Upstream LNG Technology
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Lecture – 24
Heat transfer in natural gas systems

Welcome back. See, we have learnt about the fluid mechanics, but we also know that whenever we are doing some processing that heat transfer becomes an integral part whether we are cooling a fluid or heating or when the fluid is flowing through the pipelines there could be external heat, it can heat of the fluid or there could be some other cooling down process.

So, and also we are using many types of heat exchangers during the processing of the natural gas in each of this cases, we need to know, how the heat transfer takes place with in a medium or between two medium.

So, for this, we will be looking into some basics of the heat transfer which would be necessary for evaluation and analysis of the various types of processes in the natural gas systems.

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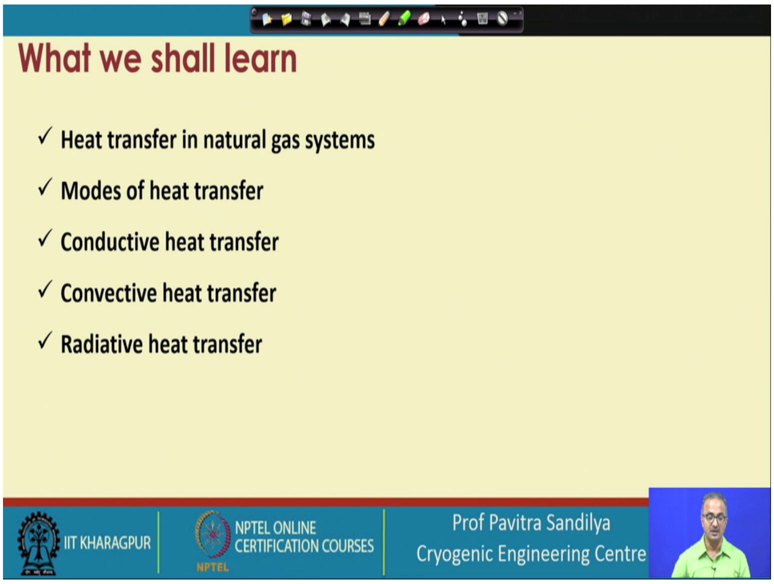

So, we shall be talking about heat transfer in natural gas systems. In this particular lecture, we shall be learning about heat transfer in natural gas systems, then whereas, modes of heat transfer like conductive heat transfer, convective heat transfer, radiative heat transfer,.

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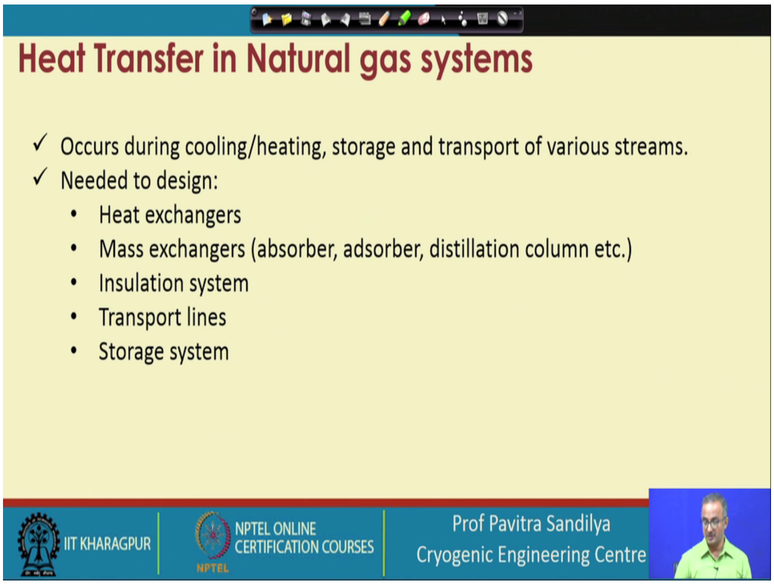

So, let us first figure out that where do we encounter heat transfer in natural gas systems. Now this heat transfer occurs during cooling or heating as I told you of the various types of process fluids during storage because whenever we are storing the natural gas. It is some time stored in is liquid form.

So, we need to take out the extra heat. So, that it can be condensed to liquid or during storage of the liquefied natural gas that from external surroundings will be some heat flux which will be going inside the storage tank and that will cause some evaporation of the natural gas.

So, there also be need to know that what is the heat flux from the ambient in to the storage tank and later on the various types of transport of various streams, we were there will be some kind of heat transfer involved. Now as I said that by the knowledge of heat transfer, we can design the heat exchangers or the mass exchangers like absorber, adsorber, distillation column, etcetera, then we have insulation system and transport lines and the storage system for designing of each of this components, we need to have some understanding of the heat transfer.

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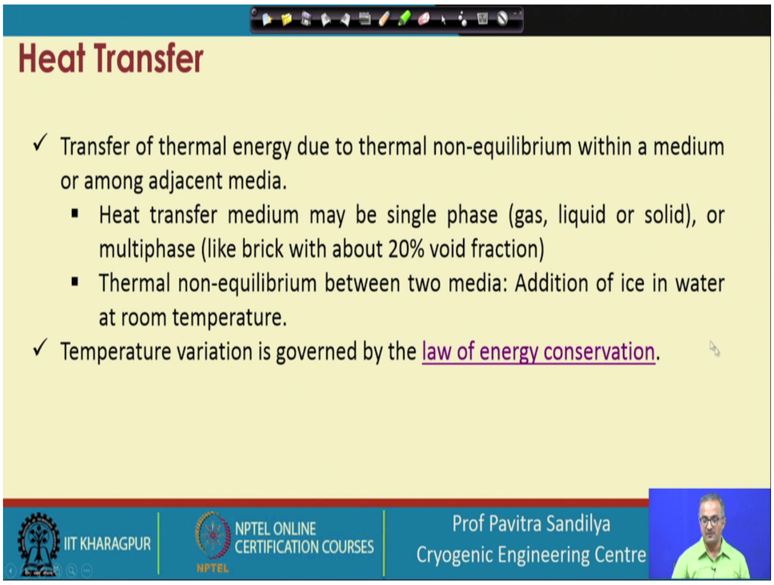

Now, first let us see that what is meant by heat transfer. Heat transfer is the transfer of thermal energy due to thermal non equilibrium with in a medium or among adjacent media; that means, the heat transfer will be or taken in terms of only thermal energy transfer and not any energy form because we know that energy can exist in various forms like sound energy is another form of energy so, but this heat transfer is mainly concern with only thermal energy transfer and that is due to a thermal non equilibrium.

So, whenever a system is under not under thermal equilibrium; that means, there will be some kind of gradient in the system or with between two systems. So, this is non equilibrium, there could be this heat transfer taking place. Now, heat transfer may be within a single phase for example, with in a gas or a liquid or a solid or in a multiphase system, for example, we are brick in the brick, we know that brick is a pours material and the void age that is a void fraction in the brick is about 20 percent; that is it has both solid phase as well as a gases phase core existing and that is how it becomes a multi phase system and there will be some kind of heat transfer through the brick.

