Fluid Mechanics
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Lecture - 21
Laminar and Turbulent Flows

Welcome all of you this course on fluid mechanics. As you know it we have now in the last chapters, the chapters is on incompressible viscous flow through pipes. Before starting this course, let me tell you that when starting the industrializations, the most important things is required to design the pipe networks. Pipe carries gas, the liquid. We need to design an efficient energy efficient systems for transporting gas or the liquid from one place to other place.

So these chapters what I am going to teach you is very complex chapter but you can understand the way conducting a series of experiments in the universities in Europe they make it these chapters quite interesting and they solve the problems and by their solving these problems, they design efficient energy efficient pipe networks for transporting fluid from one place to other place.

Because of that, if you know today we have a transportations of gas networks. You have a transportations of liquid from one place to other place, the water pipe network, all these design is possible because of these the combinations of experiment works and conceptualizations. So that is the reason it is a very interesting chapters and this is the last chapters in my series of the lectures here.

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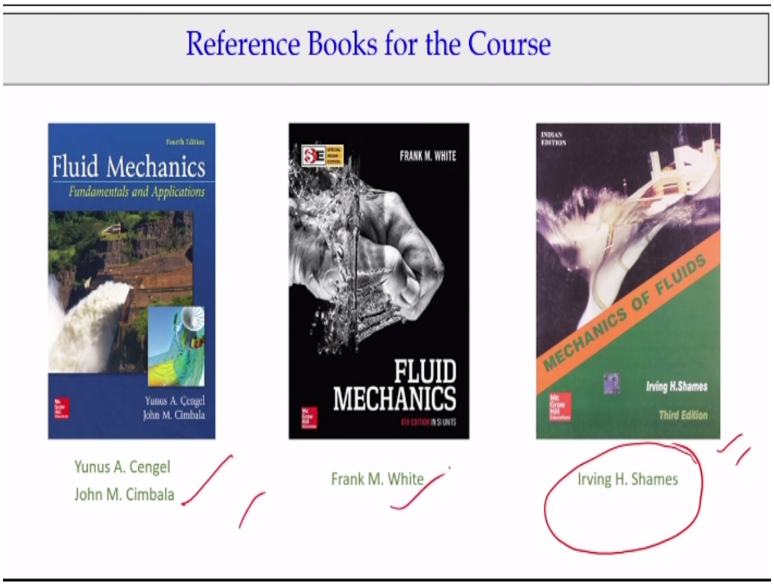

Let us start with this with considering these chapters I have emphasized in, on new book, that is what Irving H. Shames books which exclusively for this flow through pipes and other books also we have a Cengel Cimbala and F. M. White.

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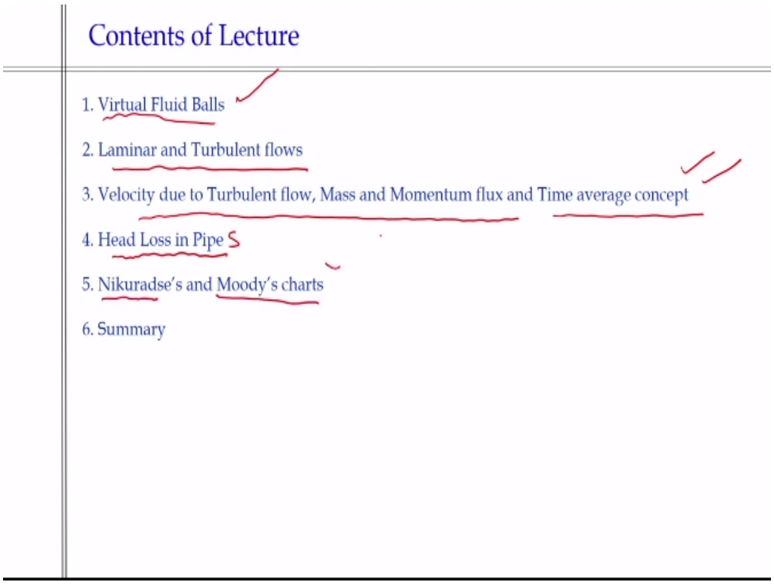

So what we will today we will do it again I will repeat this virtual fluid ball concepts, so that it can be used for understanding the turbulence flow, which is otherwise it is very difficult to understand what is a turbulent flow and how the turbulence are exchanging the momentum from one layer to another layers. So I will introduce again, virtual fluid balls.

Then we will talk about the difference between laminar and the turbulent flows. And we also we talk about how these mass momentum flux transported from one layer to another layers and the time average concept. That what we will also discuss it. Then we will go for the head loss in pipes and followed by to the experiments what is conducted to simplify this energy loses part by conducting a series of experiments with commercial pipes or sand roughened pipes that what we will discuss thoroughly.

After that, we will have the summary. So today we will start from virtual fluid ball concepts.

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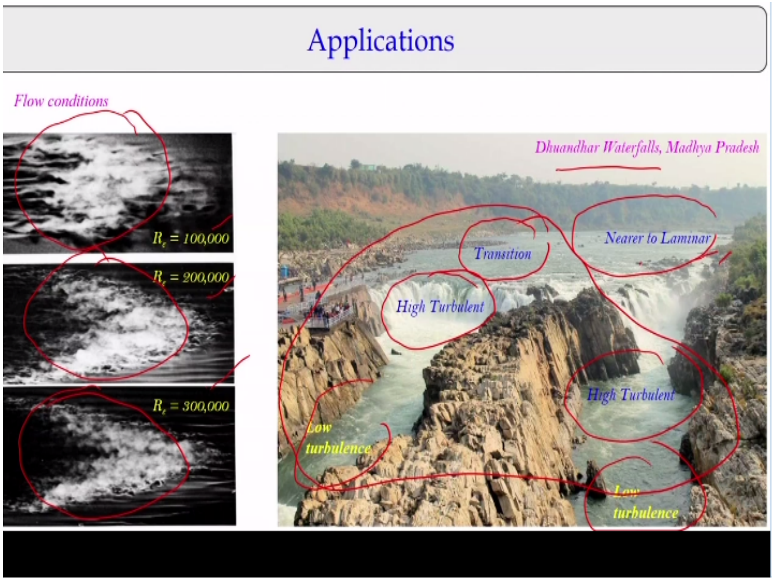

Let us before that if you look at this turbulent flows okay, most of the places we have the turbulent flow. If you look at the conditions of very high Reynolds numbers, you can show this turbulence phenomena the hotspot of the turbulent structures what is going on. Exactly same we can see the turbulent structures of what it happens it when you have a waterfalls okay.

So you have the transitions then highly turbulent zones, then you have a low turbulent zones and the high turbulence and the low turbulence. Very close to this could be the laminar conditions. So most of the, that means you can see it these natural conditions where you have a transitions high turbulent zones and low turbulent zones.

So we will try to know it how this turbulence playing the role for energy dissipations, mass transport and also the momentum transport mechanisms.

