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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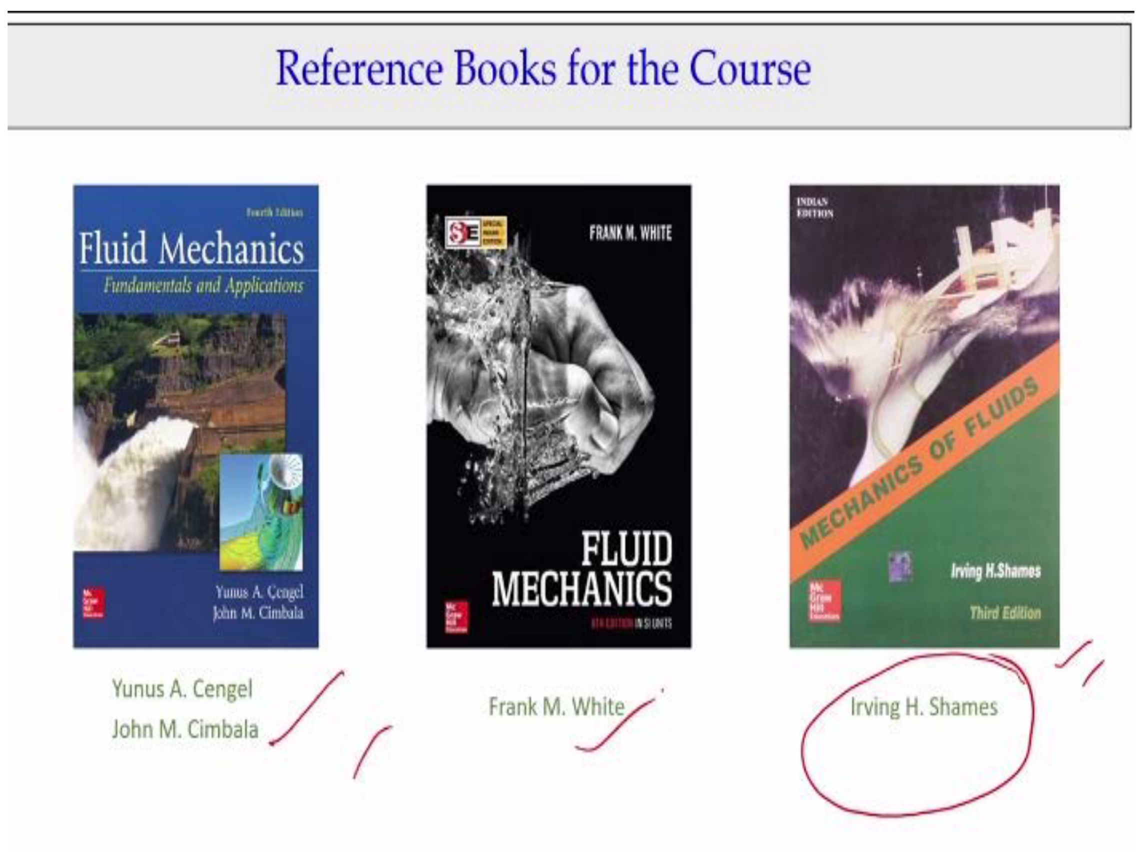

Let us start with this with considering these chapters I have emphasized in, on new book, that is what Irving H. Shames books which exclusively for this flow through pipes and other books also we have a Cengel Cimbala and F. M. White.

