Modeling of Tundish Steelmaking Process in Continuous Casting

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Lecture – 16
Fluid Flow Fundamentals

Welcome to the lecture on Fluid Flow Fundamentals. So, as we know that we will be dealing with the flow inside the tundish and this flow is of the molten steel. So, we need to have the proper understanding of the flow behavior inside the tundish, molten steel will be flowing and then accordingly I mean, when it is flowing inside the tundish.

So, there will be many phenomena which will be occurring inside, there will be you know flow around the corner in the tundish then during that process. There may be floatation of inclusions, then you will be associated phenomena like there will be heat transfer from the walls and from the top.

So, we need to have the proper understanding of the fluid flow as well as the heat transfer phenomena. We should have some basic understanding about the fluid flow phenomena and how to model it. So, what are the different terms which we need to know, what are the fundamental principles, what are the governing equations, all is needed to study the behavior of different processes inside the tundish.

So, in that line initially we need to have the understanding about the fluid flow fundamentals, and in this lecture we will have some light over the initial you know fundamental understanding about the fluid flow phenomena.

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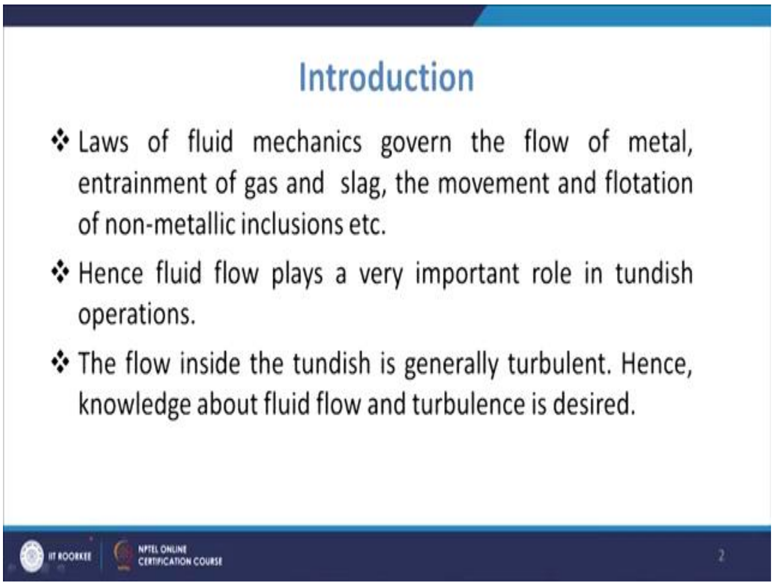

So, you know laws of the fluid mechanics govern the flow of metal and entrainment of gas and slag, the movement and flotation of non-metallic inclusions etc. So, as we discussed that here in all these cases the laws of fluid mechanics which will be governing the flow of metal they will be important. And that is why we need to understand the fluid flow behavior especially if you talk about the tundish.

So, in the tundish you have different regions. Now, there is a region where the liquid metal is coming from the ladle and then you have the remote regions also. So, in most of the cases generally the tundish flow is considered to be turbulent. So, we need to also have the understanding about the laminar as well as the turbulent regions; what are the laminar regions, how there is turbulence region you know defined.

We need to have understanding about the you know characteristics of the laminar flow as well as the turbulent flow because there will be mixing which will be going inside the tundish, there may be you know different kind of processes heat transfer there may be 1 phase, 2 phase or so.

So, actually we know we need to know about the fluid flow, turbulence, heat transfer and all that. So, during this week we will be talking about the fundamentals about the fluid flow. So, coming to the fluid flow regimes so, as you know that when we talk about the fluid flow.

