Fundamentals of Convective Heat Transfer
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Module - 01
Introduction
Lecture - 01
Application of convective heat transfer

Hello everyone. Welcome to this course on Fundamentals of Convective Heat Transfer. I am Professor Amaresh Dalal from the Department of Mechanical Engineering of IIT, Guwahati. In today's lecture, we will introduce convective heat transfer, then we will see few Applications of convective heat transfer, then finally, we will discuss about the course contents.

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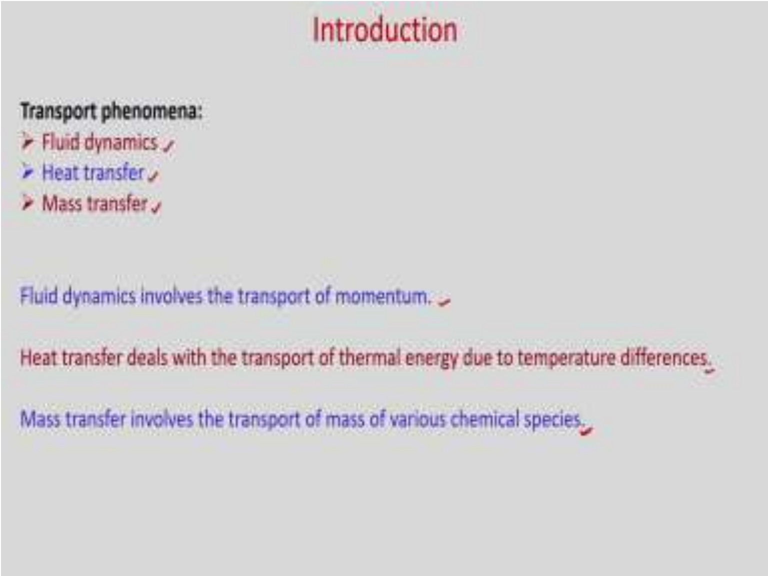

Transport phenomena: what is transport phenomena? Transport phenomena is the subject which deals with the movement of physical quantities in mechanical and chemical processes and describes the principles and laws of transport.

Transport phenomena includes three closely related topics; these are fluid dynamics, heat transfer and mass transfer. You can see fluid dynamics involves the transport of momentum. If you consider flow inside a pipe, then you know that fluid flow occurs from high pressure region to low pressure region.

So, pressure difference is the driving force for this fluid flow. Next, heat transfer deals with the transport of thermal energy due to temperature difference. So, heat transfer takes place from higher temperature region to lower temperature region. So, obviously you can see that temperature difference is the driving force for heat transfer. Mass transfer involves the transport of mass of various chemical species.

So, if there is a concentration difference, then mass transfer will take place from higher concentration region to lower concentration region. So, here concentration difference is the driving force for mass transfer.

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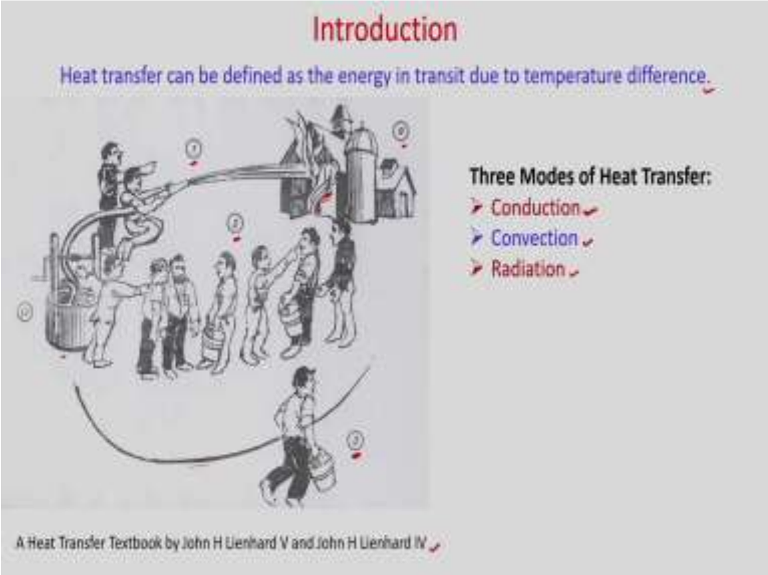

So, as we discussed, heat transfer can be defined as the energy in transit due to temperature difference. We all know that there are basically three fundamental modes of heat transfer namely; conduction, convection and radiation. You can see these illustrations. These we have taken from this book. From these illustrations, it will be easy to describe this heat transfer mechanism. This is the building which is on fire and this is the closely available well where water is available.

Let us assume that there is no quick availability of the fire engine, so this group of people is trying to extinguish this fire. So, here you can see that this group of people in three different ways, they are trying to extinguish this fire, taking water from this well. You can see in the first one, these people are taking the water from the well directly and with using some pump through this hosepipe, they are directly putting this water on the fire.

