature, T_w = 110° C.

C_{sf} = 0.0132

To find :

1. Power input, (P)
2. Rate of evaporation, ($\dot{m}$)

Solution :



Solution :

We know that,

Saturation temperature of water is 100° C.

i.e., T_{sat} = 100° C

Properties of water at 100° C.

[From HMT data book page No.21, (Sixth edition)]

Density, ρ_l = 961 kg/m^3

Kinematic viscosity, ν = 0.293 × 10^{-6} m^2/s

Prandtl Number, P_r = 1.740

Specific heat, C_{pl} = 4216 J/kg K

Dynamic viscosity, $\mu_l = \rho_l \times \nu$

$$= 961 \times 0.293 \times 10^{-6}$$

$$\mu_l = 281.57 \times 10^{-6} \text{ Ns/m}^2$$

rom Steam Table *[R.S. Khurmi Steam table, page No.4]*

At 100° C

Enthalpy of evaporation, h_{fg} = 2256.9 kJ/kg

$$h_{fg} = 2256.9 \times 10^3 \text{ J/kg}$$

Specific volume of vapour, v_g = 1.673 m^3/kg

Density of vapour, $\rho_v = \frac{1}{v_g}$

$$= \frac{1}{1.673}$$

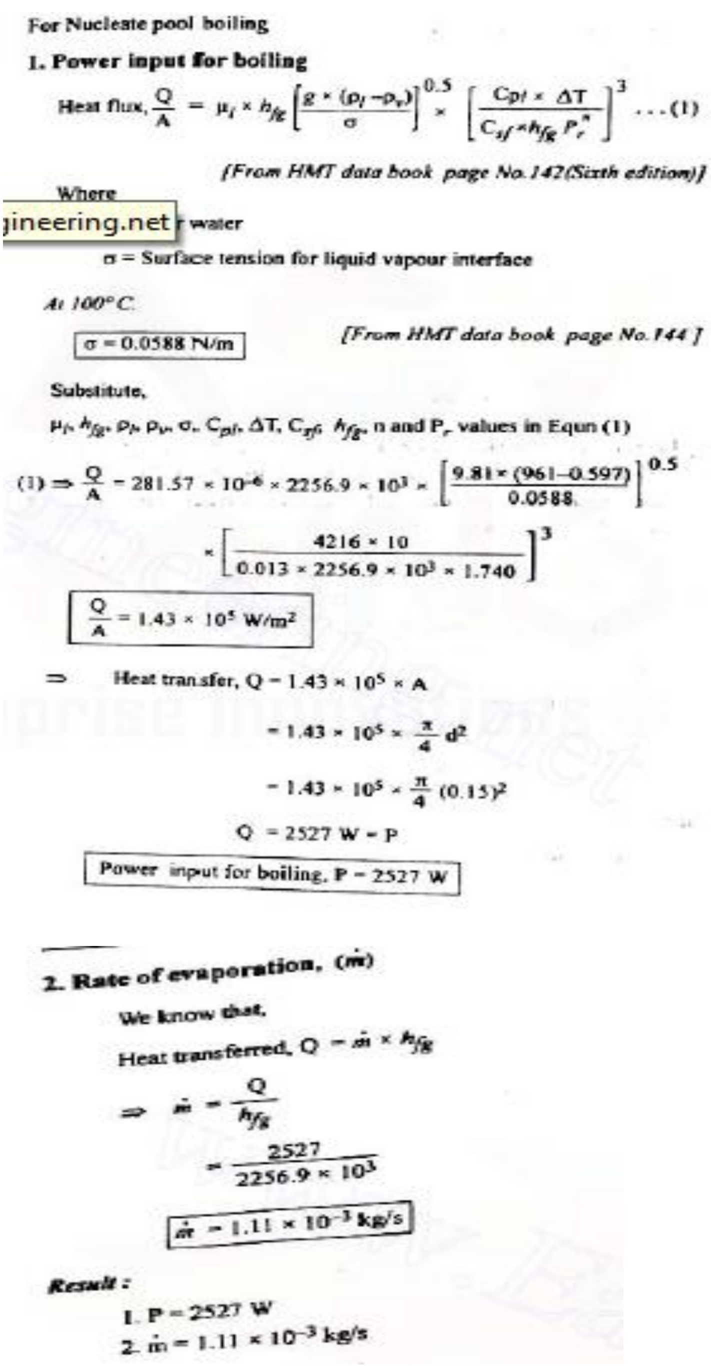
$$\boxed{\rho_v = 0.597 \text{ kg/m}^3}$$

ΔT = Excess temperature = $T_w - T_{sat}$

$$= 110°C - 100°C$$

$$\boxed{\Delta T = 10° C}$$

ΔT = 10° C < 50° C. So, this is Nucleate pool boiling.



