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Video lectures on convective heat transfer

Prof. AjithKumar Kolar

Department of Mechanical Engineering
Indian Institute of Technology Madras

Lecture 2
Introduction to convective heat transfer- Part2

Earlier we used to have a full fledged the convection course long back like these 40 hours then we compressed it into advance heat and mass transfer course some of you have taken that course and now this has been made into an elective so that more of convective topics can be covered basically in that what dr. Aravindh has done so far is do new the for almost 30 hours laminar he transfer conductive heat transfer.

Studies incomplete without the study of turbulent heat transfer but turbulent heat transfer cannot be done without the knowledge of turbulent bound layers which cannot be done without the knowledge of turbulence per se so this is a very unique and complex kind of a convective heat transfer compared to the laminar convective heat transfer which you have done so far in your course on incompressible compressible flow you have done incompressible.

So boundary layer theory mustst have been done there turbulence was done turbulent boundary layers was it one classes we will try to do something about it although the time is a little limited but we will try to do this but before I go into turbulent heat transfer and free convection dr. aravind I can do the quiet flow you said quiet flow can done I would like to tackle one other particular problem in convective heat transfer.

Which is called quiet flow is a very simple geometry it is not about layer flow but it gives us tremendous amount of experience actually exercise experience in simplifying the total overall complete naval-stokes equations to a very very simple set of equations and then you are able to solve it by hand in the class without necessity of any other complex solution methodologies like series solutions or transformations numerical methods especially you can get with certain assumptions.

Which are very reasonable you can get solutions for heat transfer in a very direct complete fashion without resort to computers are any other complex mathematical techniques number one number two what is so great about it why should we do that we have we have very nice quotes available today you know if you put in all these things into your code whether the finite difference technique finite volume or finite elements you will get.

The answer that is true but the the beauty of this particular problem as I see it and and it is really exciting that very important concepts in convective heat transfer at least couple of them three of them come out of this very simple solution so basically there are three reasons why this particular flow situation that I am going to do is important one it is considered in literature as one exact solution of the complete naiver- Stokes equations.

If you please make a difference between the complete set of naiver-stokes equations and the prentice boundary layer equations what is the difference between these two by the asking some questions please respond I do not write too much on the board I want you to write down what is the difference between the navier-stokes equations and the parental as the name suggests boundary layer equations what is the bound layer.

What is the boundary layer what is different about earlier don not say all that you be a little bit more firm yeah you are right so where the viscosity affects therefore what particular force does viscosity effect huh no you have to answer me what force does this property of viscosity of fluid affect control something should not take so much time to answer this question you know so viscosity property of the fluid there is a force shear force these.

Together a lot rather along with the velocity actually give you the shear stress fine so there is a layer as you said very close to the surface where when you say this viscosity is important it is not viscosity that is important actually it has an effect it is the shear force shear stress that is important and this shear forces are of a magnitude much higher than what it could be outside the boundary therefore that important the property of the fluid.

Which comes into picture is the viscosity for you to have a shears shear force shear stress it is not simply viscosity that is enough there should be a velocity there should be a relative velocity actually if you look at what is the fundamental expression for a shears for viscosity okay defining viscosity or the shear stress equation give me the complete thing say it loudly if we make mistakes it is okay no problem so you must have the viscosity there.

Should be a gradient it is not simply the velocity the gradient so tau equal to $\mu \nabla$ du/ dy ∇ u/ ∇ y is the what is this law called Newton's law viscosity so it is actually a definition for viscosity in one way so what does the punt holds boundary layer equation how does it now differ from the navier- Stokes equations if you want I will go back a little bit before navier's stokes equations what kind of equations were present were used for fluid flow.

Euler’s equations so Euler's equations now can you tell me what the difference between Euler’s equations is and the navier's stokes equation that they look very very similar almost identical except for something what is the difference between Ailers or Euler's equations and the neiver Stokes equations this which cause term is coming into picture in the name that is a very big achievement find out when the navier why is it called as a nevier stokes.

Equations please find out if you have not when was it actually proposed please find out I want all of you because I am interested all of you to me interest in the history of these things history of science person history tells you a lot today when I am talking about this Dr.Aravind is talking about it is as if we know about it forever it has been as a given thing for us to come to this stage lot of work lot of thinking lot of research has been expended in the last 200 years.