So, this also is a multi phase system heat transfer and thermal non equilibrium between 2 media and example, we can see from date today life that. Suppose, we are having a glass of water at ambient condition and in that we add ice say from a refrigerator into the water and if we add it the ice may be at very low temperature 0 to centigrade and water ambient temperature.

So, because of this 2 temperature differences there is non equilibrium between the 2 systems. So, what we observe that the water will tend to cool down, whereas, the ice will tend to melt and slowly, it will also resist temperature. So, because of this differences in the temperature where there will be heat transfer between the liquid water and the solid ice.

Now, the temperature variation is governed by law of energy conservation and what is this energy conservation.

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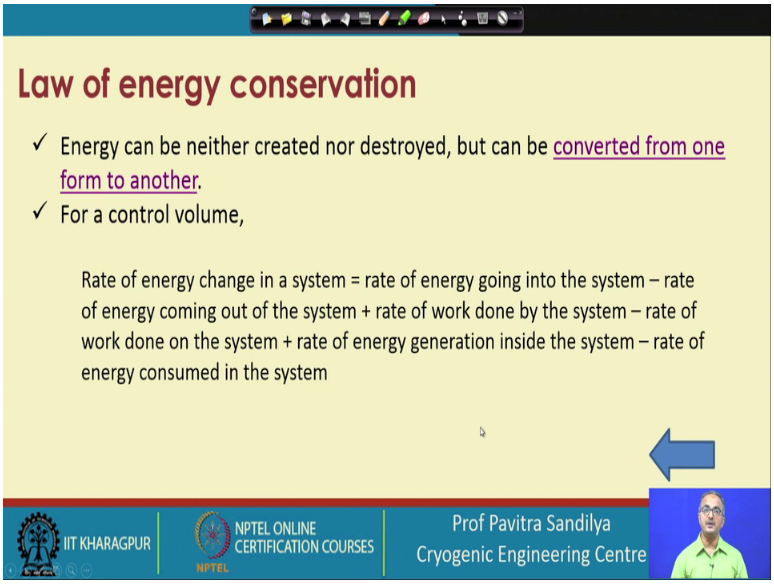

We know that this law says that energy can neither be destroyed nor can be generated or created. Now but it can change its form, it can be converted from one from to another and we can see this.

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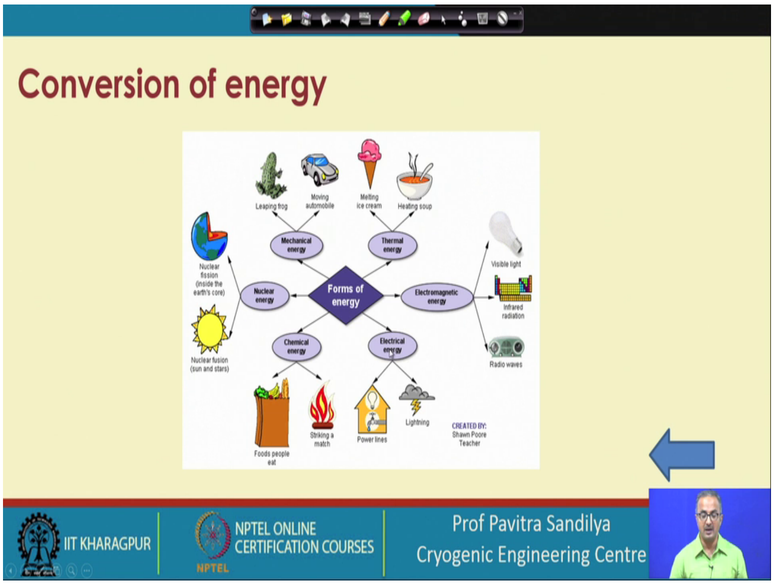

In our day to day life, like here, we have different forms of energy like mechanical energy, thermal energy, electromagnetic energy, electrical energy, chemical energy, nuclear energy.

Now, here we see that for example, mechanical energy. Now mechanical energy is used by us for every human being or the animals for their movement. So, for here, we have shown a frog which is leaping and it is using the mechanical energy. Similarly, a car driving is using mechanical energy, then we have thermal energy. For thermal energy like the melting of the ice cream is a thermal energy, then we have heating of some kind of material like water like when we are making tea or we are heating of from milk, coffee, etcetera, they all are coming to thermal energy.

Then we have electromagnetic energy in this we have the visible light we have infrared radiation which we use a many a times for medical purposes performentation and then we have radio webs, then we have electrical energy and this electrical energy as you see that we are using electrical energy for heating up they are our geysers, we are even electrical energy to heat up water.

So, here we have lighting also lighting in the during the rainy season lighting also produces electrical energy and when we are power lies. So, these are using the electrical energy and then we are chemical energy due to the combustion of some material or the food we are in taking that food is also getting combusted inside our body and producing energy for our activities.

So, it is that is why it is shown food that is food using the chemical energy and then you have a nuclear energy that is coming by fusion and fission that is that from solar energy. For example, that is coming through the nuclear fusion and then we have nuclear fusion fission that is which is happening inside the core of the earth. So, this is how we find that we have we have dealing with various types of energy in our day today life for various types of activities.

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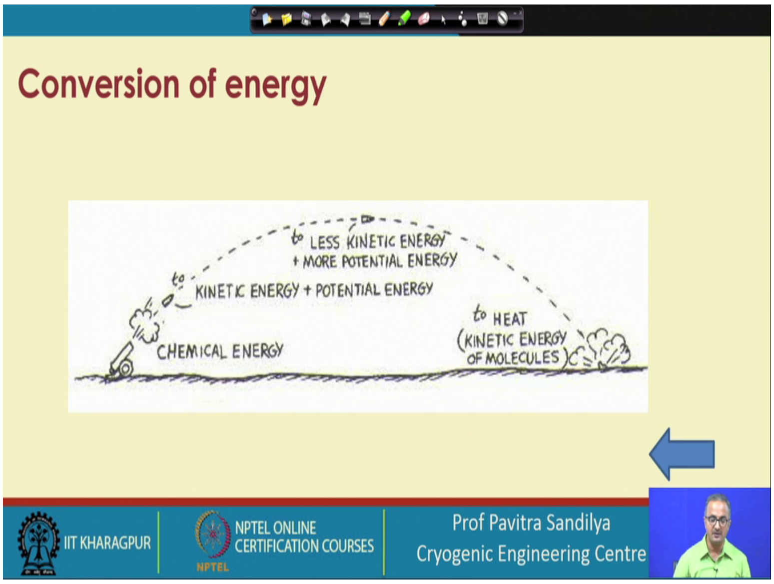

In this particular figure, we are showing that how a particular energy is getting converted from one form to the other during a process, here, we have showing that there is some kind of missile which is being a shooting some missile will being shot here and initially, we have the chemical energy and as the missile is moving up what we are finding that it is gaining the potential energy and the kinetic energy and the total energy remains conserved that is it is the constant.

Now, as it moves some at certain point of time that we find that it will go to a particular height and then it will again start coming down as it is starts coming down, we find let it loose it the potential energy, but gains in the kinetic energy and ultimately when it heats the target what happens the chemical energy within the missile gets converted to heat energy.

