Fluid Mechanics
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Lecture - 22
Losses in Pipe Fittings

Welcome all of you again for the second lectures on viscous flow through pipes, which is quite interesting for you if you are preparing for GATE or engineering service. So this part of the lectures if you see that is quite interesting in the sense that it has the applications of Bernoulli's equations.

It has a applications of momentum equations. Also it has that how to approximate a complex flow through the pipe systems. So that way I designed this course for you so that you can have the feeling of application studies how we can do it with knowledge of the fluid mechanics.

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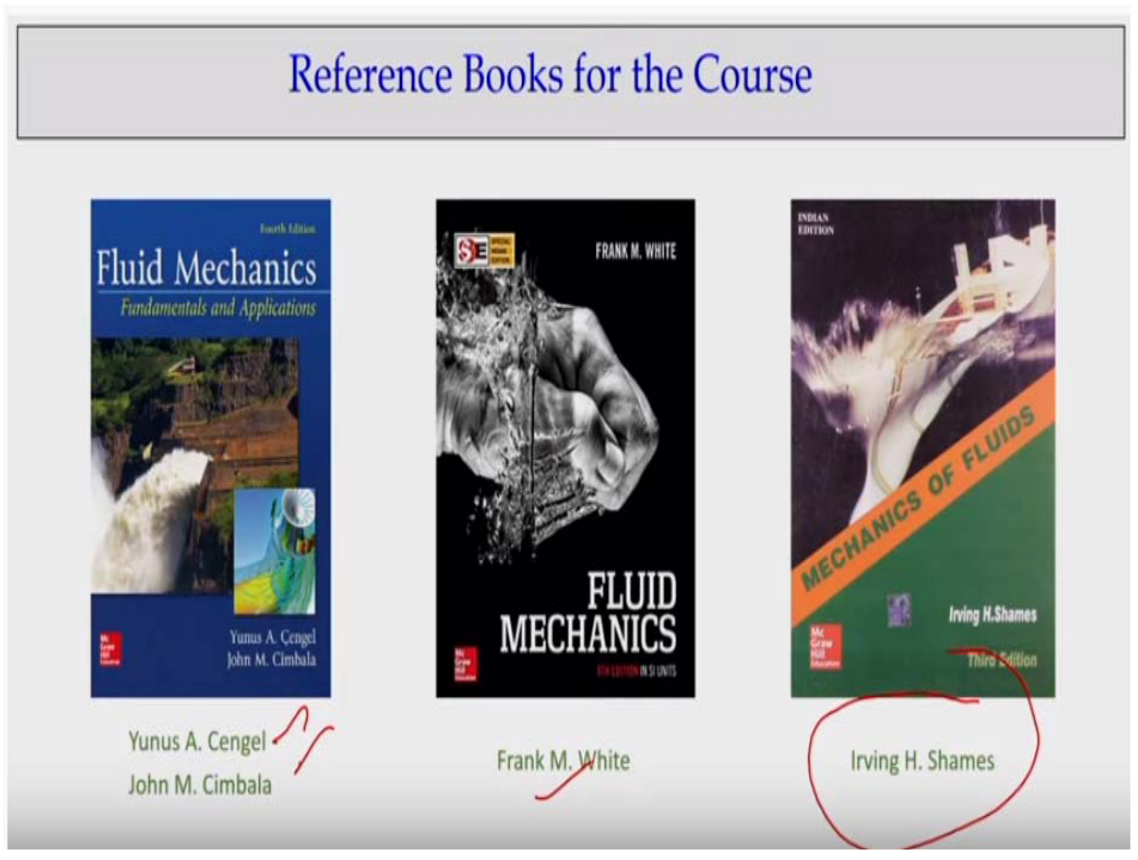

So I can see that this the books what I am following more details in for these chapters. But you certainly can have these two books which F. M. White and Cengel Cimbala. They are the books at the higher levels as you know we discussed earlier.

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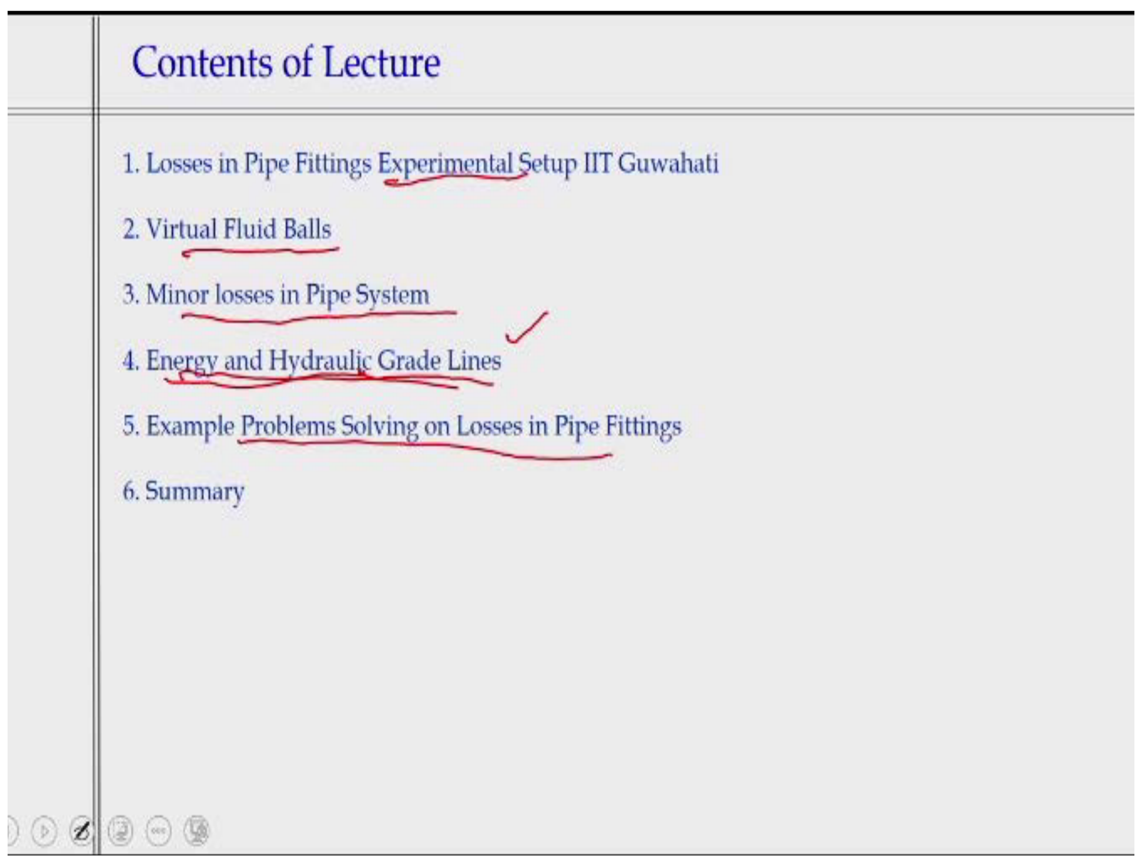