So, you can see there is no movement of the people. They are directly just using the water and putting this water on this fire. In the second mode, you can see that there are group of people and the person who is near to the well; he is taking the water in the bucket and passing to the next and next person passing this bucket to the next. And that way they are actually passing this water bucket to the person who is near to the fire and he is putting this water in this fire.

So, you can see that there is no movement of these people, but they are actually passing the water bucket from one to the next and they were trying to extinguish this fire using this bucket of water. In third way, you can see this man is very energetic and he alone is taking this water from the well in the bucket and running to this building, putting the water on the fire to extinguish the fire.

So, you can see there are three different ways they are trying to extinguish this fire. In the first mode, they are not moving, just directly putting the water. In the second mode, these group of people they are passing the bucket to the next and trying to extinguish this fire. And in the third way, the person himself is taking the water and running to this building and putting the water on the fire.

So, now you can compare these three ways with the three modes of heat transfer. First, let us discuss about the second mode. You can see they are passing the bucket from one to another and these are comparable with the conduction mode of heat transfer, because in conduction mode of heat transfer lattice vibrates. And due to the movement of these atoms heat transfer actually takes place from one atom to another and it passes the heat from one end to the other end.

So, you can compare this second way which way they are actually trying to extinguish the fire with the conduction. Now, you consider this third mode here. So, this person is actually moving and trying to extinguish this fire. So, this is kind of convection. So, convection, takes place due to the presence of fluid flow and you can compare this mode with the convection.

In the first mode, you can see here. Actually, they are directly putting the water on the fire and there is no movement. So, this mode you can compare with the radiation.

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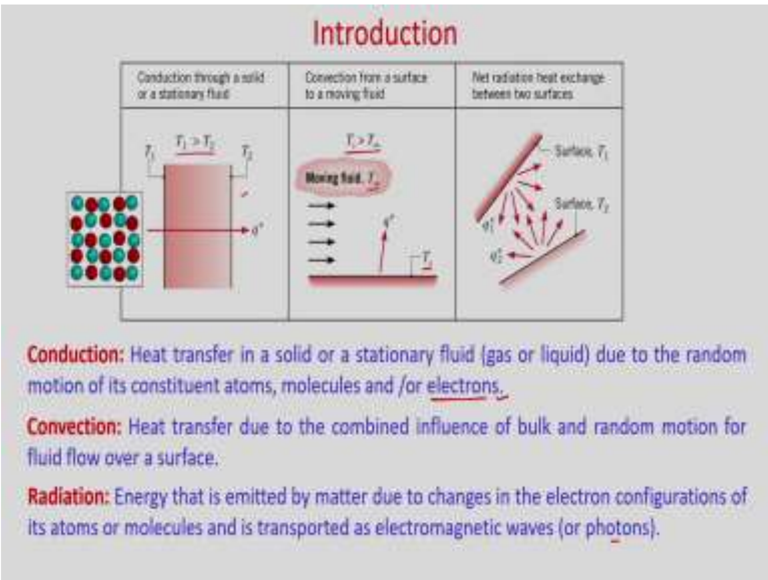

So, now let us define these three modes of heat transfer. Conduction: so, heat transfer in a solid or a stationary fluid gas or liquid takes place due to the random motion of its constituent atoms, molecules and or electrons.

You can see the conduction through a solid or a stationary fluid. This wall temperature is T_1 and the this wall temperature is T_2 and, let us assume $T_1 > T_2$. So, obviously, heat transfer takes place from a higher temperature region to the lower temperature region, so in this direction heat transfer will takes place. And as it is a conduction mode of heat transfer, you can see there will be vibration of lattices. And these atoms when they vibrate, they actually carry the heat from one to the other.

So, generally in lattice vibration, due to this lattice vibration this conduction takes place, but if it is a conductor, then there will be a movement or translation of pre electrons and due to that there will be heat transfer. Next, let us discuss about the convection. Heat transfer due to the combined influence of bulk and random motion for fluid flow over a surface. So, you can see this convection heat transfer takes place due to the combined influence of bulk and random motion of fluid flow over a surface.

So, this is the surface that maintains the temperature T_s and there is a moving fluid over the surface and this moving fluid temperature is infinity. Let us assume that surface temperature is higher than the fluid temperature, then obviously, heat transfer will take place from surface to the fluid. In this mode, you see that the fluid which is just residing on the top of the surface, it is in direct contact with the surface. And here, conduction mode of heat transfer will take place; from the surface to the immediate fluid molecule.

From those fluid molecules, due to the advection there will be heat transfer. So, you can see in convection heat transfer, there are two different ways heat transfer is taking place. First from the surface to the immediate fluid molecules heat transfer is taking place due to the conduction, and then due to the fluid flow means advection. So, you can say that it is advection influenced conduction. Now, you see the radiation.

