Indian Institute of Technology Madras
NPTEL

National Programme on Technology Enhanced Learning

Video Lectures On
Convective Heat Transfer

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Lecture 1
Introduction to convective heat transfer-Part 1

Good morning all of you and welcome to a new semester so, this semester the course convective heat transfer is being offered by me and Professor Rajat Koehler. From the heat transfer and thermal power laboratory of our department of mechanical engineering and so this is primarily targeted towards.

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A research student who is pursuing their MS and PhD in the area of convective heat transfer and apart from them the regular undergraduates. Who are in their senior year and who are interested to get more deep insight about convective heat transfer apart from their basic heat transfer course? They had taken in their pre final year they are also welcome to take this course. So to just begin with so since today is an introductory class we will take look at the basics of the fundamentals of what this course has to offer and let us look at some of the applications.

Where convective heat transfer is used also to give an idea about the problems that we will be looking at and depending on the classification that people is following. Okay so, this is the objective of this particular course.

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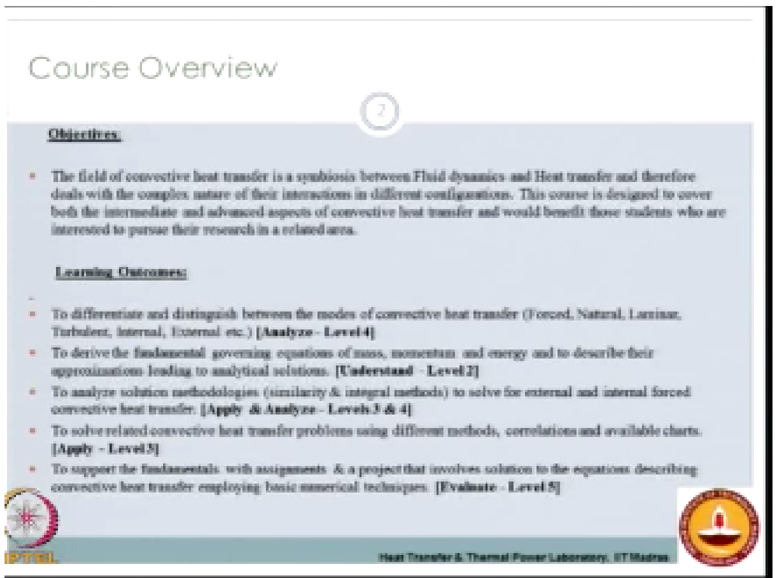

As you all know this the field of convective heat transfer. I would say is a symbiosis between two important subjects. One is the fluid mechanics of fluid dynamics. And the other being heat transfer and if you look at the aspects common aspects of fluid mechanics so that is basically offering what is called as the advection to heat transport and that is what you can - heat transfer.

Heat transfer is all about and naturally since the advection process is nonlinear and this brings in the complex. Nature of the interaction between the flow and the heat transport in many cases the flow and heat transport are usually coupled and typically if you are looking at say the buoyancy driven flows so there the temperature and the energy equation is coupled to the momentum equations and so on so there is a complex nature in the interactions between the momentum and the energy equations which makes this course a lot more interesting and also more challenging to learn and so this course would benefit those students.

Who are particularly interested to pursue their research in related area now I have also written down a set of learning outcomes according to the Bloom's taxonomy as you all know Bloom's taxonomy is used all over the world to classify the different levels of a learning process so there are totally six levels according to the modern Bloom's taxonomy. The highest level being creativity and if you can guess the lowest level so that is basically recollecting what you have memorized.

Okay so we as we go from the lowest level as you had progress from your email from your school education. Where your emphasis was mostly on the remembering or the recollection part that is the lowest level and we will move on as you progress in your courses here at IIT as well as doing related research work that you will go several steps in the hierarchy of the Bloom’s taxonomy. And finally be able to reach the highest level which is the creativity so according to the different levels I have classified the outcomes of the learning process in this course.

I would say the one of the important learning outcomes would be two first you should be able to differentiate and distinguish between the different modes of convective heat transfer. So you all know that your conventional heat transfer consists of primarily three modes that. Is your conduction convection and radiation even within convective heat transfer you can classify different modes based on the classification of flows and the regime with.

Which you are dealing with so you could look at things like force convection or buoyancy driven convection which is called the natural convection or free convection. Then depending on whether the Reynolds number is less than a critical Reynolds number you can look at flows which are laminar or flows. Which become unstable and transition and finally become turbulent and depending on the flow configuration weather?

They are internal or external boundary layers so this part of differentiation and distinguishing between the different modes of convective heat transfer. Would be on the level of analyzing so this is on a pretty moderately high level. That is your level number four and the Bloom’s taxonomy and apart from that. So you will be able to derive all the fundamental governing equations of mass momentum and energy and also we should be able to describe.

What approximations are being used when we apply them in the solution to say the boundary layer equations? For example, so these fanatical solutions are for determined. From your actual name of Stokes equations based on certain approximations and you will be able to understand. How to derive these equations and also the approximations involved. So that will be on the level two which is on the understanding level the third objective will be to analyze.

The solution methodologies that you have derived analytically either by using similarity which is the exact technique or the approximate technique which is basically the integral method and you will be applying this to solve for both external as well as internal force convective heat transfer so this will be on the level of applying and analyzing that is involving both levels three and four and the objective number four would be to solve related convective heat transfer problems this is more on the applying level and I think most of you knew heat transfer course have already done this where you are given a set of heat transfer correlations.

And then you just use that either use the correlations or you use available charts to solve problems. So that will be on the level of applying and level three and finally you will be not just doing the understanding or applying or analyzing. But you will have to go a little bit higher in the hierarchy of the Bloom's taxonomy two level number five. Which is to evaluate so in that you will be given a computer-based assignment and also?

Some of your regular assignments will involve numerical solution to some of the equations the ordinary differential equations. That you will be solving and by applying these numerical techniques. You will be able to evaluate your understanding as far as this course is concerned so on a particular application level. So you have a certain problem to solve and also apart from that to enhance your fundamental understanding.

You can also supplement them with doing rigorous numerical solutions okay which will be given as a project at the end of this course as well as the regular assignments. Which will also involve numerical aspects? So, this will take you to the level of evaluation which is level number five. Okay I hope by doing all this will be very useful for your research work which will probably utilize your final level of the Bloom’s taxonomy that is your creativity.

So coming to the course content of this course, so this is a very structured course and so it's pretty rigorous and time-consuming.

