Conduction and Convection Heat Transfer

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Lecture - 01
Introduction and Fundamental Concepts

Good Morning to all of you and I welcome you all to this very first lecture on the course title conduction and convection heat transfer. Before I provide you with the detail contents of the course, I like to tell very briefly what the subject heat transfer is and what is its implications, relevance or importance in practice. We have already been aware of the word heat in thermodynamics.

Heat is a form of energy in transit means which is recognized only in flowing condition that means energy which flows or being transported due to a temperature difference and it flows from a high temperature to low temperature. So, temperature is the potential for heat energy in transit to flow. In thermodynamics, we have observed that the quantitative energy has got two distinct status.

Thermodynamics has taught us that the quantitative energy has two distinct status, one is the energy in storage where is the energy enjoys the characteristics of a property and it becomes a point function that is energy stored in a system. And another is the energy in transit that means the energy which takes place in transit when the two systems interact with each other. And there are two form of energy that appear in the form of energy in transit which behave as a path function.

They are work and heat. And heat is that kind of energy in transit which is transferred because of temperature difference from high temperature to low temperature. Now thermodynamics deals with system at equilibrium states and then system undergoes a process from one equilibrium state to other equilibrium state.

Thermodynamic tell us what is the amount of energy directions with the surrounding or with another system by virtue of which it under goes a process and that is also related to the energy stored by the system in the perspective of the conservation of energy which is precisely known as first law of thermodynamics. But where thermodynamics fails is to determine the rate at which these energy will be transferred.

How much time will be required to transfer the energy from one equilibrium state to another equilibrium state. In classical reversible thermodynamics, the concept is such that system undergoes from one equilibrium state to another equilibrium state through a series of equilibrium states where the process is quasi static or reversible and time taken is infinite. But in practice, we have a transfer a quantity of heat within a given interval of time.

So, there for what is most important information in this regard is the rate at which heat is transferred between a system, another system. So, the rate is to be known so that we can find out the time taken to transfer a given amount heat and accordingly we use this information to determine the size of equipment required to accomplish this process. So, there for information on the rate of heat transfer is very much important though we know the definition of heat and also the definition of temperature by thermodynamics.

Temperature is defined by the zeroth law of thermodynamics as you know in classical classical dynamics which tells the ability of a system to be in thermal equilibrium is another. So, though we know the heat and temperature from thermodynamics but what is the rate of heat transfer and how is it related to this temperature difference is the gamut of heat transfer. Now therefore, we see that heat is transferred because of the temperature difference since the classical dynamics deals with the equilibrium state of the system.

We always tell the system of giving temperature but when the system is not in equilibrium state there may be temperature differences within the system. So, therefore, heat can flow within the system from one point to another point when there is a temperature difference. So, therefore we can summarize these as heat is an energy in transit that flows or being transported by virtue of the difference in temperature between two points in a system or from one system to another because of the temperature difference in the system.

Now, I tell you the heat transfer, the subject heat transfer deals with this ready questions. The questions that predict the rate of heat transfer and through this some properties defined by the media of the medium that allows the heat to be transferred. This property is thermal conductivity. Many other properties are also associated in determining this laws and equations for heat transfer.

So, there for this subject describes quantitative laws for heat transfer along with the definition of those properties defining these laws and their changes. Now I come to the importance of heat transfer in practical life. In fact, heat transfer is involved in entire science and engineering and biological systems everywhere. You start from this that the growth of human being, the growth trees, plants, growth of animals, all depend upon the heat transfer process.

If you think simply what we do daily in our human activity we take energy through food and that energy after the metabolism within our body generates energy which allows the blood to flow through the arteries makes the organ alive by virtue of which we are able to do work and at the same time that makes our skin hot, high temperature. Skin arrives at a high temperature then to make us comfortable we have to transfer the heat to the ambiance.

Ambiance has to be conducive enough so that the heat is transferred and the human surface of the human body is kept at a comfortable temperature. There are all activities further growth for our daily activities are involved with the process of heat transfer and also mass transfer. I am not going into that details. Now let me come to our engineering applications. In engineering heat transfer is deeply involved in all sort of applications.

If you see the power industries, you know that we developed mechanical and electrical power that is needed for manufacturing products, for electrifications, all these power is being developed from the natural energy resources and more than 70% of the power today is a global statistics is being developed from burning the fossil fuels and what is done is the fossil fuel is burned and after burning because of the exothermic reaction a huge thermal energy is generated which results in a very high temperature, hot that means high temperature product of combustion that is used as a heat source to transfer heat.

And you know from thermodynamics that if you have to have continuous mechanical power out of these type of thermal energy what you have to do? You have to transfer heat to a working system which executes a thermodynamic cycle and you have to also reject heat by this working system to another system while working in the cycle. So, there for you see here the heat transfer process is coming where the heat transfer, heat is added to the system working system where heat is rejected.

This if you recall your thermodynamics you know that in a conventional steam power plant these heat added portion is done is boiler where the heat from the flame and the combustion gases is being transported to water. So, for efficient transportation of heat and to design the furnace, design the water valves of boiler we have to know the rate of heat transfer. Here also the face chance take place the water boils.

Similarly, the steam coming out of the turbine is being condensed in the condenser by taking the water from the ambiance as the cooling agent circulating water, water circulates takes the heat where the heat rejection takes place by second law of thermodynamics. So, therefore to design a condenser its size we have to know the rate at which steam should reject heat to the water. So, there for you see these are the heat transfer processes.

Similarly, in case turbine engines where the combustion product itself walks on the turbine but after coming out from the turbine in a close cycle gas turbine these gasses are being cooled by a heat exchanger by using cold air from the ambiance. Well again in a recycling system in case of steam turbine this water which takes the heat from the steam is again being cooled in equipment know as cooling tower by using the ambient there.

Similarly, this heat exchanger which cools the hot product by the ambient air is also being cooled by equipment, another heat exchanger. So, there for you see the heat transfer processes are inherent to the power producing devices. In a nuclear reactor, the similar thing is there. There are other places where heat transfer is very important which is also related to the power production equipment or devices where the temperature is become so high.