So today what I am talking about that we are going for a demonstrations of the pipe fitting experimental setups which is there in IIT Guwahati. Again, I will revisit the virtual fluid balls. Then we will talk about the minor losses in the pipe systems. And again, I have to revisit it what is called energy gradient lines or the hydraulic gradient line which is more important when you are solving this pipe network problems.

Then followed by I will solve the few problems on pipe networks using Bernoulli's equations, linear momentum equations, and the pipe loss equations. That is the example problems what we will solve, solving the losses in the pipe fittings and all. Let us go for the next level slide.

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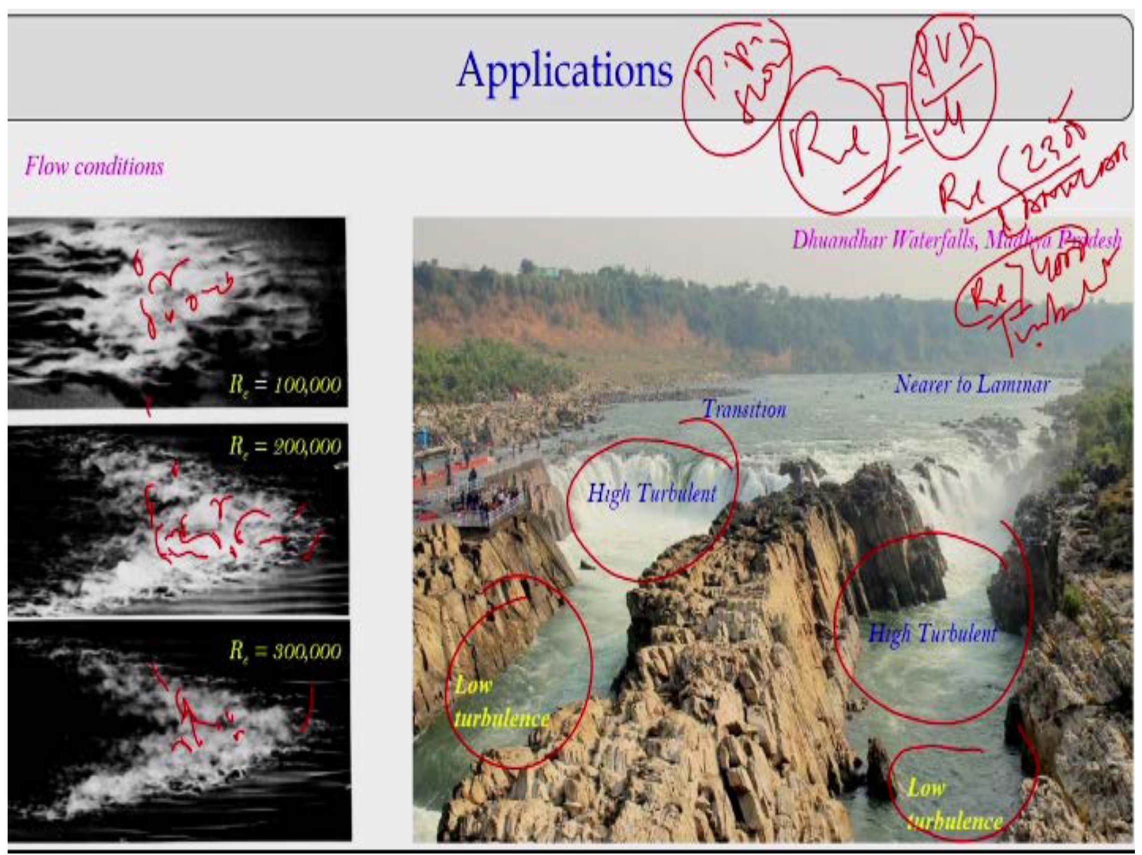

Again I am repeating these slides to just to energize to you that when you have the pipe flow, most of the times we have the turbulent flow okay. So whatever the pipe flow you consider it always we have the turbulent flow as you can visualize the turbulent flow of high turbulence, low turbulence zones, high turbulence, and the low turbulence zones.

When you talk about the turbulence, do not look at the figures like these type of vortex phenomena and all. Always we quantify the turbulence with respect to Reynolds numbers. The Reynolds numbers, if it is a greater than some threshold values then we call the turbulent flow. That means, the Reynolds numbers when you talk about that, it is a ratio between inertia forces and the viscous forces.

For pipe flow what we have the Reynolds number which is

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

The inertia force by viscous force. These values if less than 2300 the flow is laminar. If Reynolds numbers, greater than 4000 the flow is turbulent, okay? So please remember this threshold for the pipe flows. But for other flows, you can have the higher studies to look it that. So if it is a Reynolds number less than 2300 and Reynolds number greater than 4000 we have a laminar and the turbulent flow.

In between you have a transitions flow systems. And you can see here the photograph of showing how turbulence vortices are there or eddies formations are there. So we can visualize that and today many of the best fluid mechanics labs they have the facilities to measure this type of turbulent structures, they quantify it that how much of energy dissipated, because this turbulence structures.