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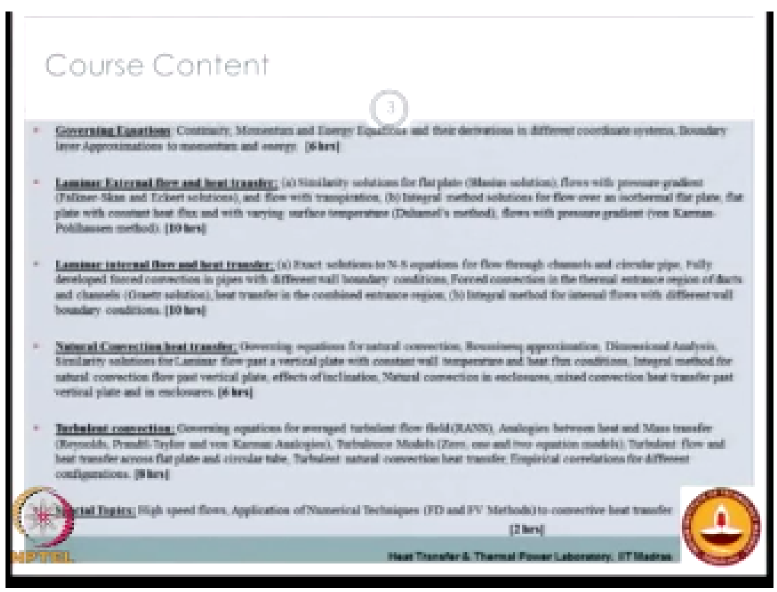

We have to cover quite a lot of topics within the given span of 42 hours and therefore it's a pretty intensive course and we'll start with the governing equations. We look at the derivation of the governing equations which are the continuity momentum and the energy equations primary primarily. We will look at the Cartesian coordinate system and you can do these derivations with a similar analogy in the other coordinate system.

Such as the cylindrical and spherical we will also look at the approximations that we can make to the full set of governing equations and reduce them to amenable form. Which we can solve during the regular lecture hours so these are typically something like the boundary layer approximations. Where we'll be able to reduce the full complexity into something which we can where we can find analytical solutions. So we look at the boundary layer approximations to momentum and energy so this will take about six hours six lecture hours the next topic that.

We will be looking at will be the laminar external flow and heat transfer so in this first we look at the similarity solutions for flat plate. This is popularly referred to as the Belasis solution named after Russia? Who first came up with the solution and we will extend this blush a solution to flows including pressure gradients. Which I'll call the Falkner Scan solutions and if you have a heat transfer problem with adverse pressure gradient.

It is referred to as, I cut solutions we'll also look at the flows with transpiration also in this course and these are some of the exact solutions. We can supplement the exact solutions by reducing the complexity in solution by means of the approximate methods called the integral methods. So we will apply integral methods for the above problems including the flows with and without the pressure gradients and for the flows the pressure gradient.

This technique is called the form Carmen called Hassan method so about ten hours of lectures will be spent on the laminar external heat transfer part. And the next one will be the laminar internal flow and heat transfer. Which will involve the exact solutions with navies-stokes equations for flow through channels circular pipes. We will be looking at different regimes of internal heat transfer which starts from your the simplest. One will be to look at the fully developed both thermally and hydro dynamically fully developed.

A flows with different wall boundary conditions and we look at slightly more complicated solutions. Which in which behind it is hydro dynamically fully developed that is the velocity profiles remain invariant of the distance downstream but there is a change in the thermal boundary layer. So that is your thermal entrance region of the ducts and these are called as great solutions and of course you know will also apply.

The approximate solutions to these problems so this will again take about ten hours and the LA the last about 15 hours are. So we will spend time on the natural convective heat transfer which is a very unique problem. And, we will also look at some similarity solutions and if possible integral method for natural convection so turbulent convection is a very challenging task. You know we have to start talking about how the equations representing the turbulence flow and heat transfer.

Ought to be model, so we can start off with the derivation of what is called as the Reynolds average navies-stokes equation and then. We list out the analogies between heat and mass transfer if some of the famous analogies are Reynolds Prandti Taylor. And Fen card methodologies and we look at very briefly about the turbulence models. Time permits and finally we look at the empirical correlations because most of the heat transfer problems cannot be solved.

analytically in turbulent convection and therefore quite empirical correlations are existing for different configurations so this two topics will take about 14 hours and as a as a special topic we can look at high speed flows which could be covered with the laminar external flow and heat transfer and as I said there will be a project involving the application of numerical techniques so it could be either finite difference method or finite volume methods to taking up a problem in convective heat transfer.

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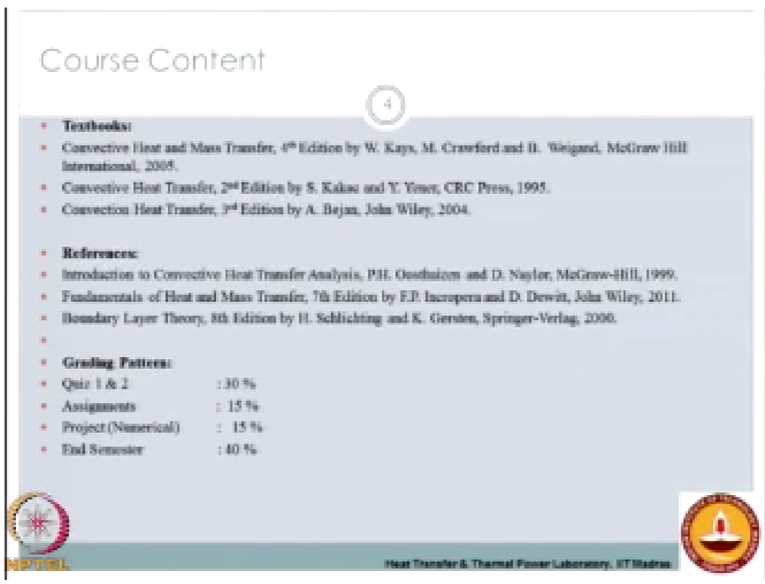

So coming to the textbooks there are quite a few textbooks available for this subject the most important ones which I will be following here. I have listed them as the textbooks the convective heat and mass transfer by case in Crawford is an excellent text. Just been followed for several decades as a classroom teaching aid to this course convective heat transfer by Caucasian Janna is a pedagogical style textbook for this course. Where all the detailed derivations have been explained to a great extent the text by beige on convective heat transfer convection heat transfer is also a good textbook.