Because of the generation of thermal energy though colloquially many places we use heat generation but these as a contrast. A pure thermodynamics will not allow it because heat is not stored energy which can be generated and stored. So, it is the generation of the thermal energy heat transfer comes when it is in transit we allow the energy to flow by virtue of temperature differences.

So, there for as much as possible I will try to tell generation of thermal energy. So, generation of thermal energy makes the system so hot it has to be cooled otherwise the metal will not sustain that high temperature which happens in the engine of a reciprocating internal combustion engine that cylinder of an our automobile engine where the fuel is injected in the air and the warming takes places.

And because of that exothermic combustion reaction energy is generated so that the cylinder wall becomes very hot. What is required is the effective cooling of the cylinder wall to maintain its temperature so that it can work well. For that effective cooling system is made again the water which is used to cool the cylinder is again being cooled in a radiator to have a recycling system. Now a days, the coolant is used for effective cooling.

Similar thing happens in a combustion chamber. Combustion chamber where the burning takes place we have to cool the combustion chamber so that the combustion chamber wall can sustain it. There are for your popular knowledge probably you do have all this information today. Another very interesting thing is that for gas turbine power plant or steam turbine power plant, finally what happens?

The high temperature steam in steam turbine power plant coming from the boiler or a high temperature burning products in case of gas turbine power plant coming from the combustion chamber comes to a steam turbine to develop work and steam turbine is difficult turbo machines which works on the principle of change of angular momentum of this fluid while it flows through that and develop power.

And basically, it has some blades mounted on a shaft which is rotating and these blades fail miserably if the temperature of the fluid flowing through it is very high and that mode of failure is known as Creep failure. To avoid that there is always a restriction of the inlet temperature at the turbine blade but we cannot reduce the inlet temperature of the steam or gas to that level so that turbine maintain its temperature well below the creep failure.

So, what is done? So, affective pulling of the turbine blade is made and that is entirely different subject at pulling of the turbine blade. So, there for you see in the power industry heat transfer is totally involved. If you come to the process industries, in all process industries in manufacturing products we require some part heating of the materials, somewhere cooling of the materials.

I am not going into that details for example spray drying things where the products are made by spray drying. The solution is sprayed into a chamber or dryer where the hot air is allowed to flow and which allows the solvent to evaporate so that the dry product comes out. This is one example there are number of process industries where heat transfer is associated. Next we come to a very, very great application of heat transfer is electronic industries.

Today we are proud of our advent in the electronic industries. The invention of electronic chip, VLSI, large scale integration all this miniature electronic circuit board couldn't work successfully if they couldn't have been cooled. This is because of what? That is small electronic components in the development of VLSI they dissipate electrical energy in generating thermal energy for what the electronic component becomes hot but at high temperature the electronic component can perform their function they are incorporated.

So, there for what is most important to make these electronic component cool depending upon the circuit board or the component we may cool it naturally by putting it into the air or we may allow to flow air to cool it so this design of this circuit board and the cooling system. In this case for cooling we use semiconductor that I will tell what is a semiconductor for cooling purpose.

So, therefore all electronic components, electronic circuit board cooling is extremely important sometime the fan is giving, sometime we take the help of the natural convection but we have to know the equations. We have to know the laws, principles so that we can tell yes the fan will not be required. Okay, it is okay in the natural ambient condition it will automatically be cooled to the temperature below the operative level. So, this you see that heat transfer is involved in electronic industries.

In biological system heat transfer is very much involved because our entire biological process along with our growth is involved with heat transfer and scientists are utilizing this in the applications those who are involved in the development of healthcare system. In the microfluidics research, a lot of heat transfer studies are being done for the application to the biological systems.

So, with this in our background as the definition of heat transfer and overall understanding of the gamut of heat transfer and its practical relevance now I will show you the course contents. Now course content when I show you I tell you this is an introductory course on conduction and convection heat transfer. We will emphasis the underlying fundamental concepts on this two modes of heat transfer conduction and convection and will enumerate the laws, principles and the governing equations based on derivations from fundamentals.

The coverage I tell you will be well balanced with physical concepts, analytical operations along with examples and exercise problems of practical importance and I am sure that after completion of this course a student will have a strong foundation on this conduction and convection heat transfer and you will be competent enough to apply the laws and equations appropriately to practical scenarios. This is the learning objective.

Now, my job is to tell you about the detail content of the course. In fact, this course will be taught by both of us myself and Prof. Suman Chakraborty and I introduce the teaching assistance Mr. Sayan Das who is a research scholar you come here and show your face and Mr. Shubhadeep Mandal, Shubhadeep please show your face the students must know that Mr. Sayan Das and Mr. Shubhadeep Mandal.

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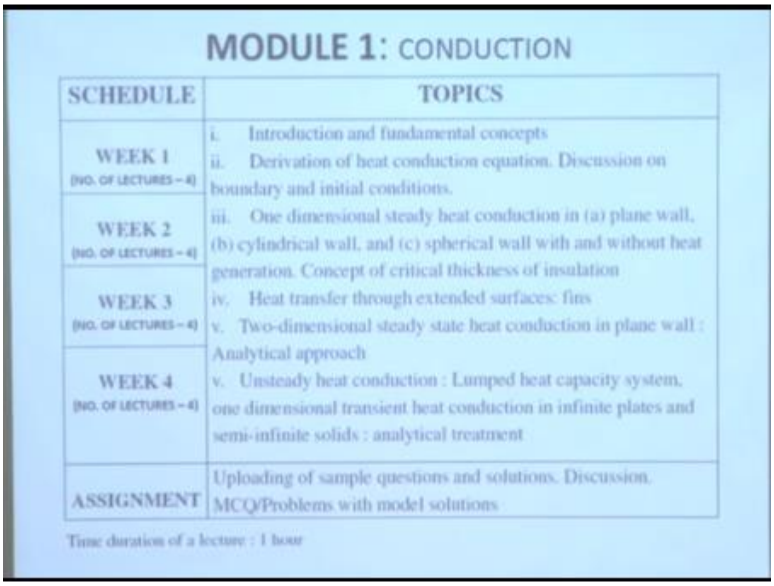

Now this is the course content just I tell you hurriedly this course is divided into basically three modules. The module one is the conduction and this is a tentative schedule we will try to follow as much as possible this schedule. Introduction and fundamental concepts which will be given for first, for two lectures.