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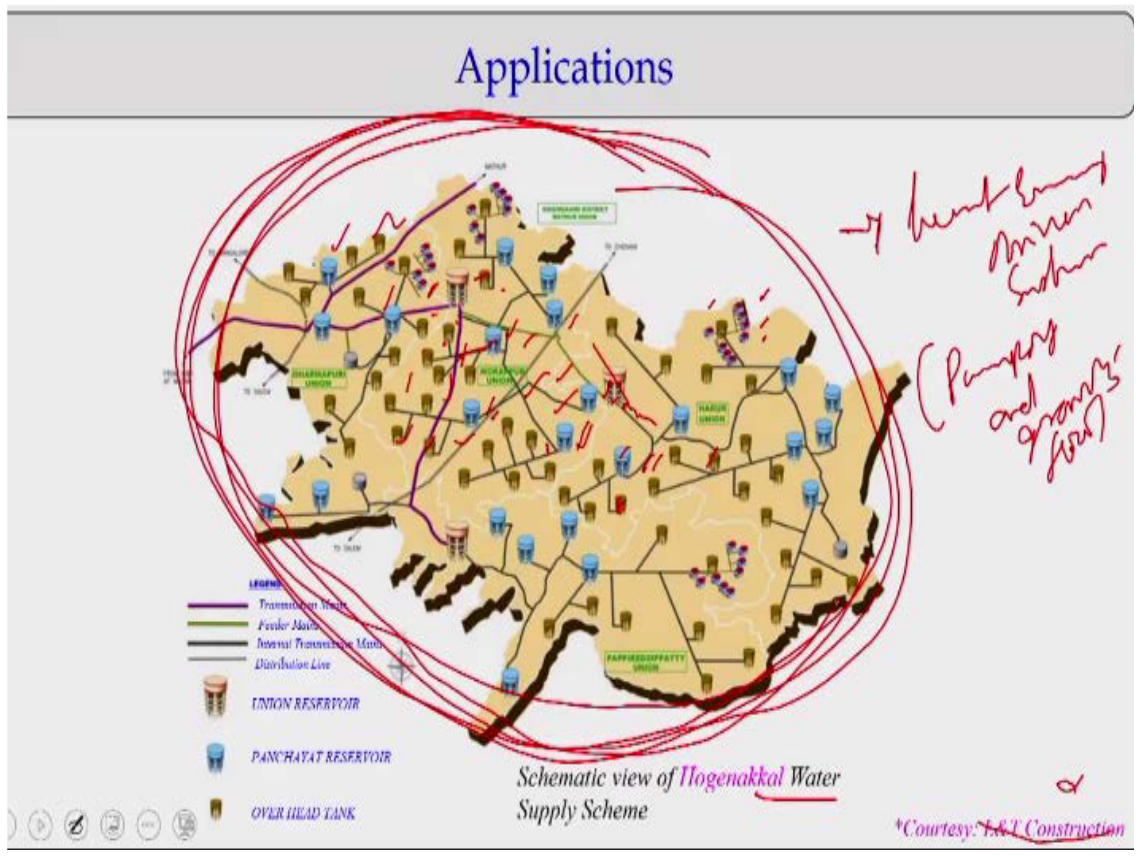

So looking, this is just a introductory to start our things. Just I am taking one of the example of water supply schemes from L&T constructions were fetched. You can see this the planning of water supply systems, you just look it. So there is a source, there is the supply systems. There is a source points and there is a supplied at the individuals the house level.

But for that if you look it that it will be a series of the tanks. What is it dedicate? The series of locations where you will have a augmenting the additional energy in terms of pumping the waters. The additional energy you want to give to the flow systems and store these waters. Then you have a second line of again you have the tank systems. So if you look at these systems which look at the water supply system, is like a power grids.

So when you plan these type of water supply systems, we need to know how much of loss is happening it. How much of pumping is the requirement is there. How many overhead tanks are we should design it. What should be the network of these pipes? What could be the diameter of this pipe and what type of pipes would be there?

All these things these complex systems what we design it to make it so that this totally should have a the least energy driven system Okay. That means it is a combinations of pumping and the gravity flow system. So you will have a certain systems. You will have a pumping systems. Then you have also the gravity flow from that. So all these components of these water supply systems, we need to find out how much of energy loss is happening it and what will be the available discharge at different points.

Like considering this point what will be available discharge at this point. So these analysis if you look it that what we are discussing it those are very preliminary levels. But when you design this type of water supply systems that are commercial softwares or the free softwares are available so that you can design these systems to know it at each point what will be the available energy, what is the amount of discharge will be available, all these things you can quantify under different scenarios.

Like you have a summer water supply system, winter water supply system where you need different amount of the waters. So all the things we consider it considering this basic the pipe flow what we are discussing it that. So with this note, let us go for the next slide.