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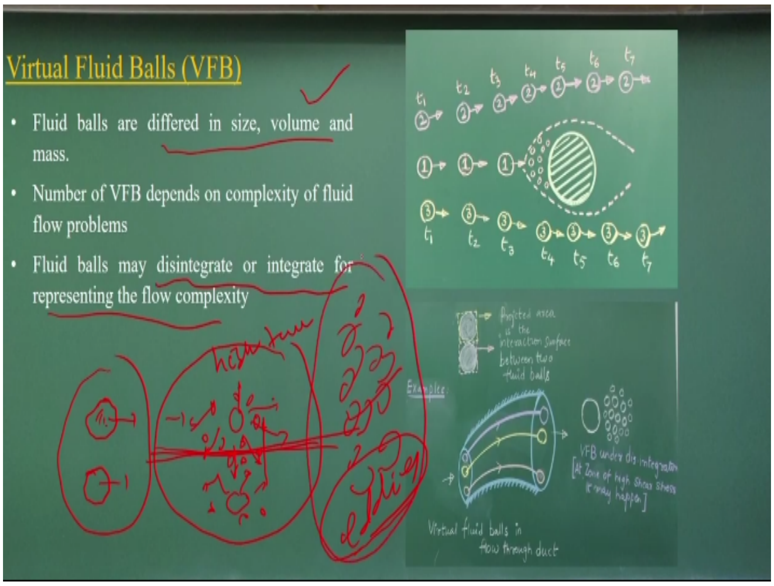

Now coming to the virtual fluid balls. As I said it that earlier we are looking to conceptually the fluid mechanics considering there are series of the balls are moving from one place to other place. If I have a different fluids, I can have a different color of the balls, different size of the balls, and different mass of the balls. So that is what we discussed earlier.

But this part today I will emphasize that when you have a turbulent flow, mostly you can imagine is that this fluid balls are going to disintegrated or integrated depending upon the turbulence behavior. That means what I am talking about that if I have a ball is coming it if it is the high turbulence zone, this ball will be split it disintegrated to number of smaller balls and these smaller balls will move with a different velocities and they may carry certain mass fluxes.

The similar way if two balls are moving it, so if they are disintegrating it they will have a the disintegrated ball the smaller balls which are disintegrated, there will be actions of mass flux, also actions of momentum flux. That is what we will go through it. If imagine is that there is the virtual balls. Whenever we have a turbulence zones and these zones, these balls disintegrates.

As they disintegrated there is actions of mass fluxes as well as actions of the momentum flux. And if you visualize that two balls are moving it and they are coming closer to the turbulent zone where they themselves disintegrated. As they themselves disintegrated, there will be the actions of the momentum flux, the mass flux.

And if you take a particular horizontal line, then you can visualize that there is a momentum flux and mass flux is going on and that what making a turbulence flow behaviors. Or if you thinking that let us assume is that I do not have a two balls I have 100 balls or more than 100 balls, then what will happen it that not only will be disintegrated and these disintegrated the smaller balls, they can group them and create a some sort of vortex formula, which will be called eddies.

There will be some sort of eddies formations will forming it. That eddy equivalent that four and five the smaller balls, they are grouping together and they are rotating it. And that what type of the eddies formations can happen it. So let me repeat that things that we knew how the turbulent zones the flow what is going in this ball start disintegrating it.

That means, the balls become the smaller number of balls will be there and as they have the smaller balls, there will be a mass actions, the momentum actions at different axis. If I conceptually that I have 100 number of balls or more than 100 number of balls, the same things happen. There is disintegrations. As the disintegrations has happens it this thus a cluster of the smaller balls, they can make a small vertices which we call eddies. So there will be the eddies formations.

Or turbulence generations process which is happening. The turbulence generate it. And how it is going to decay it. That process also, we will talk about. So basically you try to understand it that when you go for a turbulent zone, the process changes it. And we will talk about with respect to the virtual fluid balls and which is having the interfaces and they have the characteristics for disintegrate or they integrate depending upon turbulence behavior.

If a turbulence behavior is more, intensity is more they disintegrate it. When turbulence intensity decreases, they can again integrate it. So considering this, let us try to have a more discussions on this.

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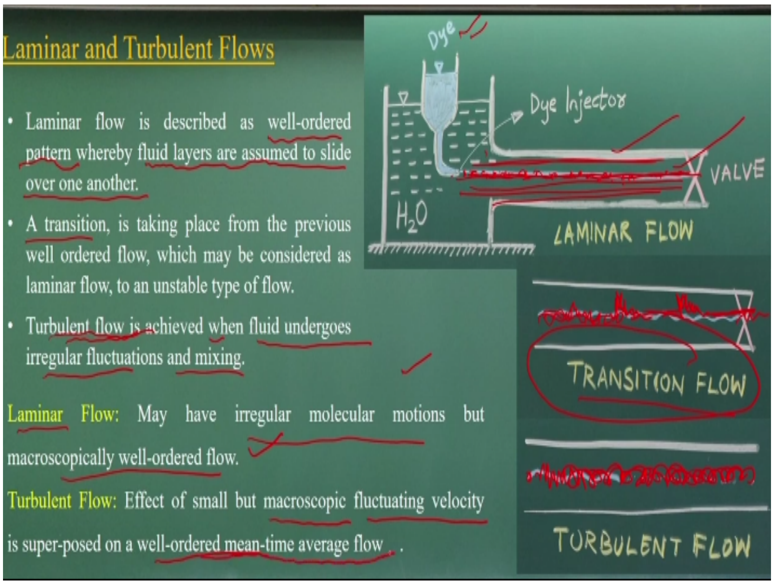

Let us come to the very simple experiments as you know, Reynolds apparatus or Reynolds experiments which is very simple experiments conducted with waters and you have a dye. The last class I show the Reynolds apparatus. Injecting the dye here, then you have you can visualize the dye movement. That means what? It is same virtual fluid balls. That means, I am giving a virtual fluid bed of the colors to here.

So as they are moving the straight lines or they are well-ordered patterns or the fluid layers assumed to slides over one anther. That is what is called laminar flow. Or other way round what it happens is that this flow represent us that a series of the virtual fluid balls they are moving it. They are exchanging the mass flux integration disintegration happening it but exchange of the mass flux and the momentum flux it is not that significant order. It is not that significant order.

So because of that, again it comes to the viscous force is still dominates it. It come back to the same positions. So we will have a colored dye when you put it or you put the virtual ball which moves very smoothly like this smooth layer formations happens it. So because of this is it laminar flow. But if we increase the flow velocities, other components like Reynolds numbers we will discuss more, then what we will observe is the color dye will not have a flow like a laminar, like layer and layers.

There will be tried to go deviated again deviated again deviate like this. So when you have these conditions, then we call transition states. That means what it happens? As we increase the velocity of the flow in this case, we are not changing the density, we are not changing the flow, the mu value the dynamic viscosity values, only we are changing the velocity.

As you change the velocity that means you change the inertia force. The ratio between the inertia force and the viscous force that what increases. As it increases the balls what is moving it, if I look it in terms of virtual fluid balls, then what it happens it they also start disintegrating. Start disintegrating, but still there is a viscous force dominated is there, they again integrated. That is the reasons we have a fluctuations here against go that fluctuations and like this.

So we can see the colors are trying to diffuse it against stream lines that. So in this is the positions then we call transitions flow. So that regions is intermediate of laminar and the turbulent flow which considered is unstable type of flow because it is occurs for a very smaller range of the Reynolds numbers. So that is what is unstable type of that. Then we had the turbulent flow okay which we many of the textbook is called chaos flow is chaotic processes is what it happens it.