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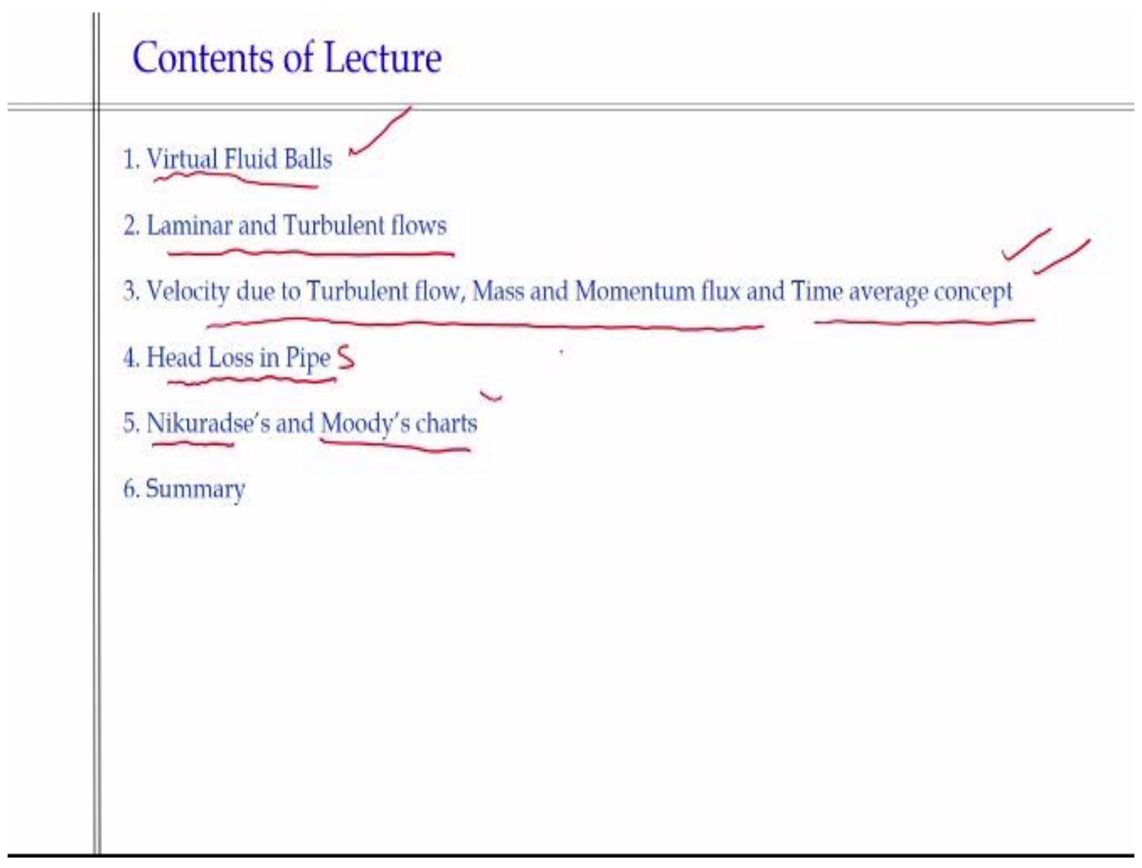

So what we will today we will do it again I will repeat this virtual fluid ball concepts, so that it can be used for understanding the turbulence flow, which is otherwise it is very difficult to understand what is a turbulent flow and how the turbulence are exchanging the momentum from one layer to another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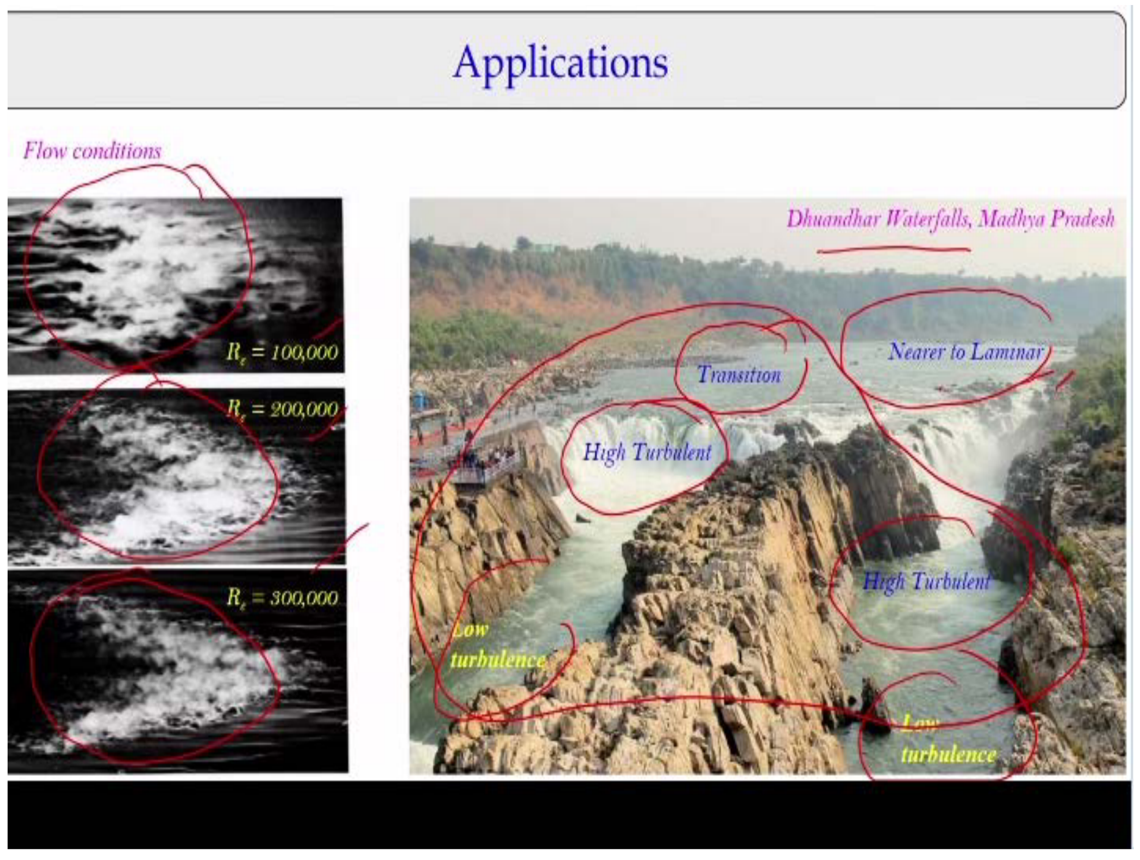