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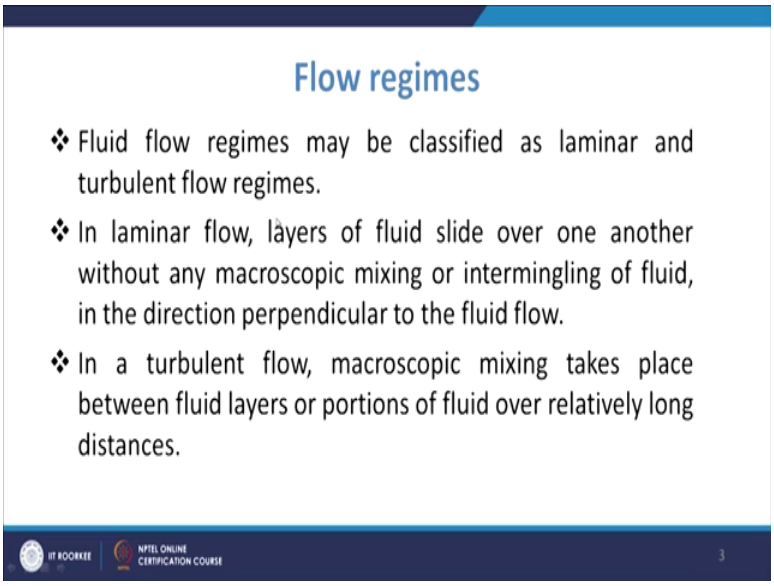

Then, the flow regimes are basically classified as either the laminar or the turbulent flow regime. So, as we see that when we talk about the laminar flow, in that the layers of fluid will be sliding over one another without any macroscopic mixing or even the intermingling of fluid, in the direction perpendicular to the fluid flow.

So, that is normally the laminar flows, in the laminar flow if you talk in a very rough sense. So, you have the layers which will be moving over one another. So, there will not be any kind of vortexing, they will not be intermingling of fluid in the direction perpendicular to the fluid flow like when you have suppose you have the concrete; so, the layers move one over other.

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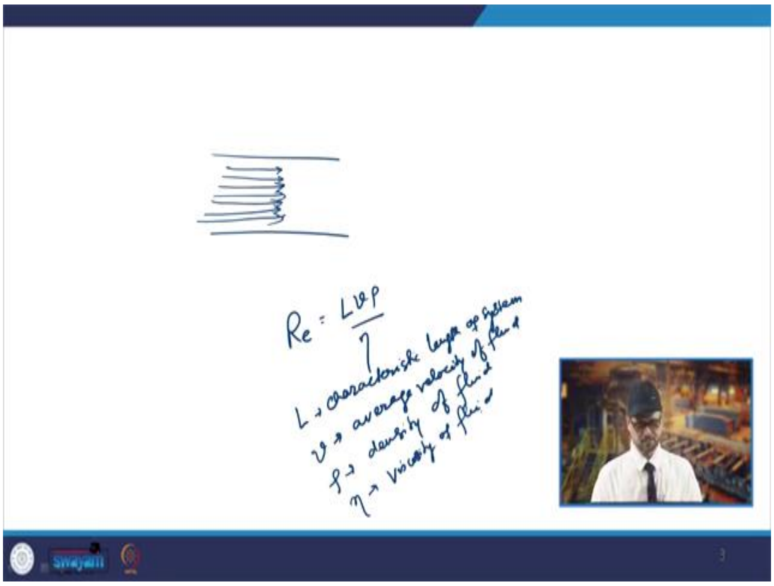

So, this is a kind of flow that is you are laminar flow; whereas, you know and in this case you know there will not be intermingling as definition tells that they will not be intermingling of the layer which is one of others, they will not you know by intermingle with one another. Whereas, in the case of turbulent flow that is not the case. In the case of turbulent flow, macroscopic mixing will be taking place between fluid layers or portions of fluid over relatively you know long distances.

So, in this case you will have the macroscopic mixing, you know taking place and that will be also taking place between the fluid layers or portions of fluid over large distances. So, you will be talking about those distances or length scales or so. So, in that we need to understand about you know different type of models which should you know be talking about these turbulence behavior and then it is associated effect on the on predicting the you know output parameter.

So, we will have the discussion about the turbulence itself in the coming week. So, there we will be talking about these you know over a relatively long distances. So, how these layers are interacting you know how there is intermingling and how these distances are taken into account. So, these things are discussed as you know that the demarcation between the turbulent flow and the laminar flow it was done by then it is done by a very Reynold number that is Reynolds number and it is by the very renowned researcher scientists Osborn Reynolds.

So, he you know devised or he has given this number that is known as the Reynolds number. So, this is the criteria for you know for differentiating the laminar flow from the turbulent flow and Reynolds number will be defined as $\frac{LV\rho}{\eta}$. So, you know many a times we write $\frac{LV\rho}{\mu/\rho}$whatever. So, in this basically we take this you know L as the characteristic length of the system.