So, that is how we see that how this particular missile is gaining the kinetic energy gaining the potential energy and again losing them and ultimately the chemical energy is coming into effect which is causing the heating up of the material and this heat, we know that this causes explosion and by this explosion many destruction takes place.

So, when whenever we want to analyze this kind of energy conservation which is also the statement of the first law of thermodynamics, it says that it pertains to a particular system and we call it a control volume, this we perhaps know that rate of energy change in a system is given as the rate of energy going into the system minus the rate of energy coming out of the system plus rate of work done by the system minus the rate of work done on the system, the rate of energy generation inside the system minus rate of energy consumption inside the system.

The energy generation or consumption may occur due to some kind of reactions like fission fusion or some kind of chemical reactions, if there is no chemical reaction or any kind of there is kind of fusion or fission with generally neglect the consumption or the generation of the energy.

Work done has you know that we in is to get the work to we do the work on a system took to or we can get on the work out to the system also like in gets of pump for compressor, we are doing work on the system whereas, for the turbines we at the work is produced by the turbine.

So, in this way also, we find there will be some energy change inside the system.

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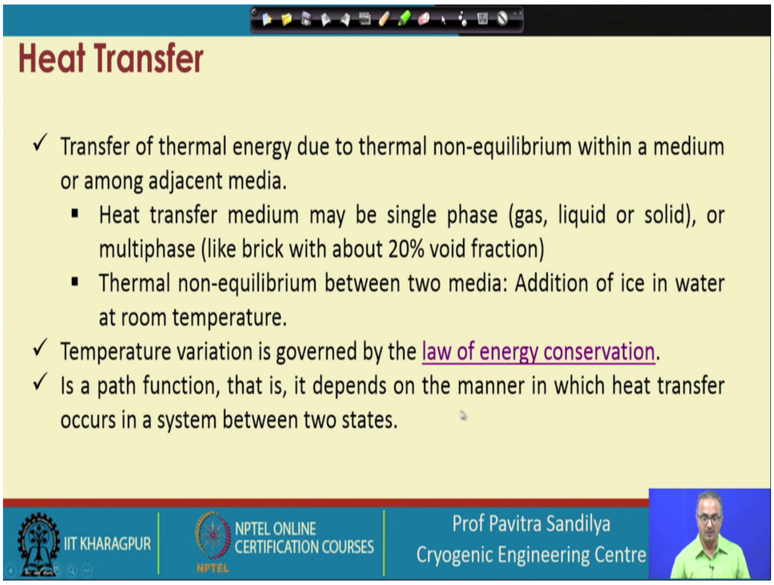

Now, the energy transfer is a path function by path function we mean that whenever there is a energy transfer, the a system can go from one state to the other. Now by the way the energy is getting transferred the within this two states, we will find the amount of energy required will be different, yes, we contains different ways of going from 1 state to the other.

For example, if we are heating up from one temperature to other, we can heater either we can heat up by say some any means electrical heating or be we can is a chemical heating ah. So, various waves I can heat of the system and for each of the systems I will find, I will be requiring different amount of energies.

So, that is how the energy becomes a heat transfer becomes a path function.

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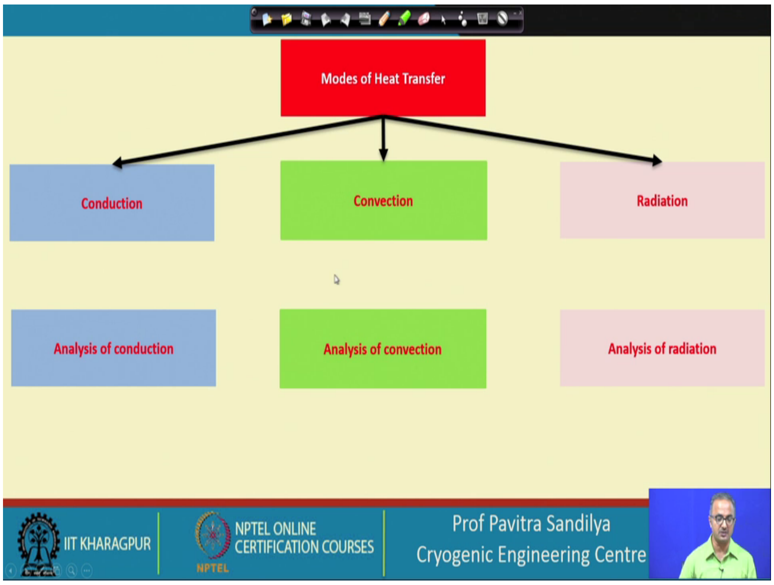

Now, there are different ways, the heat can get transferred and these ways are broadly classified into three ways that is conduction then convention and radiation. So, we know that what is conduction.

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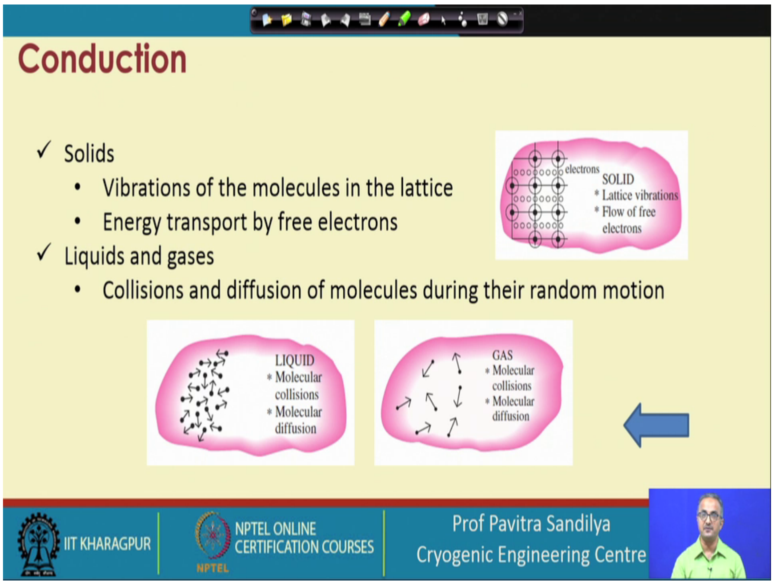

In the conduction, heat may heat transfer, what happens in case of solids, here what we are showing that is a solid the vibrations of the molecules in the lattice and the energy transport by the free electrons.

So, these are the two modes by which within a solid, we find that the energy gets transferred the lattice means a particular structure which holds the various molecules inside the solid and there are may be some free electrons which will moving freely here and there and depending on the number of free electrons available the rate of a conduction will change.

And similarly we also have a conducting a heat transfer in the liquids and gasses and in this case we know that in case of liquids and gases the molecules are held loosely because of is they random motions. So, this the random motion causes collisions between the liquid and solids and they will diffusion; that means, penetration of one a molecule into the other molecules.

So, this way what happens both collisions and diffusion they help in the conductive heat transfer within the liquid and gas and that is how this mechanism of conductive heat transfer is liquids and solids is different from the mechanism the of conductive heat transfer in a solid.