And what we are given today is as if it has been there forever you should really look at how the history of a fluid mechanics has developed history of heat transfer has developed who have contributed to all this and what were they doing today the moment I talk over friends will you you will get an expression what were they doing when they did not have they did not have the equation who developed this equation for example you know.

I want you to please think look at history today everything is available at your fingertips so near we have Stokes equation fundamentally was a great jump in knowledge as well as utility compared to the Euler equation this was in the 19th century 19th century was the time when tremendous advances were made in both in fluid mechanics to an extent and heat transfer but the real advances in heat transferred have been in the 20th century we 1900 to 2000 has been a great

Period for advanced advances in heat transferred per say but as far as at least we are concerned convective heat transfer the real foundation for that was in the 19th century starting from Euler's equations in the navier-stokes equations what was what is the fundamental heat transfer equation which was developed in the 19th century which you use it all the time in convection also use it four years law of heat conduction find out go to the original paper if you have a chance go to

The paper Fourier James Fourier the French mathematician he gave this heat conduction law Navier’s and Euler’s all of the equations were there without miss customs in navier-stokes never and so these though different people by the way find out why therefore two names there navier is different Stokes is different you might have heard of the Stokes hypothesis you would heard not of the neighbors hypothesis so find out why this source was called so.

So navier Stokes equations finally in the late 19th century really gave a push to the science of fluid mechanics from one particular point of view there is consideration of the shear stresses and only then really the Aeronautics industry developed it aeronautics industry rub once this point was understood that even for air which has a very low viscosity shear stresses could be important under certain conditions tau equal to μ du / dy so you can neglect the shear stress in

A flow either when du/ dy is 0 or vanishing or nu is vanishing air has a very low viscosity but even though air has low viscosity many engineering several engineering fluids including water low viscosity in their flow shear stresses become important when velocity gradients become important that is the point you should look at otherwise viscosity was known they did not know how to bring this into mathematical form what is the D ambit's principal at D Amber's paradox

If everything is considered as ideal you know in visit ideal fluids so a solid body can move through it forever without being retarded but experimentally everybody would see everybody could see it was retarded and that was what was the tremendous retardation tremendous slowing down of any vehicle which moves in the air including the automobiles for example so there was tremendous researcher was going on at that time and credit for bringing in shear

stress into our engineering consideration and mathematical possibilities is going to navier Stokes and the four years law of heat conduction from the heat transfer point of view but in 1904 something extremely important also happened 1904 so negative Stokes equations were available 1904 something else happened what is that pantry write with pantal please find out about his life you have a book by him in the library green bound book please go on study that

hit with prenatal proposed after studying navier-stokes equation after lot of experimentation he was the first one to propose the shear stresses are very important it were all very fine but these are important only adjacent in a very thin layer adjacent to a solid surface on which the fluid is flowing this was a it would now appear to be as a as a what is called as given but for him to come up with that physical idea concept and then take care of the complex now only a neighbor strokes equation that was a huge achievement of those times now you are coming to that so

from Euler you graduated to navier-stokes from nevier stokes I would say you graduated upwards to practice boundary layer equations because he simplified them tremendously he said all these complete neighbor Stokes equations need not be considered in their completeness in the layer very close to the surface it is enough if I take certain terms certain assumptions I can make and then a mathematical equation I can derive a mathematical mo∇ the solution of

which will give me the shear stress what is the major major mathematical impediment I was in difficulty with neighbor Stokes equations the complete neighbor Stokes equations are nonlinear look at the left hand side you $\nabla u / \nabla x v \nabla u$ but non linearity and non-linearity and this is the problem with neighbor Stokes equation of a Matic my mathematical point of view for engineers why pure science is important pure mathematics is important but for engineers certain Assumptions are okay certain overall picture is okay as long as we get engineering wise applicable solutions without bothering too much about how they originated a scientist need not know engineering but an engineer should know the science behind boundary science meant fluid mechanics then you will be able to appreciate it better but more than that you will be able to correct yourself later also so let me partly simplified the navier-stokes equations into.