So, it is normally like the diameter of pipe when we are talking about the pipe flow similarly you have v. So, v is the average velocity of the fluid, then you have ρ and η is there. So, ρ is the density of the fluid and η is the viscosity of the fluid.

So, you know depending upon so, once you have any you know geometry or container in which the it is flow going on. So, using this correlationship you will find the Reynold number and if this Reynold number is more than certain critical value for a particular configuration of vessel. In that case, it is said to be you know turbulent or an if it is less than that so, it will be laminar.

So, there will be transition from laminar to turbulent you know and that will be defined by that will be at a limit to that number that is known as the Reynolds number. So, certain resource for the pipe flow it is given by 2100. So, that may be different for the different type of you know cases and similarly, you know we can have surface flows so, and there the this number will be different.

So, similar; so, that way when we talk about the flow of molten metal even in the tundish also. So, in that case we can very much find whether the flow is turbulent or laminar depending upon the value of these Reynold numbers; so, Reynolds number.

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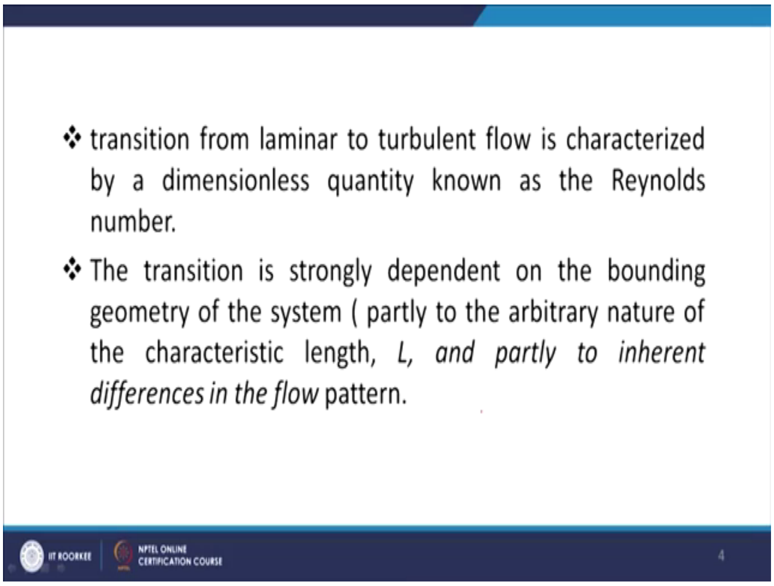

Now, next thing which will be you know further required to know to us. So, you will have the transition from laminar to turbulent is characterized by dimensionless quantity known as the Reynolds number that is what we have seen and this will be this transition will be dependent on the boundary geometry of the system.

So, they will be basically partly to the arbitrary nature of the characteristic length L and partly to the inherent differences in the flow pattern; so, they will be you know dependent upon that way. So, depending upon the geometry you will have the maybe the different value of the Reynolds number which will be demarcating the place; I mean, and the point at which there will be transition from the laminar to the turbulent region.

So, then we need to know also a very important property of the material that is viscosity and that is basically defined by the law. So, this law is the Newton’s law of viscosity. So, you will have you know as we see that there will be a velocity gradient and that will be creating the you know shear stress.

So, what was seen that the you know the shear stress which was plotted against the velocity gradient. So, you know it was seen to pass through the origin and a that was you know by an experiment and this experiment was basically that you had a you know stationary plate. So, this was the stationary plate and you have you know fluid in between and this is a plate which is you know this is allowed to move.