But let us try to understand many of the process in nature process also behaves like this okay. It is not only the turbulent flow. We need to have a mathematics to understand this process. I as a undergraduate courses, I am not going to that levels. I am to simplify you to learn the turbulent flow as a virtual fluid ball motions. I am not going beyond a mathematical statement of turbulent flow but we generally do for postgraduate students. That is what I am not going for that.

If you look it for the turbulent flow is achieved when fluid undergoes irregular fluctuations and mixing. That means what it happens is that when you have the color dye you put it, so it start having very irregular motions okay. If it is that what it indicates? If you in terms of virtual fluid balls, they start disintegrating it. They start disintegrating it.

So as there are 100 balls are moving, they are disintegrating and all the things so you start having a irregular fluctuation spot. That is what we will go more details that what type of happens it okay. So basically when you talk about the laminar flow it is irregular molecular motions, macroscopically well-ordered flow. But macroscopically it is a fluctuating velocities superimposed with well-ordered mean time average flow.

What do you mean by that? Let us we will go more detail on that. Now if you look it that when these transitions happen from laminar to turbulence zone, laminar to transition zone, that what we call the critical Reynolds number, the transitions.

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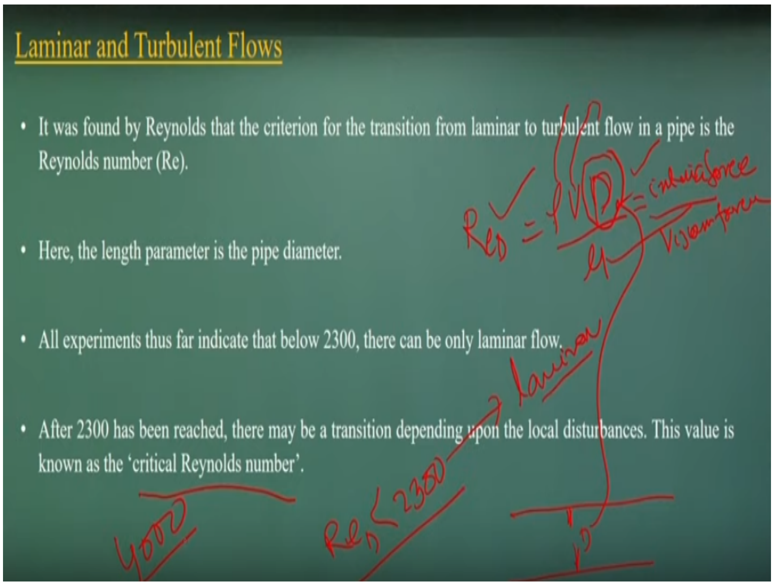

The threshold of the Reynolds number that what is changes from laminar to transitions and transitions to the to turbulent flow. If you look it that the Reynolds conducted series of experiment on that for different type of diameter of pipe, different fluid properties like different density, dynamic viscosity, that what he found it, if we computes the Reynolds numbers, which is the ratio between inertial force by viscous force. That means rho VD by mu.

Here we consider the each characteristic length and in this case because we are talking about the pipe flow, the characteristic length we consider is here the diameter of the pipe. So the Reynolds number in terms of diameter will be rho is the density, V is the average velocity and the D is the diameter of the pipe and the mu stands for dynamic viscosity of the fluid. If this is the conditions what we have seen it that the Reynolds numbers when it is below 2300 then the flow is laminar. What do you mean by that?

If I write this Reynolds number is equal to inertia force by viscous force. That means when the inertia force will have a lesser than the 2500 times of viscous force, then flow becomes laminar. When this is more than that, then we start the transitions. And further another threshold it comes about the 4000 which will transitions to the turbulent vapors.

So these thresholds what we are talking about, it is a linked with Reynolds numbers, which is a function of inertia force and the viscous force. So if we can see that there is a dominance is comes for a particular level. After that, the inertia forces is so large as compared to the viscous force it start virtual fluid balls as a disintegrated level or the fluids start fluctuating. Inertia force is so high as compared to the viscous force then it start going to have a the turbulence nature it comes it.

The fluctuating velocity components this comes to pictures. Reynolds numbers less than 2300 it is laminar flow and then it comes a transition phase. Reynolds numbers greater than 4000 it is turbulent flow.

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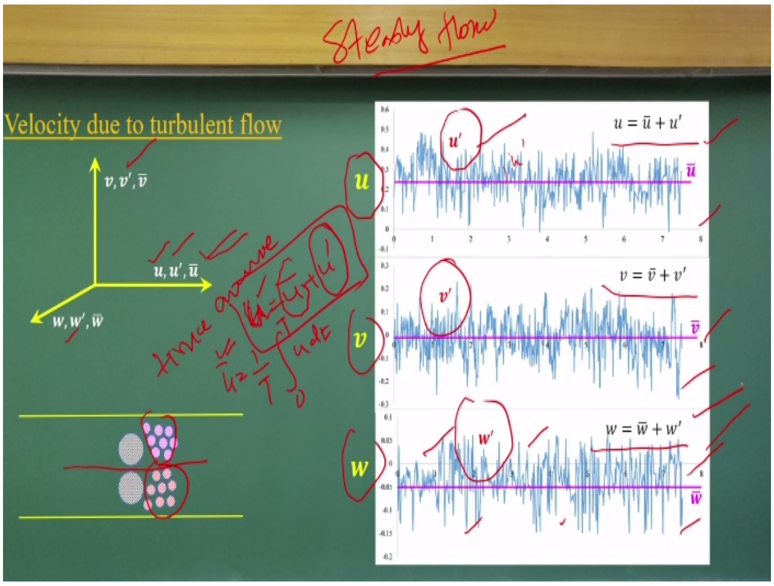

Now if you look it if I have a instrument to measure the velocity in the turbulent flow. Previous class we shown the instrument like acoustic Doppler velocity meters where you can measure the velocity. When you in a turbulent flow you measure the velocities. What we get it to these, this type of curve you get it, the fluctuations component, okay. So you get the fluctuations component.

That means the velocity what you get it, it has two components. One is the average velocity component and other is fluctuating component. So you really the turbulent flow whether in a pipe flow or the channel flow if you measure it, you will see these type of fluctuations. In use color velocity v and w they are in x, y, z direction respectively.

So in that case what you are doing that each the velocity components having the fluctuating velocity component and here I am considering the steady flow, steady turbulent flow. In the steady turbulent flow, it is not unsteady flow. This is steady flow conditions also we get it the velocity fluctuated components. In y directions v directions and w direction. That means x, y, z.

So when you comes to turbulent flow do not show only u, v, w. You should show three components. That is fluctuating velocity components, which varies instantly at that measurement locations and you have a time average velocity component and this the velocity of u which is the a particular point the velocity u is equal to average velocity and the fluctuating velocity.

The summation of that is represented to you. So these are the fluctuating velocity. Now we can ask me that how do you compute average velocity, the time average velocity. The time average velocity we compute like 0 to T into u and dt. That means we time average or time integrated the velocity component we integrate over the T domain and compute it what is average velocity.

To know it if there is no fluctuations components, the average is the velocity is going on time average. This is called time average velocity component, then what is that plus you have a fluctuating component. If you look at this if you just look at any of census data also fluctuates like this. Delhi to Delhi if you look the census data the economy census data most of the shareholders they look it, they also fluctuates that.