Especially in the parts where Bayesian proposes simple scaling analysis for external boundary layer flows rather than going through complicated derivations. To understand the nature of boundary layer thickness and so on also Bayesian is credited. With coming out with his own theories primarily the on heat lines that is one thing and on entropy generation the analysis of entropy generation due to heat transport convective. Heat transport and using constructor theory for design of heat exchangers and so on so Baden is of course an authority in this particular subject and he has his contributions.

Towards, understanding through scaling analysis is particularly quite interesting for students and coming to the references few references listed. Here are from one of them which is introduction to convective heat transfer by Louisa and Naylor. So this is a free eBook which is available and you can probably just download and read it and this has also a good description of some of the numerical methods used in the convective heat transfer.

Of course, your fundamental texts on heat transfer by Inca para will always be very handy in this course and coming to the grading pattern. So I wanted to distribute the grading pattern uniformly in all the assignments and the project as well as your exams so that's how I distributed them in this manner your quiz has a weight age of 15 percent each for the two quizzes so it's about 30 percent. Totally and coming to the assignment so we will be given about six assignments including some of the assignments which where you need to apply numerical methods. So that will be a given weight age of 15 percent and your final project will carry about 15 percent weight age and your end semester will be about 40 percent so totally so you have out of 100 percent you have a equitable distribution in the assignments in the project and slightly higher weight test is given to your end semester examination.

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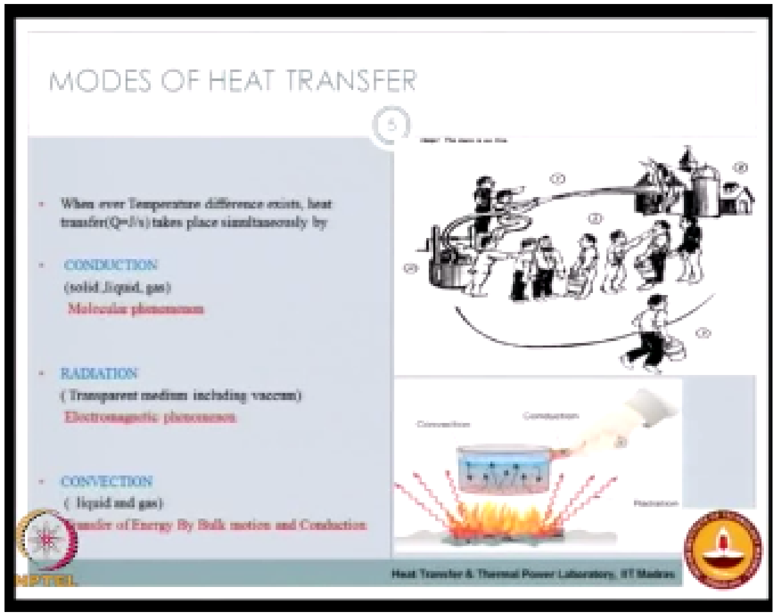

Okay so let us get into the introduction of this course as you all know that there are different modes of heat transport.

Which you have come across in your basic heat transfer course so rather than going through explaining conduction radiation and convection in the usual way. I will take a more contemporary path. So this is a graphic from an online textbook which is the heat transfer by John Leonhard a very nice illustration. Here with which you can completely understand the basic three modes of heat transfer. So here you can see that there is a bond or there is a house which is on fire in some countryside.

Where you do not have say access to a fire engine very quickly so a group of people are trying to douse the fire and you can see the numbering. One is given to people who is actually pumping water from a well through a hose and directly pour pouring this water over the barn and trying to douse the fire. Whereas number two is given to a set of people who are using buckets to pull water out of the well and then successively passing this bucket to the other person and finally. The person who is closest to the barn will be reaching it to the fire and there is another guy who is really smart here who is physically fit and then he is capable of carrying water.

All the way from the well to the barn by himself running around and then trying to douse the fire so there are three sets of processes. Which are happening to douse the fire here and as you can see that process number two here refers to the conduction process in heat transfer. So essentially this is happening due to the collision between the molecules in a particular medium and here it's something like an exchange or transport of heat between the different persons or different molecules.

Who are participating in this medium in this way you can see that the process is slightly slower than processes 1 and 3 because essentially. It has to depend on passing the bucket of water from one person to the other in a sequential manner. So this is a slightly slower process so the time taken for dousing the fire will be longer. Whereas if you look at process number 3 so this is similar to your advection process. So in the when you look at convective heat transfer essentially you have processes 2 and 3 happening simultaneously. Where that is a background effect of diffusion or conduction.

Through the medium by wearing the heat is transported and apart from due to the bulk motion or you know here as you can see due to the motion of this particular person. From the well to the barn you could also achieve efficient heat transport. Ok ay so this is a combination of two and three now if you look at radiation that is similar to the process number one. Where you don't rely on any medium to transport but you directly you can transport. Heat even in the presence of you know in the medium law in case even in a the outside of the Earth is atmosphere so in this case it's direct ballistic transport from one surface to the other like the way you see the process number one where the host pipe.

Is being used to directly target the flame so this is very effective provided it can reach from the well all the way up to the bond so the radiation is something similar. To that so it doesn't require any medium in fact I using a medium will impede the quality of heat transport by radiation so it's a purely. Electromagnetic phenomena and it can perfectly work in any media including vacuum and it in fact works best without any participating medium so this is how you can look at the three processes and three more and relate them to the three modes of heat transfer and we are in fact you cannot really say that a particular mode is always important.

Because if you look at any real-life process for example if you boil water in a pan all the three modes of convection conduction and radiation happen to act simultaneously but when you when you look at the process involving the water as such and decouple that from the process involving the heating of the pan due to conduction and radiation. Then you can isolate convection as the dominant mode and you can study that separately. So in this particular course we will be concentrating on this mode where you have both advection coupled with your conduction which is a background heat transfer mode always happening before going further we have to be clear about a few definitions. That we will be using in this course so first we will be looking at the definition of heat flux.