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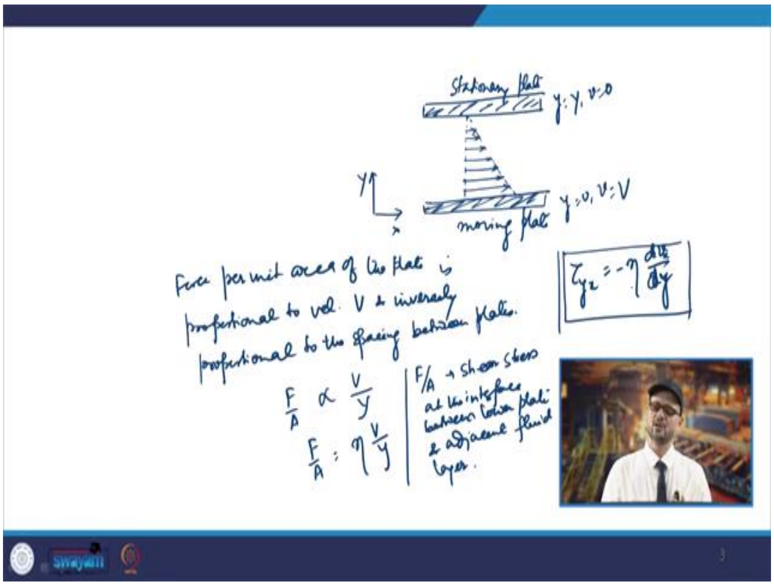

So, this is a moving plate and similarly you have this as the stationary plate. So, initially you know upper plate is this is a stationary so, you will have if you see that this is your x-direction and this is your y-direction. So, here you have y=Y and you have v=0, and here you have y= 0 and v=V actually you are moving this plate with velocity V.

So, you know and if you assume that there is no slip in this case. So, what will happen that the layer of fluid which will you know this will start you know that moving with the velocity V; so, that this is a in between there is fluid.

So, once you are moving it the fluid which is in connection with in contact with this moving plate, it will also start moving with a velocity V. So, this is a stationary so, you will it will have you know the same it will be stationary itself, but the fluid which is here they will be, they will start moving with the velocity V. So, you will have you will be seeing the a kind of velocity gradient as we see as we move in this direction.

Now, here; so, the lowermost this you know this lowermost this fluid layer it will be gradually transferring, this momentum to the upper fluid layers to the upper fluid layer although it is in you know contact. So, they will this because of the movement it will be transferring this momentum to the upper fluid layers.

And, you know initially there will be some unsteady kind of situation, and then you will have after a sufficient time you will have a steady state which is reached, and then you can have this velocity profile and you know at that time the fluid velocity will not change with time. So, this kind of velocity profile you will be getting it.

Now, in this experiment what is observed that you will have when you have the attainment of a steady state, in that case a force you know must be exerted on the lower plate. So, to keep it in motion; so, you will have to have this a force it needs to be exerted. And, Newton has found that this force you know per unit area of the plate that was found to be proportional to the velocity and inversely proportional to the spacing y.

So, what was seen that the force per unit area. So, force per unit area of the plate is proportional to velocity V and inversely proportional to the spacing between the plates; so, that is what was found by Newton. So, so, what we he found that F/A. So, this is a proportional to v/y.

Now, you will have to give so, A is basically the surface area of the plate, V is the velocity, y the distance in y direction. So, now so, if you put the constant of proportionality F/A will be $\eta v/y$. So, this η that is; so, F/A if you look at force per unit areas that we will be talking about the shear stress. So, this is the shear stress; so, F/A will be a shear stress at the interface. So, this is known as the shear stress you know that will be at the interface between lower plate and adjacent fluid layer.

So, accordingly you what you see that the shear stress that is basically what you see, so, you can express it as the velocity gradient. So, if you talk in terms of the velocity gradients a change of velocity with respect to the y. So, what we see that if you denote this as the τ_{yx} and this is as $\frac{dv_x}{dy}$.

So, form by dy basically change in distance that is y. So, you can write if you write in the differential form. So, you can write in the differential form as $\tau_{yx} = -\eta \frac{dv}{dy}$. So, as because as you are increasing y the change in velocity is negative that is why, when you are writing you know in the case of differential in differential form.

So, you see that this is τ_{yx} that is known as $-\eta \frac{dv}{dy}$. So, this you know rule is known as the Newton's law of viscosity because it is defining this term η that is your viscosity.