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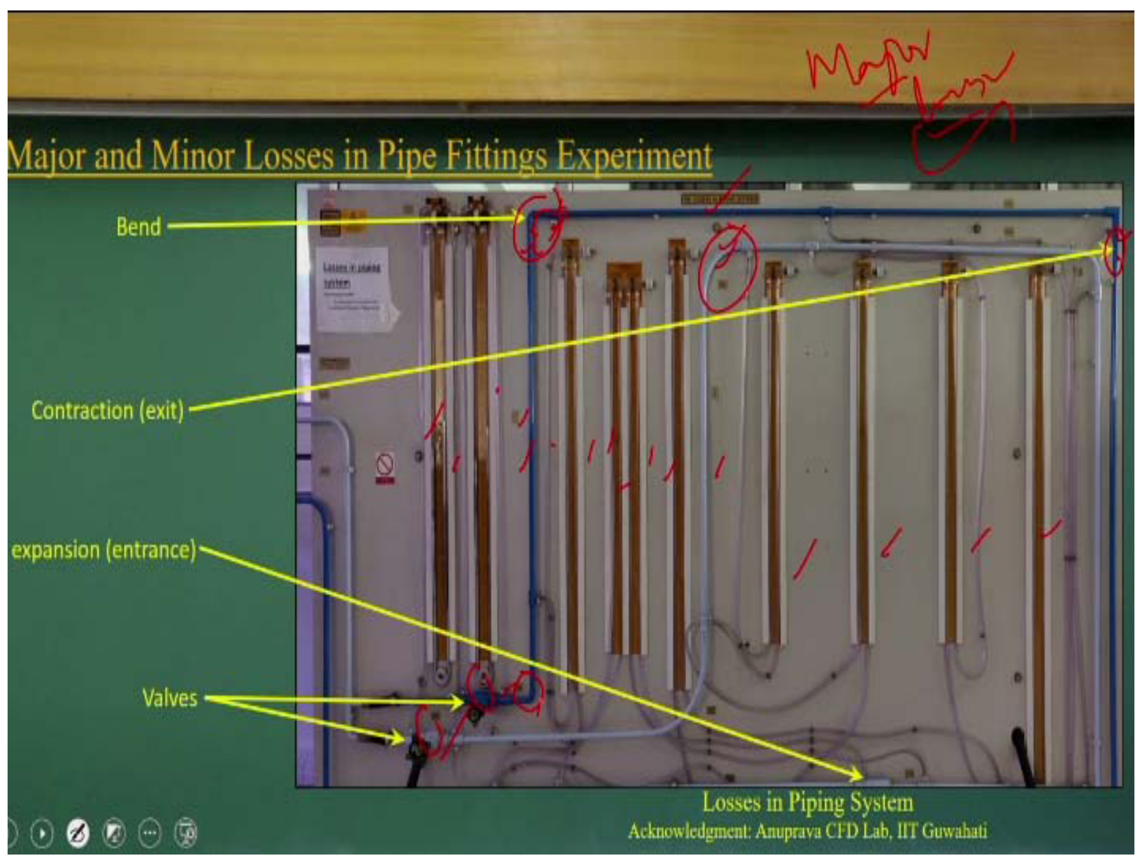

On the next slides what I am showing it that how we conduct the experiments to quantify the how much of losses are happening, energy losses is happening it. So one if you look it, we call major losses. Major losses, that is the losses due to the frictions. So that way if you look it there are the two pipes are there. And in these two different pipes there are the manometers are attached to determine what is the pressure difference at the two points, you just closely look it.

So as we will measure the pressure difference, and as you know the how much of discharge is going through this pipe systems for a steady flow conditions, we can compute the velocity, we can know the pressure difference, then we can quantify the energy losses just following Bernoulli's equation with some modifications. That what we will discuss.

So the basically these type of systems we have to quantify what is the amount of major losses. But there are minor losses like this is the band is there. There are loss will be there. The band is here, there will be loss. Here also we have the band and there are the valves are there. So all these are called minor losses, as well as there will be the exit loss or contractions loss.

All these loss components which are called the minor losses that what in terms of energy, how much of energy losses when flow is going through that. So those things also today we will discuss it. So these are the experiment setups, the students conduct the experiment with a different research and find out, measure the pressure difference.

And with a simple calculations they quantify it how much of energy losses or the head losses happens for minor component as well as the major components like the pipe due to the frictions and the fitting, the elbow, the bends, the exit, the valves all we consider it to find out how much of energy losses are happening it.

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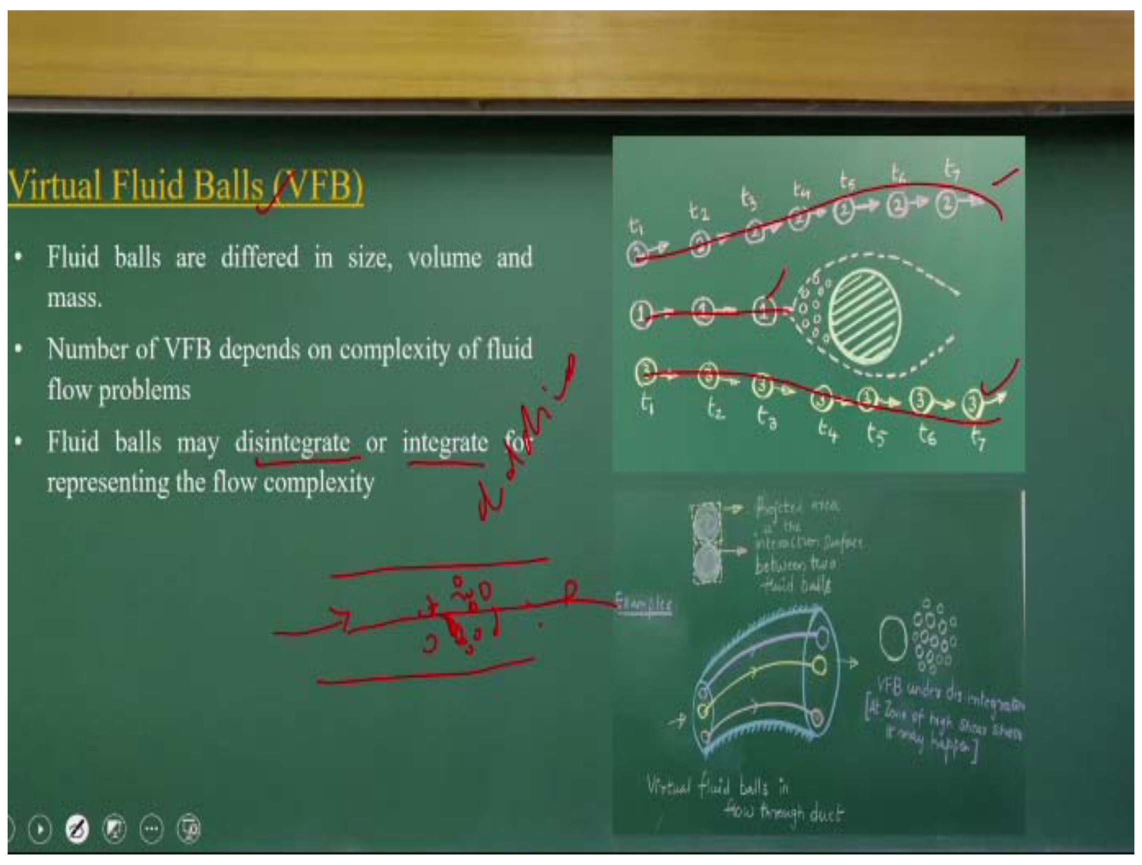