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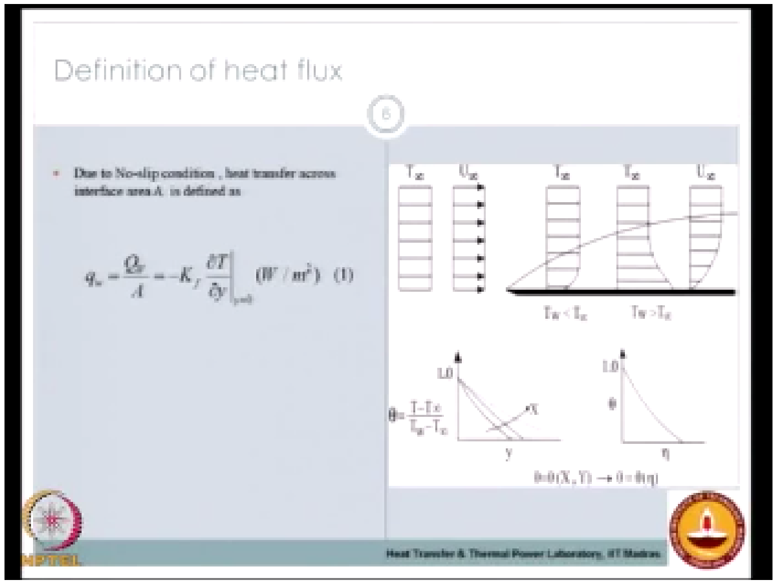

So which will be defining as the heat transfer rate per unit? Surface area and according to the four years law of conduction your heat flux can be related to the gradient of temperature as -. K DT by day at if you are applying the Fourier law at the wall so we define the wall heat flux as - K which is K KF is the thermal conductivity of the fluid times the gradient of the temperature at the wall. So that that is at y = 0. So if you consider a flow past a flat plate here if you assume.

That you have free stream velocity u infinity and a free stream temperature T infinity approaching the plate and once the flow encounters this plate. You will find a growth of what is called as a boundary layer and which is gradually growing in thickness as it goes downstream and therefore accordingly you will have a development of the velocity and the temperature profiles gradually. So this boundary layer is attributed to the no slip boundary condition at the wall where the fluid has to be taking the velocity of the solid here which is stationary and therefore the fluid has to be at rest and essentially the lower layers of the fluid has lower momentum compared to the higher layers of the fluid and this gives rise to the concept of boundary layer and if you look at the profiles of velocity you can see that they keep changing and the gradient of the velocity being highest.

At the near the leading edge and as you go downstream in the gradients become more and more benign similarly associated with the velocity gradients you see the development of temperature gradients so you see temperature. Profiles which are also changing downstream at any location downstream at any axial location say here if you draw the temperature profile if you assume that the plate is heated therefore the wall temperature is greater than the free stream temperature this is how the temperature profile comes out to be and from.

This you can define the heat flux at the wall okay so that is - K DT by day at y =0 that is the gradient of this temperature at y equal to zero at the surface and the good thing about this flat plate boundary layer problem it is very interesting and more fundamental when you develop what we call a similarity solutions. So if you define a non-dimensional temperature Θ and plot that you will find this non-dimensional temperature is a function of both the x coordinate that is your axial distance along the plate as well as the y coordinate or the height across the plate now if you plot these profiles you found you find that it is a dependent it is dependent on both x and y however if you define. What is called as a similarity variable? Which is a combination of both y and X you can reduce the dependence of Θ on a single variable which is a similarity variable ETA. Okay so therefore, you can transform your dependence on the two coordinate systems x and y into a single non dimensional coordinate system ETA which is the similarity variable and therefore wherever you plot whichever axial location you will find that the variation of Θ.

With respect to the ETA s is the same so this is something which is a very unique to similarity solutions and which we will be looking. At later on in this course now coming to the definition of heat transfer coefficient so whenever we look at convective problems we want to define the rate of heat transport from the surface and we do this by defining what is called as a heat transfer coefficient which is defined as the ratio of the heat transfer rate from the surface to the temperature difference the temperature difference.

Usually is between the wall temperature and some reference temperature in the case of external flows we will use the free stream temperature T infinity as your reference temperature so your heat flux at the wall is essentially - K DT by day at y equal to 0 and divided by T wall - TF which is your T infinity so you can consider two cases two cases where you apply a for example a constant isothermal temperature boundary condition to the wall and in one case that is on the Left where you see a temperature profile like in the case of a flat plate flow where you see a continuous decrease in the temperature as you increase the Y distance in this case if you define.

Your heat transfer coefficient in this manner - K DT by day at y equal to zero by T 1 - T infinity you find that the gradient DT by day is continuously decreasing with increasing Y and therefore this will be negative and negative so this becomes positive and therefore your heat transfer coefficient comes out to be positive whereas on the right hand side if you have a flow situation where the wall temperature the T wall is actually greater than your T reference but you can have you can have a jet of hot fluid which is actually greater than T wall but which is greater than T wall as well as greater than your T infinity which is blown over the surface and due to this you can have a temperature profile distorted in this manner.

So where if you now take the temperature gradient you find that at the wall the DT by day is actually positive with Y and therefore you will find that the value where as you are in the denominator you find your T infinity is still less than your TW. So therefore the denominator is positive and the numerator will be negative so in that particular situation your heat transfer coefficient will actually be negative so therefore contrary to the popular belief that you encountered a value encountered problems with the positive heat transfer coefficients when you define your heat transfer coefficient in the in this particular manner it could be both positive or negative depending on how the near wall temperature gradient behaves okay so for all these you should be able to define a reference temperature depending on whether it's an external flow or internal flow and you should also have an idea of the fluid property typically the thermal conductivity.

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So having defined your wall heat flux and the heat transfer coefficient for convective heat transfer let us look at some of the applications of convective heat transport so typically wherever you encounter heat exchangers where the heat is transferred between two fluids two moving fluids so there you are talking about convective heat transport so you could look at for example in your air conditioners where fin type of heat exchangers are being used and there is a flow past these fins from outside where air cools down.

The working fluid through this passing through these tubes and so this is one type of heat exchanger where you have a internal flow through this tube so the working fluid flows through the tubes and then you have external flow that is the air going across the fins placed outside the tubes and if you look at heat exchangers in your automotive applications for example in radiator cooling so that is one good example of a compact heat exchanger where you have a very high surface area to volume ratio and there you are also looking at external flows that is flow of air over the heat exchanger here you can also look at things like phase change material based heat exchangers where essentially you have a cyclic process in.

One half of the cycle you pass the hot fluid through a porous membrane which could actually melt upon heating whereby they take the latent heat of melting from the hot fluid and then stores it as a capacitor and in the next half of the cycle the cold fluid flows through this medium and then this releases the heat back to the cold fluid where the cold fluid gets heated and in the process of losing the heat the phase change again happens from the liquid to the solid phase so it's solid if I sewed the material as such repeatedly melts and solidifies continuously depending on whether you are using the hot fluid or cold fluid and therefore can indirectly transport.