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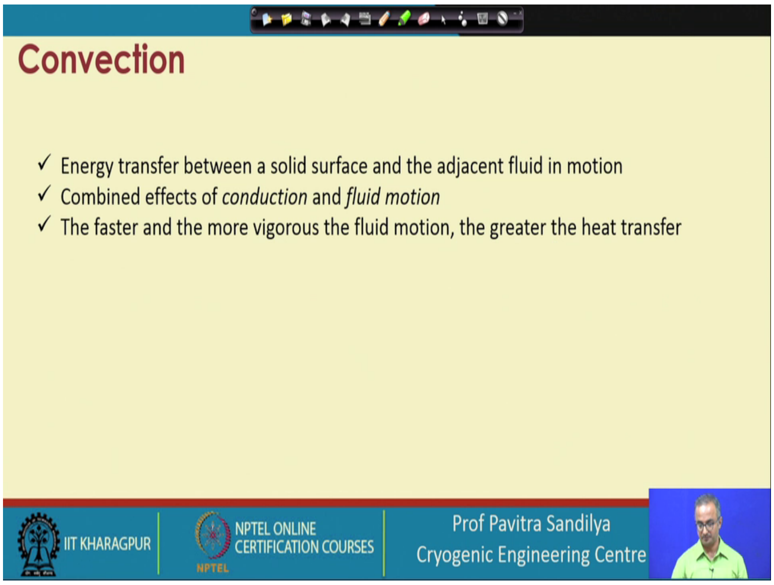

Next we come to the convection heat transfer in the convective heat transfer, we know that energy transfer is happening between a solid surface and some adjacent fluid in motion. Now this is very important for us to know, but in this case the fluid must be motion, if it is tangent fluid, then it will be only conductive, but when there is a motion involved. So, it will be both conductive and convective which will coming into picture and if the fluid flow becomes more and more the convective the heat transfer becomes more and more dominating over the conductive heat transfer.

So, the faster the and more vigorous the fluid motion the greater is the heat transfer due to convection.

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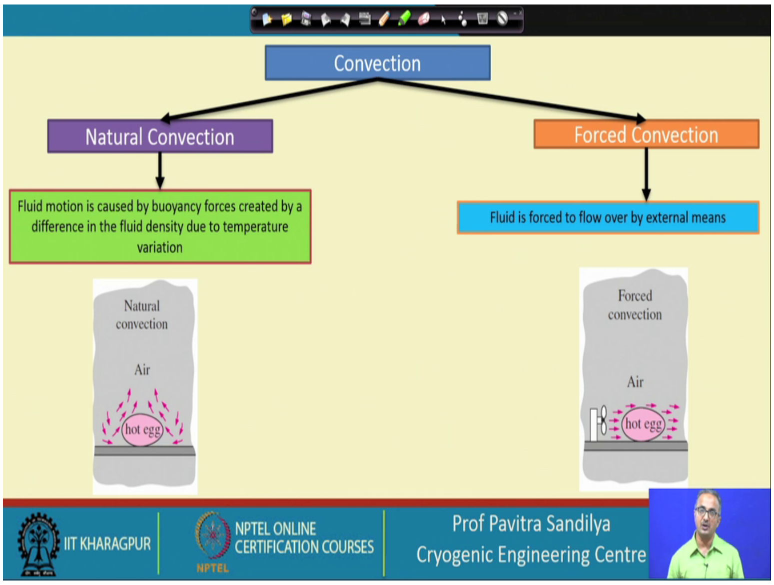

And here we have that two types of convection. One is the natural convection, another is the forced convection. Natural convection occurs due to the buoyancy force and buoyancy force comes into effect whenever there is a density difference.

So, for example, if there is some whenever we are heating a water in a pot over a oven, what we find of water which is in touch with the surface of the oven will get heated up and it density will decrees and that is how it will try to move up whereas, the water which is away from the cattle surface cattle wall will be at a lower temperature. So, it density will be more. So, it will tend to come down.

So, because of the density difference, there will be a motion will come into effect that that is the water the cooler water from top will come down and the hotter water from the bottom will move up. So, this is the natural convection, here it is shown that the hot egg and air is there. So, the hot egg is the air near the hot egg is getting heated up and thus, it density is decreasing whereas, the air away from the egg is having lower temperature. So, that is denser. So, what will happen? There will be a convective current from the egg to into the air and then we have the forced convection in this we find that with the medium is forced to move.

Here we have shown it by some fan. So, whenever we are having hot egg what we do sometimes we switch on the fan. So, water whenever we want to cools something say, we want to cool milk or we want to cool some food what we do we switch on the fan at our home and by switching on the fan.

What we are doing? We are trying to brief the convective heat transfer and this convective heat transfer that is causing the forced convection over the hot surface and that is how we find that the material the hot material it get cool down faster than when it is under natural convection.

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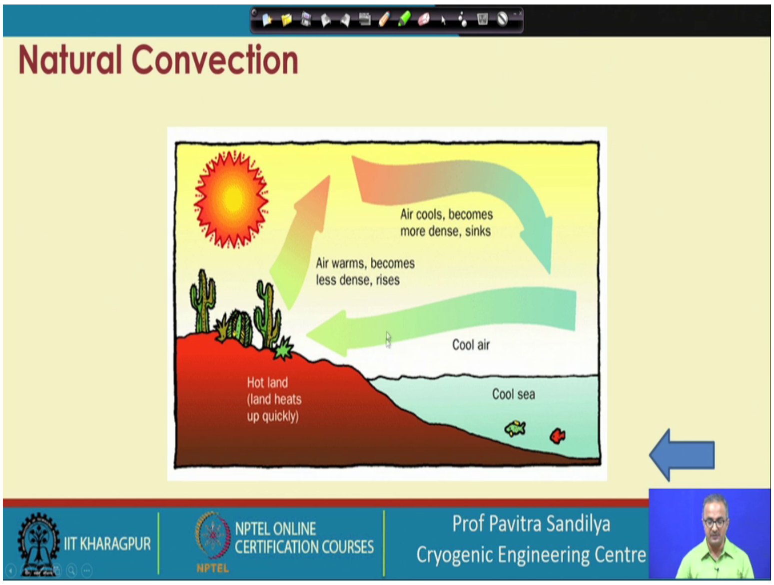

And here, we have shown the a picture where be find that how the natural convection can be seen in nature here we find that there we have a sea and there we have hot land.

Now, what happens? The cool air, we tend to go towards this hot land and because of the sun there will be this air near this one will be heated up. So, the hot air which will try to move up and then as it moves up. It gets cold and colder and then as it get colder, it is density increases and now it will tend to come down and as it tend to come down.

Again this air gets cooled and again if move towards the hot land and this way there is a circulatory motion which starts in this particular way and we get this warm and hot air circulating over the land and the sea.