Let us before that if you look at this turbulent flows okay, most of the places we have the turbulent flow. If you look at the conditions of very high Reynolds numbers, you can show this turbulence phenomena the hotspot of the turbulent structures what is going on. Exactly same we can see the turbulent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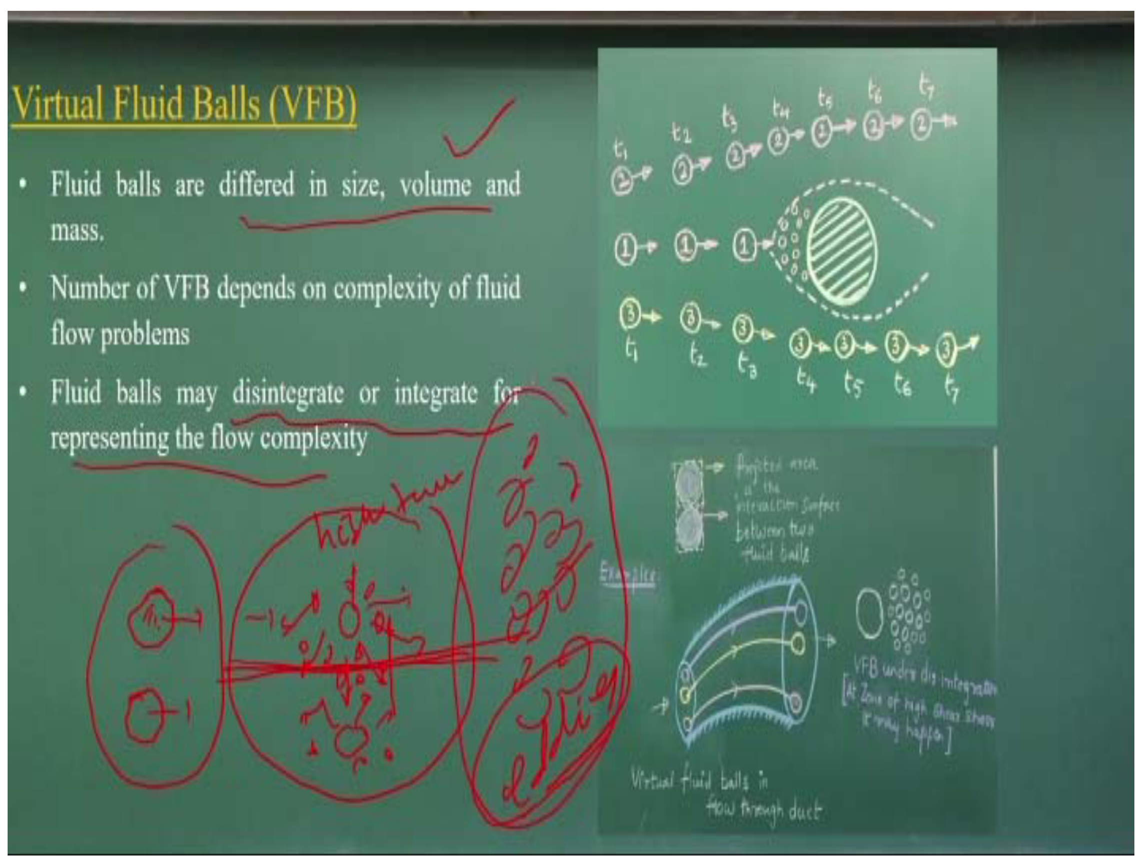