So, energy that is emitted by matter due to the changes in the electron configurations of its atoms or molecules and is transported as electromagnetic waves or photons. So, here you can see that net radiation heat exchange between two surfaces. So, this surface is maintained at temperature T_1 and surface temperature T_2. So, there will be just heat transfer due to radiation. Any matter at any temperature can emit radiation and generally radiation does not need any medium to transfer the heat.

It actually effectively transfers the heat in vacuum; however, in conduction and convection you need medium for heat transfer.

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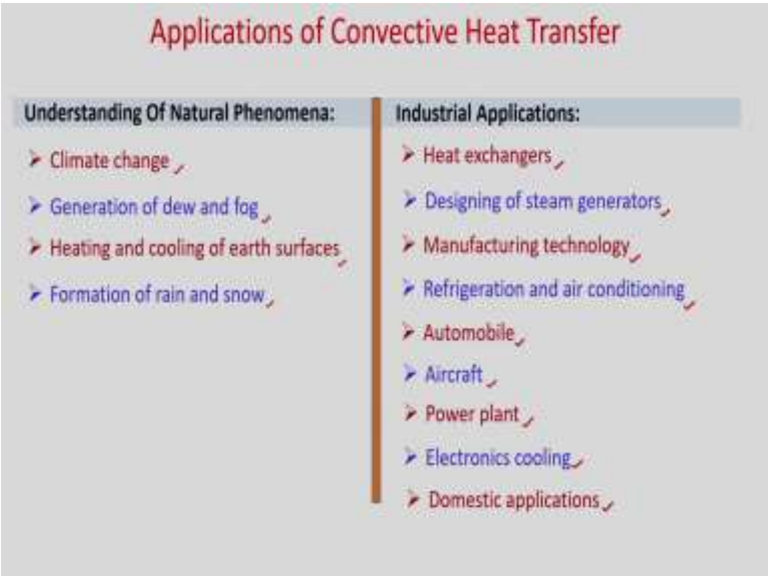

Now, let us see few applications of convective heat transfer. You can see there are many applications in natural phenomena as well as in industrial applications. And in daily life also you can see the application of convective heat transfer. Let us take a simple example. When you take a tea in a cup and you are in hurry so you need to drink the tea quickly and tea is very hot. So, what do you do?

So, generally we put this hot tea on the plate and we blow the air through the mouth, so that it cools down. So, you can see it is a simple example of convective heat transfer; one way you are increasing the surface area putting the tea on the plate. So, on the plate you can see that you have more heat transfer area and you are blowing air through your mouth.

So, that means, forced convection is taking place. So, there is heat transfer from the hot tea to the air. So, it is a simple example of convective heat transfer. And in daily life you can see there are many applications of convective heat transfer. Now, you can see in understanding of natural phenomena like; climate change, generation of dew and fog, heating and cooling of earth surfaces, formation of rain and snow, you can see that these are examples of convective heat transfer.

In industrial applications, you can see this in heat exchangers, designing of steam generators, manufacturing technology, refrigeration and air conditioning, automobile, aircraft, power plant, electronics cooling, in domestic applications and many more. Now, let us see some pictorial examples of these applications of heat transfer.

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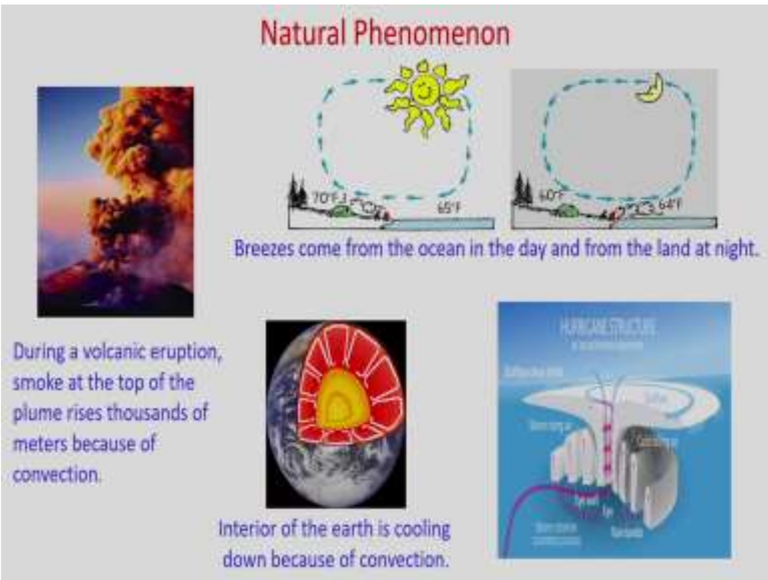

So, you see this is the natural phenomena. Breezes come from the ocean in the day and from the land at night. You consider this figure.

So, in the daytime you can see the land is at higher temperature than the ocean. So, obviously, the air which is in contact with the land will have the lower density due to the higher temperature and it will go up. And to fill up this place, the air will come from the lower temperature region which is having high density or higher density and it will move from here to the land and that way there will be formation of breeze, but at night this direction of breeze reverses.