So many of the process if you try to understand it, it has a average behavior and instantaneous fluctuating components. In nature we get it. Similar way, in a turbulent flow we have time average velocity component and the fluctuating velocity component. Now if you look it the physically or the conceptually, if I have a two balls which are disintegrating because their inertia forces is much larger than viscous forces, what is happening in the fluids.

If that is the conditions as I said it earlier it will be disintegrated. As it disintegrated, you will have a mass flux change and the momentum flux change. Those quantities can give a additional mass components if you are looking at the layer level, additional momentum flux. Those things will detail we discuss it. So that way again I am to summarize that, in case of the turbulent flow, we have two components.

One is the time average velocity component another is fluctuations component as similar to if you look it a economic data with a census data all behave like this behavior, because there are different process works at the different levels.

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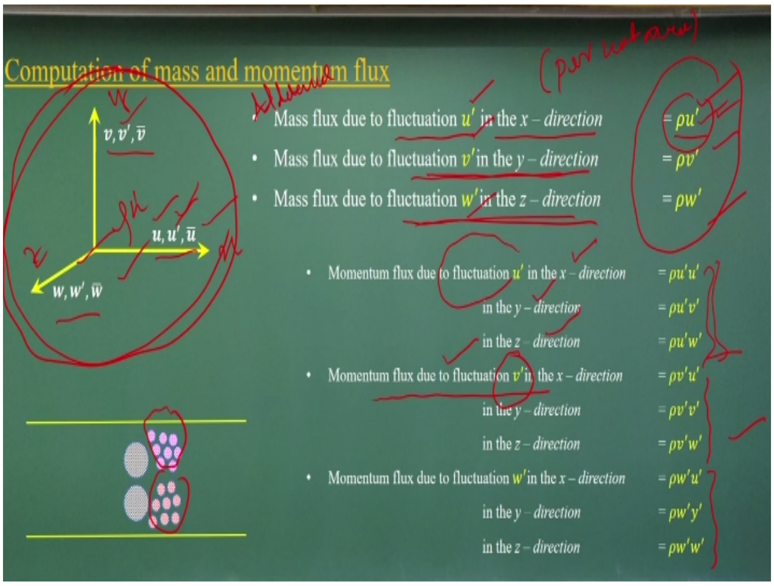

Now if you look it, if I consider is that there are three velocity components okay in x, y, and z directions. If I have three velocity component, if you wish to compute it, how much additional mass flux is going on, additional mass flux due to the fluctuating u dash component in the x direction per unit area. All these components were per unit area. Then as you know it rho u dash you will get it.

So this is the mass flux is coming as a fluctuating velocity is there, or we can try to understand from these after the disintegrated, the component of the disintegrated virtual balls is giving an additional mass flux in the x directions. That what will be the density times of velocity. That is what you will get it. Similar way you can have a y direction and the z direction.

This is what we are talking about additional mass fluxes will be there because of. We remember that this u dash component, the fluctuating velocity component can be positive directions or the negative directions. It can move in any of the direction. So that means mass flux can go out or come in it, okay. You can try to understand. If a mass flux if are computing in a particular layers can come in or go out depending upon the directions of u dash.

The similar way if you look at this the mass flux, additional mass flux, which is coming due to the fluctuations components of v dash w dash will come it to that. But same way if the mass flux is going on in area, so you will have momentum flux, that mass flux into velocity. And this momentum flux because of u fluctuations you will get in x directions, y direction, z direction having this three velocity component you have a momentum flux.

That is due to only fluctuations component due to the disintegrated of the virtual fluid balls they are additional momentum flux is coming it and that has a three components, x, y, and z directions. Because of the fluctuating velocity component we generated the mass here and the corresponding momentum flux. Same way, we can find out what could be the momentum flux due to the fluctuations of v dash in the x directions and the y and z direction.

So you can write these components very easily just you look at the notations. You keep track of that, the notations. Because of that, I always advise you to draw this type of axes. Then you write the u, u dash, v dash component and rho, u component dash component and all you write it and then you can understand it there is a mass flux is coming, momentum flux is coming all.

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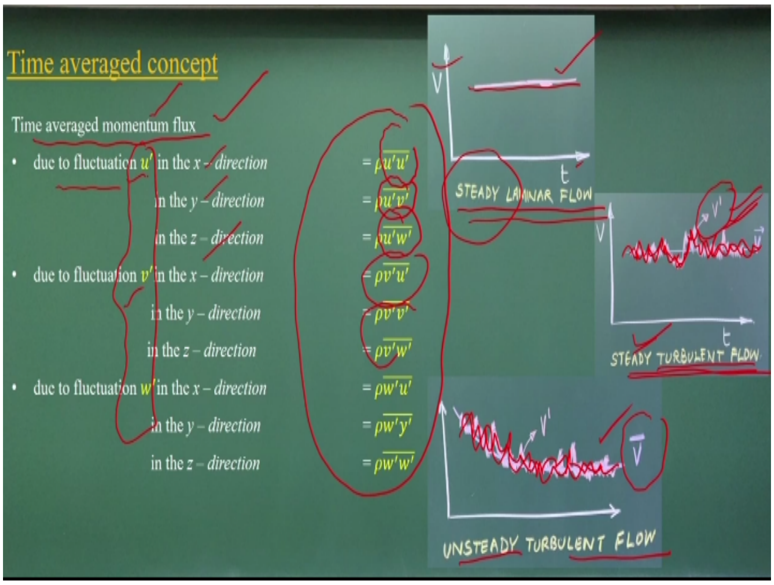

So but here also because we are not worried about the fluctuations components at that instantly we look it also a time average concept. So same way we are giving these the bar to represent these are time average momentum flux, okay. So you can write it if there is a momentum flux there is a force or the trace components are there. So we will discuss that in the next class in terms of stress components.

So if you can try to understand it, because of this, the fluctuating velocity components now you have a time average, the momentum flux in x, y, z directions because of the fluctuating velocity component of this. So additional force component or additional stress components, we are getting it because of fluctuating velocity component. So that is reasons you have a steady laminar flow, the steady it does not change with the time.

You can see the velocity and the time will have a more or less constant, is a steady flow. But the steady turbulent you will not have a constants, you will have the turbulence nature if you look at this. It is very easy to draw turbulence behavior because it is a randomness is there, chaos is there. So it does not follow the pattern. It is easy to draw the chaotic patterns because as you like you can sketch it.

So that way it has the turbulence, the chaotic behavior with a steady flow. But if you have unsteady flow that means velocity varies with respect to time, your time average velocity is varying it and over that you have a fluctuating velocity component. It is quite interesting. So this is a unsteady turbulent flow. This is steady turbulent flow, this is steady laminar flow.

And already we discuss it because of these fluctuating velocity components, how much of momentum flux is there. What is a mass flux is there and this change of the momentum flux which indicates for us that is change is force components or as equivalent force per unit area is a trace component or (()) (29:22) trace component.

We will revisit again to give it more time to you to think about this turbulence behavior because if you understand the turbulent behavior then really you will appreciate the fluid mechanics. That is my job you to revisit again turbulence again talk about the same things we again in a repeating way.

