Heat Transfer
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Lecture - 01
Introduction to Heat Transfer

So, good morning; this would be the beginning of a new course Heat Transfer, but first of all little introduction about myself. My name is Sunando Dasgupta. I am a faculty of the Chemical Engineering Department of IIT Kharagpur and together we are going to learn Heat Transfer.

So, as you are well aware of the abundance of examples of heat transfer around us it still required, that we need to know what are the governing principles, the rules and the correlations, which 1 should use in order to understand. And more importantly apply heat transfer in a multitude of applications that we see around us every day. So, from an automobile to a petroleum refinery to any anything that you can think anything that you see around you will see examples of heat transfer.

We have you have also studied fluid mechanics before this course. So, some of the concepts of fluid mechanics will also be used in heat transfer. But first of all we must understand; what is the distinguishing feature of heat transfer in comprising to thermodynamics. Because thermodynamics also deals with temperature; we under we know that heat transfer and thermodynamics are closely related, but they are not the same.

So, what is the difference? The first difference lies in that heat transfer is energy in transit due to the presence of a temperature gradient. So, thermodynamics tells us about the ends states of a process. However, heat transfer tells us more about the kinetics of transfer of heat from one to the other where wherever whenever there is a difference in temperature between the 2.

So, one can see heat transfer around us, but in most importantly in many of the industrial processes you will encountered that heat has to be transferred from one fluid to the other, heat has to be dissipated from a hot surface to the environment and if you just look at your laptop, I mean the in most of the cases the heat transfer from the chip, the heat that the chip generates has to dissipated otherwise you would not be able to use your laptop.

I mean the operating temperature; the safe operating temperature is roughly about 80 degree centigrade. So, you would like to keep your laptop at a temperature lower definitely significantly lower than that of 80. So, there are several ways by which people are trying to address this problem, which is also known as the electronic packaging.

So, from your laptop to your cellphone and to your television set everywhere the control of temperature within a certain level is important. If you look at the inside of an automobile, if you if you just open the open the hood of a car, you would see that there are fins thin fins which are attached to the radiator where the coolant come coolant is stored.

So, the coolant is pumped to the to the to keep the engine cool and when that coolant gets heated it comes back to the radiator, where it has to radiate heat to the environment, in order to again reduce the temperature of the coolant such that it can be pumped back to the engine. So, you would see the radiative heat transfer the convective heat transfer and I will I will tell you about more what are these radiations, convection, conduction, and so on.

But, you would also see a thin fins, which are attached to the walls of the radiator these fins are also known as extended surfaces. So, they are attached to places where it is difficult to get the heat out. So, from your laptop to your car and to a petrochem, if you if you ever visit any chemical plant you would see that there are several utilities, which are present which are which are there in a chemical plant. For example, if may hot steam, you may have hot fluid, you may have a reactor in which the reactant has to enter at an elevated temperature or you are getting a product out which is coming out at a very high temperature.

So, you do not want to waste that heat. So, how you are going to utilize the hot stream to heat the stream which is entering the plan? So, that you do not lose the heat which is either otherwise going away with the hot stream. So, you need to design exchangers. Exchangers are heat exchangers are devices in which a hot and a cold fluid exchange heat between one another without actually physically coming in contact.

So, you may have a tube through which a cold fluid is flowing you may have a significantly large number of tubes, which are all in contact with the fluid, which is the tubes are encased in a shell like structure. So, through the shell the hot fluid will flow and through the tubes, which are encased in the shell the cold fluid will flow. And as they flow they are going to exchange heat among each other and by this way you can use steam to heat the reactant, which is entering the discretion column, which is entering the reactor and so on or you can use the product streams which are at a high temperature to heat the streams which are coming into your process plant.

So, the heat transfer not only is important from a technological point of view it is also extremely important, when you decide about the economics of the plant that you have designed. So, the we understand we all understand the important role energy plays in the economics of any project. So, how do we minimize the waste of energy? How do we transfer energy efficiently from one point to the other is essentially the subject of heat transfer. So, there are several basic fundamental physics which is involved in describing heat transfer, but at the same time the applicative examples are many as well.