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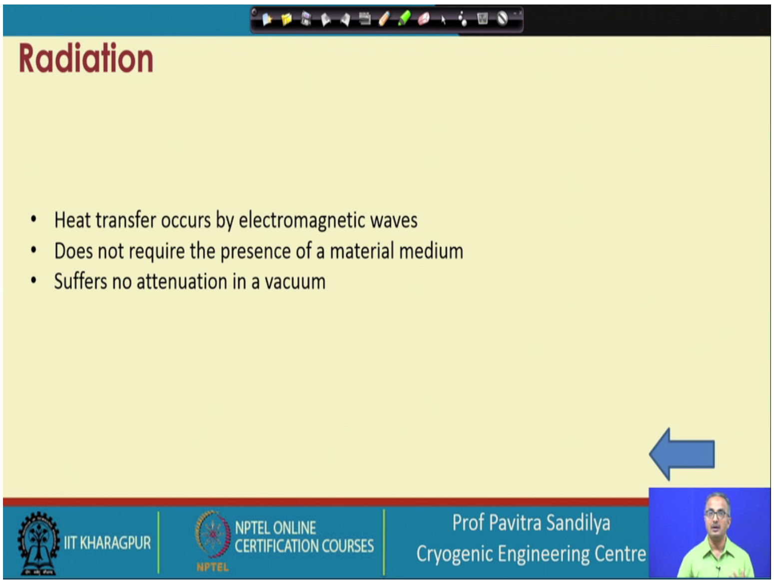

Next, we come to radiation heat transfer the radiation heat transfer occurs in entirely in different manner and it occurs due to the electromagnetic waves. Now whenever there electromagnetic waves, we do not need any kind of material medium that is we do not need any solid or liquid or gas, it can also a occur in a vacuum due to the existence of the electromagnetic waves.

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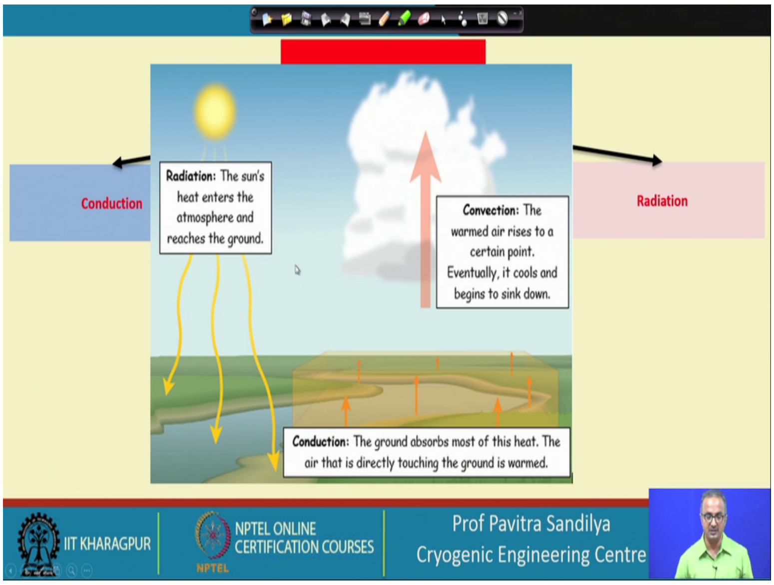

After learning about three modes of heat transfer next we come to a combined heat transfer effect which we seen the nature that the sun’s ray is causing radiation heat transfer with enters the atmosphere and its heats up tends the heat up or the water bodies or land, then we have conduction in this conduction what is happening that a ground is observing the heat from the sun and the air is which is in touch with the ground is getting heated up by the conduction and then this air is going to the sky and it is forming the along with it, it is also carrying the water vapor which is forming the cloud. So, this is occurring due to the convection.

. So, here we find the nature that how radiation conduction and convection take place it simultaneously, after learning about this 3 modes of heat transfer in brief. Now we go to again some rudimentary analysis of this 3 modes of heat transfer first, we come to the conductive heat transfer in the conductive heat transfer; we go with the Fourier’s law of heat conduction.

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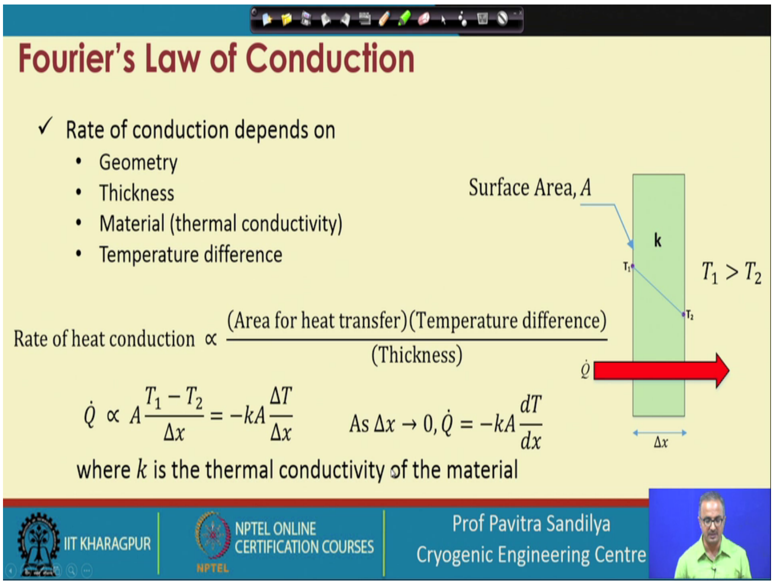

Now, in this case the rate of heat conduction depends on the geometry of the material the thickness of the material through which the heat is getting transferred the material of construction because there is some particular property thermal conductivity which depends on the material and the temperature difference. So, this can be written like this the rate of heat conduction is proportional to the area for heat transfer the temperature difference and inverse a proportional to the thickness of the material that is the more the thickness then less the rate of conductive heat transfer.

Here we have shown the material of certain thickness delta x and there is a temperature gradient T 1 to T 2; T 1 is more than T 2 and this is the surface area through which the heat transfer Q dot is taking place. So, if I put this, we put this thing, we find that we can replace the proportionality constant with a proportionality with a proto constant k and this k; this k is the thermal conductivity of the material and in the extreme them delta x that is a thickness of the material tends towards zero that is goes very small then this delta t by delta x is given by dT by dx.

So, this particular equation is the Fourier's law of heat conduction.

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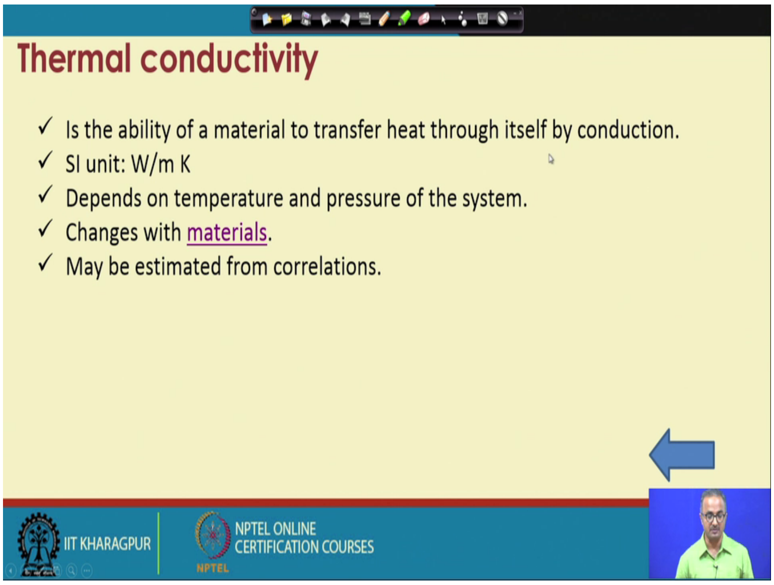

And the thermal conductivity is the ability of a material to transfer heat through itself by conduction. So, it has it has a SI unit of watt per meter per Kelvin, the value of this thermal conductivity is a function of both temperature and pressure of the system and it is a function also of the materials.