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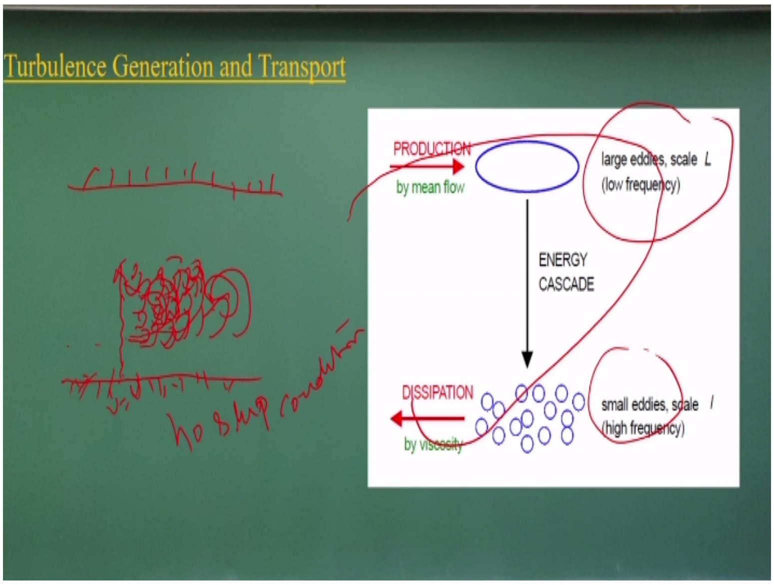

Now if you look at the next levels if you will talk about that what it happens in turbulence. That if you look it that, I have the pipe flow. I have the pipe flow and I know is very well is that the no slip conditions happens near the wall. That is what we studied in the first class. So once you have a no slip conditions, when you have a no slip conditions then what it happens is that you will have a velocity is equal to zero and velocity is going to increase from this place.

So as the velocity increases, then what it happens because this is turbulence nature of the flow, there is a generations of eddies. As I said it that in terms of virtual fluid balls, the fluid balls are goes as disintegrated and they group themselves, they create the eddies okay which is not visible by naked eyes, okay, do not think it that. These are all conceptualization. So when you have this, the eddies formations, these eddies becomes bigger and bigger size, bigger and bigger size.

That is what is happened it, okay. But they are the lowest frequency component. Then they disintegrated into a smaller radius okay, the number increases, the high frequency component, the number of the smaller radius much larger. But when the eddies are smaller, then you have the viscous components which reduce it and dissipate the eddies formation.

So that means always a energy cycles is goes on like you have a very high flow, the turbulence is generated. It generate the large eddies. Then again it split it into the smaller eddies. The smaller eddies again dissipated it due to the high viscosity zones.
So there are the zone of turbulence generations. They are decaying it, energy cascading and the dissipations.

So we are not going more details as I said it earlier. But try to understand it when you have the turbulent flow, the your energy dissipations, the mass flux computations, the momentum flux computations because of the fluctuating velocity components we are getting additional terms. And which are very complex process. If you have a very complex process only options is left to us that you conduct series of experiment.

And you simplify the flow problems. That is what did it in Europe in early industrialization periods.

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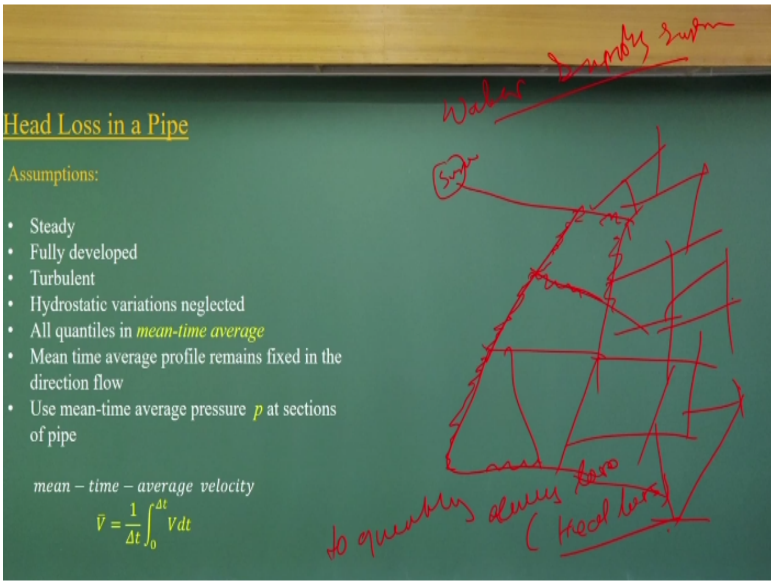

So what they did it that to design this pipe systems like for examples, we have a water supply systems, okay. So if you have a water supply systems, there could be a source and there could be the pipe network to different locations. There will be you can imagine it that can have a very complex pipe networks supplying to water to different locations. How to design these pipe networks.

So now it is coming it that we can find out how much energy losses, how the head losses in the pipe flow systems. You can know the how much of energy loss is here, how much of energy loss is here, how much of energy loss is here, then I can quantify it the energy availability at different parts. That energy availability will give us the flow is coming or not coming it. And that is what do we do it?

This is quite analogous to your power transmissions, electrical power transmissions like similar way. But here we are talking about the head losses the energy losses in a pipe network or in pipe flow. Now come it to that. So we needs to do the experiment to quantify energy losses and that in terms of head loss. That means in terms of Bernoulli's equations point of view we are talking about head loss.

But we are looking it what will be the energy loss part. Now we look it any turbulent flow going through a pipe systems then we can easily we can make it what are the governing or depending dependent variable components.

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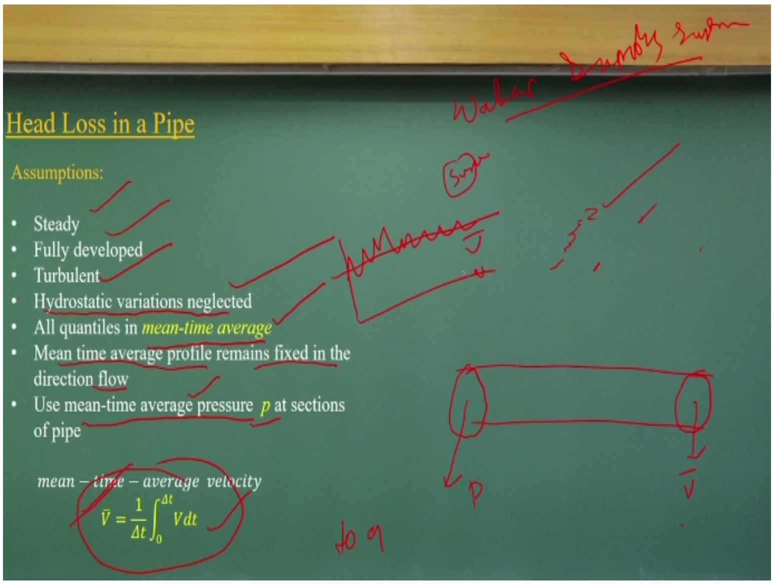

Like I have a pipe. As I have the pipe part is going through these I have to look it the average conditions the time average P and time average velocity. So we talk about the time average or mean time average pressure component. We all quantile is in terms of mean time average and mean time average profiles remains fixed in the directions of flow. Flow is turbulent.