You can see at night the ocean temperature will be higher than the land temperature. So, obviously, you can see the density will become low and it will go up and higher density fluid will try to fill up the space and there will be formation of breeze. This is one example of natural phenomena. Here you can see, during a volcanic eruption smoke at the top of the plume rises thousands of meters, because of convection.

Here you can see, interior of the earth is cooling down, because of convections. There will be natural convection here. And in different types of cyclones, it moves from one place to other and it rotates. So, this is also one example of convective heat transfer, because the cyclone is actually formed due to the change of temperature.

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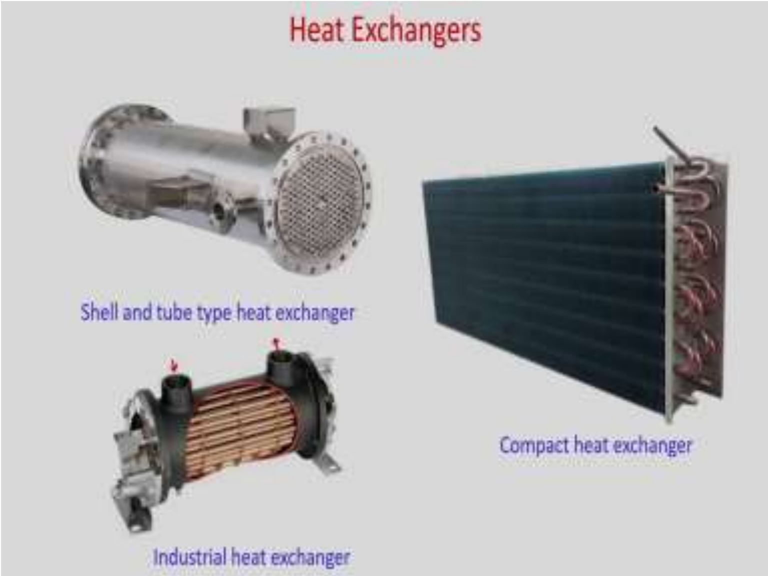

Now, let us see few examples in heat exchangers. This is cell and tube type heat exchanger. You can see there are small tubes. So, hot fluid goes inside and it is to be cooled. So, there will be some openings like here and here. So, the cold fluid will go inside from here and it will exit from other side, you can see in this picture. This is one example of industrial heat exchanger.

So, you can see inside these tubes are seen and hot fluid flows inside these tubes and cold fluids come in here and goes out from here, so there will be heat exchange between the cold fluid and hot fluid. So, this is one example of convective heat transfer.

This is one example of compact heat exchanger. So, in compact heat exchanger you can see that heat transfer area to the volume ratio is very high. It is more than 700 m^2/m^3. Here, you can see there are fins and heat transfer area is increased and through these tube hot fluid flows and it is to be cooled. And from outside maybe there will be an external fan or forced convection which actually cools these fins effectively cooling down this hot fluid inside the tubes.--

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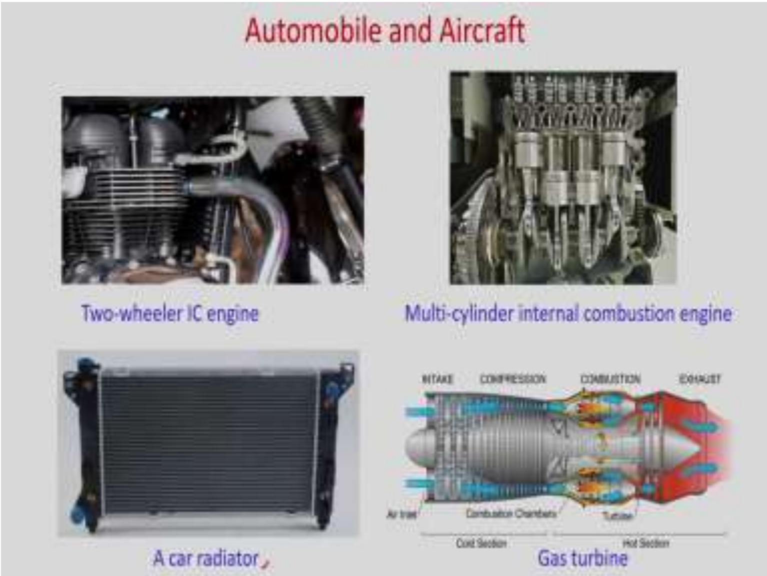

Now, let see some examples in automobiles and aircraft. You can see in your bike or two-wheeler. So, there will be IC engine, it has single cylinder and over it there will be some extended metal strip. So, those are known as fins. So, it increases the surface area and due to conduction from the cylinder surface actually, heat transfer takes place due to conduction. Inside the IC engine you know due to the combustion there will be high temperature and that is to be cooled.