Now let us go for the next slides which is again I will talk about virtual fluid balls. Here again I have to repeat it to tell it the virtual fluid balls to understand how the vortex formations happens within a pipe flow systems, okay. Like the last class I discussed about the pipe flow systems, when I am considering it, the pipe, a horizontal pipes and because of the turbulence how the eddies formations happen.

These are eddies, these are eddies formations happening it and those what we try to understand because if there is a horizontal flow is coming going out and we quantify in terms of the balls moving with disintegrated, integrated concept. But for to define the streamlines for a complex fluid flow problems, today we will use to same virtual fluid ball concept to define the flow streamlines.

Because, as you know it when you try to apply the Bernoulli's equations the first assumption is that you should apply along a streamline. Or if you consider the flow is irrotational. So it is very difficult to quantify the flow is irrotational, but always we can draw a streamlines, draw a streamline like this cases and I can apply the Bernoulli's equations.

That is what today we will discuss more when I will give the applications and also the some few example problems.

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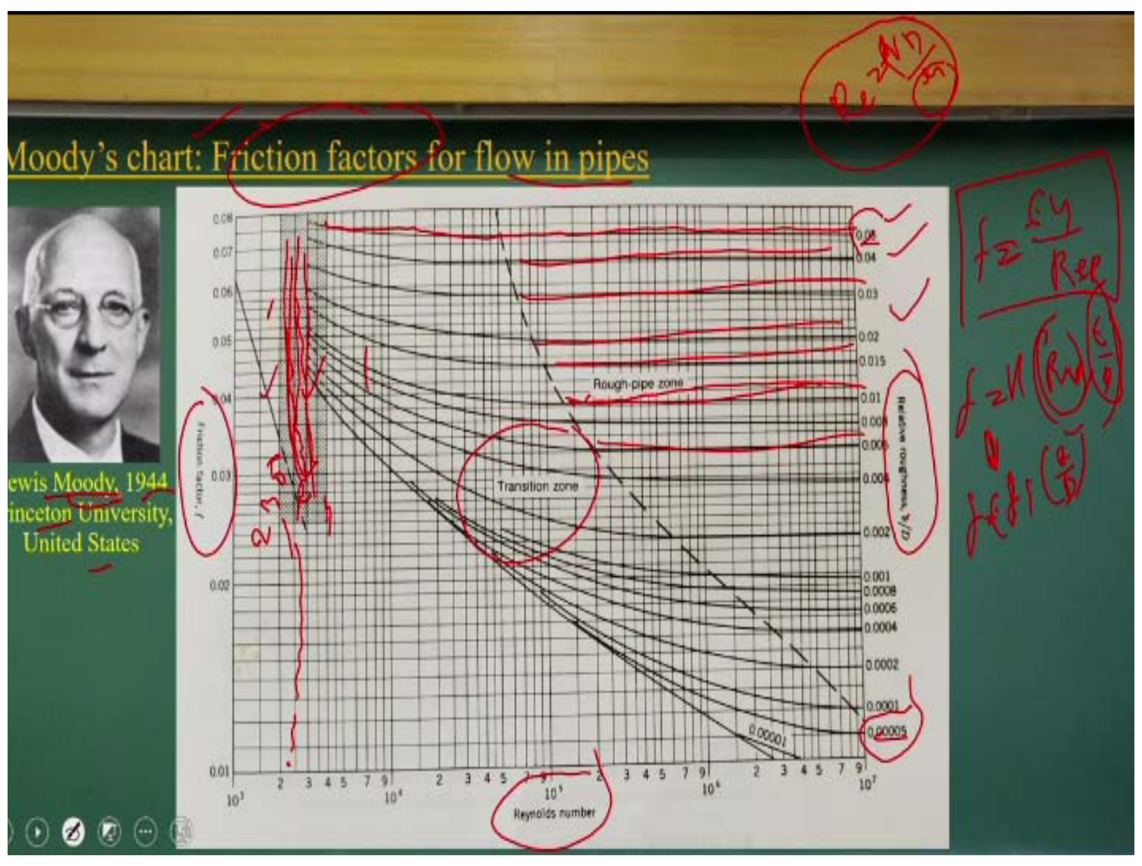

Now let us go back to the Lewis Moody 1944 Princeton University, USA. What he has developed is from the experimental data. If you try to look it, he has not pulled out only his experimental data, but long back the data from others researchers. All the data he combined it for the developing this Moody's charts to compute friction factors, compute the friction factor, the flow through the pipes.

Mostly this commercial pipes, what is use it. So now, if you try to interestingly look at these things, which is, I can say that is a knowledge of the fluid mechanics. If you try to understand these curves is the representing the knowledge of the fluid mechanics in a just compute the friction factors. If you look at the friction factors, here we have a Reynolds numbers.

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

The x axis is Reynolds numbers in a logarithmic scales and the y axis we have the friction factors, which is normal scale. If you look at this part, what it is indicating for us the first condition is laminar flow. This is a laminar zone as I repeatedly showed that this is up to 2300. So the relationship between the friction factors and Reynolds numbers you have

$$f = \frac{64}{Re_t}$$

So it is a linear functions you can see it that. But when you have a transition zone which is 2300 to 4000s in those regions, we cannot compute this friction factors because so fluctuation behaviors are there. We cannot compute it. If you compute it there will be a lot of erroneous will be there as the experimental data is showing it. So most often when you design the pipe systems we ever to have laminar flow and the transition zones.