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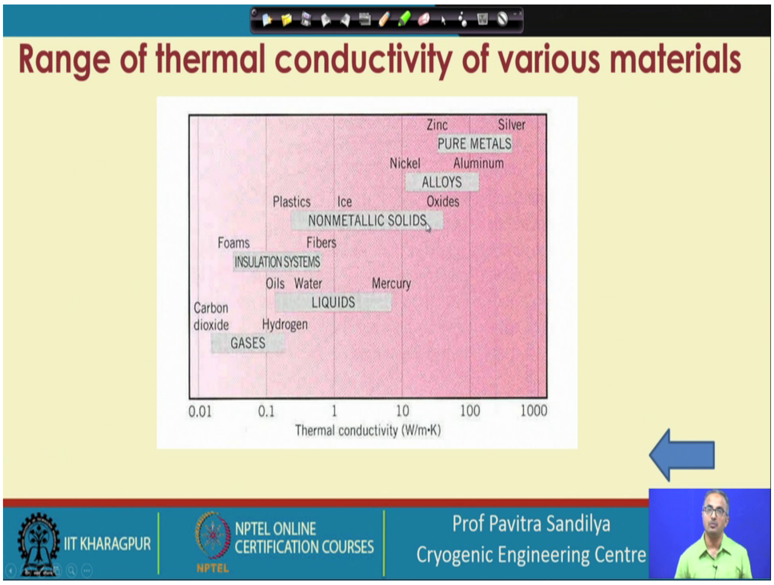

And as we know there are various types of materials like very highly conductive materials like pure metals, silver, aluminum, zinc, etcetera and then we have very low conductivity material like nonmetallic solids ice plastic fibers etcetera.

Then we have insulations, then we have liquids and lastly, the gases or the once which have the lowest of the thermal conductivities. So, depending on the type of material, we find that the it can have very high thermal conductivity to very low thermal conductivity and this thermal conductivity may be estimated from various types of correlations which are developed from excremental data.

Next, we come to the convective heat transfer analysis.

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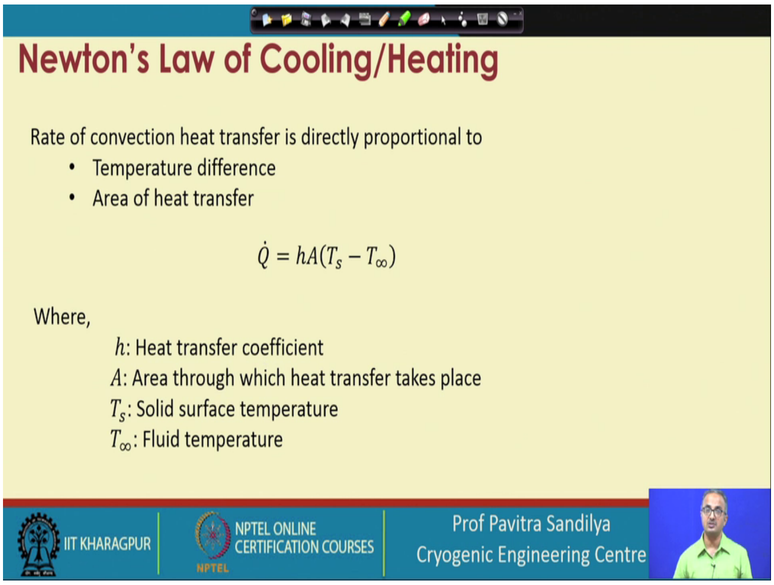

Here we use the Newton's law of cooling or heating and this is says that the rate of the convection heat transfer is directly proportional to temperature difference and the area of heat transfer. Now here is the statement that Q naught is equal to dot is the proportional to area and the temperature difference and the proportionality is repressed by a proportionality constant that is h.

And this h is the heat transfer coefficient unlike the thermal conductivity heat transfer coefficient is not a property of the material, but a property of the system has a whole that is how the particular fluid is moving what kind of geometry, it is moving through this all dictate the value of the heat transfer coefficient.

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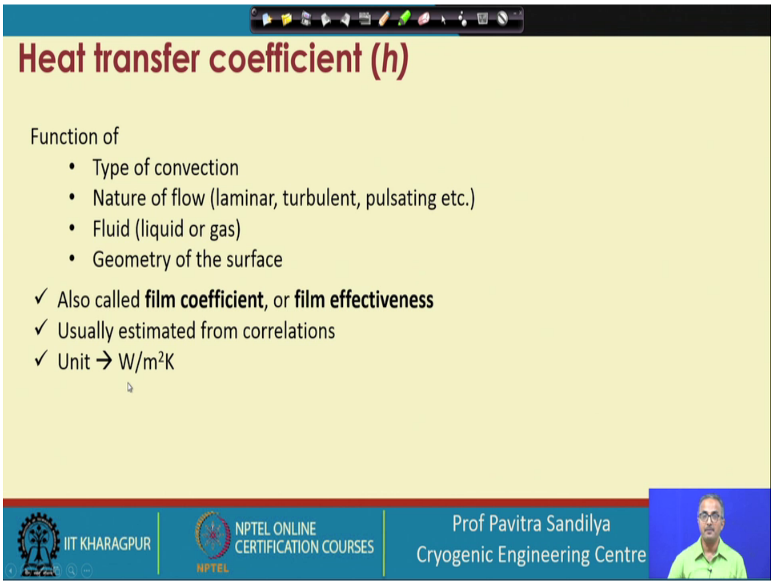

So, here we see that it is a function of the type of convection that is natural convection or force convection nature of the flow whether, it the flow is laminar turbulent or pulsating flow etcetera then what kind of fluid we are handling where it is gas or liquid and the geometry of the surface, it is sometimes also called film coefficient or film effectiveness and it is also estimated from various types of correlations for various types of systems the SI unit of this is watt per meter square per Kelvin.