So, it is a course which is designed to give you a flavor of the physics the basic physics from and then will move towards applications. And, how the concept developed in the initial part of the course can be utilized to obtain, generalized, governing, equations, design equations, correlations, and how that can be applied for the actual design of a heat exchange equipment.

So, this is more or less the going to be the flow of the course in the coming months to and at the end of the course I expect that you will have ideas about heat transfer. How does it take place? What are the factors on which this heat transfer would depend? What are the different modes of heat transfer? Is it a steady state process or an unsteady state process, in which the in the unsteady state process temperature is not a function only of space coordinates like x y z.

It is also a function of time and whenever let us say in a steel plant, you are producing sheets of steel at very high temperature, you would like to quench it you would like to reduce the temperature of that steel very quickly and the property of the steel many a times would depend on how you cool it? How fast how slow? What is the rate of cooling the cooling curve that it takes place the property of the steel would in some cases would depend on that.

So, it is a transient process it is a process in which the temperature of the steel plate will reduce sharply with time. So, we need to look at the transient part of heat transfer as well. So, this therefore, is in a nut shell what we expect what you can expect out of the course. From fundamentals to design equations, an application for the actual design that is what we are going to cover in this course, but first of all what is the textbook that we should we are going to follow in this.

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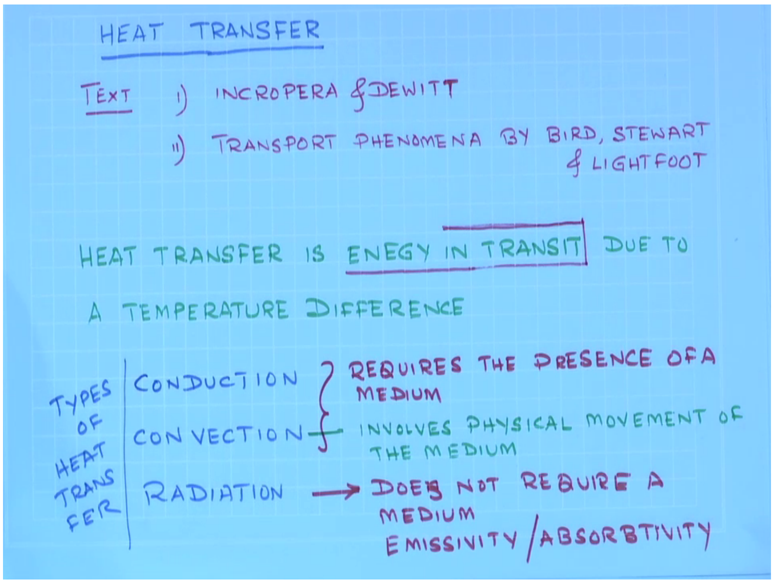

So, the first textbook that I have written down over here is by Incropera and Dewitt and the name of this book is heat transfer heat and mass transfer, by Incropera and Dewitt and the second book that a would occasionally will refer to is transport phenomena by Bird, Stewart and Light foot. So, if you see the description of the course you would see both of these courses these books are listed as prescribed textbook for the course. So, we come to this point, which I have already discussed that heat transfer is energy in transit due to a temperature difference.

So, wherever whenever there is a temperature difference you are going to have heat transfer, but how heat is going to get transferred from one object to the other would depend would vary. So, the modes of heat transfer that one needs to understand one needs to have an idea of what is the mode of heat transfer prevalent in a specific situation.

So, we all understand that there can be 3 modes of heat transfer, the first is conduction the second is convection and the third which is omnipresent is radiation. So, conduction is essentially the molecules the adjacent molecules 2 adjacent molecules, transfer energy from the hot to the, from the hotter to the cooler molecule, because of their vibration and their interaction.

So, conduction requires the presence of a medium. And the heat gets transferred through a solid or a liquid or a gas by means of these molecular vibrations. So, heat gets transferred from the hot side to the cold side by means of conduction. However, the molecules actually do not move the molecules are static at their place and they only flat fluctuate they only oscillate and through this vibration they transfer the energy from 1 point to the other without living their average position.

So, that is what conduction is on the other hand there are situations in which the molecules around a hot object or a cold object would start to move. So, you may have a hotplate which is kept in atmosphere, where there is a slight breeze blowing on the plate.