Because in the transition zones, the frequency factors can fluctuate very wide range from this to this. And most of the times we design the flow which is a turbulent flow, okay. Then it can start from smooth pipe to rough pipe. That means, it can start with a relative roughness, which is $\frac{e}{D}$. That means roughness by the D values can have very very small to 0.05. Each lines are representing for you the 0.05, 0.4.

So this is the turbulent zone spot. Now if you look it try to understand it as you know it the friction factors for the turbulent flow is a function of Reynolds numbers and relative roughness value. But it is there if you look it that function dependency is there still at this point after the pipe we call rough pipe zone. That means, after that the friction factors as a single functions of only the relative roughness.

Not, it does not depend upon the Reynolds numbers. Now if you try to understand the physics wise, what it happens it as we increase the roughness, then the Reynolds numbers which represent you the $\frac{\rho VD}{\mu}$, this part does not have a much significant. The viscous effects are not significant, more the effect of the roughness is comes it.

The mu components, not much significance as you are going more the roughness, it becomes independent to the Reynolds numbers. That is the reason it is a constant, independent to the Reynolds numbers. It is just depend upon the roughness factor. So we divide into two zone. One is a transition zone, where the fiction factors is depends upon the Reynolds numbers and the relative roughness.

Now you try to understand it that if you have a increase the relative roughness of and the higher Reynolds numbers, you it depends upon the friction factors. Only these relative roughness, not the Reynolds numbers. These things you can conceptually just think it that how the process happens it. I am just leaving to you.

So these diagrams what is prepared from the experimental data not from only from his data set also the data set what were prepared from the artificially glued the roughness pipes in Germany, the combining the all the data Europe data and the USA data he prepared this map which still date mostly used or we have been using this the chart to determine their friction factors.

Because once you the friction factors it is easy to compute energy losses. So once you know the energy losses then you can quantify it that what type of pipes we need it. What type of diameter pipe you need it, all we can link with the energy losses.

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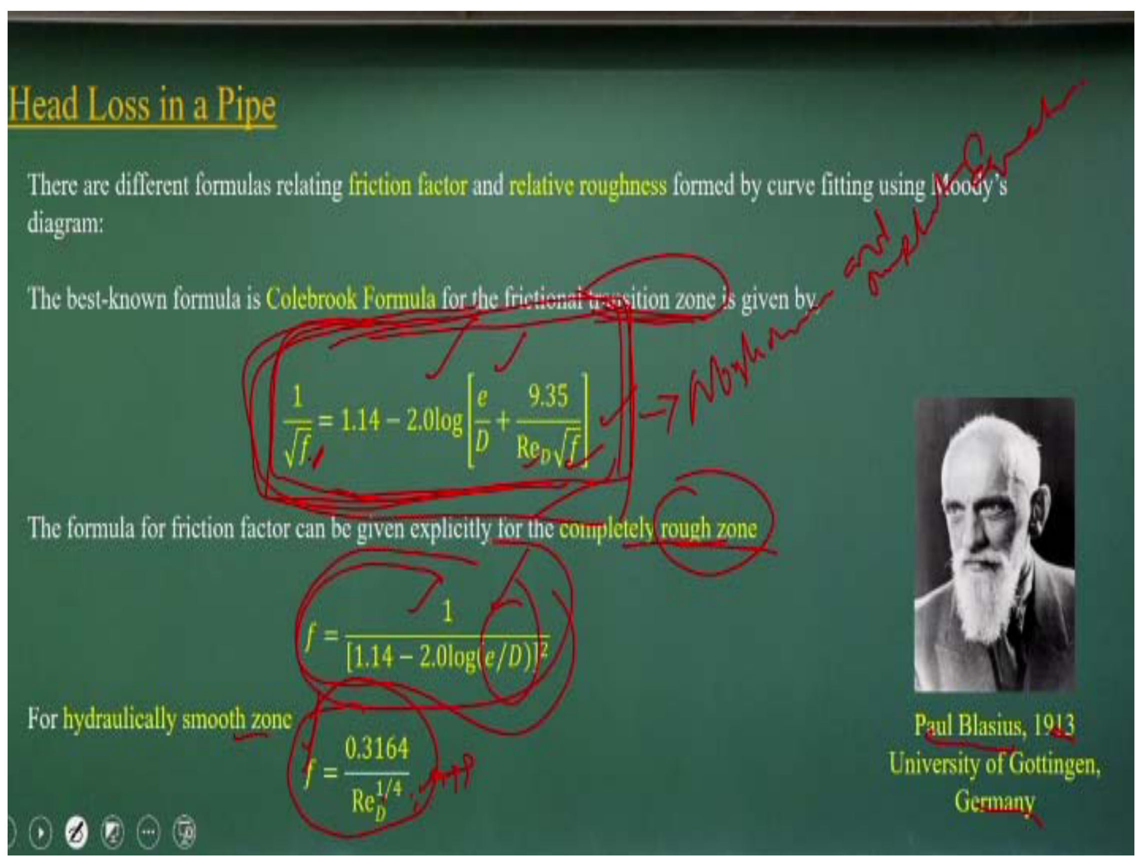

Now if you look it if you do not have a this chart okay then there are two parts as I say that for the transition zone there is a developed equations like this okay. You can see that it is called implicit equations because the friction factors also here, okay. So it we cannot directly compute the frictions factor because this is a implicit equations which is there in the both the sides and is also nonlinear and implicit equations okay.

Because of that, nowadays we can estimate these ones because there are a lot of mathematical tools are available like the Microsoft Excels and all we can iterate it and compute it what will be the f value if I know the e, you know the D and if I know the Reynolds numbers. So we can compute it. It is not that difficult today when you have a good computation facility with us.

$$\frac{1}{\sqrt{f}} = 1.14 - 2.0\log\left[\frac{e}{D} + \frac{9.35}{\mathrm{Re}_D\sqrt{f}}\right]$$

But when you go for the rough zones, which is as I had already said that it has a function of only the relative roughness factors. That is what is defined it here. So you can use for this part for the transition zones, this is a part you can use for the roughness zones. But earlier for the smooth zones also we can approximate like this which is explicit equations.