For Nucleate pool boiling

1. Power input for boiling

$$\text{Heat flux, } \frac{Q}{A} = \mu_l \times h_{fg} \left[\frac{g \times (\rho_l - \rho_v)}{\sigma}\right]^{0.5} \times \left[\frac{Cp_l \times \Delta T}{C_{sf} \times h_{fg} \, P_r^{\,n}}\right]^3 \quad \ldots (1)$$

[From HMT data book page No.142(Sixth edition)]

Where

gineering.net r water

σ = Surface tension for liquid vapour interface

At 100° C

$\boxed{\sigma = 0.0588 \text{ N/m}}$ *[From HMT data book page No.144]*

Substitute,

μ_l, h_{fg}, ρ_l, ρ_v, σ, C_{pl}, ΔT, C_{sf}, h_{fg}, n and P_r values in Equn (1)

$$(1) \Rightarrow \frac{Q}{A} = 281.57 \times 10^{-6} \times 2256.9 \times 10^3 \times \left[\frac{9.81 \times (961 - 0.597)}{0.0588}\right]^{0.5} \times \left[\frac{4216 \times 10}{0.013 \times 2256.9 \times 10^3 \times 1.740}\right]^3$$

$$\boxed{\frac{Q}{A} = 1.43 \times 10^5 \text{ W/m}^2}$$

$$\Rightarrow \quad \text{Heat transfer, } Q = 1.43 \times 10^5 \times A$$

$$= 1.43 \times 10^5 \times \frac{\pi}{4} d^2$$

$$= 1.43 \times 10^5 \times \frac{\pi}{4} (0.15)^2$$

$$Q = 2527 \text{ W} = P$$

$$\boxed{\text{Power input for boiling, } P = 2527 \text{ W}}$$

2. Rate of evaporation, ($\dot{m}$)

We know that,

Heat transferred, $Q = \dot{m} \times h_{fg}$

$$\Rightarrow \quad \dot{m} = \frac{Q}{h_{fg}}$$

$$= \frac{2527}{2256.9 \times 10^3}$$

$$\boxed{\dot{m} = 1.11 \times 10^{-3} \text{ kg/s}}$$

Result :

1. $P = 2527$ W
2. $\dot{m} = 1.11 \times 10^{-3}$ kg/s

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=TiPzV15AIIs

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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L 28

LECTURE HANDOUTS

MECH

III/V

Course Name with Code : **16MED13 Heat and Mass Transfer**

Course Teacher : **Mr.R.Ramesh**

Unit : **4 – RADIATION** **Date of Lecture :**

Topic of Lecture: Basic Concepts, Laws of Radiation

Introduction : **Radiation** is the process by which energy is emitted as either particles or waves. Broadly, it can take the form of sound, heat, or light. However, most people generally use it to refer to **radiation** from electromagnetic waves, ranging from radio waves, though the visible light spectrum, and up through to gamma waves

Prerequisite knowledge for Complete understanding and learning of Topic:
Radiation is energy that comes from a source and travels through space at the speed of light. This energy has an electric field and a magnetic field associated with it, and has wave-like properties. You could also call **radiation** “electromagnetic waves”.

Detailed content of the Lecture:

There are four major types of radiation: alpha, beta, neutrons, and electromagnetic waves such as gamma rays. They differ in mass, energy and how deeply they penetrate people and objects.

X-rays, a form of invisible, high-energy radiation, was discovered by German physicist Wilhelm Roentgen. X-rays have been used to both diagnose and treat diseases. X-rays can penetrate through many objects, forming images covered by other objects. This is the principle on which x-ray imaging of the body for medical diagnostic purpose is based. It was later discovered that x-rays can kill cancerous cells and shrink tumors because of the high energy emission. This method of treatment is called radiation therapy.