Now coming to the virtual fluid balls. As I said it that earlier we are looking to conceptually the fluid mechanics considering there are series of the balls are moving from one place to other place. If I have a different fluids, I can have a different color of the balls, different size of the balls,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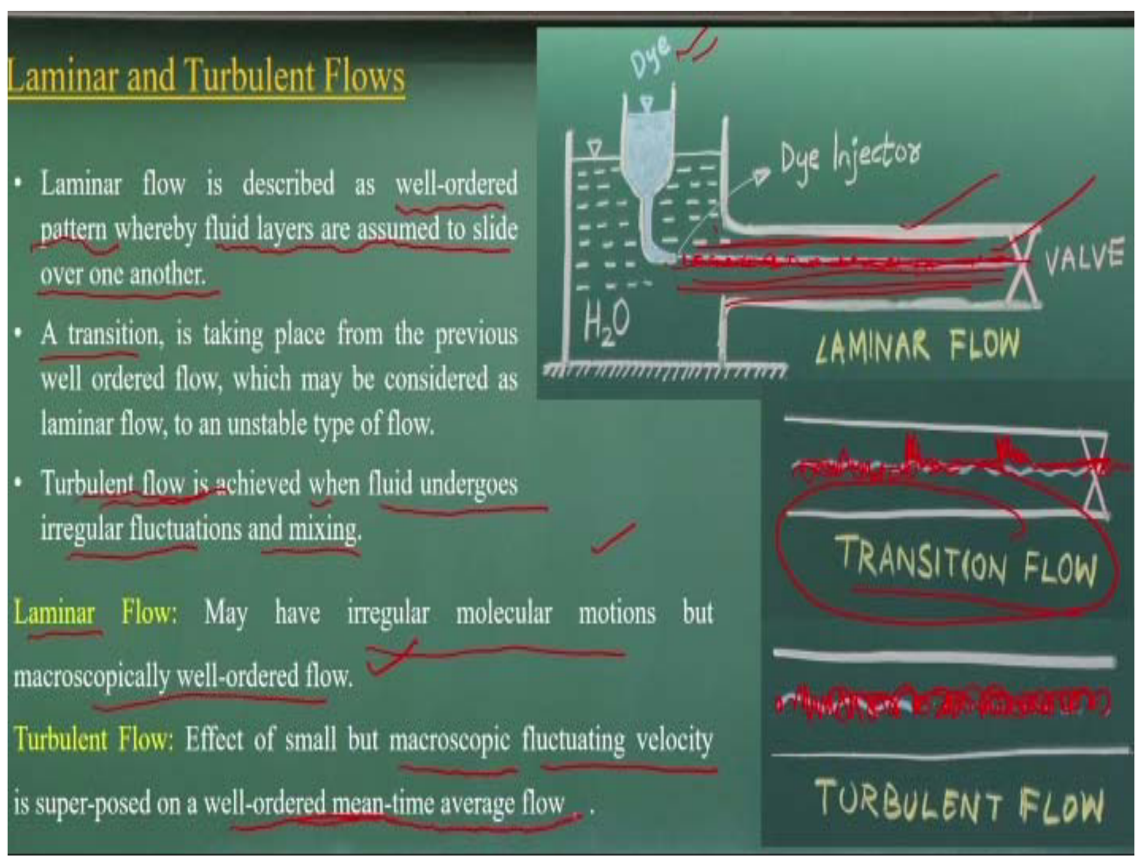