So, the molecules very close to the solid surface will get the heat will attain the temperature of the solid plate, but at the same time they will be swept away from the hot surface to be replaced by other molecules which are coming in behind. So, there is a motion there is an imposed or a naturally occurring motion, which is the hall mark of the convection process. When I said imposed and naturally occurring I am referring to 2 different types of convection which I will come in a minute. So, therefore, the convection is characterized by the actual movement of the medium around the hot or the cold object.

So, in this way it is different from conduction. And, when you think of a hot plate which is which is just kept hanging in a room of in a normal room, then there is no flow the fans are not working, it is just a closed room where the air is stagnant. So, what is going to happen is the air which is very close to the hot surface will get heated up it is density will change. In fact, it is density will reduce and it is starts to rise due to buoyancy along the plate and then move away from the plate.

So, the current the set by the temperature difference between the solid wall and the surrounding fluid creates a flow, which is not imposed by an external agency. So, this type of convection are they these types of convections are generally known as natural convection or free convection. In many other situations mostly in enduring applications, you make the cold or the hot fluid move by the application of a pump or a blower for if for the case of your laptop or a fan, which is which is attached close to the hot close to the hot point the point where the temperature is a maximum.

So, you are forcing the air to move over the hot surface there by taking the heat out by convection this is known as force convection. So, we have free or natural convection which is buoyancy driven and force convection, which requires an external agency pumping the fluid over the hot surface. So, that is convection and in many situations you would see that to find out what is the amount of heat transfer that one can expect in a given situation for a definite set of operating parameters like velocity of movement of the fluid, the thermo physical properties and we will discuss what those thermo physical properties could be.

So, they depend the total amount of heat transfer depends on all these operational parameters, the thermo physical properties, the geometry of the system and question and so on. So, we have to find out the appropriate relation for a given geometry given fluid and when the velocity of the fluid is known. So, that is what we are going to do in convective heat transfer the third one is unique because it does not require the presence of a medium and we are referring to radiation.

So, any object which is at a temperature higher than the absolute 0 will emit some radiation and it is going to exchange heat with it is surrounding. So, it does not require the presence of presence of any medium in any object, which is going to emit energy the amount of energy that it would emit, would principally depend upon what is the temperature of the object.

So, the temperature is the temperature of the object is will tell us the quantum of energy which is coming out, but there is a property there is a property involved as well. Fundamentally theoretically the maximum emission, that you can obtain from an object at a given temperature those type of objects are known as black bodies.

So, black bodies can provide can deliver the maximum amount of emissive energy compared to any others any other object. So, then there comes the property emissivity into question the emissivity, tells you the emissivity multiplied emissivity tells you how close the real surface is to and to a black body. So, the emissivity being 1 emissivity has a value from 0 to 1 if the emissivity is 1 then; that means, the surface is behaving like a black body.

So, it is emitting the maximum amount of energy possible at that given temperature. So, emissivity tells you something about the nature of the surface in terms of how close it is to an ideal surface known as black body. Secondly, any energy which is incident on an object is going to be absorbed. Now, the fraction of the energy which gets absorbed in such a case is denoted by another property, which is known as the absorptivity.

Again the black body has an absorptivity equal to 1; that means the anything which is incident on the black body would be absorbed by it and a surface can have an emissivity less than can have an absorptivity less than 1. And there are some surfaces, which are highly polished highly reflective and they do not absorb much of it.

So, for those cases the absorptivity will be close to 0. Now we are going to talk about so what we have done in this is the fundamental concepts of, so, this is the summary of what we have covered; so, far the types of heat transfer and some of their characteristics which are apparent after this discussion. We are now first going to start with conduction.