Radiation therapy uses x-rays, gamma rays and other sources of radiation to destroy cancer cells. Radiation kills cells by breaking up molecules and causing reactions that damage living cells. Sometimes the cells are destroyed immediately; sometimes certain components of cells, such as their deoxyribonucleic acid (DNA), are damaged, thereby affecting the ability of the cell to divide.

The radiation treatment is usually given using sophisticated equipment which produces a beam of high energy x-rays. The patient lies on a bed under the machine and the beam is directed at the site of the cancer. Due to the advancement of technologies, newly developed machines are able to produce radiation beams of much greater energy while maintaining pinpoint accuracy. Therefore, severe skin damage during treatment, which was common in the early days of radiation therapy treatment, is very rare with modern techniques.

Since emitted radiation energy does not distinguish between cancer cells and normal tissue, radiation fields are very carefully planned, during the process of radiation treatment, to protect uninvolved tissue and vital organs of the patient. Certain predictable side effects may occur after radiation treatment, with fatigue being the most common one. However, most side effects are temporary and easily treated.

Two main types of radiation treatment exist: external beam radiation, known as teletherapy, and internal therapy, or brachytheraphy. External beam radiation directs radiation from a remote source aimed at the body while with internal therapy a radioactive source is placed inside the body close to cancer cells or the tumor mass.

The goal of radiation therapy can be curative or palliative. Radiation therapy is frequently used as adjuvant therapy to other treatments, most often with surgery and chemotherapy.

The decision to treat a tumor with radiation is based on the location of the primary tumor and whether the tumor cells are radiosensitive. Although radiation therapy and surgery have similar cure rates for some types of cancer, radiation therapy is preferred to surgery if the patient has a preexisting condition that makes surgery impossible or if surgery would require removing part or all of an organ. For example, radiation therapy may be chosen to treat cancer of the larynx in order to preserve the voice.

In addition to its curative purposes, radiation therapy may also be given to relieve pain in cancer patients. For example, radiation therapy can often relieve the pain caused by secondary bone cancer despite the uncertainty about how it works. For palliative purposes, lower doses are given than for curative treatment, usually over a shorter period of time.

In order to achieve the most effective cancer curative results, radiation treatment is frequently used as adjuvant therapy to other treatments. Radiation treatment may be administered before or after surgical treatment. Sometimes, surgery may effectively remove the gross tumor, but there may be a limit to the amount of adjacent tissue that can be removed without impairing function. Post-surgery radiation treatment can be administered to destroy microscopic residual cancer cells left after surgery. Sometimes, pre-surgery radiation treatment is administered to shrink the tumor so that it can be surgically removed more easily or make the operation less radical, thereby preserving more normal tissue. Based on studies, better cancer treatment outcomes result after the combination of radiation therapy and/or chemotherapy after surgery.

To ensure the success of radiation treatment, the radiation oncologist tailors each patient's treatment to make sure it is safe and effective. A careful treatment plan is often made, and then practiced using a simulator before any actual treatment begins.

Depending upon tumor location, different levels of radiation are used for external beam therapy. Low-energy radiation does not penetrate very deeply into the body and is used mainly to treat surface tumors such as skin cancer. High-energy radiation is used to treat other deeper cancers.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=CA3GnfImGmw
https://www.youtube.com/watch?v=BRkf-bi6_zM&list=PLajYbKcP5kMrwzHq5Z3dUjbRXt-bc3PAt
https://www.youtube.com/watch?v=yoUxqeAN0So

Important Books/Journals for further learning including the page nos.:
Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010.

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LECTURE HANDOUTS

L 37

MECH

III/V

Course Name with Code : 16MED13 & Heat and Mass Transfer

Course Faculty : Mr. R.Ramesh

Unit : V –Mass Transfer **Date of Lecture:**

Topic of Lecture: Basic Concepts of mass transfer

Introduction : **Mass transfer** is the net movement of **mass** from one location to another or travel of individual chemical species from high-concentration regions to low-concentration regions.

Prerequisite knowledge for Complete understanding and learning of Topic: Mass transfer operation plays an **important** role in many industrial processes. A group of operations for separating the components of mixtures is based on the **transfer** of material from one homogeneous phase to another.

Detailed content of the Lecture:

Depending on the conditions, the nature, and the forces responsible for **mass transfer**, **four** basic **types** are distinguished: (1) diffusion in a quiescent medium, (2) **mass transfer** in laminar flow, (3) **mass transfer** in the turbulent flow, and (4) **mass** exchange between phases.