Let us come to the very simple experiments as you know, Reynolds apparatus or Reynolds experiments which is very simple experiments conducted with waters and you have a dye. The last class I show the Reynolds apparatus. Injecting the dye here, then you have you can visualize the dye movement. That means 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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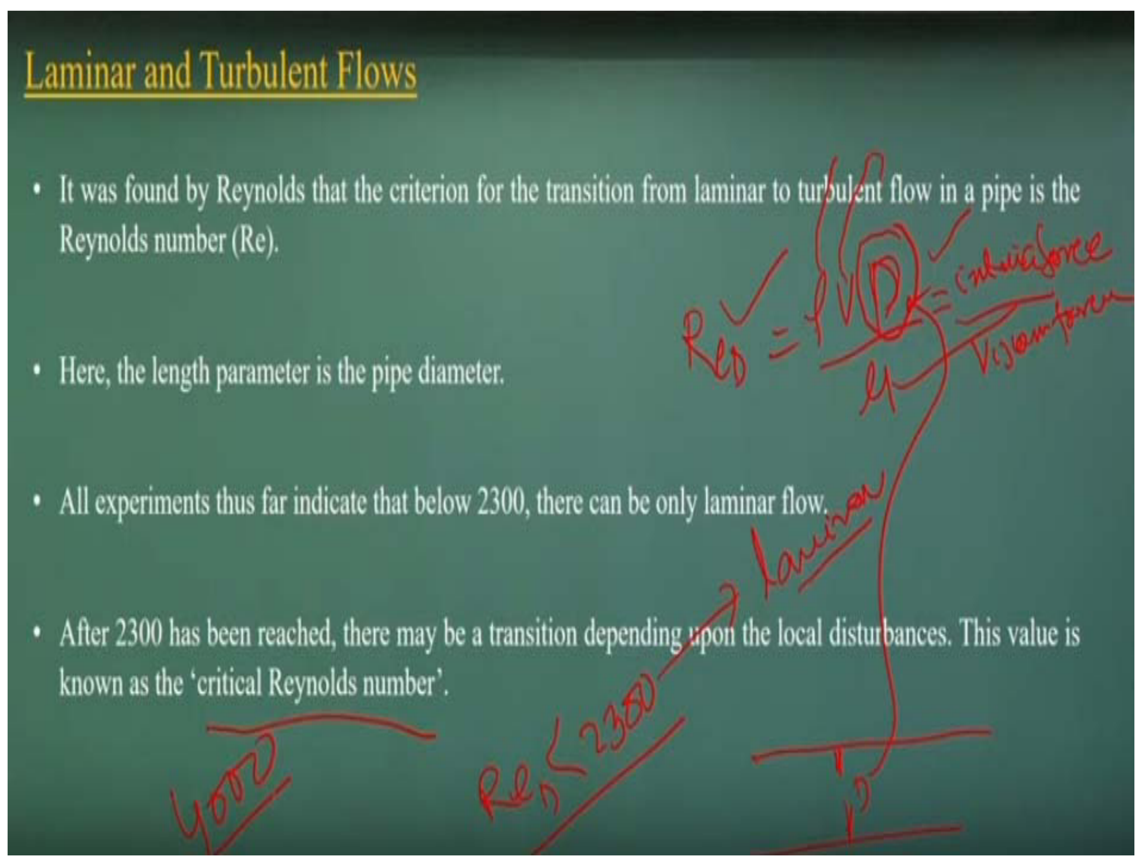

The threshold of the Reynolds number that what is changes from laminar to transitions and transitions to the to turbulent flow. If you look it that the Reynolds conducted series of experiment on that for different type of diameter of pipe, different fluid properties like different density, dynamic viscosity,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