The heat from the hot fluid to the cold fluid of course you are also looking at heat exchanges for example in solar panels also in other industries like chemical industries or any process industry requires the heat exchanges where you transfer heat from say your hot gases in a in a furnace where the combustion is happening to the working fluid which is water mostly in the process industries to generate steam for all that process requirement so therefore convective heat transfer is present in many instances and most of the heat exchangers require a very in-depth knowledge of convective heat transport.

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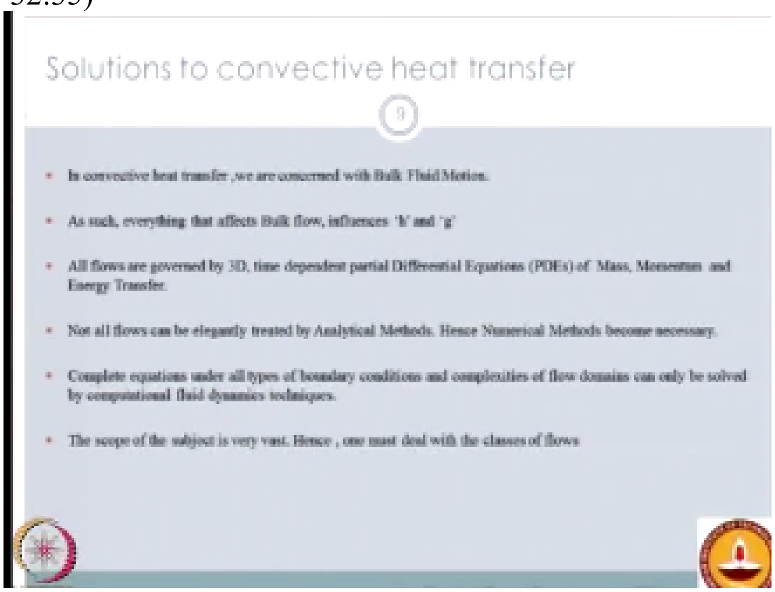

So when you look at the solutions to convective heat transfer we are mostly concerned here with the bulk fluid motion and so anything that affects the bulk flow influences your heat transfer coefficient effectively so and also the mass transfer coefficient okay here I call the mass transfer coefficient as G and heat transfer coefficient as H now in order to derive relations go for he finding the heat transfer and the mass transfer coefficients as a function of the flow properties.

As well as the properties as well as the flow we have to look at the complete solution of partial differential equations governing the mass momentum and energy transfer now not all these now the complete solution of course has to be numerical they have to be time dependent however we can see that in many instances we can reduce the equations to forms which are amenable to analytical and approximate solutions and in some cases this cannot be done and therefore you have to look at the full numerical solution to these equations and if you want to do this numerical solution.

You need to look at boundary conditions for a particular problem and that is done by using the computational fluid dynamic techniques therefore the scope of the subject is very vast if you want to look at more accurate solutions to complex configurations we go for the complete solutions numerical solutions to the governing equations using CFD techniques however if you want to restrict that to simpler configurations we can reduce them to equations where we can do then article solutions. Okay so that therefore the scope is very vast and we have to be looking at both these aspects as a classroom.

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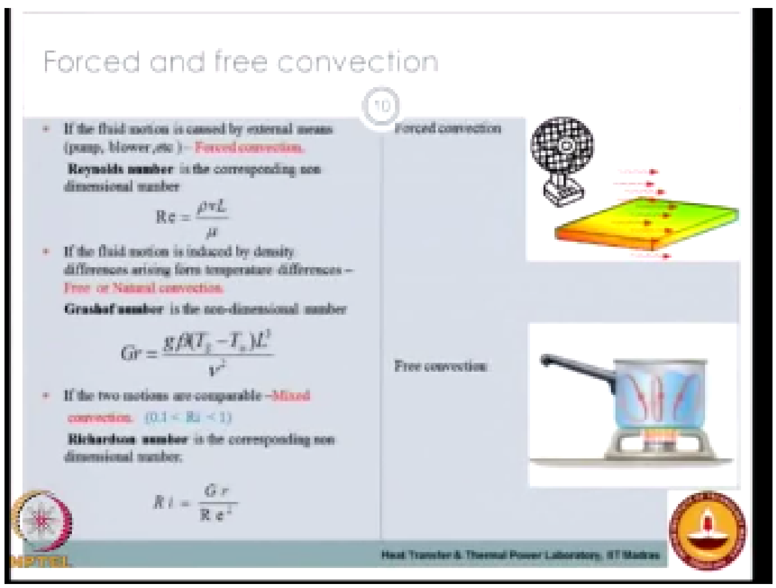

We will look at the fundamental configurations mode and once you go to doing research in this particular area you look at solving them numerically so now we can start looking at the different classifications of convective heat transfer one of the most important classifications which is followed is classifying the regimes of heat transfer into a either forced or what is called the free or natural convection so typically you can look at this particular figure which illustrates the idea of forced convection.

So where you use a fan or a blower to blow fluid over a plate which is heated to cool it down so this is a very intuitive thing which all of us practice it every day now if you use a large-scale pump or a blower you need a substantial pumping power to pump the fluid past the surface and therefore you need a mechanical aid to drive the convection process so this is called as the forced convection so where the fluid motion is caused by external means and here to characterize the flow we use what is called the Reynolds number which is the ratio of the inertial force to the viscous force which is defined based on the characteristic dimension of the heat transfer object okay and the density viscosity here are defined.

With respect to the free stream properties or maybe the average properties between the surface and the free stream temperatures and V is the velocity of the fluid now this is one category of flows which we will be looking at in the initial part of the course and most of the times there are flows where you don't have to put any effort or you do not have to really drive them and they happen all by themselves and this happens due to density differences essentially if you have a stationary media and then you have a temperature difference so this will cause the fluid near the higher temperature surface.

To become lighter and rise up and the fluid near the cold surface to become heavier relative to the hot fluid and they move down and therefore there is a convection current which is set up and in this process you have a bulk motion of the fluid arising out of the temperature differences so this is called as the free convection or natural convection and we cannot use the concept of Reynolds number here because essentially we do not really push the air by means of an external pumping device so therefore here we define another non-dimensional number to characterize the strength of natural convection by means of grash of number.