A vessel contains a mixture of2 kmol of CO2 and 4.5 kmol of air at 1 bar and 25°C.ifair contains 21 % oxygen and 79% nitrogen by volume, calculate for themixture:

i) The mass of CO_2, O_2 and N_2, and the total mass;

(ii) The percentage carbon content by mass;

(iii) The molar mass and the gas constant for the mixture;

(iv)The specific volume of the mixture.

Solution: (1) Number of moles of $O_2 = 0.21 \times 4.5 = 0.945$ kmol, Number of moles of $N_2 = 0.79 \times 4.5 = 3.55$ kmol

Mass of $CO_2 = 2 \times 44 = 88$kg; Mass of $O_2 = 0.945 \times 32 = 30.24$ kg Mass of $N_2 = 3.55 \times 28 = 99.54$ kg

The total mass = 88 + 30.24 + 99.54 = 217.48 kg

(ii) Percentage of carbon in the mixture; (24/217.48) × 100 = 11.035% by mass.

= (2/6.5) × 44 + (0.945; 6.5) × 32 + (3.555/6.5) × 28

= 33.5 kg/kmol

And the gas constant of the mixture; 8314/33.5 = 248.18 J/kgK (iv)Specific volume of the mixture, v = RT/p = 248.18 × 298/ (l × 10^5) = 0.7395 m^3/kg.

2.The air pressure inside a synthetic rubber ball (400 mm inside diameter and 15 thick decreases from 3.5bar to 3.45bar in seven days. Estimate the coefficient of diffusion of air in synthetic rubber if the temperature is 25°C and the solubility of air in the rubber is 1.8 ×
10^{-3} kmol/m^3 bar.

Solution: Since the pressure change is very small during a period of seven days, the problem can be treated as quasi-steady. The initial mass of air inside the ball

$$m_1 = p_1 V/RT = \frac{3.5\times10^5\times(4/3)\pi(0.2)^3}{287\times298} = 0.137 \text{ kg}$$

$$\text{The final mass, } m_2 = \frac{3.45\times10^5\times(4/3)\pi(0.2)^3}{287\times298} = 0.1352 \text{ kg}$$

$$\text{The rate of leakage } = \frac{0.137-0.1352}{7\times24\times3600} = 2.976\times10^{-9}\text{kg/s}$$

The average pressure inside the ball = (3.45 + 3.5)/2 = 3.475 bar
Concentration inside the ball = = 0.1814 kg/m^3

$$= 0.1814 \text{ kg/m}^3$$

Concentration at the outside surface = $p_2 \times S = 1\times1.8\times10^{-3}\times29$

$$= 0.0522 \text{ kg/m}^3$$

Since conduction heat transfer is analogous to diffusion mass transfer, the diffusive resistance for the spherical shell can be written as

$R_D = (r_2 - r_1)/(4\pi D r_1 r_2)$, and

$$\dot{m}_A = (C_{A_1} - C_{A_2})/R_D = 4\pi D r_1 r_2 (C_{A_1} - C_{A_2})/(r_2 - r_1)$$