The hydrostatic variations is also neglected and fully developed and a steady flow okay. These are the simplifications. The mean time average as I did it earlier you can compute it what will be the mean time average and you just integrate v over the delta t and 1 by delta t will be the mean time average.

Or indirectly what you are looking it that if our velocity like this, you are just taking the average velocity which is the representing the area of this total area. So that is the average velocity what we are getting it.

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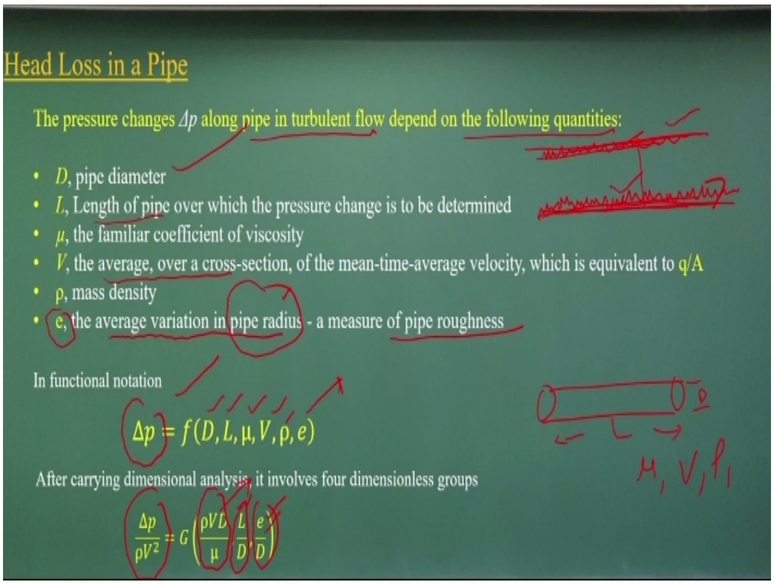

Now let us now what we are doing it first the dimensional analysis. So if there is a pressure drop along a pipe in a turbulent flow depends upon the following quantities. Pipe diameters, length of the pipe okay diameters, the length of the pipe mu is similar to the coefficient of viscosity, familiar to the coefficient of viscosity and average velocity rho and the small e represents the average variations in pipe radius.

Now you can understand what is that. If you look at the pipe the different pipe will have a different roughness like this glass surface maybe looks for me is a smooth surface. But if you look at microscopically there is a roughness is there. That means if I take the surface for my hand it may looks like a smooth surface, but microscopically if I look it there is a roughness is there okay.

So if you have a roughness in the pipes, then you have a more problems behavior happens it. More energy dissipates it. Smooth the pipes less the energy dissipate, the less turbulence behavior happens it. So if you look at that if you have a pipe, we can see there is a smooth pipe, but really it is not a smooth pipe. Even if a glass panels, what you have all have a certain degree of roughness.

So there is a variations of the pipe radius. The pipe radius but it could be a sub millimeter levels, what we are talking about. We are not talking about the centimeters which you can see, some millimeter level one 10th of the millimeter level, that type of roughness what we are looking it and that what we are getting it. And if we are getting it how these things are affecting this the turbulence behaviors and the energy dissipations. The first let us look it the dimensional analysis.

That means delta t will be the pressure difference will be the functions of the D, L, mu, V, rho and e. Here e stands for pipe roughness. If you conduct a dimensional analysis, this is a non-dimensional path. This is a non-dimensional and this is the non-dimensional.

So the dependent variable non-dimensional form or dependent variable this form we got it where this is the Reynolds numbers, this is the dimensions or geometry of the pipe length and the diameters and this is with respect to the roughness height and the D.

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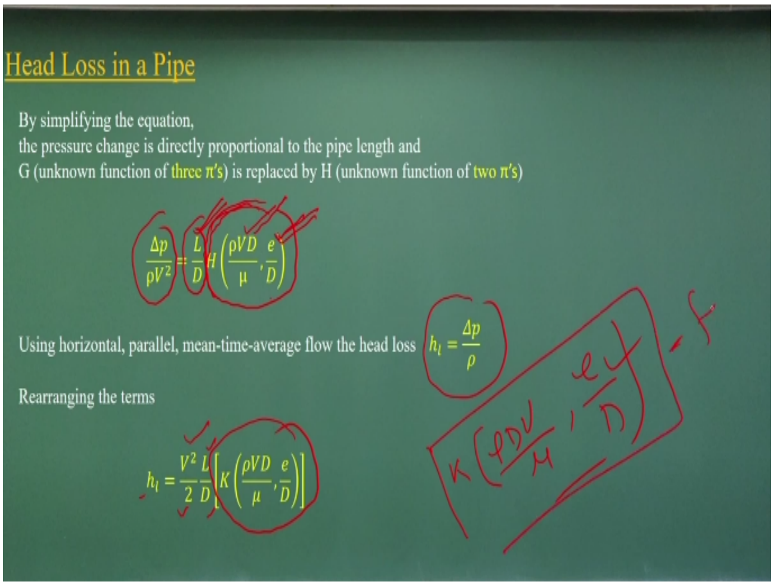

Just these equations if I further simplified it that if this L by D if I come out and make it p rho V square here the L and D ratio I know it. So my mu function of h which will be a function of Reynolds numbers and e by D ratio okay? So we are replacing with a unknown function with h and which is the functions of Reynolds numbers and the roughness by D that ratio and we have a L by D.

That is what if you rearrange it as define its head loss is rho p by rho, if you look it what you are getting it V square by 2 L by D h l and there is a function which is a function of Reynolds numbers and roughness height by the D diameters. These can be considered as a constant. And we define it is a friction factors.

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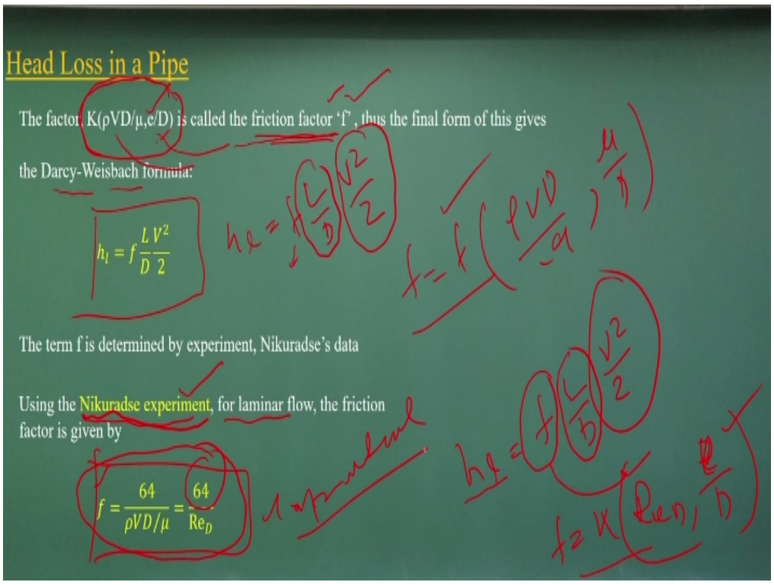

This is new definitions we put it that this constant, it is not a constant, it varies with respect to the Reynolds numbers with respect to the ratio of roughness height and the diameters which we call a constant, the friction factors. Because for particular flow systems, you know the Reynolds numbers for a particular pipe, the type of the pipes, we know this the roughness height and the D.