What now we call as planters they are referred to as planters boundary layer equations meaning they are fully applicable in that boundary layer which is a very thin layer next to the surface this he made it only for the shear stress not for the heat transfer actually although we then expanded up extended upon it is one part I will come back to this what now we will come to the heat transfer sign what is the fundamental objective of convective heat transfer H why do we want it

Why give me a complete answer yeah that is yourself number is then you know simply a non-dimensional what is that equation give me give me the equation I know you know all of it not that you do not know I am trying to I am the my first class I am in the developing region I want to develop by tomorrow day after into my fully developed flow conditions q is equal to and what is it called huh is it really a law there is a point now I wanted to ask can you okay no let us

Go later what are the most fundamental modes are mechanisms of recurrence so there is these are the left is these are the right is here they do not want they say only conduction radiation there is a conduction convection areas yeah actually convection if you see is a modified form of conduction the ultimate mode of heat transfer right at the interface at that first micro layer is conduction how do you know this mathematically what do you do how do you know this no

Sleep okay you know I am looking at that so how do you connect conduction to convection with this concept let me put it the other way how do you conduct connect conduction to your heat transfer coefficient conduction at the wall at the interface to the heat transfer coefficient what is it so h Δ T is equal to minus K DT by dy equal to zero now on both sides what is the difference in the in the coefficients in terms of the future the characteristic of the coefficients h

Δ T you have kdt/ dy no unit wise okay but anything more than that okay one on the right hand side DT / D U is a gradient under on the left side it is not a gradient okay number that's very clearly seen but I want you to tell me the difference between the other two factors the other factor on the right-hand side and the left-hand side what is property now you come K is the property of the fluid H is not actually a function of what then you give me the variables there is

A flow condition yeah geometry and the properties therefore it is not a property it is a characteristic now therefore now I am coming to this point Q is equal to H Δ T H a Δ T we should not be stick to calling it a law now come to conduction write down the expression for conduction for your slope you know that if you want to curl Q is equal to minus K DT / dy write down for radiation Q is equal to Σ Epsilon t1 4- t2 4 write down for convection

H ^ T now look at these three expressions for conduction you have K is the thermal conductor which is a property on the right hand side for radiation your epsilon property coming into picture and in both of these cases of Poe there is no flow in the convection case you have Q is equal to X ^ T where there is no property alone properties incorporated in H while you call correctly for years law of heat conduction 6 Stefan Boltzmann's law of radiation it is not

Strictly right to call this Newton's expression as Newton's law of cooling because it depends upon geometry flow and the property you might say what is so great about it I want you to understand the difference you do not have to accept everything as it is said you know to understand the convection is not in a way not a fundamental mode of heat transfer modified form of conduction it does not matter in your calculations but you should understand as scientists

Engineers similarly Newton's law of cooling so then if it is not allow what is it it is simply a relationship it is simply a definition of H know like tau is equal to μ du / dy Newton's law of cooling is a law of its a law because μ comes into picture as a property q is equal to h a^ t h ^ t flux h is a characteristic it is a definition of H this was a very fundamental thing find out how this came up after you called it Newton's law anyway already so although heat transfer develop

Tremendously in the 18th and 19th 19th and 20th centuries Newton himself has contributed certain things especially Newton's second law of motion you are going to use Newton's law of viscosity you are going to use and the so called Newton's law of cooling so called am saying so some of these concepts came from the time of Newton it is at the in the 18th century 17th 18th century there was not much of work then four years law of heat conduction came into picture

Euler's equations came into picture graduated to navier-stokes equation then came this seminar layer of 1904 when Patrick said I do not have to solve the entire nevier stokes equations because these the engineering at that time the engineering object you of the study was shear stress as far as the Aeronautics is concerned that was the the drag coefficient that they wanted that was the purpose black coefficient cannot come from your Euler's equation this does not exist

Them the complete navier-stokes equation has this custom it has to be solved then prenatal said no not how to solve this let me try to simplify order of magnitude analysis scale analysis finally he gave those the even though they are nonlinear still they are much less formidable than the neighbors Roxie questions you tell you but X plus V ∇ u by ∇ y equal to nu ∇ square by ∇ Y square minus 1 by Rho DP by DX so many terms mathematical terms he canceled out
With certain argument assumptions some very write some approximately write but his intent to ask can I handle the navier-stokes equation a much simpler simpler way for me to get my skin friction coefficient that will only from the fluid mechanics part of you then came of course much later the energy equation the same concept of boundary layer for viscosity and shear stress was extended to the energy equation 2 then term a thermal boundary layer they simply surmised as