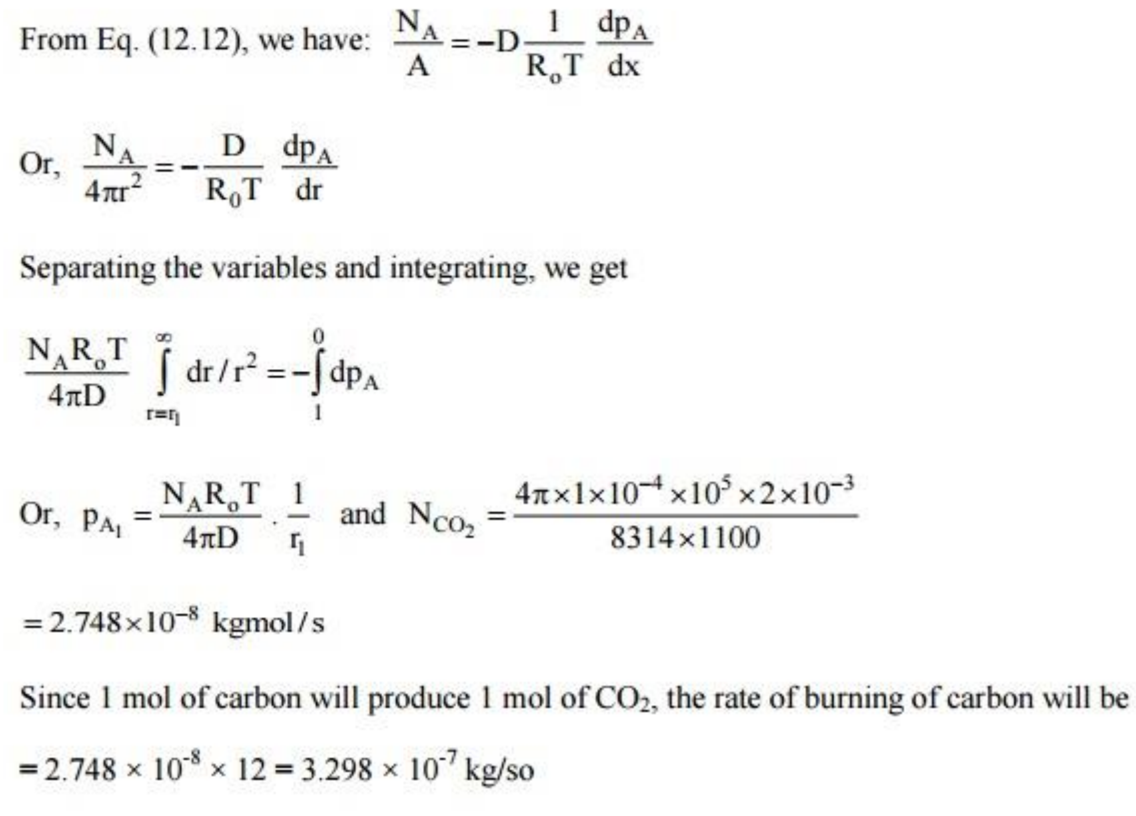
Or, $D = \dot{m}_A (r_2 - r_1)/\left[4\pi r_1 r_2 (C_{A_1} - C_{A_2})\right]$

$$= \frac{2.976\times10^{-9}\times0.015}{4\times3.142\times0.2\times0.215\times(0.1814-0.0522)} = 6.4\times10^{-10}\text{m}^2/\text{s}$$

3.Estimate the rate of burning of a pulverized carbon particle in a furnace if the diameter of the particle is 4 mm, pressure 1 bar. The oxygen is available at 1100 K. Assume that fairly large layer of CO_2 surrounds the carbon particle. Take D = 1 cm^2/s.

Solution: The combustion equation is $C + O_2 \rightarrow CO_2$, i.e., there will be an Equimolal counter-diffusion between O_2 and CO_2,

Since a fairly large blanket of carbon dioxide surrounds the carbon particle, the partial pressure of carbon dioxide at the surface of the carbon particle will be 1 bar and the partial pressure of oxygen will be zero. Similarly, the partial pressure of carbon dioxide far outside will be zero and the partial pressure of oxygen will be 1 bar.



From Eq. (12.12), we have: $\frac{N_A}{A} = -D\frac{1}{R_oT}\frac{dp_A}{dx}$

Or, $\frac{N_A}{4\pi r^2} = -\frac{D}{R_0T}\frac{dp_A}{dr}$

Separating the variables and integrating, we get

$$\frac{N_A R_o T}{4\pi D}\int_{r=r_1}^{\infty} dr/r^2 = -\int_{1}^{0} dp_A$$

Or, $p_{A_1} = \frac{N_A R_o T}{4\pi D}\cdot\frac{1}{r_1}$ and $N_{CO_2} = \frac{4\pi \times 1\times 10^{-4}\times 10^{5}\times 2\times 10^{-3}}{8314\times 1100}$

$= 2.748\times 10^{-8}$ kgmol/s

Since 1 mol of carbon will produce 1 mol of CO_2, the rate of burning of carbon will be

$= 2.748 \times 10^{-8} \times 12 = 3.298 \times 10^{-7}$ kg/so

Video Content / Details of website for further learning (if any):

Can be added as link

Important Books/Journals for further learning including the page nos.:

Yunus .A.Cengel ,Heat transfer a Practical approach. Tata Mac Graw Hill 2010

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