Then derivation of heat conduction equation, discussion on boundary and initial conditions. Then one dimensional steady heat conduction different configuration. Plain wall, cylindrical walls, spherical wall with and without heat generation again this is a very conventional but colloquial and truly speaking incorrect statement heat cannot be generated. Heat is an energy in transit sometime.

I ask this question to the student just I tell you now. This is all of you have completed the thermodynamic code, you have an insulated vessel within which there is a reactant reacting you make a spark you initiate the reactant what happens? The temperature becomes high but a colloquial statement said heat is generated. Where is heat? It is insulated, no heat is transferred.

Where the heat is transferred? That means it is the generation of thermal energy because of the exothermic reaction which makes the product hot. If you remove the insolation, then only heat will come. If I stand by this side of the reactor, huge reactor and hugely insolated I do not find any heat transfer. I do not find any heat coming to my body so why the heat is generated? Where it is gone?

It is the thermal energy that is, no sir heat is generated; I think it is stored in system. Heat cannot be stored in the system; it is not a stored energy. So, thermodynamic teacher will be very annoyed so therefore it is the generation of thermal energy not the heat but colloquially people tell conventionally that is why I am telling with or without heat generation concept of critical thickness of insolation, heat transfer through extended surfaces fins. Two-dimensional steady state heat conduction in plane wall.

Analytical approach. Unsteady heat conduction, lumped heat capacity systems, one dimensional transient heat conduction in infinite plates and semi-infinite solids: analytical treatment. This is the topic of the conduction and then it will be followed by an assignment of questions and solutions with discussions.

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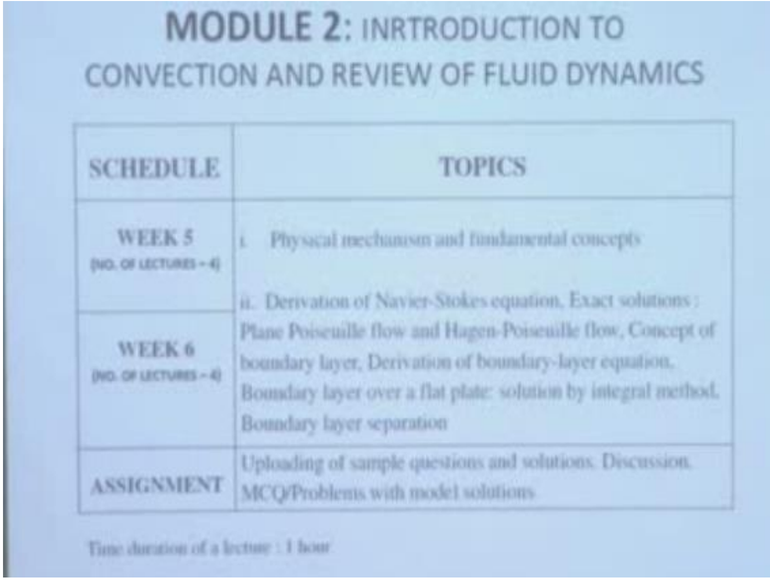

Second module is the Introduction to convection and review of fluid mechanics. And this include topic physical mechanism and fundamental concept because the conviction mode I will you tell you afterward is not a basic mode of heat transfer. It is the conduction which is the basic mode which is affected by the flow of the fluid that is they the name convection comes. So, therefore in the convection the first part we will make a review of fluid mechanic that you have already studied.

After the physical mechanism and fundamental concepts, we will for recapitulating the fluid dynamics that is derivation of Navier-Stokes equations, exact solutions, Plane Poiseuille flow and Hagen-Poiseuille flow, concept of boundary layer, derivation of boundary-layer equation, boundary layer over a flat plate solution by integral method, boundary layer separation. Then uploading of sample questions and solution, discussion with MCQ problems.

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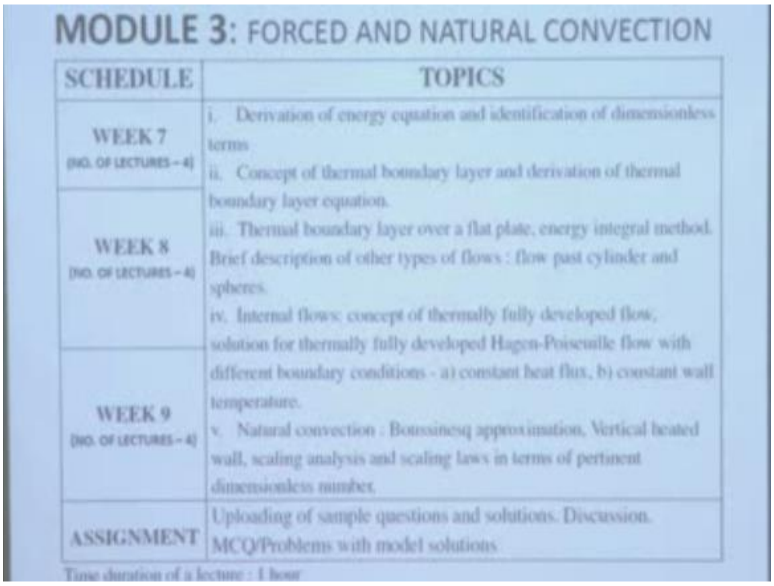

Next the third module is the continuation of the convection and there are two types of convection which will be told in detail afterward force and natural convection. Derivation of energy equation identification of dimensionless term. Then concept of thermal boundary layer and derivation of thermal boundary layer equation. Then thermal boundary layer over a flat plate, energy intefral method, brief description of other types of flows, flow past cylinder and spheres.