$$Re_D = \frac{\rho V D}{\mu}$$

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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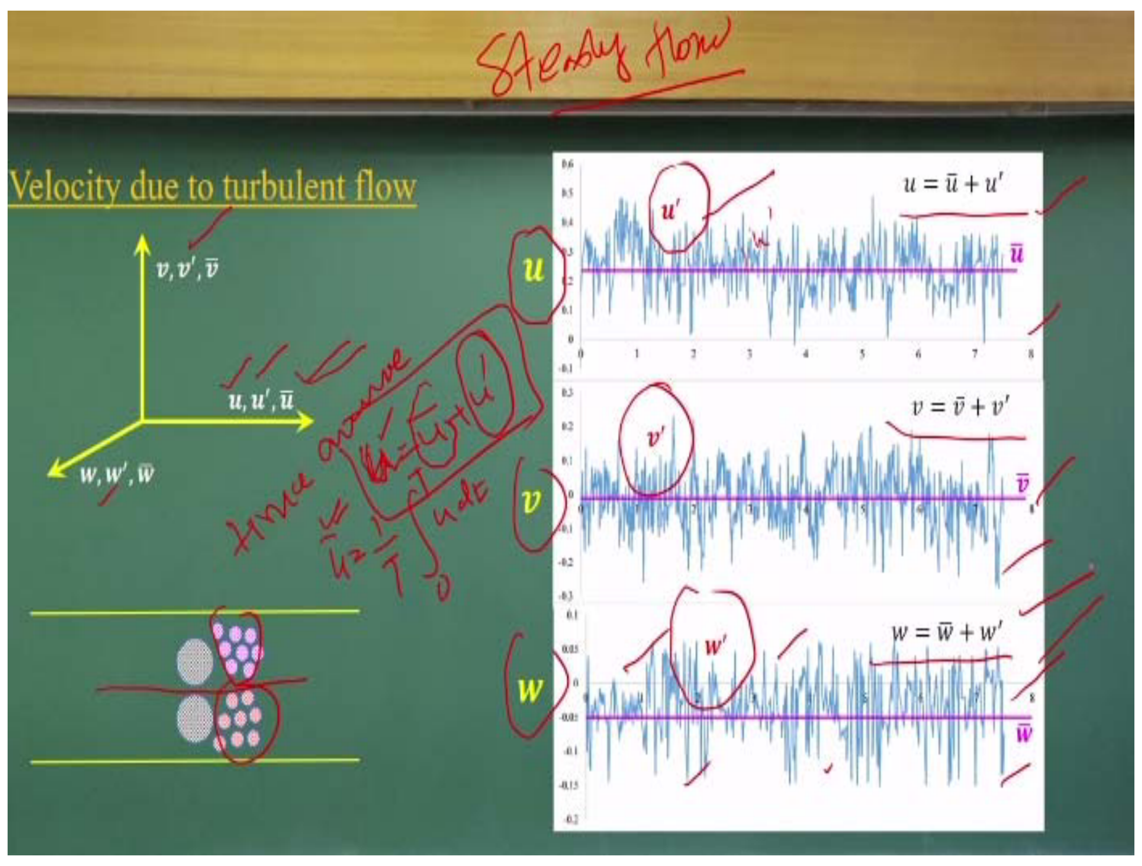

Now if you look it if I have a instrument to measure the velocity in the turbulent flow. Previous class we shown the instrument like acoustic Doppler velocity meters where you can measure the velocity. When you in a turbulent flow you measure the velocities. What we get it to these, this type of curve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

$$u = \bar{u} + u'$$

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.

$$\bar{u} = \frac{1}{T}\int_0^T u dt$$

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 force 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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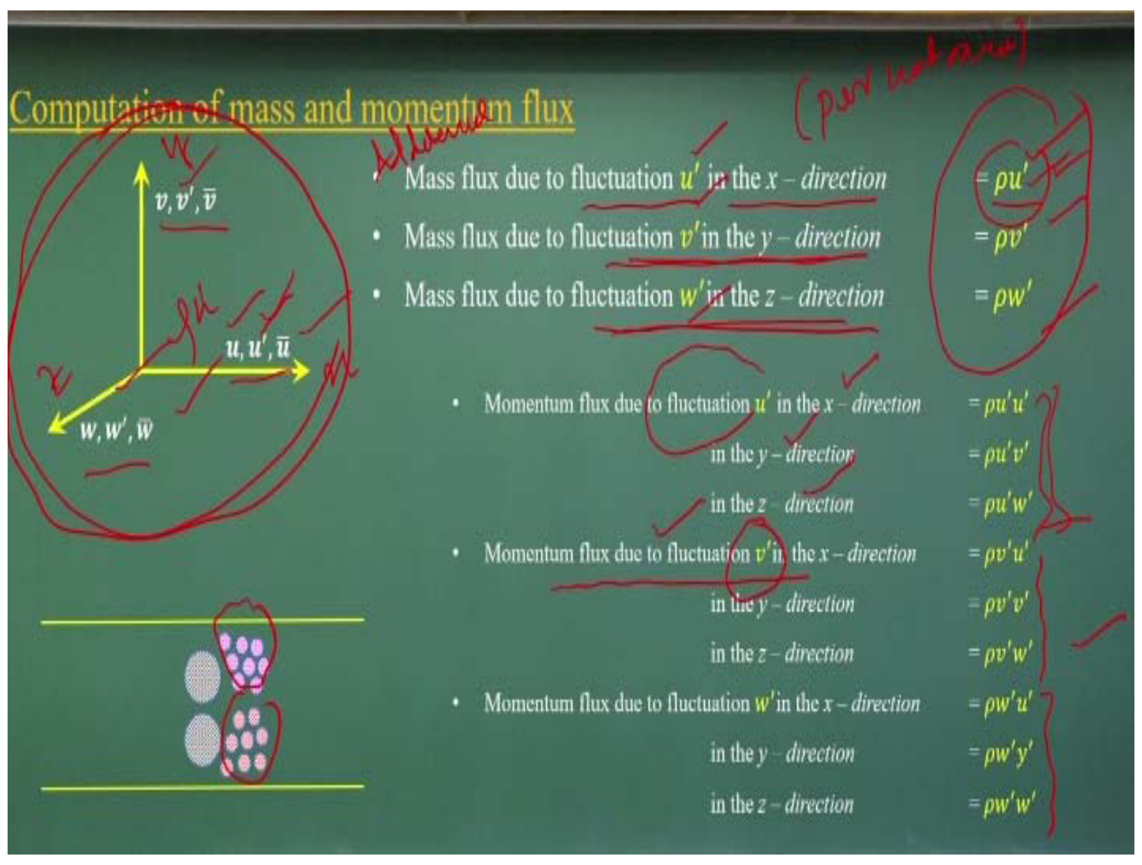