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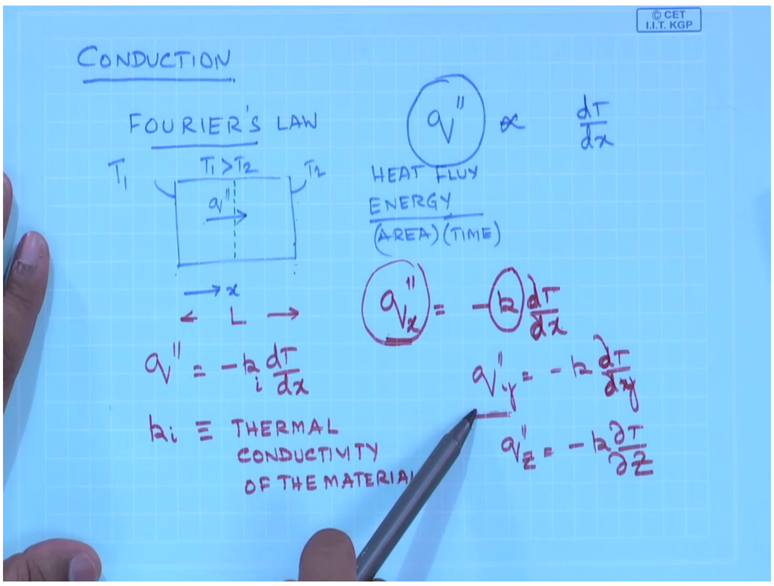

So, when we start with conduction the first law which I think many of you are aware of this is known as Fourier's law. This Fourier's law connects this q double prime, which is heat flux and you understand what a flux is. So, it is energy per unit area per unit time. So, it is a rate of energy which gets transported which gets transported from 1 point to the other per unit area in a. So, if this if we have an object, and this temperature is maintained at T 1 and this is maintained at T 2. And let us assume that T 1 is greater than T 2 then of course, heat is going to move from 1 to 2 location 1 to location 2.

And the heat flux q double prime is the amount of energy transferred from 1 to 2 per unit time and per unit area, when I talk about per unit area it is the area which is perpendicular to the flow direction. So, that is what I mean by area it is the area which is perpendicular to the direction of the flow.

Now, what Fourier observed is that the transfer of heat by conduction between 2 points it is governed by an unique relationship and it is not an equation it is not an law which can be derived from first principles. So, in that way it is similar to Ohm's law. So, when you think of Ohm's law it is the flow of the current is proportional to the potential gradient, so the difference in potential over a certain length of time.

So, the current is proportional to the potential and the proportionality constant is known as the resistance. So, more the resistance less should be the flow or the less the resistance more would be the flow. So, ohms law is obtained not from any first principles, but they have looked at ohm have looked at a large number of experimental data of potential drop verses current and then he realized he understood that there is a linear relationship bit exists between the potential drop and the current.

Similarly, when you look at the amount of heat transfer, which is taking place due to a temperature difference not only difference due to a temperature gradient the heat flux is proportional to the temperature gradient. So, in that sense it is this law is derived or this law is proposed by looking at a number of large number of phenomena, which are related to conductive heat transfer.

So, in this way this Fourier's law is a phenomenological law, which tries to give the express the phenomena that you observe over a large number of systems large number of temperature drops, but interestingly what is observed that this q the heat flux is proportional to d T d x. Where this direction is x and it is proportional to d T d x.

So, what is proposed as known as Fourier's law is equals minus k d T d x. So, this k is the proportionality constant it is it is the conceptually it is similar to resistance or similar to it is it is essentially 1 by resistance. So, this is the cause d T d x and this is the effect which is the heat flux. So, heat flows because of a temperature gradient and the proportionality constant is k. And, you can see that with higher value of k more heat will get transferred by convection for the same temperature gradient. So, if you keep temperature gradient fixed and you choose materials with higher and higher values of k then the heat transfer is going to be more.

So, let us say this slab is of length l and you are maintaining T 1 and T 2 at 2 different temperatures. So, what this simply tells you that q double prime and the double prime denotes that it is a flux is simply going to be equal to minus k d t d x. And, I will call write not k as k i so, where k i is known as the thermal conductivity of the material.

So, the proportionality constant k here is the thermal conductivity it gives you an indication that how easy it is to transfer heat from 0.1 to 0.2. And higher the value of k the amount of heat transfer would; obviously, be more.

So, to give you an example let us think of this as an wooden block. And secondly, let us think that this is a block of copper which has the highest thermal conductivity. So, the materials can be characterized based on whether it is a good conductor of heat or a bad conductor of heat. The same way it has been defined for the case of Ohm's law the whether some material is a good conductor of electricity or a poor conductor of electricity also known as insulators, which are where the conductivity is really small.