That means you just substitute the Reynolds numbers you can get the f value okay. You can always debate it what is the difference between these two? This is approximations of this part. It is valid for certain regions, but the exact equation is that this is the one okay. So that is what is the Paul Blasius in 1915 from Germany that is what he develop it.

The formula for friction factor can be given explicitly for the completely rough zone

$$f = \frac{1}{[1.14 - 2.0\log(e/D)]^2}$$

We can explicit equations you can develop it, which is just substitute the Reynolds numbers you will get the f factors. But for getting the accurate f vectors for the transitions zones, we can use these equations which is nothing else the fitting of the Moody's charts and similar way you can get it for the rough regions the equations. This is also is derived from the Moody's charts.

For hydraulically smooth zone

$$f = \frac{0.3164}{\mathrm{Re}_D^{1/4}}$$

So if you do not have the chart, you use these equations. If you have a chart you do not need to compute these equations. Directly you can get it the values from the chart itself.

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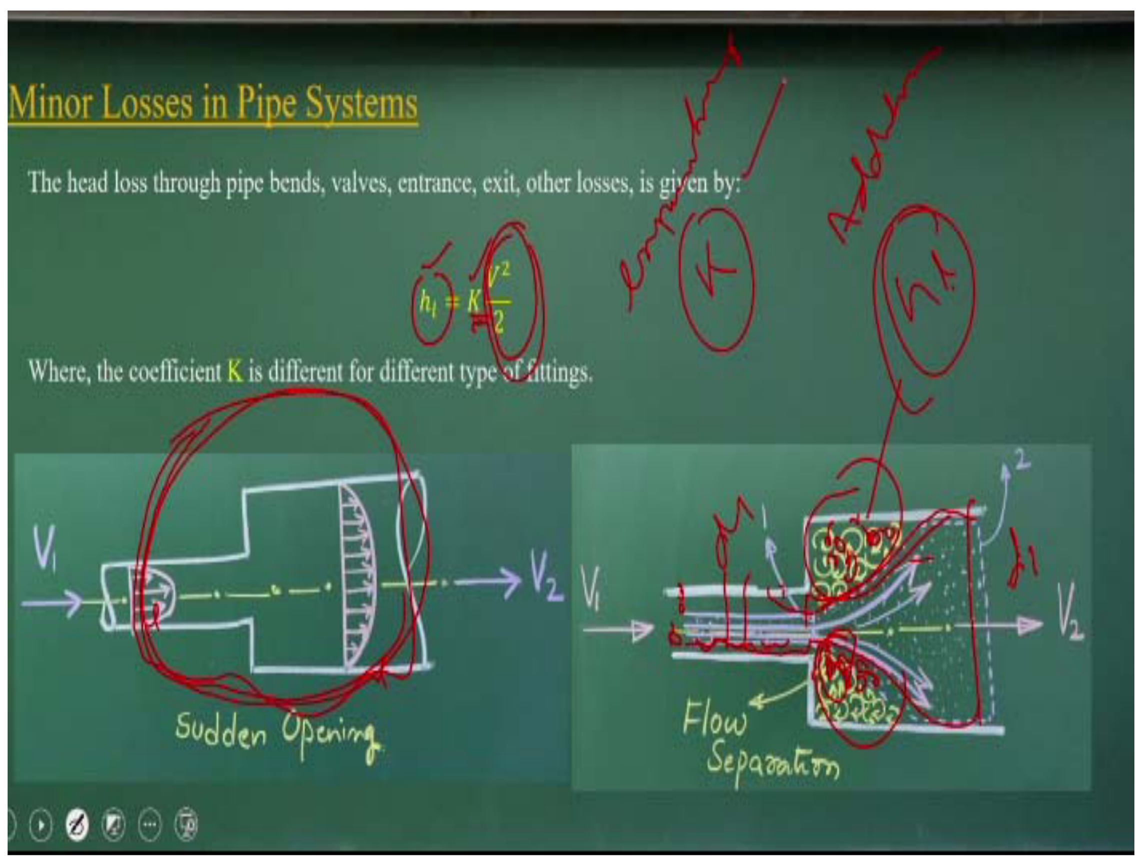

Now let us go to the minor losses in the pipe systems. As I told it when you have the pipes, it can have a regions you have a smaller pipe to bigger pipe or bigger pipe to the smaller pipe. When you have a these conditions that means the flow is coming it here and going out, the smaller diameters and the larger diameter. If you have these conditions, what we do it that when you compute the energy losses, for this total regions, we compute the analysis this.

You can understand it energy losses will have a functions of e square by 2 which is kinetic energy per unit mass into a vectors, which will be responsible for how the flow patterns, how the streamline patterns, how the vortex patterns are (()) (21:31). If you know that, you can quantify it or you conduct the experiments. It is very easy to conduct the experiment of different pipe diameters, different configurations you can compute it.

You just measure the pressure at these two point and you know the velocities like the manometers you can put it then you can measure the pressure difference and you can easily quantify that how much of K value from experimentally. That is what it was done so far to compute this K value from experimentally. But for your point of view, I am just explaining it how the flow process happens within the pipes.

Now let us look it how would it happens it. That again I am considering virtual fluid balls okay. If I consider the virtual fluid balls, the balls which is going very close to the wall, which will go straight and inject here as a tangential and go like this, okay. What will happen to this? Here also we have the particular liquid, but that liquid will have a vortex formation. They will start rotating it, start rotating it.

So immediately your flow will pass this, these regions will have a vortex formations. Because of these vortex formations, you will have a energy losses. You will have the energy loss, the additional energy loss you will have because of this vortex formations are there. And this the quantity of the vortex formations, quantity of the energy losses happens it depends upon the d_1, d_2, V_1, V_2 what type of flow is happening it.