If you notice here in a two-wheeler IC engine, so you can see these are the fins attached with the cylinders of IC engine and when it moves, these bike moves obviously, this air will pass through these fins and this is one example of convective heat transfer.

So, these fins will be cooled down due to the forced convection. There will be multi-cylinder internal combustion engine. Here, sometime these cylinders are cooled using cooling fluid and this is also example of convective heat transfer.

You can see this is the car radiator. Generally, it is placed in front of the four-wheeler. So, engine in a car is cooled by a cooling fluid and this cooling fluid is passed through this radiator to cool down. So, once the hot cooling fluid is coming out from the engine, it is passed through this radiator.

And in this radiator you can see, there are multiple fins and it is placed in front of the car and when the car moves, air will pass through these fins and it will be cooled and this hot cooling fluid when it comes out, it will become cold.

So, this is one example of convective heat transfer. In gas turbine of aircraft engine you can see that there will be cold air inlet and it will pass through this compression and it will go to the combustion chamber and in the combustion there will be high heat generation. And there will be a high temperature and the fluid which is hot; it will go out through this exhaust. And this combustion chamber is cooled using some cooling fluid.

So, you can see in this hot section, this is cooled using some cooling fluid and this is one example of this convective heat transfer. In addition, you can see in automobile and aircraft, for the passengers comfort, inside you have this flow of cold air which is coming from the air conditioner. So, obviously, you need to have the knowledge of convective heat transfer, so that you can design the seats and the interior, so that this cooling fluid passes through all the passengers. So, that is also one example of convective heat transfer.

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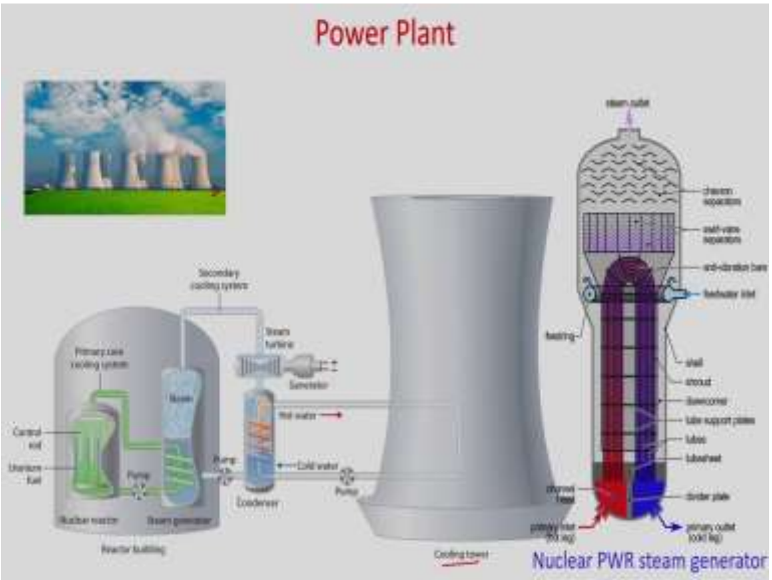

So, now, let us see their application of convective heat transfer in power plant. This is one typical nuclear power plant. Here in the nuclear reactor this cooling system, hot fluid comes through here and this water actually becomes steam. So, this steam passes through this steam turbine and in the steam turbine; obviously, it generates power and this steam now, is to be cooled. So, now, this steam is passed through this cooling tower.

So, you can see the cooling tower in any power plant. And when it is passed through the cooling tower, this hot water becomes cold and again it is pumped to the steam generator. So, you can see in many processes in this power plant, you have the examples of convective heat transfer.

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In household applications, we have air conditioner, air cooler and refrigerator. And in these processes you know that there are many applications of convective heat transfer. So, we are not going to discuss in detail, but you know that all these cycles if you study; obviously, you will find the application of convective heat transfer.

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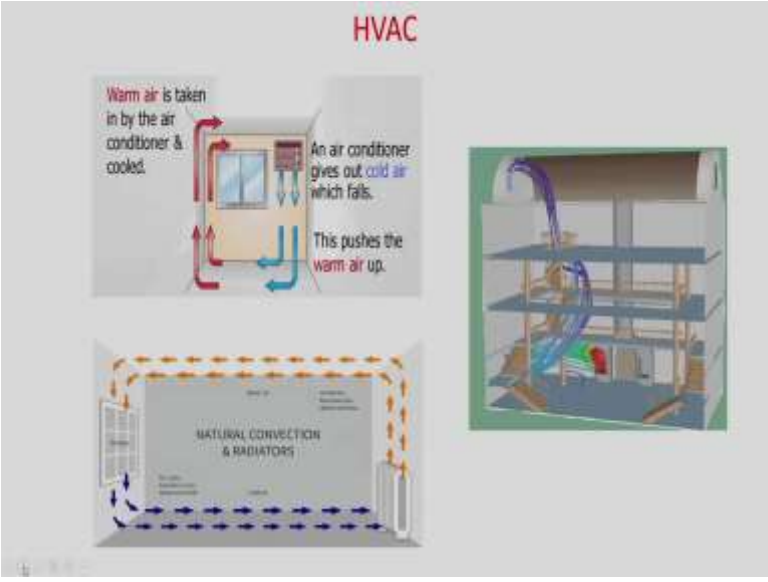

Now, we will discuss about the HVAC, Heating Ventilation and Air Conditioning. So, you can see the room where AC is there, so obviously this air condition gives out cold air and as it is cold air it is having high density. So, it will move inside the house and these pushes the warm air up.