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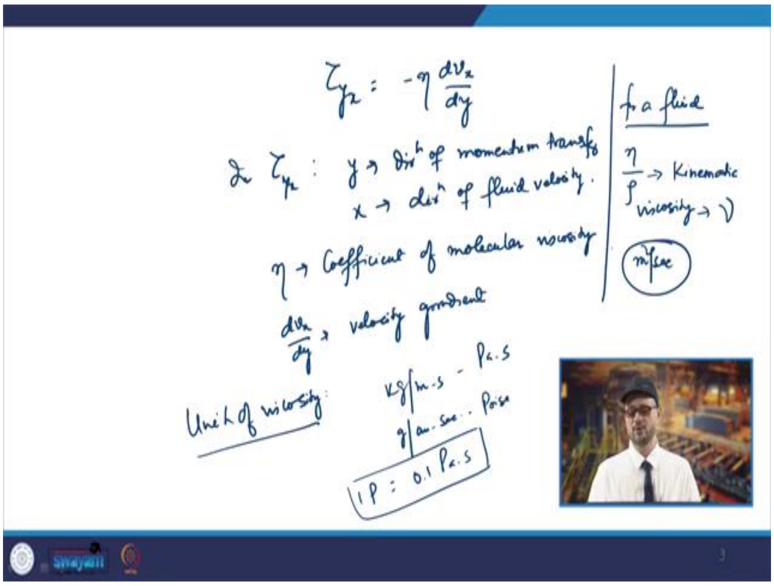

Now, in this term you see τ_{yx} . So, this τ_{yx} if you see so, your τ_{yx} becomes minus of η $\frac{dv_x}{dy}$. So, your you have y as well as x. So, this will be in τ_{yx} , the y will be in the direction of momentum transfer. So, in τ_{yx} , y is the direction of momentum transfer and x is the direction of fluid velocity.

So, so that way we are writing this τ_{yx} , then η is known as the coefficient of molecular viscosity or we also call it as simply the viscosity of the fluid, then you know and $\frac{dv_x}{dy}$.. So, this is known as the velocity gradient as because the eta has to be always positive.

So, this term we are putting one negative sign and that will be having certain meaning because that has to be having the you know positive value always, the viscosity value cannot be negative. So, what we see that this viscosity that is the molecular viscosity and it is because of the molecular exchange of the momentum should taking place you know in this kind of flow.

Now, this is normally in the case of laminar flow where we assume that there is you know movement of layer one over other in a in laminar manner. Now, without the liquids which obey these law where the shear stress will be proportional to the velocity gradient. So, they will be known as the Newtonian fluid and these fluids like water or so, or molten steel or. So, they are at that temperature molten steel.

So, they are considered to be the Newtonian fluid. Whereas, there are fluids which do not obey this law. So, in those cases there is no linear you know relationship or there may be different relationship then what is being observed by this kind of by these fluids Newtonian fluids. So, they are known as the non-Newtonian fluids. So, the aim is basically to have the prediction of the shear stresses and because you know so, that is why now in the case of our analysis mostly we will be dealing with the Newtonian fluid only.

So, mostly we will have the dealing with these principles. Now, when we will see that we do not only concerned with only these molecular viscosity, but as the flow in the tundish is turbulent.

So, in that case you are not assured only and you are bound to have the intermingling of the fluid layers. So, you will have not only the momentum exchange across the layers only so, that maybe over the large distances. So, you will have you know other viscosity component also because of the turbulence and that is known as turbulent viscosity, and then you will have the effective viscosity as the sum of these two. So, that is what some idea we had got in the earlier lectures also.

So, in those cases we will have the prediction of that turbulent viscosity and that we will study when we talk about the turbulence how that is taken into account. So, that will be seen in our coming lectures.

So, if you talk about the viscosity. So, viscosity has a unit and that is you have many kind of either you have SI unit or you have the you know in CGS system also you may have the poise or stokes or so. So, if you talk about the unit of viscosity. So, what we do is in SI unit τ has the unit of Newton/m^2 and then you will have this is meter and this way you have m/s.

So, accordingly you can have the unit of viscosity and that is kg/m-s. So, that is your unit in the for the viscosity and if you go for the CGS system then it is the poise. So, 1 poise will be 1 gram/centimeter-second. So, you will have either you know unit of kg/m-s or you may have the gram/centimeter-second. So, that is you know 1 poise and this is 1 Pascal second.

So, if you; so, this is you know Pascal second and this is you will have the poise. So, if you see that 1P, 1 poise will be 0.1 Pascal second. So, that way this relationship also is coming up you know for the unit of viscosity, and unit of viscosity you know it has some standard value at some standard you know temperature and pressure.

Now, we have another term you know with viscosity. So, in that case of engineering analysis, what we do is we normally define the viscosity also in terms of viscosity to density ratio. So, for a fluid when we take the ratio of the viscosity to it is density. So, that is known as the kinematic viscosity, and this kinematic viscosity is represented by the term ν and it is unit is actually m^2/s.