Internal flows concept of thermally fully developed flow, solution for thermally fully developed Hagan-Poiseuille flow with different boundary conditions. Constant heat flux, constant wall temperature. Then the natural convection part we will teach Boussinesq approximation, vertical heated wall, scaling analysis and scaling laws in terms of pertinent dimensionless number. Than uploading of sample questions and solutions. Discussion MCQ problems with model solutions.

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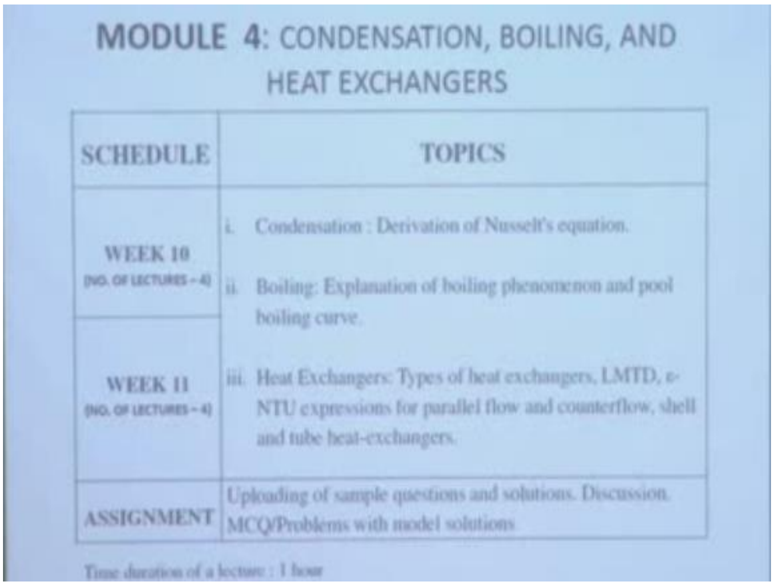

And the last part of the last module of the last part of course is on application side that means after that okay sorry there is condensation it is a basic thing derivation of Nusselt's equation and the boiling phenomena. Explanation of boiling phenomenon and pool boiling curve. This two will be taught in brief then the application mainly the heat exchangers type of heat of heat exchangers LMTD, log mean temperature difference.

If epsilon into expression, if epsilon is the effectiveness NTU stand for number for transfer units this just for your information you do not know anything this will be taught that what the abbreviation is for parallel flow and counter flow, shell and tube type exchangers and this will be followed by uploading of sample questions and solutions then discussion MCQ problems with model solutions.

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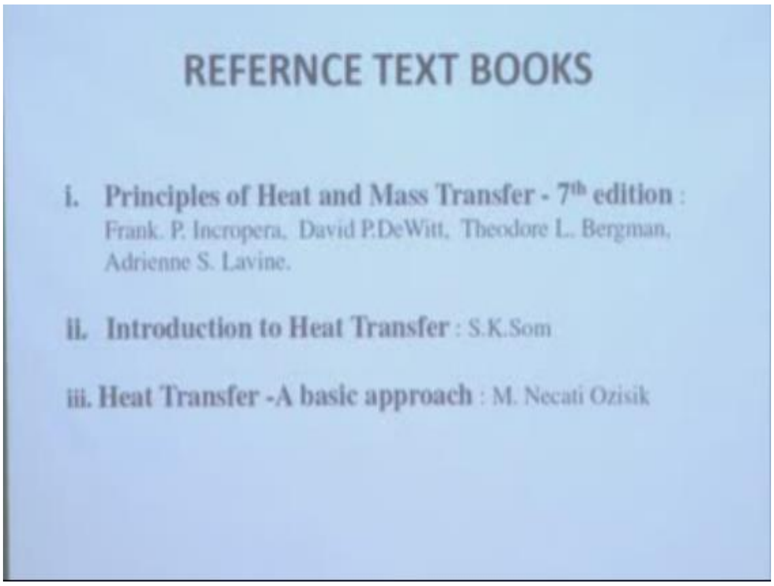

Next is the reference text book. First of all, I tell you any text book will do. I or Prof. Suman Chakraborty will not follow a text book in ditto. What is my suggestion that class room will be substitute of you text book not in 100% you must read a text book for follow-up which contains these things which are taught in the class. All text books are equal if you understand things in the class; any text book will be supplementing you concept.

But as a reference we list these text book Principal of Heat and Mass Transfer-7th edition, Frank.Incropera. It is a very good book along with other authors. Introduction to Heat this is published by Wiley. This is a text book by me. This is published by PHI Learning and another Heat transfer is basic approach by Ozisik. There are number of heat transfer books, any book you can see, we will not follow a particular book.

We will take problems from any of these three books from other books also. So, you take any reference text book just for the sake of showing the text in a priority wise we have shown this text that does not mean that we will rigidly follow this text. Now I start the subject with these things in backdrop. The overall understanding what the subject gamut is? It is importance and the course content now I start the subject.

Now conduction, there are basically three modes of heat transfer conduction, convection and radiation. Incidentally, in this course conduction, convection heat transfer, radiation will not come into picture, conduction, convection. Now between these two modes conduction is the basic mode of heat transfer, convection is not an independent basic mode. It is artificially confide by as I will tell you in detail the concept of convection heat transfer.

Convection comes into picture when there is a flow it only occurs in case of heat transfer through fluid where the flow can take place and because of this flow the conduction phenomena is affected the basic mechanism of heat transfer. So, there for this affected convection that is flow affected conduction we define artificially as a different mode of heat transfer as convection though convection is not a basic or independent mode of heat transfer this particular thing you can write.

There are certain things you must write. There are things which you may not write or may write as note but this is very important thing though we tell two modes of heat transfer conduction, convection but basic mode of heat transfer is conduction and radiation which is altogether governed by different physics and which is not included in this course of conduction, convection heat transfer.