So, warm air will go up due to the low density and this warm air is taken in by the air conditioner and cooled. So, this way there will be a natural circulation and this is the natural convection taking place inside the room. Similarly, if you use heater, room heaters or radiator.

So, here also the fluid which is coming into contact with the radiators, the density will become low and it will go up and this warm air will flow. And when it will come to some cold place like window, its density will become higher and it will go down and this way cold air will come. So, there will be a natural convection.

In any building, how effectively you can cool you need to have this knowledge of convective heat transfer, so that effectively you can cool the building.

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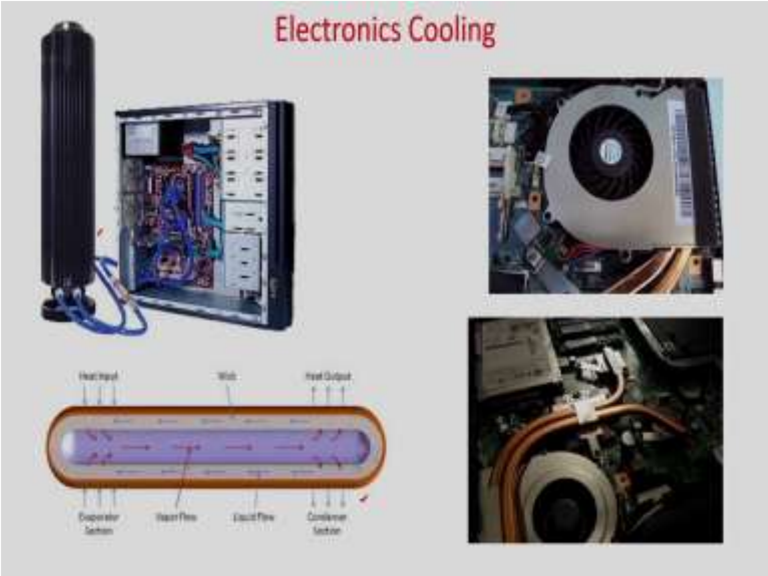

There are many applications of convective heat transfer in electronics cooling. You can see that day by day the size of the chip is decreasing and heat generation inside the chip is increasing.

Hence, you need to remove the heat from this smaller chip. If you notice that in a desktop the board is placed vertically and different electronics components are cooled in natural way by natural convection. But the chip which is your Intel chip, this generates very high temperature. It generates heat and the temperature will be very high on the surface of the chip.

So, it has to be cooled. If you notice that in the PC generally, there will be fins which are cooled by a fan. So, you can see that there will be forced convection and due to the forced convection, there will be heat transfer and heat will be removed from the pin and that way the chip is cooled. If you see the laptop or any mobile you can see that it is very thin and it is very difficult to put the fan over the chip. So, for that generally heat pipes are used.

So, you can see this is the fan over this chip and in forced convection these are cooled. And in laptop you can see these are the heat pipes. How the heat pipes works? In heat pipes this evaporator section is put on the chip. So, due to the high temperature the fluid will become vapor and this vapor will pass inside this hollow space and it will come to the condenser section which is put outside the ambient.

So, due to this condensation this vapor will become liquid and this liquid will pass through this wick. And it will pass through this wick and it will go to the evaporator section. So, you can see it is natural way this fluid flow is taking place, so there is no external force and the advantage is that you can bend it. So, here you can see you can bend it and put it towards the outside and the evaporator section you can put on the chip. And that way naturally this heat is removed from the chip to the ambient.

So, this is one example of convective heat transfer. Nowadays, these chips are also cooled using some fluid and this fluid is passed through these tube. And for more heat transfer or effective heat transfer these fluids are used to remove the heat from the chip.