So grash of number is the ratio of the buoyancy force to the viscous force so in the case of Reynolds number we used the definition of inertial force to the viscous force so here the inertia is being replaced by the strength of the buoyancy force which is related to the temperature difference between the hot side and the cold side and so typically you can look free convection which is happening in your when you boil a liquid you do not boil it too much you just during the initial stages of boiling.

When you apply lower heat flux as you can you can find these convection currents happening from the heated surface at the bottom and rising upwards towards the cold surface outside so these are like small currents which are being set up and which can improve the heat transport now there are cases in real life where both the regimes are equally important and that's called the mixed convection which is characterized.

By the ratio of grash of number to Reynolds number square also called the Richardson number and depending on the range of Richardson number if you are looking at Richardson number between 0.1 to 1 so this is called the mixed convection regime if you look at very high Richardson numbers much greater than 1 so there the natural convection is dominant over the forced convection so that there's your natural convection regime and for very small values of

Richardson number where your Reynolds numbers are more dominant than your grash of number that is your force convection regime.

So you are depending on the values of grash of number and Reynolds number we can look at classification based on forced free or mixed convection regimes. Now the other important classification is based on.

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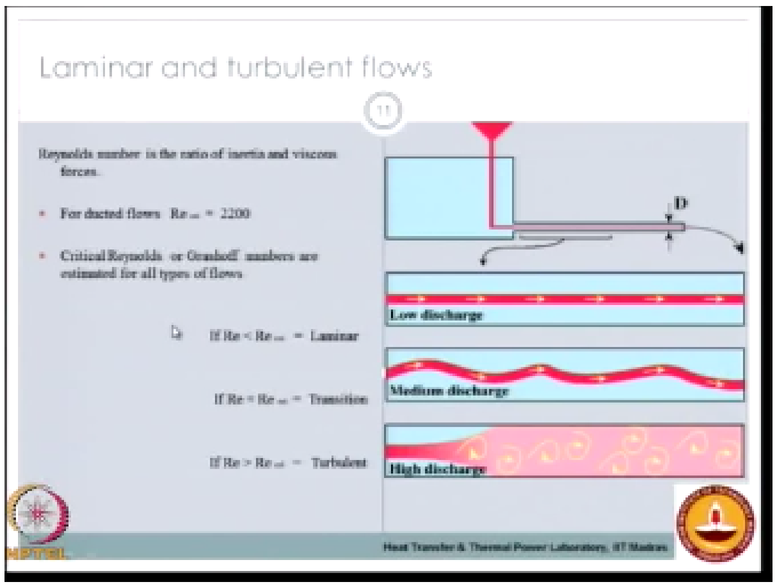

If you are looking at forced convection then your characteristic classic the characteristic Reynolds number is your Reynolds characteristic number dimensionless number is your Reynolds number and for values of Reynolds number typically for external for internal flows where you have say flow through ducts or channels the critical Reynolds number is somewhere like 2200 and if you have your Reynolds number is less than the critical value typically you find a very orderly behavior of flow in a stream line pattern this is similar.

To what Reynolds did in his experiment isn't in his dye experiment very injected dye into the flow of fluid and then varied the Reynolds number and see the path of the path taken by the dye so you can visualize and see exactly the path of the dye according to the fluid behavior so in the case of low discharge .Where your announce numbers were less than your critical Reynolds number he found a very orderly streamlined pattern of the dye and which is basically the nature of laminar flows and once the Reynolds number approaches the critical Reynolds number of 2200 so there was instabilities in the fluid which resulted in the dye pattern being a little bit irregular and this is the marking the transition of the flow from lamina towards the turbulent regime.

So at Reynolds numbers greater than the critical value you find that there is a lot of chaotic motion in the fluid and a lot of mixing happening and therefore the dye diffuses into the fluid completely this is the nature of turbulent flow.

So when you look at heat transfer again you have to look at the laminar heat transfers separately from the turbulent heat transfer because of essential nature of high diffusion happening in the turbulence which is not present and laminar case. So you can again classify your convective heat transfer.

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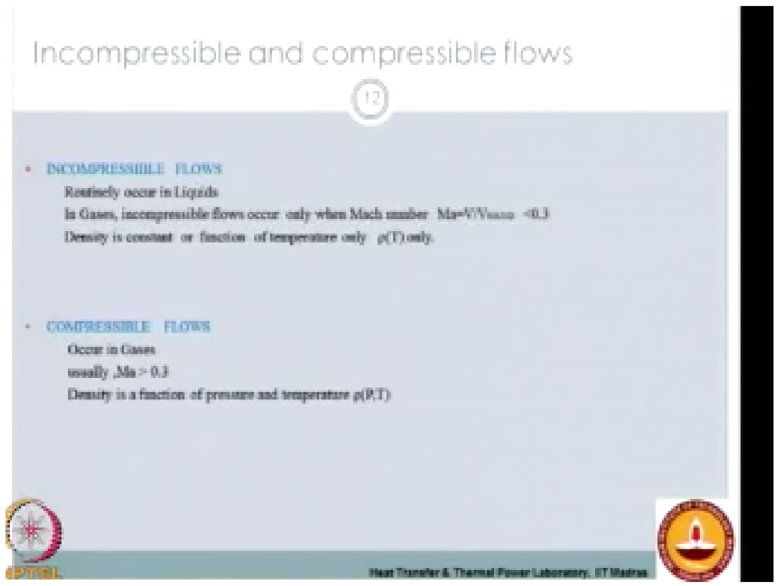

Based on the flow classification of whether you are looking at incompressible flows or compressible flows if you are looking at liquids and also if you are looking at low Mach numbers primarily less than 0.3. Then you can assume that density is constant practically or whatever is it is it is a function of only temperature and when you're looking at compressible flows so compressible.

Fluids have gases so therefore a compressible flow can happen in compressible fluids and usually this is also important when you consider high Mach numbers greater than 0.3 and in which you have to consider density as a function of both pressure and temperature and there has to be local variation of density so the so in our course we will be primarily looking at application of heat transcend vector heat transfer to the incompressible flow regime we are the there are many other classifications.

So I am highlighting here all the important classifications of heat transport based on the flow classification once again you can look at convective heat transport depending on whether you are talking about wall bounded flow or of free flow in the case of a free flow like the jet flow that you see here you do not have a classical boundary layer due to the presence of a solid object however you have a velocity profiles which are changing downstream due to the diffusion due to the entrainment of the surrounding air in a surrounding fluid into the fluid that which is flowing as a jet and once again depending on whether.