Now conduction is associated with a temperature difference I already told whenever there is a temperature difference between two points in special coordinates. The heat is transferred because of conduction so there for a temperature continuous change of temperature comes into picture and it flows in the direction of decreasing temperature that means in the direction of negative temperature gradient.

Let us think in this way that let us consider a direction of heat flow Q. Q is flowing in this direction and we describe this direction as x, as special coordinate. Well and heat is flowing in this direction means there is a change of continuous, change of temperature in these direction in any medium conduction can take place in any medium and conduction is the basic mode of heat transfer in solid, in fluid, in static fluid, in flowing fluid does not matter all these things I will be telling in deep with concept.

Now if we have a temperature field which is a function of x only, x is a space coordinate I gave in the direction of the heat flow and if I make inordinate T here I can show this like this T is a function of x. So, therefore, heat is flowing like this.

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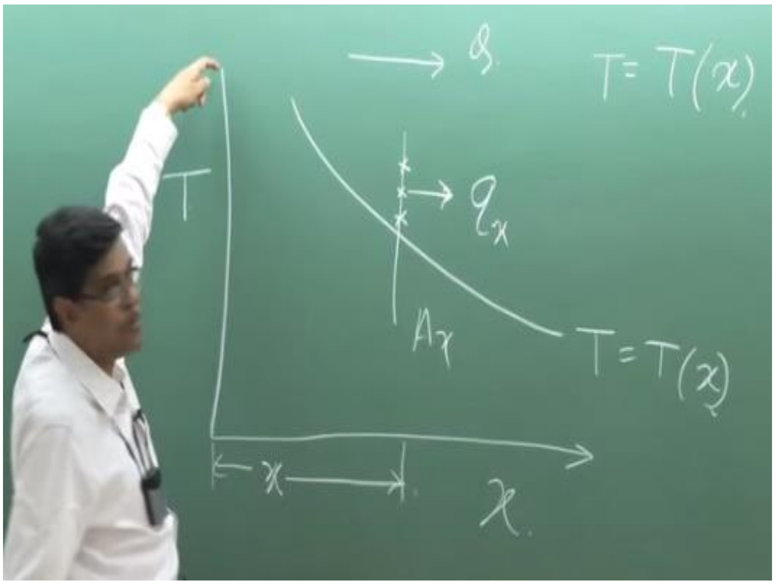

So, therefore heat is flowing like this. Now if I take a cross section at any distance x at Ax from the reference, origin or reference frame then what happens heat is flowing across this section now here one thing is very important when you define the heat we define its direction.

Heat is flowing in one direction. Okay now why I have taken an area normal to the direction this is because in this connection we define a quantity heat flux.

Now one thing is true that what is the amount of heat that is flowing in a direction to know that we have to know an area over which we are interested, the heat transfer. Across which the heat transfer is taking place. If the area is more, more heat transfer, area is less, less heat transfer. So, an area is important so in this regard a heat flux is defined qx which is defined like this that if the total heat transfer through an area Ax, a finite area.

I prescribe a finite area Ax is Q, then Q/Ax limit Ax tends to zero.

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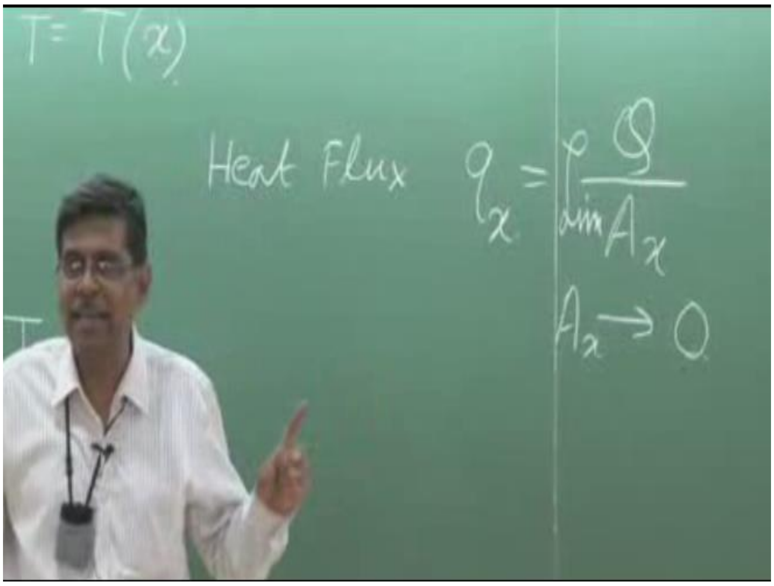

Now it is very fundamental and basic like the stress that heat transfer reduces to zero when A reduced to zero at a point. But their quotient I did not say finite value, limiting value and that is the heat flux that is the amount of heat per unite area and therefore this gets a definition at a point that means here we have heat flux at a point. So, therefore different point we have different heat flux, it may be constant may not be constant at all points on this area.

If it is constant, then simply we multiply the area with the heat flux against the total heat flux across the surface. But what is the difference with stress. Stress is a (()) (34:16). When you define stress force per unit area the area may be normal to the direction of force may be along the direction of the force. But while defining the heat, heat flux or heat transfer, it is used as a vectoring a particular direction and heat flux is defined divided by the area normal to the direction of heat flow.

You understand. So, heat flux is the heat transfer divided by the area. This x has to be normal to the direction of heat flow. So, heat flux (()) (34:58) takes the (()) (34:59) you have to know every physical quantity from his birth then step by step you will have concepts. Sometimes somebody starts giving the definition, conceptual definition from little step ahead it is nothing wrong. It depends upon the circumstances.

But when you teach somebody you start from this is the definition of heat flux which is defined at a point like a stress that is the heat flow per unit area normal to the direction of heat flow. If you this way define the heat flux then this heat flux, for example, here in the direction of x, qx can be written by an equation widely known, widely popular equation and we are grateful to the great mathematicians or physicist of France his name is Joseph Fourier who from his experimental observation told that this will be proportional.