So, in heat transfer also the value of k based on the value of k you can classify all the materials which you see every day. So, 1 in on 1 1 hand we have the very high thermal conductivity materials for example, copper aluminum steel and so on. And on the other hand you have materials for which the thermal conductivity is very low and they are known as the insulators.

So, what you what you see as let us say, what is put on the outside of a room, in order to reduce the amount of heat loss from the object let us say the foams which are placed in between the walls, they are poor conductors of heat. So, this thermal conductivity the property would tell you about how fast heat can how fast and how easy it is to move heat from 1 point to the other in the in the solid.

So, the cause still remains temperature gradient remember, it is the grade temperature gradient not the temperature difference, it is the temperature difference divided by the distance over which these temperatures are measured. So, it is d T d x not just delta t. So, conduction depends on the temperature gradient it is proportional to temperature gradient, and the proportionality constant is a property of the material, it is a thermo physical property of the material, which is known as a thermal conductivity. And based on thermal conductivity, you can differentiate between different differentiate between materials.

And you can put them into different categories based on whether it is a very good conductor of heat or a very poor conductor of heat and something in between. If you would look at carefully the equation or the law that I have written q double prime is equal to minus k d T d x, the minus sign in that law simply tells us that heat gets transferred in the direction of decreasing temperature.

So, heat always flows from high temperature to low temperature ok. So, thermodynamics tells us that heat has to energy has to move from high to low to denote the specific directional nature of heat flow the minus sign is provided in Fourier's law of conduction so, that is the significance of the minus sign in the law again. If, you look at once again the q double prime this q double prime is when you have temperature difference in the x direction that is the temperature gradient in the x direction that is the amount of heat which will travel in the x direction.

So, therefore, to denote the directional nature of heat flow sometimes it is the subscript x is provided is added to q double prime to denotes that it is the heat which flows in x direction. If there exists at the at temperature gradient in the y direction then the same Fourier's law can be written as d T d x.

But, since now I understand that temperature is a function of x and so, d T d y temperature is a function of x as well as y, I change the ordinary differentials to partial differentials. And therefore, it gives me the temperature variation with x, where the y is kept constant and this is temperature variation with y where x is kept constant and this simply gives you the heat flux in the y direction and one can similarly write what is going to be the z component of the heat flux.

So, these 3 heat fluxes which have directional dependence directional component is q x q y and q z they are nothing, but the x y and z components of the heat flux vector. So, q double prime the heat flux is the vector quantity ok. And q double prime x q double prime y and q double prime z are the x y and z components of that vector.

So, what we further understand is that heat flux can be expressed in terms of Fourier's law, it is proportional to temperature gradient the proportionality constant is a material property denoted by k the thermal conductivity, the minus sign denotes that heat gets transferred from high temperature to low temperature. And, we also understand that heat flux has to be a vector with q x q y and q z being the 3 components being the x y and z components of the heat flux vector.

So, that is all for now I think if you have any question will interact separately, but what we have in what we have done in summary is what is heat transfer, that is energy in transit, what is the difference between thermodynamics and heat transfer, the different modes of heat transfer. So, in terms of conduction convection and radiation and how radiation is distinctly different from conduction and convection in in in as it does not require the presence of any medium. Radiation also provides us some idea about the object which we which we are dealing with, is it close to a black body such that it can emit maximum amount of energy possible at a specific temperature.

So, what is it is emissivity, if it is equal to 1 it will be a black body, but most of the most of the real surfaces will have an emissivity less than 1, because black body is something like an ideal object ideal surface. Similarly when you have some energy incident on a surface it may not absorb 100 percent of it which a black body does. So, absorptivity will also play a role in defining the nature of the surface.

So, conduction convection and then radiation will constitute the modes of heat transfer which we generally encountered. And finally, we talked about the Fourier's law which is the fundamental governing principle of heat transfer from one point to the other where the heat flow is proportional to the temperature gradient.

So, we will move in to the concepts of the control surface control volume energy balance in the next class.