And since these are known to us, if I conduct a series of experiment in terms of Reynolds numbers and in terms of the roughness at D we can compute it or we can get it the friction factors. That is what it was done in earlier to conduct a series of pipe flow experiment. To find out these functions, the f functions in terms of the Reynolds numbers and mu by D.

So if you know these function, then the head loss which is the Darcy-Weisbach formula is this part, which is simple part, okay. It is easy to remember it. It is that the head loss will be the one is a friction factors L by D V square by 2, okay. This is some sort of kinetic energy per unit mass. L by D is a geometry factors and you are multiplying with f.

So you try to understand the head loss is a function of a friction factor L by D V square by 2 is the kinetic energy per unit mass. L by D is the geometry factors then f is your friction factors which is a functions of Reynolds numbers and e by D. So if I know these functions, I can easily compute it how much of head loss will be there. So that is the reasons that a series of experiment was done by Nikuradse experiments for laminar and the turbulent. Series of experiment they conducted for this okay.

For the laminar flow, what it is found it the friction factor is a just a inversely proportional to the Reynolds numbers and the constants is becomes 64. This is experimental finding with a conducting a series of experiment in pipes. In a laminar flow it is found to be the f and the Reynolds numbers in terms of diameters have a inversely proportional and that proportionality constant is the 64.

Okay, so this is experimental detail. And since in terms of Reynolds numbers so it can valid for any of fluids. That is not a big issue.

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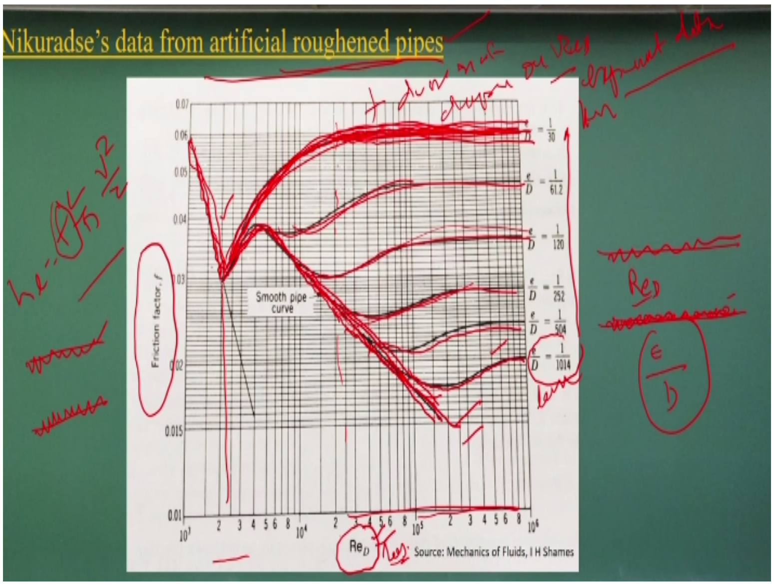

Now we will talk about the Nikuradse's data for artificial roughened pipes which he conducted a series of experiments and this x axis if you look it is a Reynolds numbers and the y axis is a friction factors, the Reynolds numbers in a log scale okay. So if you can look it these Reynolds numbers in the log scale. Let us interpret this data. These are the experiment data from artificial roughened pipes.

That means what he has done it he put the sand and glue it means fixed it, sand with a different diameters. So that way he get lot of roughness variabilities in the pipes and he conduct a series of experiment because he know this roughness part he know the D part and he also know what is the flow Reynolds numbers in terms of the diameter D. If it is this, this is what the finding of his the experiment.

Just look this graph. You can interpret many things from this graph. First is the laminar flow zone, okay. So it is just going down inversely, linearly decreasing trend, inversely proportional, is going down. Then if you consider a smooth pipe, it increases again decreases. If it is the pipe is smooth pipe. It increases with Reynolds numbers then start decreasing. This is quite interesting.

That the friction factors which is giving as indicator of energy losses, because if you look at this energy losses is f L D by V square by 2. So if f is higher value, so you have a more the energy losses. So if you look it that the energy loss is increases then it is a decreasing part in when it is coming a more the higher the Reynolds numbers. Higher the Reynolds numbers you have a decreasing trend.

As you add this roughness, the boundary roughness in the pipe okay, this is increasing trend, this is the highest roughness part. So as you increase the roughness your the turbulence intensity increases, energy losses will be the more. That is what it happens it, energy losses will be more. And that after certain Reynolds numbers, this is independent of the Reynolds values. It is a constant, it is a parallel line.

What do we mean by that? This value f does not depend on Reynolds number. That is what is indicating it. So more the rough the pipes what we have seen it the initially for a turbulent zones it increases then it became steady, becomes constant at that period it is independent to the Reynolds numbers the flow Reynolds numbers in terms of diameters.

The intermediate they have a like a roughness value is less you will have a it will act like a smooth pipe. Then the roughness effect will come it. Act like a smooth pipe, then roughness behavior will come. Like this the behavior will come it. Let me repeat these things because this is very interesting data. And it talk about the gross characteristic of the turbulence in a pipe with roughened, artificially roughened with a sand and the glue okay?

In that case, how this friction factor changes with respect to the Reynolds numbers and the ratio between the roughness and the diameters. This is less roughness to the high roughness zones. As I said it earlier this is the laminar zones. It is very clear cut. It is inversely proportional. In the laminar zones as the Reynolds number increases the friction factors decreases. That means your energy losses decreases.

But when you go for a transitions from laminar to transitions to the turbulent the smooth pipes behave like this. The rough pipe behaves like this. Intermediate they behave like a partly smooth, partly rough. If you look at these behaviors, try to understand it.

What I am to talk about that whenever you get it the experimental data which really speak about the gross characteristics, we try to understand that very detailed that how different dependent variables like in this case, the friction factors with depending upon the two variables, non-dimensional parameters is Reynolds numbers and the roughness. How it is varying it as you come it very complex things.

And these thing you just interpret it in terms of smooth pipes that means, the roughness is very less and as the roughness increases, how this characteristic or how this turbulence, additional turbulence is generated. That is what the more energy losses is happen it and which is also depends of the Reynolds numbers. After a particular threshold Reynolds numbers it also does not depend upon that part.

I just encourage you just to visualize the flow. There are many could be You Tube are there. You can look it at the wall level, at the near surface boundary of the pipe. If I have a rough pipe, how the turbulence is generated and at particular Reynolds numbers after that the effect of Reynolds numbers is not there in friction factors which remains constant.

That what you can visualize it when you just think about a gross characteristic of turbulence behavior in pipe flow.