So, in the case of SI units, it will be m^2/s and in CGS system it is cm^2/s; so, that is the stock. So, that way you have the other units you know for the you know viscosity itself that is known as the kinematic viscosity. So, this is about that property of the fluid.

Now, coming to the dimensionality of the flow. So, if you talk about the present case so, the if you see that the velocity will be changing in one coordinate direction as you are moving in the y direction. So, your velocity seems to be changing, so, that is basically a one-dimensional flow.

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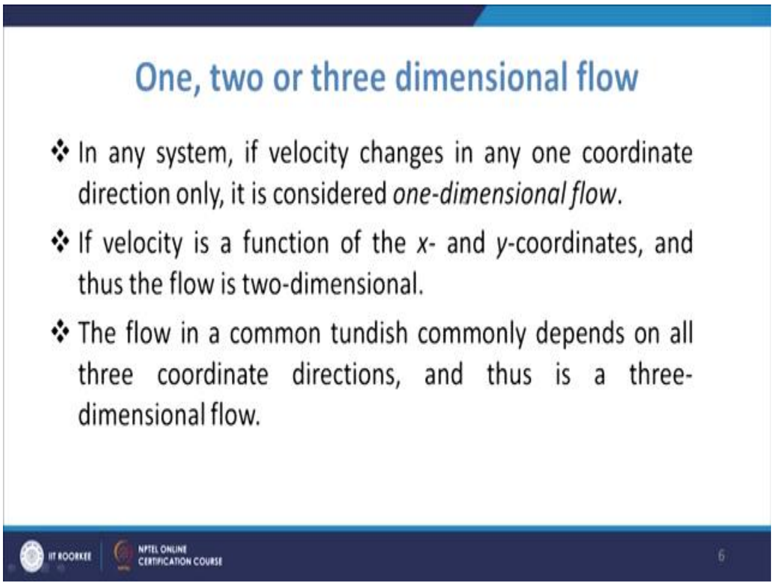

So, velocity if changes in any one coordinate direction only then it is considered the one-dimensional flow; similarly, if the velocity is function of x and y coordinates both then the flow is said to be two-dimensional.

So, if you talk about the boundary layer; so, if you see the momentum boundary layer. So, in that what you see that velocity will be changing and if you look at the; so, what you see that in this case earlier case what you have seen that velocity is only changing in the y direction.

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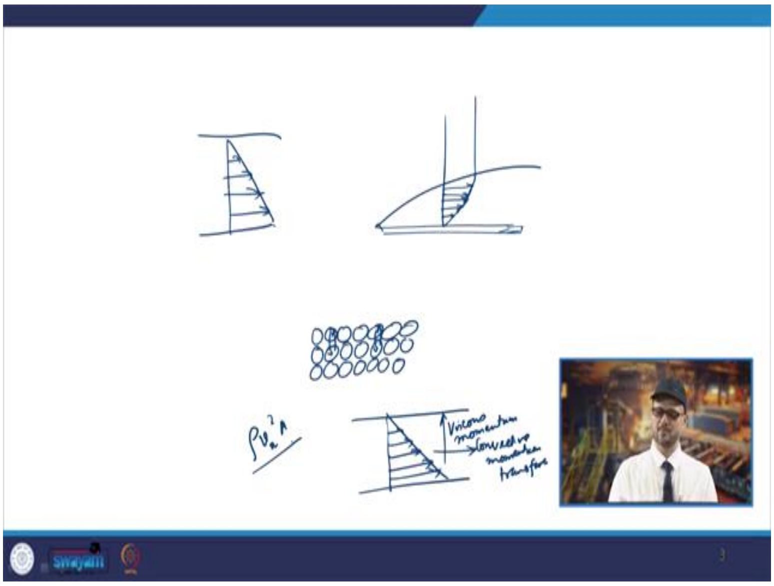

So, this is as you by changing, so that is why it is in a said to be one-dimensional. Now, if you talk about a velocity boundary layer. Now, in that case what happens that in the case of boundary layer? You might have experienced that your velocity profile goes like this in the in the boundary layer, it will be you know changing.