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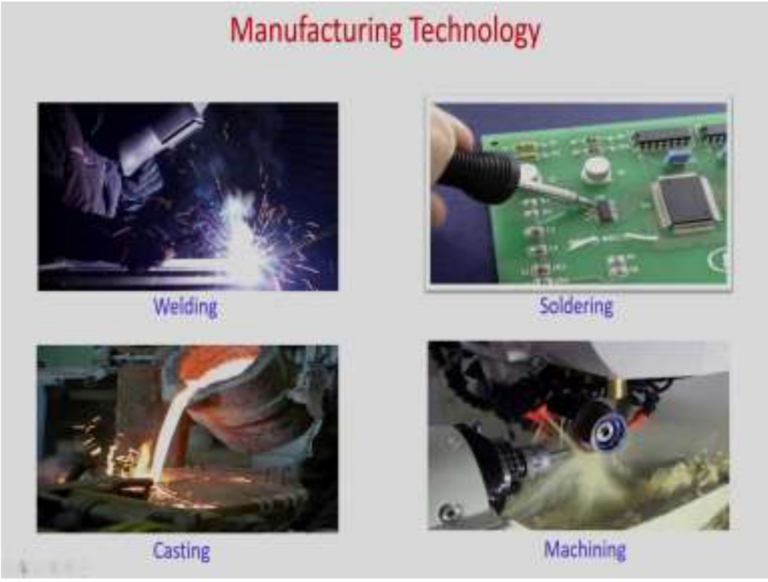

In addition, you will find there are many applications in manufacturing technology. So, in machining process when the tool cuts the metal you can see there will be more heat generation and these are cooled using some cooling fluid.

So, these cooling fluids are put near to the tool and this heat is removed. In addition, you can see in a welding, casting and soldering processes there will be phase changes and also there will be heat transfer due to convection.

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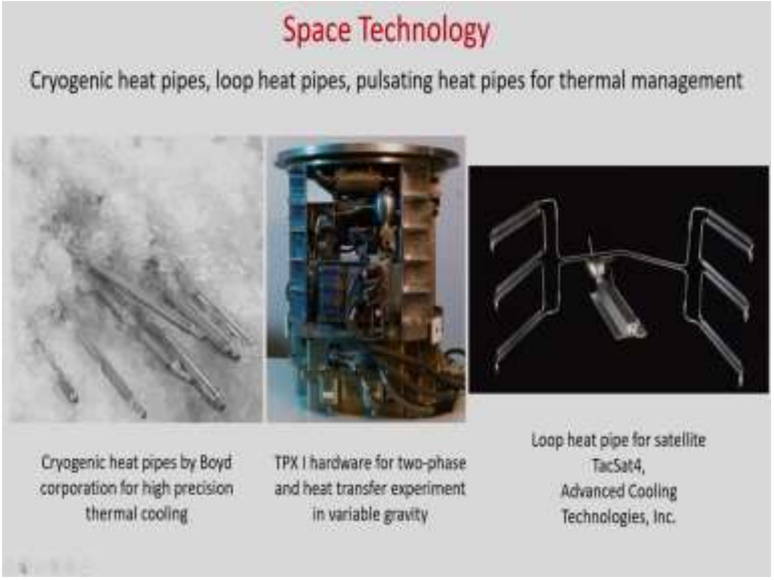

In space technology, you can see cryogenic heat pipes, loop heat pipes, pulsating heat pipes for thermal management. These are examples of convective heat transfer in space technology.

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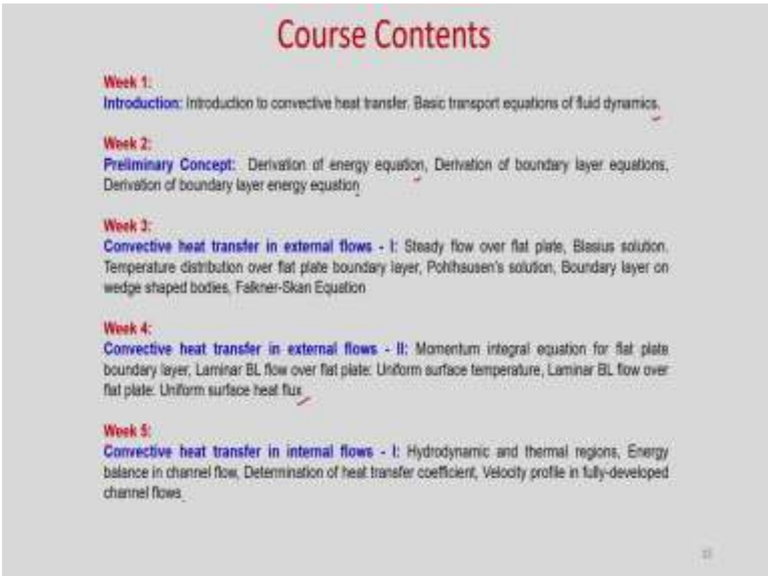

Now, we will discuss about the course contents. In module 1, we will we are introducing the convective heat transfer, we discuss about the application of convective heat transfer and we will discuss basics transport equations of fluid dynamics.

In week 2, we will discuss about the preliminary concepts. We will derive the energy equation in general and then we will derive the hydrodynamic and thermal boundary layer equation.

In module 3, we will start the external flows. We will start with steady flow over a flat plate and we will solve the Blasius equation. Then, we will discuss about the temperature distribution over flat plate boundary layer and we will have the Pohlhausen's solutions and we will touch upon this boundary layer on wedge shaped bodies and we will discuss about this Falkner-Skan Equation.