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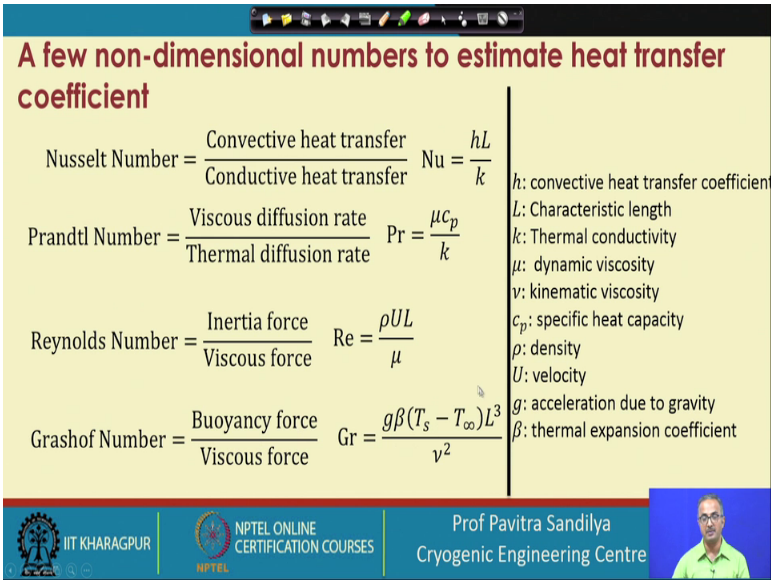

To estimate the heat transfer coefficient, generally, many non dimensional numbers are proposed some of them are given here like Nusselt number is the ratio of the convective heat transfer to the conductive heat transfer in the material and is given by a nu as hL by k h is the heat transfer coefficient l is the characteristic length and k is the thermal conductivity of the fluid.

Then we have the Prandtl number which is the ratio of the viscous diffusion rate to the thermal diffusion rate that is nu Cp by k, then we have Reynolds number that is the ratio of the inertial force to the viscous force and given by density of the fluid the velocity of the fluid the characteristic length divided by the dynamic viscosity of the fluid and we have Grash of number which is used in case of natural convection and is the ratio of the buoyancy force to the viscous force and is given by particular this formula.

Now, all this these are some of the non dimensional numbers which are used to find represent the heat transfer coefficient.

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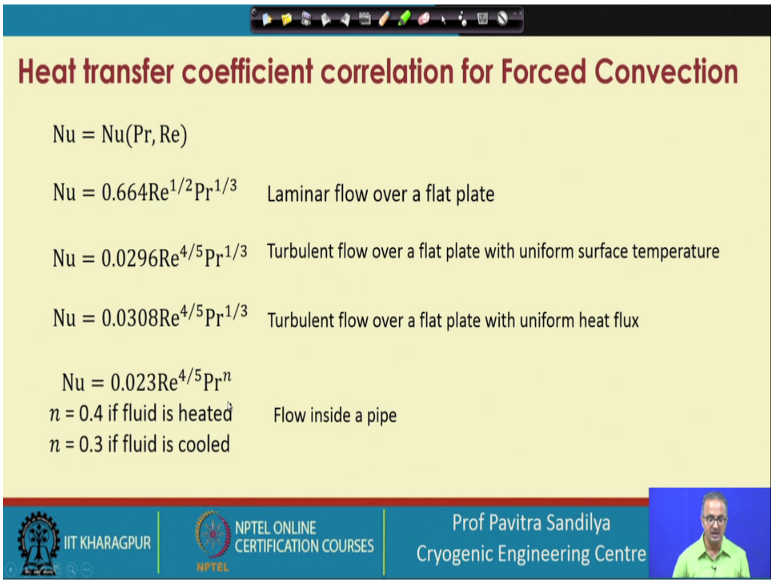

And here we are giving you some heat transfer coefficient correlation for forced convection, here we have shown for different cases like this is for the laminar flow over a flat plate and then we have the turbulent flow over a flat plate with uniform surface temperature, then we have turbulent flow over a flat plate with uniform heat flux and then we have flow inside a pipe.

So, you can see here that in most of the cases that the Reynolds number and Prantile number coming into picture for the forced convection and you see the various types of coefficients values are there for various types of flow and in this particular last one we see that depending on whether the fluid is getting heated or getting cooled we have different power of the Prantile number this is for a shows a inside a pipe.

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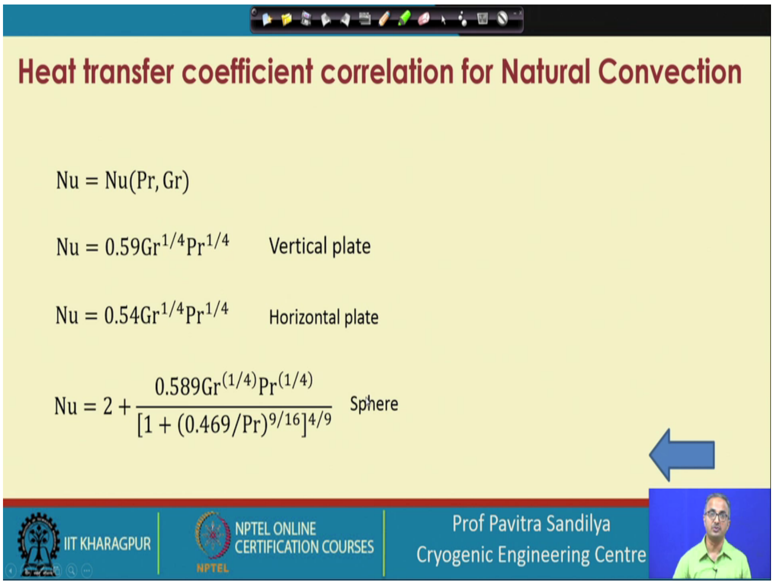

Now, we have the heat transfer coefficient correlation for natural convection here we see that the Nusselt number is given in terms of the Grash of number and the Prantile number that is for the natural convection Grash of number replaces the Reynolds number which is used in the forced convection again, we have different types of correlation for vertical plate for horizontal plate and for sphere for the natural convection.

Lastly, we go to the analysis of radiative heat transfer.

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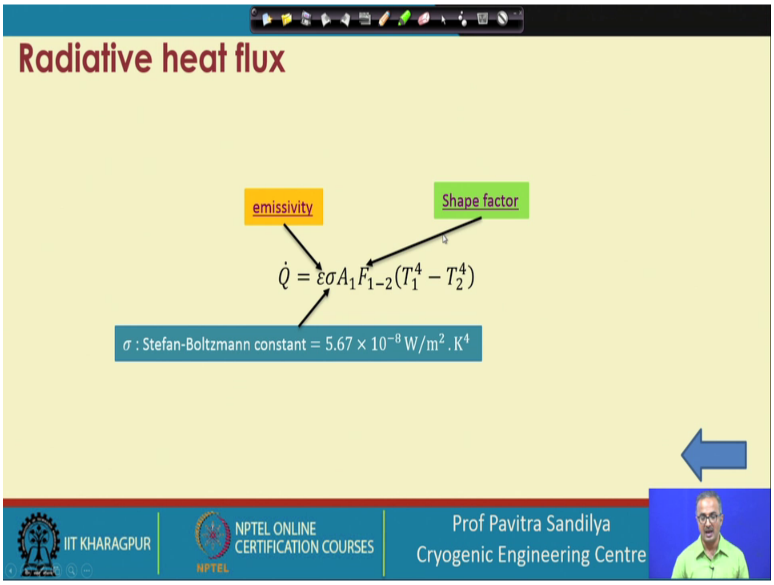

Here, we have the famous equation this is given by the this equation here we for a emissivity.