Viscosity is important in a very thin layer may be K is important only in a very thin layer although these two may not be equal but they just like a hydrodynamic is not an ice or hydro is water actually so it is a aerodynamic boundary layer fluid but it would be a fluid mechanical boundary a fluid dynamic boundary layer like that there is a thermal boundary layer these two concepts which came only in the 20th century nineteen not for prattles he presented it in an

International conference nobody bothered about it nobody bothered till 1934 in one of the international conferences there were six papers on bound layers 1945 there were 280 papers and by 2000 there is no year in which there is less than thousand papers on boundary theory that is the import the significance the importance I would even say greatness of this particular concept which we today talk as if I I came up with this concept I tell you this exists I have never seen it

We have done experts there is a different matter so 1904 was already 110 years old along with him under his contemporary was result now you know he he is remembered with his he died only in 1950s result number I am now going one step ahead that heat transfer coefficient which is a whose definition is given by the Newton's law of cooling was given a non-dimensional form by result in 1925 he said he came through non damage he did not know about the

Buckingham PI theorem at that time he simply made a scale analysis he found this group h x / K was non-dimensional and then he said I should be able to relate it by the terminal or some are was already ended there are some more when was it proposed notes number I know the Osborne Reynolds 1883 at another major experiment by Reynolds experiment please look at pure knowledge experiment where he injected a color to dye into a pipe flow under extremely

low velocity conditions and he could see a very nice as no we call a laminar filament of a layer and then when he increased the flow he started seeing fluctuations he said what is happening the velocity at every point is changing with time and space that is how the idea of turbulence was actually visualized and then that particular parameter or a period of time it was given the name in a odds number what does n all numbers signify or does it physically signify inertial by

Viscous forces so as you increase initiate or u∇ u / ∇ x action you please make it out Reynolds number is inertia by viscous so Rho UD u / DX divided by μ discord u / DX square if do that you will just get Rho V D / μ that is VD by nu we being a characteristic velocity plenty did the other thing he did not do it per se but when he non dimensionalized I mean his made a scale analysis he got this term μ by alpha actually μ cp/k sic-making that is

Called the plenty number today now you see over a period of time from the fluid mechanics point of view 1883 runs turbulent laminar turbulent transition came into picture and a number Reynolds number came into existence then pantry gave the bowlear 1904 prenatal talked about a result around 1925 apparently by plantle another thing in 1925 we have not had gone to turbulent Valdez but I will tell you now he develop to the first what we call the zero order

mo∇ for turbulent flow called the pantalets mixing length theory please note down we will talk about it later so you shall gave us the non-dimensional form of hex there is nothing more to it we can talk about convection by conduction we can then improve physical significances if they have physical significance so what a period of time you finally got convective heat transfer to be represented by mutant as a function of Reynolds and Franklin the Celt is a non-

dimensional form of the heat transfer coefficient which came from Newton's so called off cool Reynolds number from Reynolds because of the laminar that that number differentiates between laminar and turbulent flows and then prantle number what does frontal numbers signify when I give you a partial number what would you what information will you get third properties yeah pick up yeah it identifies the fluid that is the thing yeah its properties therefore it identifies the

fluid there is none you cannot miss anything if you stare prantle number is equal to 0.72 it is air and most of gasses somebody need not tell you find out whether it is oil or a liquid metal or whatever no it is gas end of the matter on the other hand if I separate this parental number of the spirits point not 01001you all right is a liquid metal sic by KK is extremely high on the other hand if I said the the   Parental number is some 1000 to 50,000 you

See P / K where K and you are varying with temperature and that has to be oils light oils heavy oils so the moment that is the beauty of this particular number where else numbers gives you the type of flow result number gives you the non-dimensional heat transfer coefficient which is actually actually by K no you can write it as H over K by D so it is a convective heat transfer coefficient divided by the conduction but it is a relation between these two and then plantle

number signifies the fluid this is extremely important so if you look at this general expression you said as a functional not sponsor you have everything coming into picture here and left hand side is what we want that is the objective of convective heat transfer steady getting you said result number in the beginning it is the heat transfer coefficient in the form of a non-dimensional number but it this is a function of the flow the geometry and the properties floor