Next, we will move to module 4. We will continue with the external flows, we will use the approximate method and we will use momentum integral equation for flat plate boundary layer. And we will also solve laminar boundary layer flow over a flat plate with two different thermal conditions: One is Uniform surface temperature and another is Uniform surface heat flux.

In module 5, we will start internal flows; first, we will discuss about hydrodynamic and thermal regions, then we will do the energy balance in channel flow, we will use scale analysis to find the heat transfer coefficients and finally, we will find the velocity profile in a fully-developed channel flows.

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In module 6, we will continue with the internal flows; first, we will discuss about thermally fully developed laminar slug flow with uniform wall heat flux condition.

In slug flow, there will be uniform velocity. Considering that situation, we will find these temperature distribution. Then, we will consider a hydrodynamically and thermally fully developed flow with uniform wall heat flux condition in two different geometries: One is flow between parallel plates and circular pipe. Then, we will discuss about hydrodynamically and thermally fully developed flow through parallel plates channel flow with uniform wall temperature condition. And then, we will discuss hydrodynamically and thermally fully developed flow through circular pipe with uniform wall temperature.

In week 7, also we will continue with internal flows hydrodynamically developed and thermally developing flow through circular pipe with uniform wall heat flux. So, in this case you can see where you will consider hydrodynamically developed, but thermally developing flow. Next, we will consider hydrodynamically developed and thermally developing flow through circular pipe with uniform wall temperature. So, two different thermal conditions we will consider, and at last we will discuss about the heat transfer in plane Couette flow.

In week 8, we will start the natural convection, we will solve the free convection over a vertical plate using integral solution and similarity solution.

In week 9, we will continue with natural convection, we will discuss about internal natural convection and mixed or combined convection.

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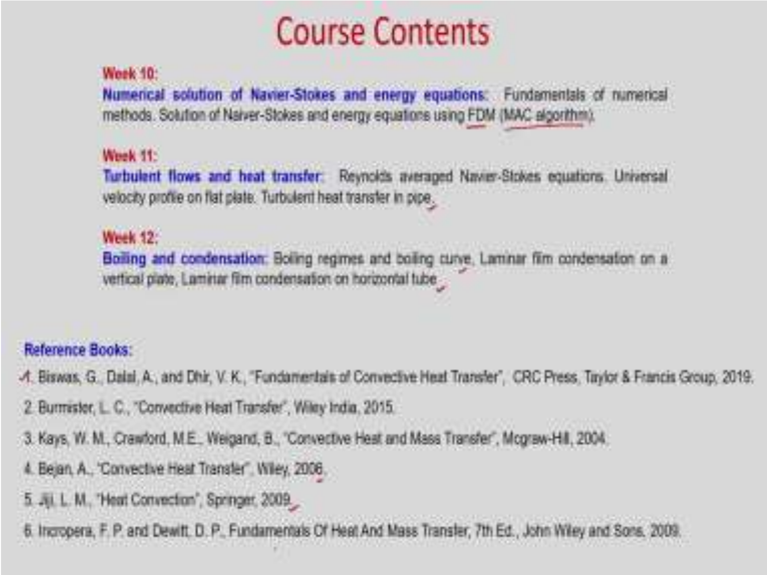

In module 10, we will solve this Navier-Stokes and energy equations, using numerical technique, we will use finite difference method and we will solve using marker and cell algorithm.

In module 11, we will introduce with turbulent flows and heat transfer. First, we will derive the Reynolds averaged Navier-Stokes equations, then we will discuss about universal velocity profile on flat plate and we will touch upon turbulent heat transfer in pipe.

In last module, module 12, we will start with boiling and we will also discuss about the condensation. First, we will discuss about different boiling regimes and we will discuss boiling curve which is your nukiyama curve. And next, we will discuss about Laminar film condensation on a vertical plate and Laminar film condensation on horizontal tube.

So, you can see the course content, it is a advanced level heat transfer, because we are discussing about one mode of heat transfer that is convective heat transfer. And it is more analytical in nature and rigorous derivation will be there.

So, you can refer these following books. Mostly I will follow the first book which is Fundamentals of Convective Heat Transfer and we will also refer these books. So, a Convective Heat Transfer by Burmister, Convective Heat and Mass Transfer by Kays, Crawford and Weigand. This is a good book on Convective Heat Transfer by Bejan and you can refer is for scale analysis.

This is also a good book Heat Convection by Jiji. And these book I think you have already referred in your undergraduate level; Fundamentals of Heat and Mass Transfer by Incropera and Dewitt. So, this book I think you will have, so you can refer in your convective books which is not mentioned here you might have other books also.

So, today we started with discussing about the transport phenomena and we introduced the convective heat transfer. Then we discussed about different modes of heat transfer: conduction, convection and radiation. And then, we show different applications of convective heat transfer in natural phenomena as well as in industrial applications.

Thank you.