So, your if you see the velocity it will be changing in because of the x and the y in both the directions as you moved here so, your you know it is changing. So, in those cases what you see that your velocity will be function of the x and y coordinates that will be changing. So, that is why the flow is said to be the two-dimensional.

Similarly, if it is dependent upon the all the three coordinate directions, then it is said to be the 3 dimensional flow. And, normally when we talk about the flow inside the tundish, then it is the you know three-dimensional flow. So, while analyzing we will have to have this in mind that it is to one-dimensional, two-dimensional or three-dimensional you know flow anyway and accordingly we will have to do the analysis of the flow, then comes you know the mode of momentum transport.

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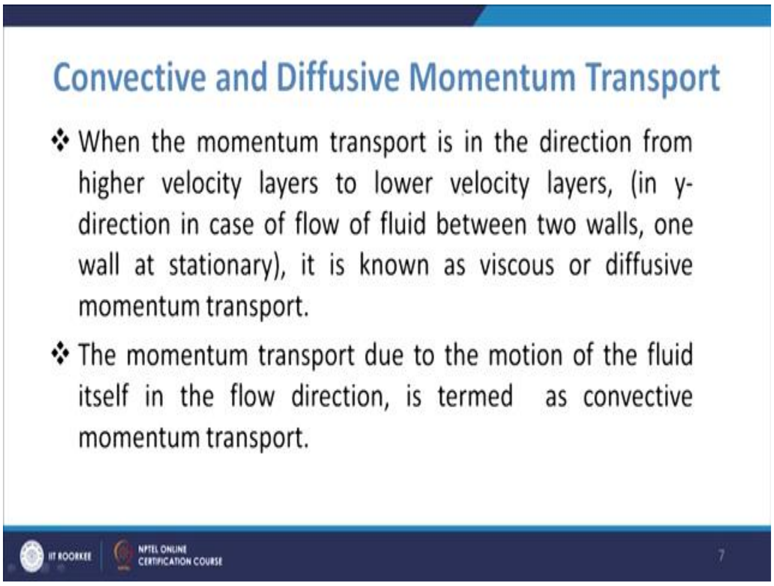

So, basically there are two modes of the transport momentum transport. One is momentum you know convective transport and another is the diffusive transport. .Now, when the momentum transport is in the direction from higher velocity layer to a lower velocity layer so, as we have seen in the earlier case. In the earlier case your you know the momentum transport is from the lower layer to the higher layer. So, you will have the velocity at lower layer you have higher velocity and at upper layer you have lower velocity.

So, when you have the momentum transport from the higher velocity layer to lower velocity layer. So, in that case you know your momentum transport is because of the diffusive diffusion. So, that is known as the because of the viscous effect, so, you have your viscosity coming into picture.

So, with this because of that mechanism so, that is why we call it as the viscous or diffusive momentum transport. Now, when your momentum transport so, that is your you know the convective; I mean, viscous or diffusing momentum transport. Now, if your momentum transport is due to the motion of the fluid itself in the flow direction, then it is known as the convective you know momentum transport.

So, if you look at the you know this viscous or diffusive momentum transports in that. Basically, the molecules will be crossing the you know layers that will be you know as per you have the molecules, like you have the top layer molecule is there, same below that you have the molecules. So, this way you have layer of molecules and you will have the momentum transport will be using you know this mechanism.

So, that is there in the case of you know; so, this is because of the viscous you know property. So, that is why it is viscous momentum transport; whereas, if you see that when you had the two plates and one is in motion. And when you are so, your if you see that when your this was the you know velocity profile which was seen in the in the in the case which we studied..

So, the viscous momentum will be in this direction so, that will be transferring the momentum or momentum transferred will be in this direction. Now, if the it is because of the velocity so, if it is because of that velocity. So, the velocity is in this direction so, that is known as the convective momentum transport. So, the rate of convective momentum transport that will be you know mass boom into velocity by time.

So, if you look at the rate of moment convective momentum transport it will be $\rho v_x^2 A$. So, you are you know that a is the cross sectional area. So, here this is the cross sectional area perpendicular to the flow direction through which the density the fluid of density rho is flowing. So, that way we are finding the rate of convective momentum transport. So, accordingly you can you know you can have the understanding about these property you can have the study of other fluid properties also like surface tension and other things which will be used in our lectures to come.

Thank you very much.