The geometry property comes through the various number it will tell you it is laminar or turbulent and the prantle number says this the free you cannot therefore use this is what I tell you a lot of so do not think the equations are available in the some tables so why should I attend my class I can simply take any equation you will get all equations in force convection but you should know what is the background of this waters its significance of all this how do

How does H which is our major goal in the conversion how does it vary with flow that is the velocity the geometry and the properties of the flow so the engineering objectives are to in convection heat transfer actually it is not gone you should say it is true because you have to get the skin friction also that is a purely fluid mechanical thing but when we were talking about convective heat transfer skin friction coefficient determination is important and heat transfer

Coefficient determination is in part when do you think viscosity or do you think viscosity will affect the heat transfer or not because the viscosity is a purely fluid property heat transfer coefficient is a function of the property these two are the objectives do they interrelate do they affect each other that affects the whole process do they affect each other how does heat transfer affect fluid flow no if μ is a function of temperature not source of pressure the Rho is a

Function of pressure and temperature so heat transfer is very important therefore we talk about low temperature heat transfer high temperature heat transfer and the effect of properties which are a function of president properties are a function of pressure and temperature so we should look at the president temperature how do they affect the properties whether they will affect my skin picture on the other hand how about friction viscosity affecting heat transfer coefficient

What is it resisting that is a new term maybe we mean the same but I am not able to get the yeah viscosity affects the flow okay yeah this is like in all of our the same thing we look at different angles so you should give me different angles to this viscosity causes friction I want I was looking at from friction generates heat sometimes it is negligible most of the time you want it to be negligible but not all the time when frictional heat is not negligible it affects your

Temperature profiles this effect is called the effect of viscous dissipation so actually you should way it is mathematically already there in your energy equation do you remember $u \nabla u / \nabla X$ $+V \nabla u$ rather $u \nabla T / X$ plus $V \nabla T / \nabla Y$ = alpha ∇ Square t / ∇ Y square simplest of the boundary layer equations plus Q triple prime by Rho CP if you have the heat generation and the last term is what μ Phi Phi is a dissipative most of the time we neglect it

We say you are causing a lot of problems so let me not bother you but imagine if that is important your whole energy equation is affected by that again it is not simply the viscosity the viscosity along with the velocity gradients that Phi is nothing but all velocity gradients as you will see so they are all mutually affecting each other so it is possible in certain conditions we we consider sometimes we do not then as scientists we should say when do you consider

Viscous dissipation when we do not that is from viscosity special value now if you come to the flow itself or you know laminar turbulent we talked about this but there is a between zone the transitions actually and I mean are what is the turbulent what is the critical Reynolds number for flat plate for flat plate file to for pipe when you say fine they perform where you you got it from Bhagavad-Gita is it where did you get it from one beautiful value actually if we go a little

Bit detail there is a transition zone so there is a initial reverse critical critical Reynolds number and a complete critical number it depends upon so many things including the surface type of surface obviously so it is not that suddenly the flow which has been very nice well-behaved it jumps to turbulent flow it happens or a Reynolds number range so initial Reynolds number in our general handling of convection we may not bother much about it but you should know that

There is a range and it can be controlled in fact a whole lot of things can be controlled by controlling the flow that is possibly in some ways it is in our control and especially also controlling turbulence itself and the transition to turbulence so if you know some of these fundamentals you would like instead of simply accepting whatever there is shear stress or heat transfer coefficient you may say can I control this can I control the flow for whatever reason

Can I control the heat exchange process within certain limits you can do it that is why we should you should try to go as deep into the fundamentals as possible as an engineer finally an actual technical person may not bother about these things but he knows if you go to a person who is handling a heat exchanger in us he knows how to increase the heat transfer rate how to decrease he may not know the basis of that sometimes he increases the flow he is actually

Increasing the rods number basically there are many ways of controlling heat transfer and if you know that Reynolds number of the flow from the flow pointer four controls heat transfer in a unit exchanger you can do something with the velocity you can some do something with the type of the surface there is a reason why I would like you to dr.aravind has done a lot of thing and flat plate and pipe I am just adding to that if he has not done that please read about the