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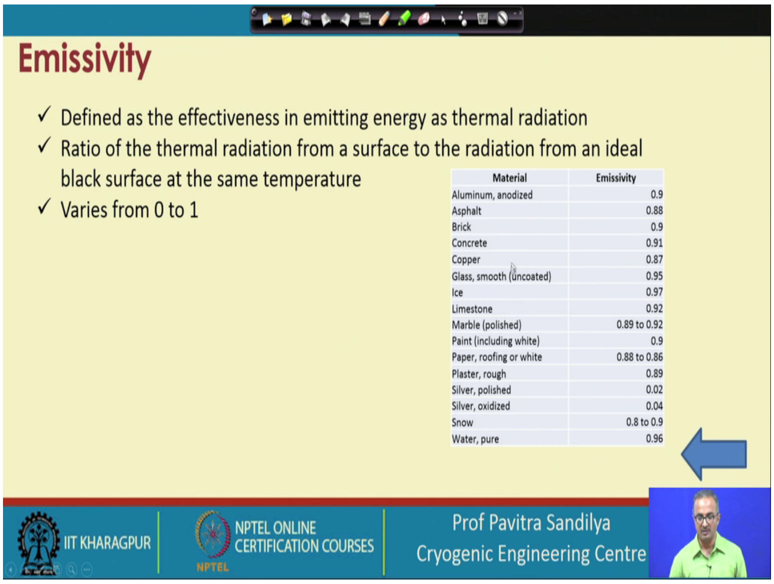

This emissivity is defined as the effectiveness of a surface in emitting the energy as thermal radiation and it is a ratio of the thermal radiation emitted from the surface to the radiation from an ideal black surface, perhaps, all of you know the black body or those bodies with absorb all the radiations incident on it and the emissivity varies from 0 to 1 and here we in this particular table we have the emissivity's of varies types of materials from the metals to the nonmetals and to the liquids.

Then we have the Stefan Boltzmann constant and a shape factor which depends on the orientation of the surfaces 1 and 2 from between which the radiative heat transfer taking place this 1 and 2 represents 2 surfaces and this shape factor.

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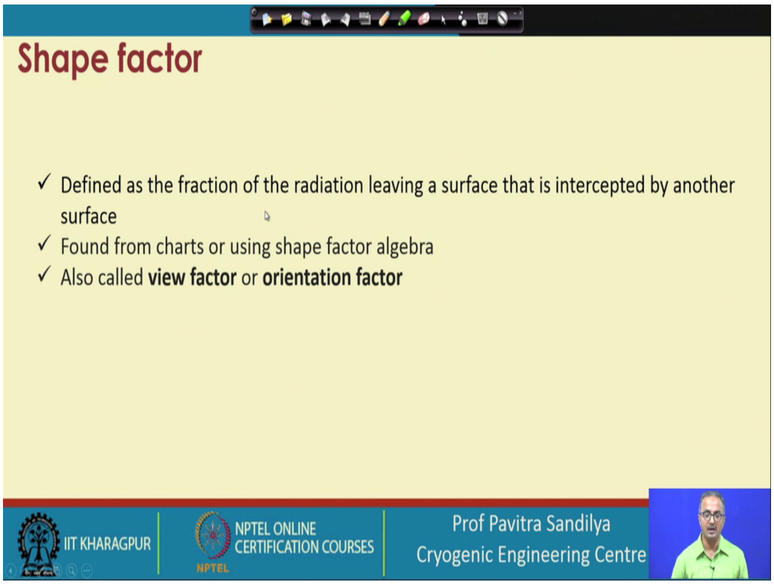

Is the fraction of the radiation leaving a surface that is intercepted by another surface and it is generally obtain from some charts and it is also called view factor or orientation factor.

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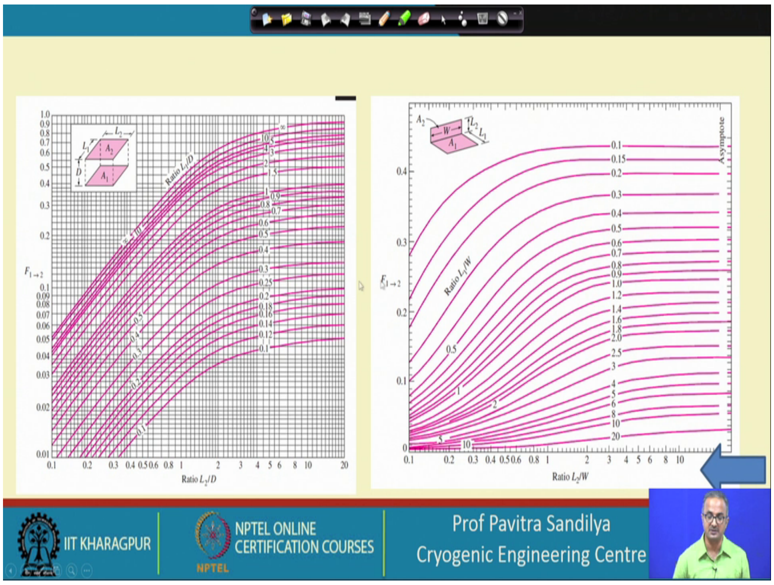

And here we find the charts are given to find out the value of the shape factor and here we find the dimensions are given we have to know the dimensions of the particular systems of the 2 surfaces A 1 and A 2 and we just find out this ratios and with ratios, we can find out the values of this F 1 2, this is the shape factor.

So, with this values, then we can use in this particular formula and T 1 and T 2 are the 2 temperatures of surfaces 1 and 2 with this we see that we look into the various types of heat transfer that that takes place.

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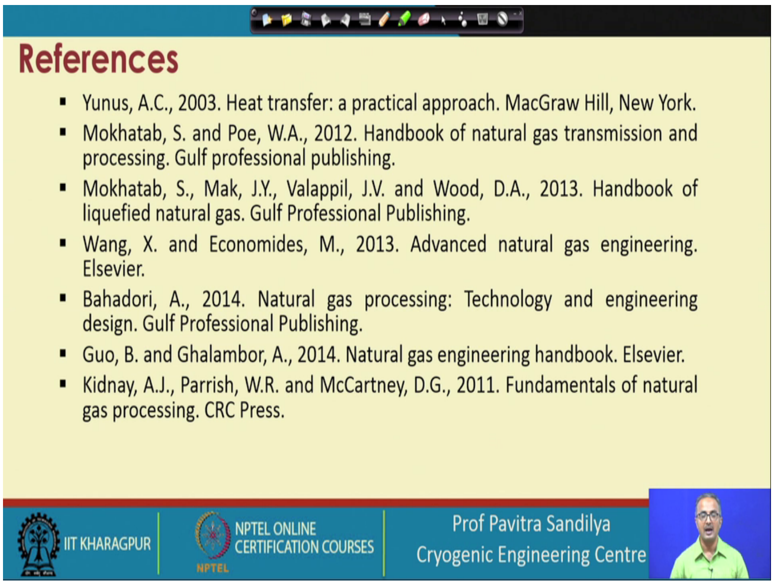

And more of this can be found from the following references.

Thank you.