Now if you look it, if I consider is that there are three velocity components okay in x, y, and z directions. If I have three velocity component, if you wish to compute it, how much additional mass flux is going on, additional mass flux due to the fluctuating u'component in the x direction per unit area.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

The similar way if you look at this the mass flux, additional mass flux, which is coming due to the fluctuations components of v' w'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', v' component and ρ, 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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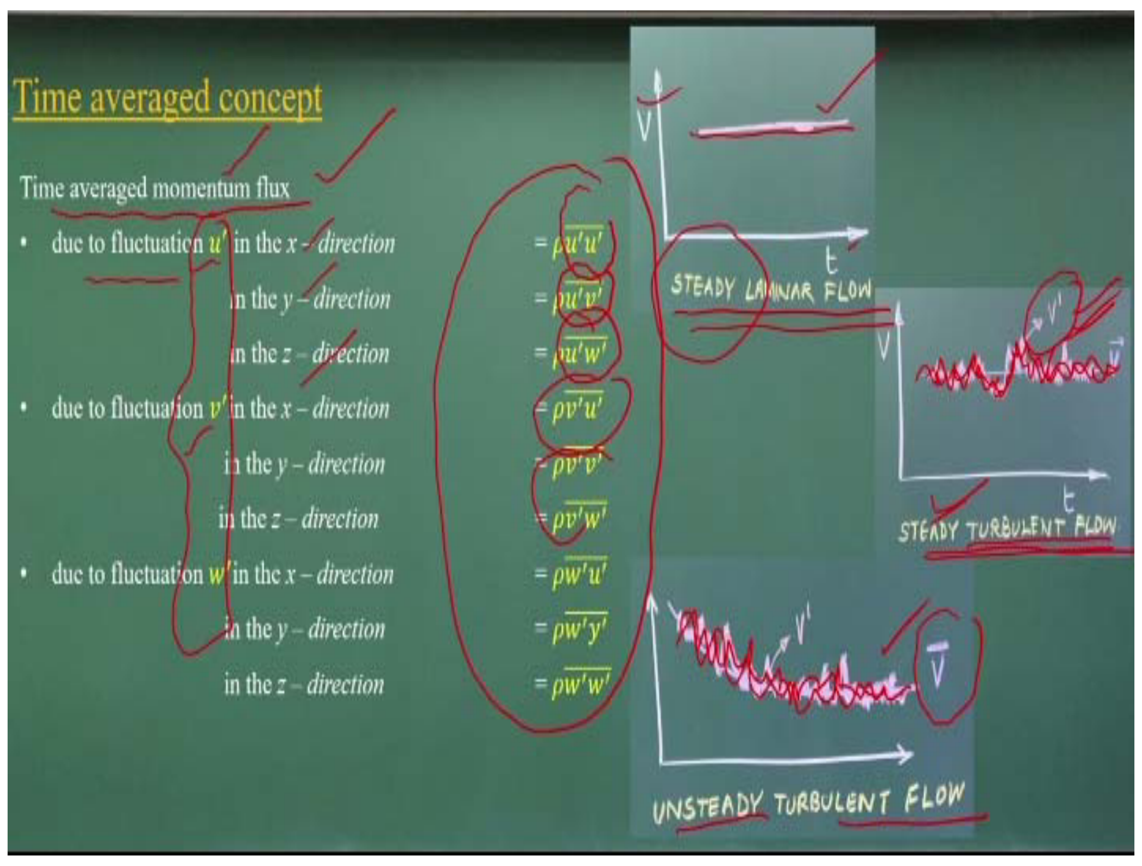