History and try to get a picture of where we are today why we want to study convective what has been the background that will give you a little bit more I would think excitement understanding of the whole process otherwise it will become a little too dry I will again talk about similar things I want you to draw start draw writing down drawing it a convection chart a conversion chart you must be able to do it on your own I will just guide you on that I like this

Particular thing I always emphasize mirage to get a full picture especially for beginners I know you have already done quite a bit of conversion but still I want to do this on the right is a chart chart or a sequence of events let me say on the right hand extreme you write the purpose of cognitive study determine and I want you to write what is it determination of I want you to write this know I want to write purpose of convection study is what determine h right down that

And go one step ahead put an arrow there how do you get this H you know what in our scientific approach what do you need to get that H mo∇ wise are experiments wise temperature difference no you have done all this I am actually trying asking you to put whatever you are done in in this chart fashion or a table fashion how do you get H actually from your analysis what is it that you use what expression for you to get h from all the analysis

Lambda itself what all you have done yeah boy what take me work for yourself at this her face no this what I wanted at the surface you apply the four years law right down so four years clock comes into picture minus kdt /dy at y = 0 equal to is not it that is how you are going to get it that is the second what box in my child where do you get the dt / dy at y equal to zero you should always say DT by dy at y equal to zero it is at the wall we are looking at convection heat

Transfer between a solid surface and a flowing fluid for me three conditions are to be satisfied in convection can you tell me what we are talking about a solid surface and a fluid okay I want three conditions for me to say this is convective heat transfer conditions is a very big word situation but I would like to use the word condition there is a solid surface there is a fluid when we talk about convective heat transfer maybe I am not a motion will it do motion that is very

Important but before that something else correctly emotions one of the conditions for me temperature gradient a temperature difference to the third one I am saying but personal convection is very simple you will say officer we know about it but that does not matter can convection occurring the surface is here and the fluid is flowing here they should be contact this is what we are talking about so convective heat transfer is that type of heat transfer which

Occurs when a fluid and the solid surfaces are in contact with each other number one there is a relative velocity and there is a temperature difference all the three must be why I am saying this if a solid surface and a flow of different temperatures are not in contact with each other also there is heat transfer occurring but what is the heat transfer radiation and if the fluid is in contact with the surface there is a temperature difference but there is no fluid motion even then

Heat transfer occurs what is that heat transfer so conduction can occur radiation can occur between a solid surface in the fluid depending upon whether in contact no motion no contact no motion but convection is contact and motion motion is created by the temperature difference motion is created by nature nature we here we are talking about the GF act actually but it better sometimes to call it free convection but you are perfectly correct what you can talk about is in

First convection there is a imposed a flow is forced by some means in free convection that flow is created inherently within the fluid itself because of the existing temperature difference so it is a good point that means I mean we know that for heat transfer first of all temperature difference must be there of course there is if there if these two are in thermal equilibrium there is no heat transfer so that is a matter I am your point is well-taken I am will emphasize that so

Convection is that mode of heat transfer between a solid surface and a fluid when they are in contact when there there is a relative motion and when there is a why I emphasize this is a fallen let us say there is a contact between the solid surface and and the fluid there is a temperature difference but if they are moving together at the same velocity there is heat transfer but that is my conduction only there is no relative motion there is no boundary layer there so

Conduction can occur in a fluid I mean between a solid surface and a fluid when they are static both of them or both of them are moving at the same velocity that is why I have to bring in that term relative motion µst be there even if there is a point one centimeters per second difference we said there is relative motion but then you can also see the convention the heat transfer due to the fluid motion is very mild it is not that µch in terms of the notes so that is my as you

Students that take on convection he is it convection only between solid surface and a fluid under these conditions do you have to stress on solid surface hmm could be heat transferred for instance number point here is that it is not necessary that we always talk about a solid surface well you know no there is a big water shortage in this city and we are going to feel it you know why one of the water shot reasons for water shortage of course there is no rain but if you go to

Any of our reservoirs they are all open surfaces of water do you think there is nothing happening there at the surface there is a wind blowing in fact at 12 o'clock the wind sets in the the Sea breeze sets in and there is a wind flow over these surfaces what is happening at that time we have pollution there is a mass transfer so when there is a concentration difference there is a master so that that we call it as a convective mass transfer so there is a concentration boundary