This is a proportionality constant to the temperature gradient in the direction of heat flow. This temperature gradient is in the direction of heat flow qx and a minus sign is deliberately given because the heat is flowing along the negative temperature gradient to make the heat flux positive direction to be identified we give a minus sign and this is an analogy which all phenomenological equations or laws like electrical current flows along the negative potential gradient like mass transfer takes place along the negative concentration gradient.

So, therefore to identify the positive direction of the flux we give a minus sign so that the positive direction of the flux is associated with the negative gradient of the potential. Now the question comes that this is very simple case but in practice temperature may be a function of that, there may be a temperature variation in this direction also, why? If you consider this as y direction. If temperature is a function of x not of y.

If you consider this also as y direction then at all points temperature gradient will be same, heat flux will be same. Similarly, if it is not a function of z at all points will be same. But in practice temperature may be function of all this face coordinates with reference to a frame for example in Cartesian frame of reference, temperature may be a function of x, y and z and all this thing today what I am telling is at a particular instance.

So, time also will come an independent variable so it may change with time. Now we are thinking of special variation of temperature so at any instance we just concentrate at any instance. So, temperature may be a function of all the three space coordinates then in that case what happens that any point there will be a heat flux in this direction. There will be heat flux in this direction and there will be a heat flux in this direction at a point.

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That means these are the respective heat flow per unit area normal to that directions. They are limiting value as the area ten to zero and in that case q is represented as a vector qx where i, j, k are the unit vector along x, y, z directions with respect to a Cartesian frame. Well q is represented as a vector in that case this law given by scientist Fourier can be written in a generalized format q is equal to -K grad T, that is gradient of t where grad T is given by

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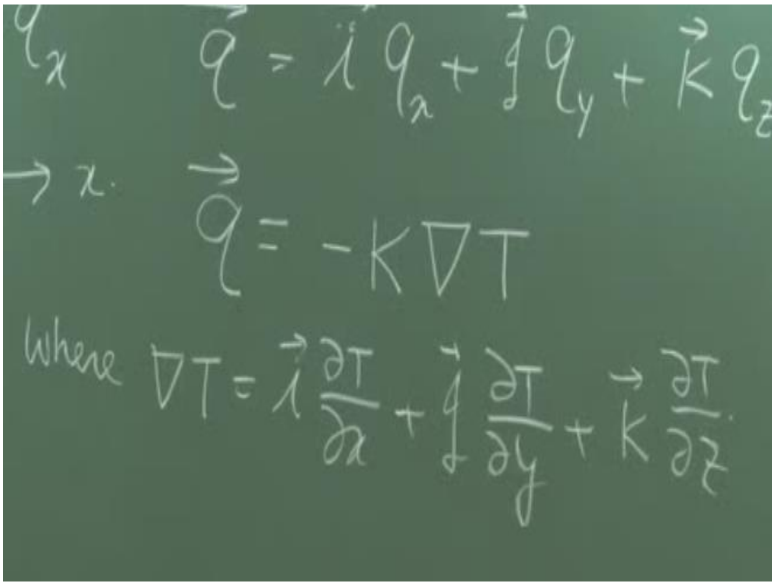

So, that qx becomes - k then dt, dx because they are partial notation, partial derivatives has to be given so in that case qx is minus k because t is a function of

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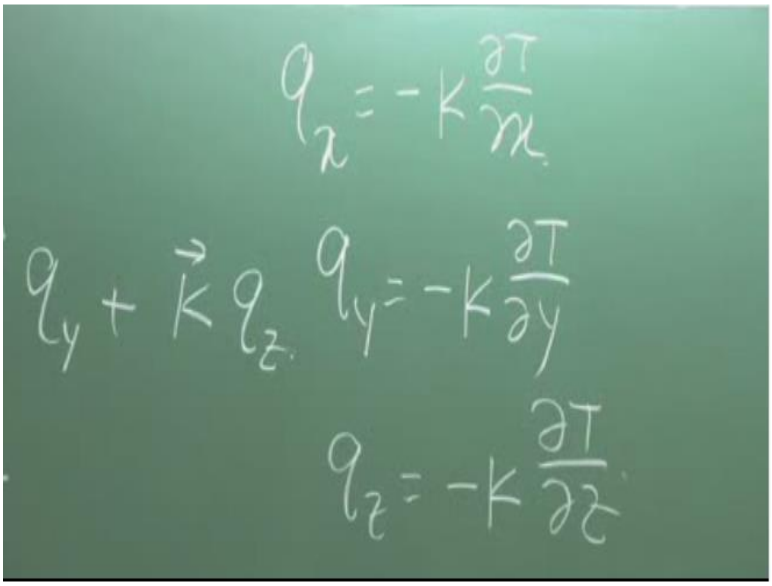

And this law q is -K grad T this law is known as according to the name of the scientist Fourier's Law of heat conduction and this forms the foundation, pillar of the conduction and the convection heat transfer that is the Fourier's Law of heat conduction that is q is equal to - K grad T.

Here the constant k is a property of a system and it is known as thermal conductivity. Well this is known as thermal conductivity. So, k thermal conductivity. K is known as thermal conductivity and for an isotropic material k is same for all directions x, y, z. It is independent of the direction of the coordinate axis as you know and in that case k depends only on temperature.

K is thermal conductivity and it is a property and for isotropic material it is independent of the direction of the axis and in that case, it is purely a scalar quantity, scalar constant which is a function of temperature only for isotropic material in this class we will discuss the things almost for isotropic materials and this thermal conductivity in a broad sense is known as transport property relating to heat transfer.

So, the property which relates the transfer or flux of quantity with the potential, with it is potential causing that flux is known as transport property. Like viscosity which relay stress with the rate of strain, diffusivity who relate the mass transfer with the gradient of concentration. Here the rate of strain is difficult at the first moment where the gradient is coming because of the rate of strain is defined in terms of gradient of velocity from the kinematics of fluid flow.