This is a laminar or turbulent case you can find the instabilities and the diffusion process completely affected by these cases and in the case of all bounded flows you clearly see a boundary layer due to the presence of the solid objects the walls and you could also look at locations where you have a clear demarcation between the viscous effects near the walls and the in viscid effects away from the walls or where you find and the merging of the two boundary layers from the top and the bottom walls and then you have a completely viscous dominated flows.

So these are classified as wall bounded flows and again you can talk about internal wall bounded flows our external wall bounded flows for example you have flow past a flat plate or a circular cylinder so that if you look at the boundary layer growing across downstream of this particular object so you are talking about external wall bounded flow and away far away downstream this is called the wake region here where the boundary layer theory cannot be applied and the flow separates and then again you have variation in the velocity profiles in the wake region.

So these are called as the wake flows so in this particular course will be focusing on wall bounded flows to a great detail because as such again focusing on jet flows and wake flows would be very exhaustive and we do not have a sufficient number of lecture hours so we will focus particularly on external wall flows as well as the internal wall bounded flows.

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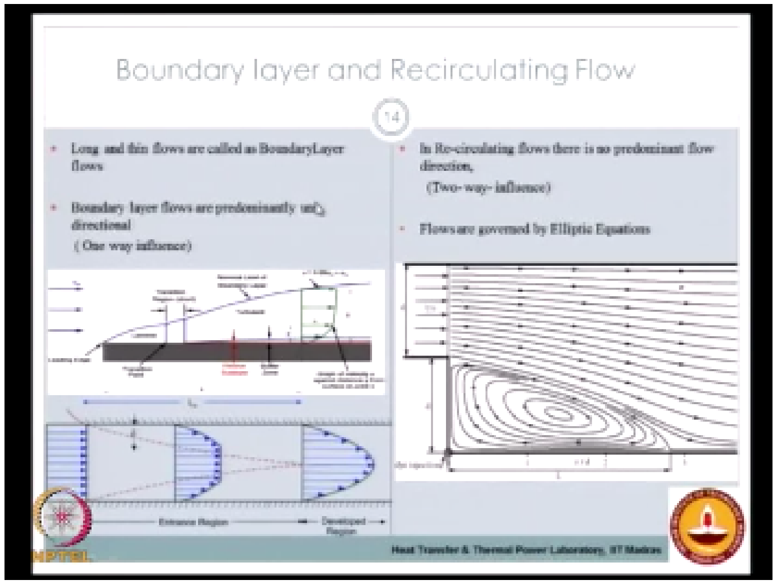

So coming to the wall flows again you can talk about two classifications. One which is called a boundary layer kind of a flow as I said due to the flow of fluid past a solid object due to the difference in the moment near the wall and in the free stream you can have this rapid growth of a boundary layer where the velocity profiles keep changing locations downstream of the plate.

And however in this case you can clearly separate the region with where the viscous effects are dominant within the boundary layer and outside the boundary layer where the viscous effects can be neglected and the flow can be treated as potential flows so here the nature of the equations is that there is a one-way influence from the leading edge of the plate downstream and these kind of equations are called parabolic equations where predominantly unidirectional influence of the flow is seen and these are called as the boundary layer kind of flows now if you look at the flows with adverse pressure gradient or where you have sharp corners like the figure right here so you can have flow which cannot flow across.

the sharp corners and therefore has to separate and that is a recalculating bubble here so in the case of recalculating flows now you cannot say that the flow here in the recirculation is dependent on the flow upstream and therefore there is no predominant flow direction here however there is a two-way influence so the equations here are governed by your form of the equations which are elliptic in nature and therefore the disturbance comes from.

Over all the directions into this particular Cardinal here so if you look at two kinds of wall bounded flows one is your where your boundary layer theory can be used such as in this case and the other case in the recirculation case where the boundary layer loses meaning once the flow separates and recirculates you can also.

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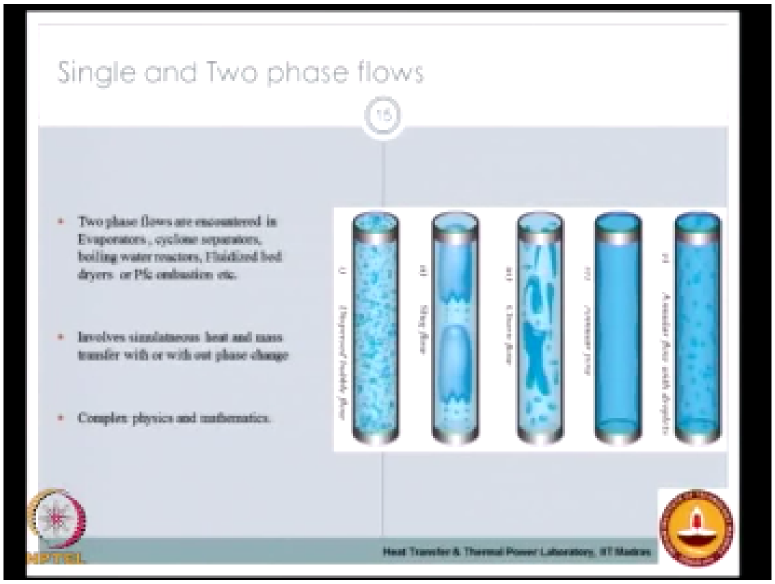

Classify your heat transfer depending on whether you are looking at only a single phase or multi phase problems so this course will be focusing primarily on single phase heat transfer however you should be also aware that most of the cases to phase flows are very important and two phase heat transfer itself is a separate subject course by itself so typically.

You encounter two phase flows in a variety of places such as where you have phase change happening such as in evaporators condensers in boiling water reactors in your nuclear power nuclear power generation the fluid ice bed right dryers are fluid as combustion etcetera so typically if you look at adiabatic two phase flows where you change the flow rates of the vapour or the gas and the flow rates of the liquid you can encounter different regimes of two phase flows which are going from say dispersed bubbly flow to all the way up to annular flow with droplets.

So in one case you have very low mass fraction or volume fraction of vapor in this case and if you go towards the right you have a very high mass fraction or volume fraction of vapor and you have a very small volume fraction of the liquid droplets which are dispersed within the vapor so these are the different transitions which are happening when you change the relative superficial velocity of the gas with respect to the liquid and of course they have their own complex physics which is still not completely understood and lot of research is ongoing.