Layer and similarly if there is a temperature difference between these two heat transfer will occur and sometimes you can have isolated cases of sorry isolated heat transfer mass transfer but there are cases where both of these are possible heat transfer mass transfer siμltaneously but in convection fundamental to heat transfer and mass transfer is the fluid motion fluid motion plus conduction for years heat love conduction is your convective heat transfer fluid motion

Plus flicks law that is your mass transfer conductive resistance so I would also therefore like to say convection is not necessarily between a solid surface although we focus on that between two flicks as long as there is contact temperature difference fluid motion relative velocity is another point about it now if this flow is from an external energy that force convection free convection there are mixed convection cases also to get a handle on quantitative handle handle

On heat transfer coefficients and skin friction we do cool things either we follow a science mo∇ or a engineering mo∇ heat transfers as a sigh as a subject has two aspects science and engineering engineering means you do actually experiment so you get the heat transfer coefficient or whatever you want measure temperatures everything but even bases for those experiments is they were actually theory part of so when you talk of getting the heat transfer

Coefficient theoretically you develop a theoretical mo∇ I want you to from this come to that point let charge so heat transfer coefficient you get by equating minus K dt / dy at y = zero or = 0 is very important y =0 is the interface is equal to h Δ t dw – t
Infinity now go to the next verse next box what do you have to get in this equation what is it that you have to get temperature no you first you should say I want you to say you want the

Temperature gradient at the one you do not really care about the rest of the thing I want dt / dy at y = 0 this is very important for me dt / dy is there from y = 0 to y equal to Δ but I do not bother dt / dx/ u = 0or wall gradient now you go to the next how do you get the wall gradient at y equal to zero only this is what is making all your convection a big issue to use a very mild word all you need it dt /dy dy is = 0 therefore when you do experiments ladies and gentlemen

You do not have to measure the entire temperature profile for you to get the in terms of coefficient just close to the surface is ineffectual you do not have to do go for the entire body layer thickness so for but mathematically that is from a theoretical point of view for you to get DT / dy =0 you have to get T as a function of Y that means now you determine the temperature profile now how do you get the temperature profile now we are talking about the boundary

Layer how do you get the temperature profile go to the next box or the next point how do you get the solving you cannot simply say energy equation energy equation is not enough by itself for you to solve the energy equation you also have to solve the why what is there in the energy equation which makes you so how you have you that's the difference between your conduction equation which is the energy equation and this equation fluid flow of fix even energy equation

So you ∇ T by ∇ X V ∇ T by ∇ Y for you to get this you have to solve the momentum equations and momentum equation you cannot solve it on their own you have to solve the continuity equation so when you solve the continue again the momentum equations you will get the velocity profiles when you take those velocity profiles and put it into the energy equation You get the temperature profile when you get the entire temperature profile you just take the DD by write y equal to 0 x k equal to h Δ t then you will get get H now from where do you get that profile which equations now you have to get the profile so from where do you get the equation you have to solve that round like what I want and such that I want plantlets boundary equations you have to solve not that not Nanaia never Stokes equations that is what I am

Coming to at this point you have to solve the planetoids boundary n equations at the entire thing momentum equation energy equation of continuity its it is understood that you have to do that so these are already simplified well do you get how do you get the paddles modular equations from where from so write down neighbor Stokes is so simplification of navier-stokes you see them all these you have done I am just putting it in a certain form which I like where do

You get the name of Stokes equations from what is the basis of the navier-stokes equation Newton's second law they weren't ever start from the beginning they say first equation first continuity equation love the of conservation of mass then next three equations yeah okay I will leave it at that three equations and then the last one love from where does the love conservation energy come which law first off some language of course if you are looking at mass time so you

Also at this spacious equation we will further present on what physics do these equations depend on I am trying to get Q related this H that you want to engineering ways required to nature basically now look at this loss you are talking about first law of thermodynamics second also he shoots a second law is important minus K DT by dy is second law of thermodynamics expression actually and then all the velocities come from the momentum so law of conservation