So but here also because we are not worried about the fluctuations components at that instantly we look it also a time average concept. So same way we are giving these the bar to represent these are time average momentum flux, okay. So you can write it if there is a momentum flux there is a force or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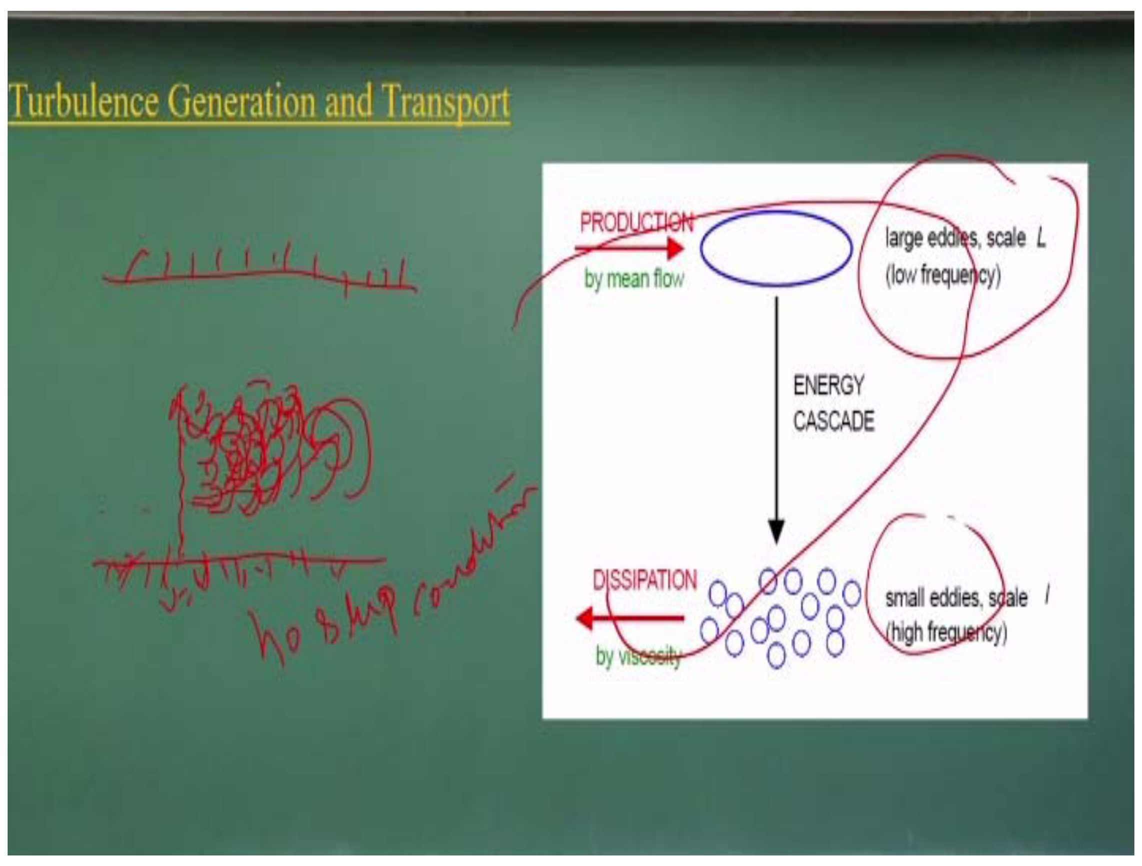

Now if you look at the next levels if you will talk about that what it happens in turbulence. That if you look it that, I have the pipe flow. I have the pipe flow and I know is very well is that the no slip conditions happens near the wall. That is what we studied in the first class. So once you have 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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