Well, so therefore this is known as in broad sense, transport coefficient related to heat transfer, thermal conductivity. Now the unit of thermal conductivity is very simple because heat flux divided by the temperature gradient.

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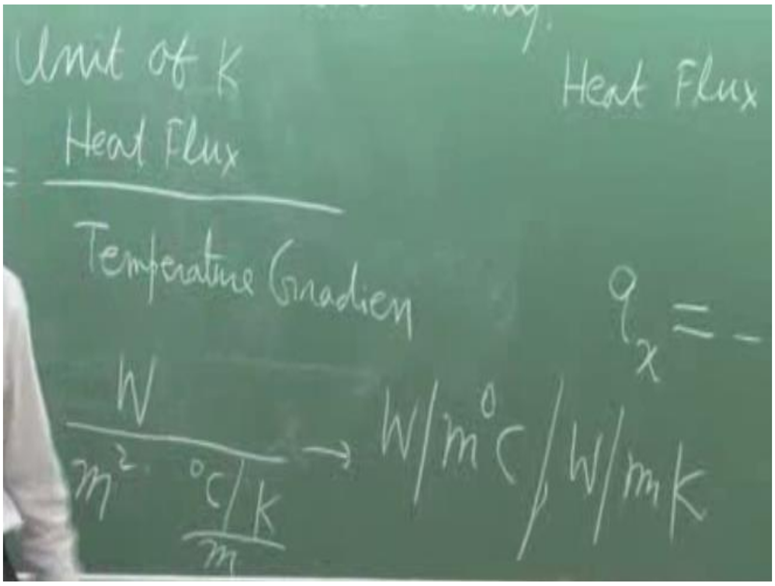

The thermal conductivity unit will be heat flux divided by temperature gradient. Now in SI heat flux is defined as unit of k. Heat flux is defined as heat flow per unit area watt per meter square. And what is temperature gradient? it is degree Celsius or Kelvin. Any one of these two divided by meter. So, therefore, the unit is watt per meter degree Celsius or watt per meter Kelvin.

This K is not thermal conductivity, it is Kelvin and Kelvin is unit is not written in terms of degree Kelvin whether it is a change in the Kelvin or it is the absolute Kelvin, you understand. If you change the temperature from 460 Kelvin to 480 Kelvin, what is the change in temperature in Kelvin? 20 Kelvin. And what is the temperature of the body? 460 Kelvin, not degree. Okay. So, therefore, it is written as Kelvin. So, this is degree Celsius. So, this is the unit either this or this.

Time left is less. So, before I finish this I will tell you this part I will extend after wards that the cause of thermal conductivity or thermal conductance in different material. As you see here the thermal conductivity is a property which allows the heat to flow for a given temperature gradient more is the thermal conductivity, more is the heat flux. Now this property of thermal conductivity is due to what?

Is attributed to certain molecular level physics because any microscopic property whether it parameter rather, whether it is a property or anything else we define through the molecular activities. Now the cause of this thermal conductivity in case of fluids comprising liquid and gases are different from that of solids. In liquid and gases, the heat is conducted by the energy transfer between the molecules because of its collision.

Molecules are always in a state of ceaseless motion as you know and this motion comprises translational motion also the rotational and vibrational motion about its own axis and because of which all molecules have kinetic energy. When a molecule is activated to raise its temperature, it is kinetic energy is actually increased and because of random collision between the molecules, it transfers the kinetic energy to the neighbouring molecules which gain kinetic energy from the upstream molecules which collides.

And there is a random collision in all directions and because of this collision when this kinetic energy is transferred the conceive this the heat transfer. So, therefore, a fluid liquid or gases I mean high thermal conductivity means the collisions for this molecules of these fluids at a given state, property is more compared to the other. So, there for this energy transfer due to the collision is the mode of heat conduction in liquids and gases and conductivity arises out that the property.

In solids, it is little different, this is because in solid as you know the basic difference with the liquid and gases is that in solid the molecules are closely packed mean three path is extremely small and the cohesive forces are very strong. The OUFC in the viscosity affect in case of liquid and gases are different. Similar way, here is not the collision rather it is attributed by two phenomena one is the flow of free electrons and another is the propagation of lattice vibrational waves.

What is flow or free electrons? Flow of free electrons take place in case of metals. In metals, the molecular arrangement is such that there are free and or valence electrons you have read in chemistry that which form a cloud in the periphery of the atom. They are not within the atom and they share with the other atom of other element for in the reaction. This cloud of electron is known as free or valence electron which are there in all metals which take part in conducting the electrical current, flow of this free electrons from the electron cloud and at the same time they take part in flow of, enhancing the flow of heat due to conduction.

So, therefore, for this reason a metal is a good conductor of both heat and electricity and the lattice vibration wave part is suppressed there. But there are highly ordered crystalline nonmetallic substances where the lattice vibrational part becomes prominent. What is this? So, in those types of solids nonmetallic solids the molecules are arranged in an order, in an array a set type of thing which is known as lattice probably you know these things.

I am not going into details of this and there the molecules start vibrating in a very synchronicity as a whole there is a lattice vibration which is propagated within the material and that is known as lattice vibrational waves. You do not have to know much in depth of it because this is not our course, this is for your information.

And for those highly crystalline nonmetallic solids specially for I am telling examples diamond, graphite, silicon, quartz is lattice vibrational law it propagates and that propagation makes the major contribution not the free electron to the conduction of heat and sometimes this becomes so high that these nonmetallic solids exhibits more thermal conductivity than the metals but electrical conductivity, they are very poor.

They are bad electrical conductor but good heat conductor and that is why they are used for cooling of electronic component and they are known as semiconductors. Now with this I will just show some for your ranges of thermal conductivity of materials for your information this is nothing great you just have a look the range of thermal conductivity of the materials. So, you see just have a look only this is the range of thermal conductivity I do not know whether you can see from the back.