Of mass now look at the hub who develop release when were these developed what is the proof of this law of conservation of mass you write down you know immediately mass cannot be destroyed created you see Newton Newton has done tremendous Newton is a really great scientist he has done in work in optics heat transfer fluid mechanics actually he was a philosopher who was looking at the celestial bodies he started developing equations for the motion of celestial bodies although he was just a banker he was in charge of the Treasury of England actually at the time so he came out with this equations which happened for us to be applicable to fluids also on the earth and then plartly made it to the border layer and thermodynamics now where is the proof of the first law of thermodynamics I am talking about a theoretical proof where is the theoretical proof the second law of thermodynamics now you see

in science we always say any model any love must have experimental validation now these are all called natural laws because nature itself is a proof for this on the other way we say in nature we have not found anything against this people have tried to prove the second law of thermodynamics actually theoretically but they got stuck what is the purpose of this for me this collects I want to cut the engineering aspect and nature finally finally we are dependent upon

these nature in terms of the loss of nature it is not that one man came up with this loss whereas you have a Fourier law of heat conduction you have so called Newton's law of cooling Newton's law of viscosity Stefan Boltzmann's but here you do not get why anyone named so-and-so first law of thermodynamics she evolved over years from 17th century and really find out when the first law of thermodynamics was given a mathematical representation try to find

out on your own now in most of the classes what we do without you know telling you this we start let us look at the law of conservation mass and then derive I am trying to tell you the reverse of it you want H and you want also tau W by the radius so the same thing you can relate tau equal to M ∇ u by ∇ Y but you want the shear stress at the 1 tau W equal to M ∇ u by ∇ y at y equal to 0 never forget that at y equal to 0 point for convection that do by dy I get from

the velocity profile now you see velocity profile you have to get from your momentum on the continued equation for shear stress that is end of the matter as well as fluid mechanics is concerned but if you think heat transfer can be obtained with how records to this it is not possible because your energy equation contains U and V so an actual law by the way this first law second law Newton's law these are called general laws physical laws general laws

Universal laws they will never be disputed anyway but nu over for years law Stefan Boltzmann's and Newton's law of viscosity these three are not general laws why tell me just look at the equation and you can make out tau W equal to M ∇ u by ∇ Y Q is equal to minus K DT by dy a Q is equal to Σ Epsilon one two for what is common in all these three equations common in terms of the nature of the equation there is a property the moment you say property

There is a medium coming into picture so these are medium oriented medium based medium controlled equations though they are called particular laws so you have particular laws general Universal natural or physical laws from a combination of these last now combination of these laws lead you to the equations which we would refer to with all along with the boundary conditions in mathematical mo∇ so from the physical mo∇ where you take a control volume

That is exactly what you are doing at control volume area system apply these general laws you come down to very broad equations they are not enough for you to get heat transfer then you give me only the profiles for you to get the heat transfer coefficient you have to come up with a particular law which is minus K DT by dy for you to get the mass times for you should have a flicks law for you to have the shear stress you must have Newton's law of viscosity so a

Combination of general laws based on nature and particular laws based on people's they have development please leave for your slop heat conduction is very nice paper it is in French some English translations are available how what now you wanna take it to be so simple Q is equal to minus KD to me what is there please look at that particular 18 29 or so it gives you tremendous information on what was his thinking at that time when you put all of these things together

Ladies and gentlemen we can then say we are ready to find out rather determine engineering-wise heat transfer coefficient and the shear stress end now.

Introduction to convective heat transfer-part2
End of Lecture 2
Next: Continuity equation
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M. Karthikeyan
M.V. Ramachandran

P.Baskar

Camera
G.Ramesh
K. Athaullah

K.R. Mahendrababu
K. Vidhya
S. Pradeepa
Soju Francis
S.Subash
Selvam
Sridharan

Studio Assistants
Linuselvan
Krishnakumar
A.Saravanan

Additional Post –Production

Kannan Krishnamurty & Team

Animations
Dvijavanthi

NPTEL Web & Faculty Assistance Team

Allen Jacob Dinesh
Ashok Kumar
Banu. P
Deepa Venkatraman
Dinesh Babu. K .M
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Udayakumar. C
Vijaya. K.R
Vijayalakshmi
Vinolin Antony Joans
Adiministrative Assistant
K.S Janakiraman
Prinicipal Project Officer
Usha Nagarajan
Video Producers
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