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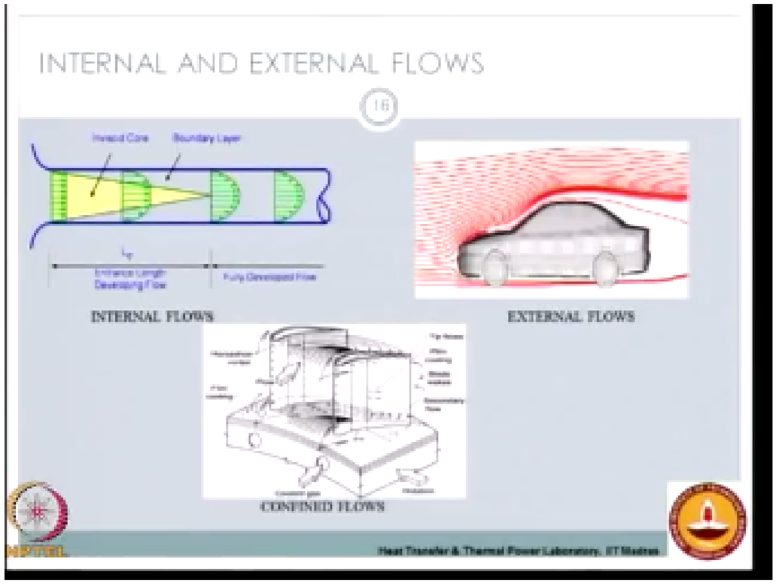

The other classification of convective heat transfer will be depending on. Whether you are looking at flows which are in a particular conduct like the case here where you have flow through a particular duct where the two boundary layers from the walls if you are looking at two dimensional plane ducts that are boundary layers growing from the top and the bottom of the duct and finally they emerge together and they have the complete region is viscous dominated so these are called as internal flows in the case of external flows you have boundary layer growth from the surface.

And you can very clearly distinguish the viscous dominated effects within the boundary layer to the in viscid or potential flow is effects outside the boundary layer so we can also look at heat transfer problems separately where you have a boundary layer approximation is valid for external heat transfer separately from the cases where you do not have a boundary layer kind of a equation when you look at the completely fully developed flows in internal flows and depending on.

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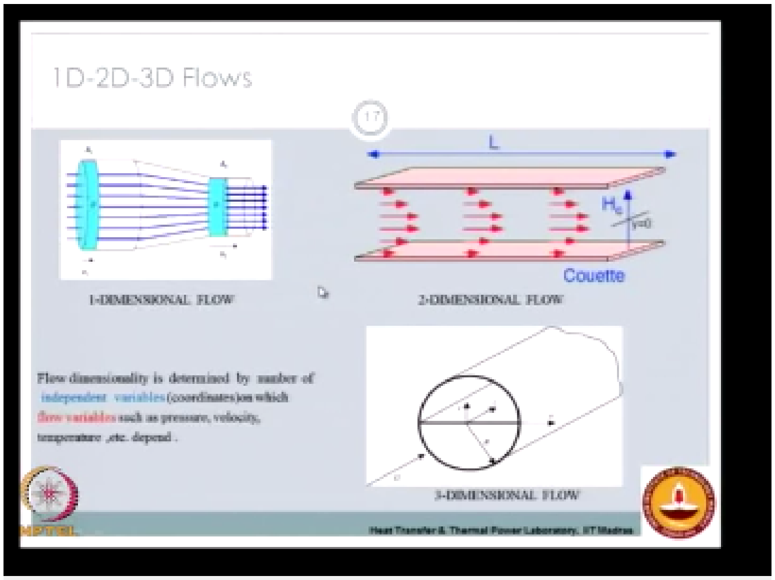

Again the computational simplicity you can take flows which are one-dimensional in nature typically where you just look at only the variation in the axial direction. You do not look at the variation in the other direction other directions this is the one-dimensional flows and the other will be your two-dimensional flows where you look at variation both in the axial as well as the vertical direction there are flows are actually three dimensional in nature where you have variation in all the XYZ directions and therefore more complicated if you look at them in this particular course will focus mostly on the nature of two-dimensional flows.

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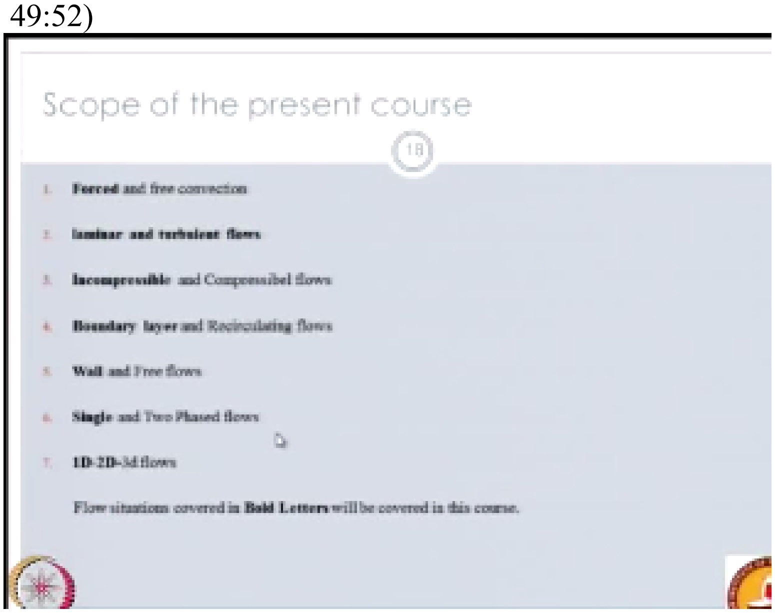

So therefore to summarize what is the scope of the present course since we have looked at the classification of a convective heat transfer into based on the flow regimes based on the geometry and based on whether you are talking about single or two phase flows. We will decide what is the going to be the scope of the present course so we will look at forced convection and free convection both and we will also look at both laminar and turbulent flows and primarily we'll be focusing only on incompressible flows here under incompressible fluids and we will be restricting our understanding to a wall bounded flows and also only in the boundary layer regions not in the recirculation regions again our focus will be on single phase flows and the two phase flow is a separate course.

By itself which will not be covering here and our scope will be restricted to 1d and two-dimensional flows so the flow situations which are covered in bold letters will be covered of course I think this is a mistake here there should be free convection should also be involved and therefore these situations will be covered in this particular course so we will stop here for today and in the next class tomorrow. We will start off with the fundamental occurring equations and we will start deriving the governing equations one after the other you.

Introduction to convective heat transfer – Part 1
End of Lecture 1

Next: Introduction to convective heat transfer – Part 2

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