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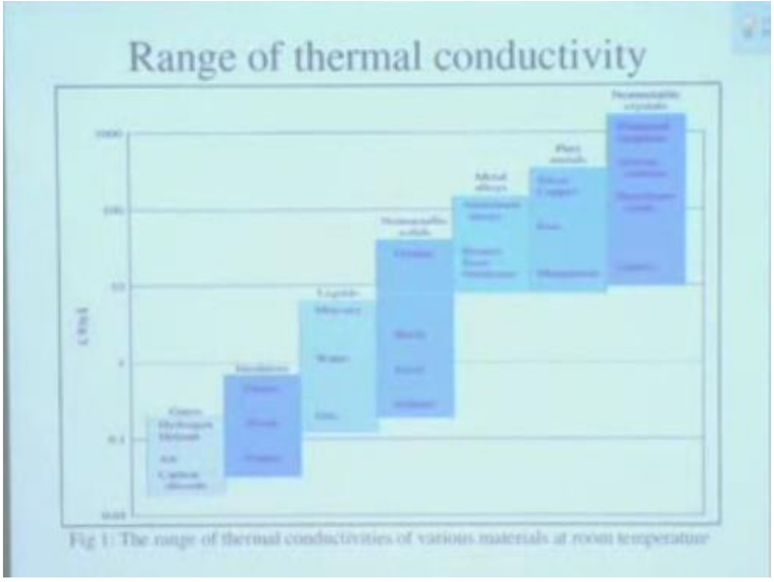

You see this is the thermal conductivity axis watts per meter k. This is point one, this is one, this ten, this is hundred, this is thousand and you see hydrogen, helium, air, carbon dioxide gases they are within that range point one to point zero five like that a little bit point six. Then comes the insulators fiber, wood, then this is foam. Then comes the liquid mercury, water, oils. They are in the range of six, seven, eight that is between one to ten and for some oil little bit of one.

The nonmetallic solids, some oxides rock they lie in this range it is the 50 we have been below one. Then the alloys aluminum alloys, bronze, steel, nichrome. These alloys fall within this range hundred, little more than hundred or below hundred. Then comes pure metals copper is one of the very good heat conductor whose thermal conductivity is somewhere near four hundred.

And you see those nonmetallic highly ordered crystalline materials that solid that is diamond, graphite, silicon, cobalt their thermal conductivity even up to thousand watts per meter k. This shows such high thermal conductivity.

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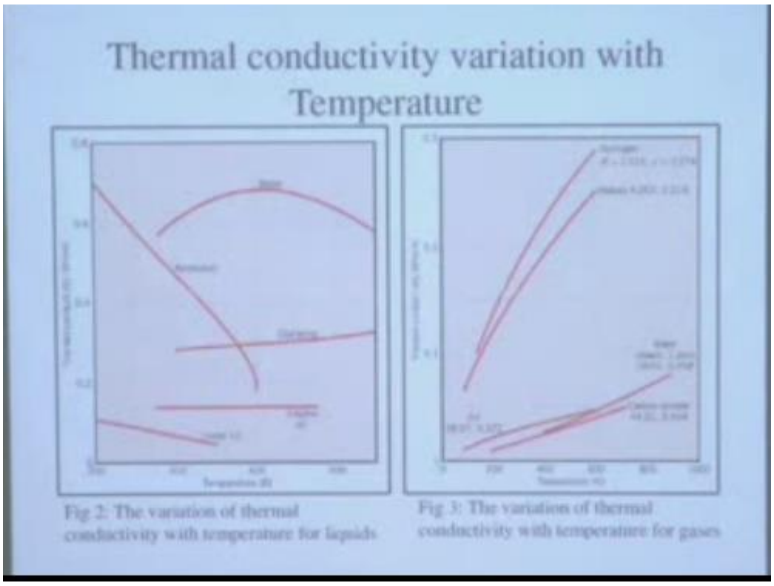

Next, this is some representative figure of thermal sorry, representative figure of thermal conductivity variation with temperature this is for liquids ammonia there is a strong decreasing trend this is for gases, for hydrogen and helium there is a strong increase, strong influence of temperature in increasing the thermal conductivity whereas for air the thermal conductivity is less influenced by temperature then it is water and carbon dioxide.

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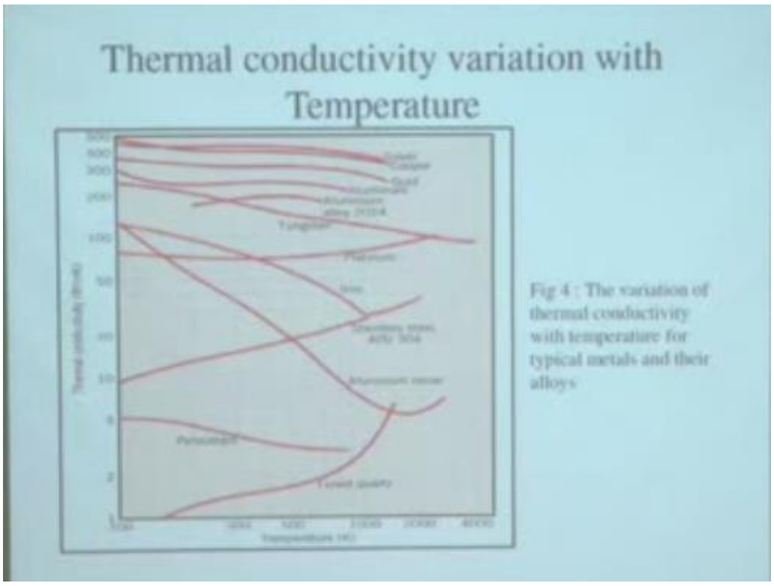

Next is these are just for your understanding for solids you see the thermal conductivity of different solids are there, not much of a difference for some solids there is a sharp decreasing trends for silver, copper, aluminum these are very important. The influence is not very mark with the temperature the thermal conductivity change. So, these are certain information that how do thermal conductivity varies with the temperature. Okay. Thank you for this class.