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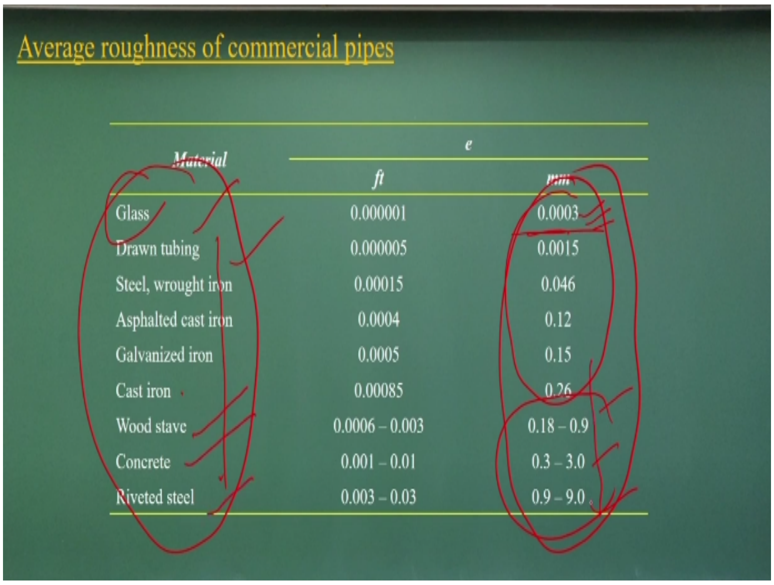

Average roughness of commercial pipes

Material	e (ft)	e (mm)
Glass	0.000001	0.0003
Drawn tubing	0.000005	0.0015
Steel, wrought iron	0.00015	0.046
Asphalted cast iron	0.0004	0.12
Galvanized iron	0.0005	0.15
Cast iron	0.00085	0.26
Wood stave	0.0006 – 0.003	0.18 – 0.9
Concrete	0.001 – 0.01	0.3 – 3.0
Riveted steel	0.003 – 0.03	0.9 – 9.0

Now we have the tabulative values of the pipe. If you look it from the glass to the concrete this as you know it glass will be as smooth as but still it have a in terms of millimeters you have the dimensions but when you go for concrete will have a dimensions if you can look it okay. So you just look at this diagrams, the values and this part. Different type of pipes you have.

The concrete pipes for certain case of the transporting or some you have a glass pipe, you have a cast iron pipes, riveted steel pipes. So all will have a different roughness behavior values for the commercial pipes they will have. So glass pipes are smooth pipe, is close to the smooth pipe and as you go for the cast iron, wood stave, concrete and this the roughness is increased. So more the turbulence behavior happens it.

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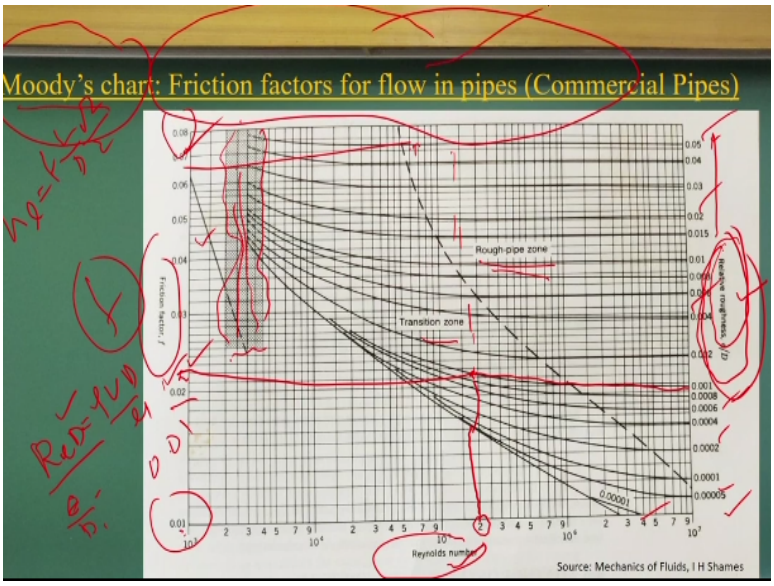

Now this Moody chart compiles for conducting series of experiment in using commercial pipes or artificially roughened pipe. So again plotting with the Reynolds numbers and the friction factors. This side is friction factors. Again I am writing f equal to L by D V square by 2, okay? So if you look it that there is not much difference between the commercial pipes and the roughened, artificial roughened pipes. The characteristics more or less same, okay.

But this is the laminar zone, this is the transition zones. Here you will not have a much fluctuatings of the component of this. Then you can look it the transition zones and rough pipe zones and these are the relative roughness values what is given it. So if you try to interpret it the similar way, but here we have divided for a for the different roughness.

Now let us tell you that how you use this Moody's charts for real applications. For a real applications, first you compute for a particular discharge and the mu and the rho you can compute what will be the Reynolds numbers. And you know the type of the pipe what you were using and the diameters. So you know these two values. As I have these two value what I will do it le be I have a this Reynolds numbers and I will go for particular e by D. That value will come as effect.

So these graphs are used to interpolate the f value, if I know Reynolds numbers and the relative roughness value. So if I know it, Reynolds number then you straight like go it, find out which curve is representing relative roughness. And that curve corresponding values will give me friction factor.

If you look it that way we just interpreted if you have a different pipe, different roughness pipes like as the roughness, relative roughness values increases in these directions your, the f value is also increasing trend. So if you just look it if a f value is 0.01 to 0.08 means the energy losses will be eight times higher. If you keeping everything is constant, the energy losses will be the eight time higher between 0.1 to 0.08 because this is a multiplication factors.

So energy losses will be the eight times higher. So and we can compute the energy losses if you have a Moody's chart which is the experimentally determine the friction factors from the flow in the pipes.

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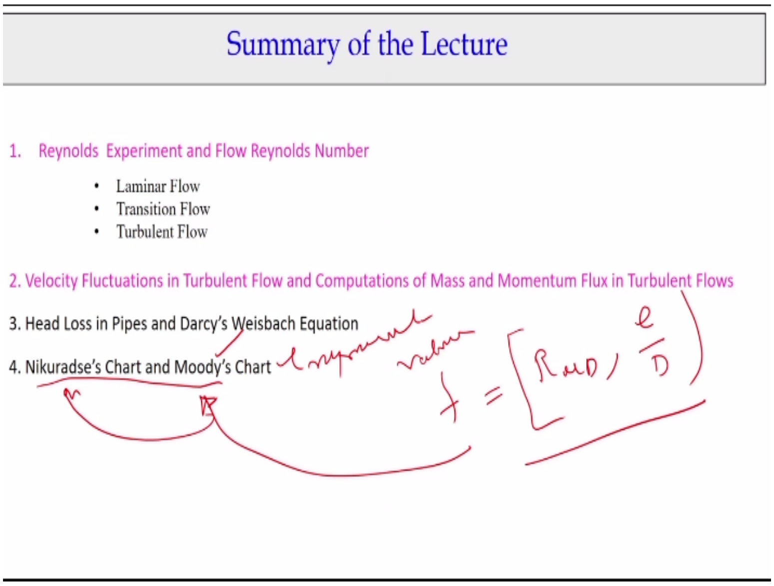

With this let me conclude today's first we discussed about the Reynolds experiments, how the three different type of flows, they are laminar flow, transitions and turbulent flow. We also discussed the virtual fluid balls how we can compute the mass and momentum flux. In turbulent flows the head losses in pipe and Darcy's Weisbach equations also we discussed.

And also we discussed about the experimental relationship between friction factors as a function of Reynolds numbers and relative roughness e by D and that is what is Moody's chart for commercial pipe, Nikuradse's chart for the artificially roughened pipe. So with this, let me conclude this lecture. Thank you.