Because your streamline patterns will change depending upon the V_1, V_2 the flow Reynolds number energy, what is the energy is coming this. So from the experimentally for different d_1, d_2 we can compute it how these things are changing it. From experimental data, we can get it the energy losses in terms of,

$$h_l = K\frac{V^2}{2}$$

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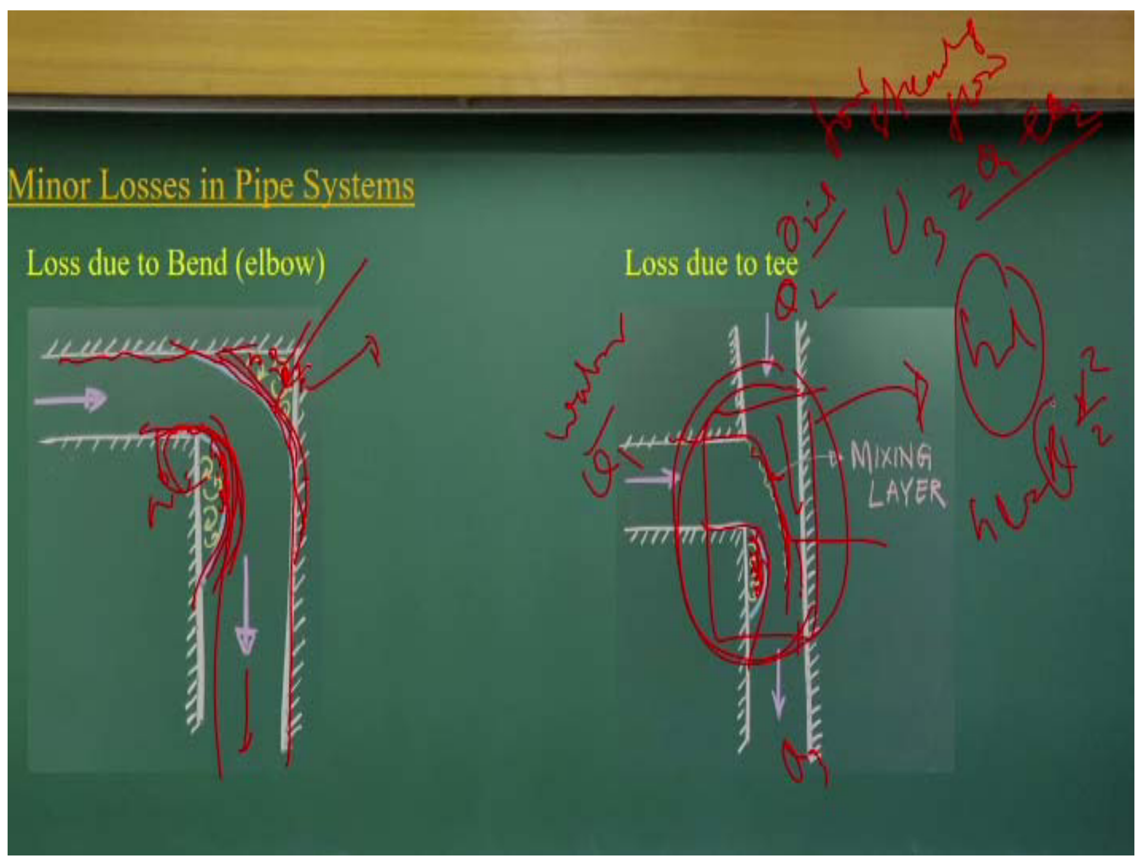

Now we go to the next ones, it is quite interesting. You have a bend. Most of the times we avoid the bend, but it is okay looking the topography and all we need to have a bend, the pipes. So when you have the bend the pipes okay the flow is coming like this and it is going like this. You can easily draw the streamlines okay considering this, the balls virtual balls. Similar way, this is like this.

In this and these regions the vortex will be there. This is for energy loss. This is because of this vortex process are there, that is what is additional energy losses will be there. Those energy losses depend upon what is the angle of this one. This is case is 90 degree. So if you have a different angles this the zone where the vertex is happening, that is what will be the different.

So you**,** the angle of this part also depends upon what is the flow is coming, that also depends upon. But on average we consider it even if you have this case. But if you looking these figures what it showing, how to avoid these vortex. It is easy you make a instead of straight 90 degree elbow, you give a curvatures here which will fit it exactly this part.

If you do that the pipe systems with a then there will be less energy losses. So instead of having just 90 degree bend of the elbow, we can have a curve at this point. You can give a bend pipe. So that what will be the lesser energy loss as compared to these ones. That is what most often in industries they use it. But if you look it that we have the T joint.

That means I have the discharge is coming Q 1 here and the Q 2 is here okay. And this is the Q 3 which is going out okay. Looking these figures you can say that Q 3 is equal to Q 1 + Q 2, it is not a big issue, for steady flow, okay. But let us look it that inside what it happens it. It depending upon if this you look it if flow is coming like this, the flow will follow this and will go like this.

This flow will come like and here this vortex also will be there. And this flow what is coming it they will come like this. And this is what the mixing zones. This is a very interesting phenomena if you can look it that many of the times if you look it that if there is a two fluids are there if you just put a two fluids okay, fluids like maybe this is waters, this may be the oil or something, you can see how the mixing zones is happening. How the vortex zones is happening. It can easily quantify it.

So now if you visualize that, so now if you look it that the because of this mixing layers, because of the vortex formations, and the presence of the vortex formations you can feel it if you are engineers just touch these pipes, you can see this heat is generating it. You can see the temperature difference. So that means, indirectly it indicates for us there is a vortex formations are happening it.

The energy dissipations are happening it So we can identify which are the regions are the heat generating it or it is so those regions you can identify and also we can measure this vortex phenomena and but more of the times we just try to look it that how much of energy loss is happening to this case h l part okay. So we can define in terms

$$h_l = K\frac{1^2}{2}$$

This K we compute it with a different configuration. That is already experimental done it. So there are the table, we just follow it.

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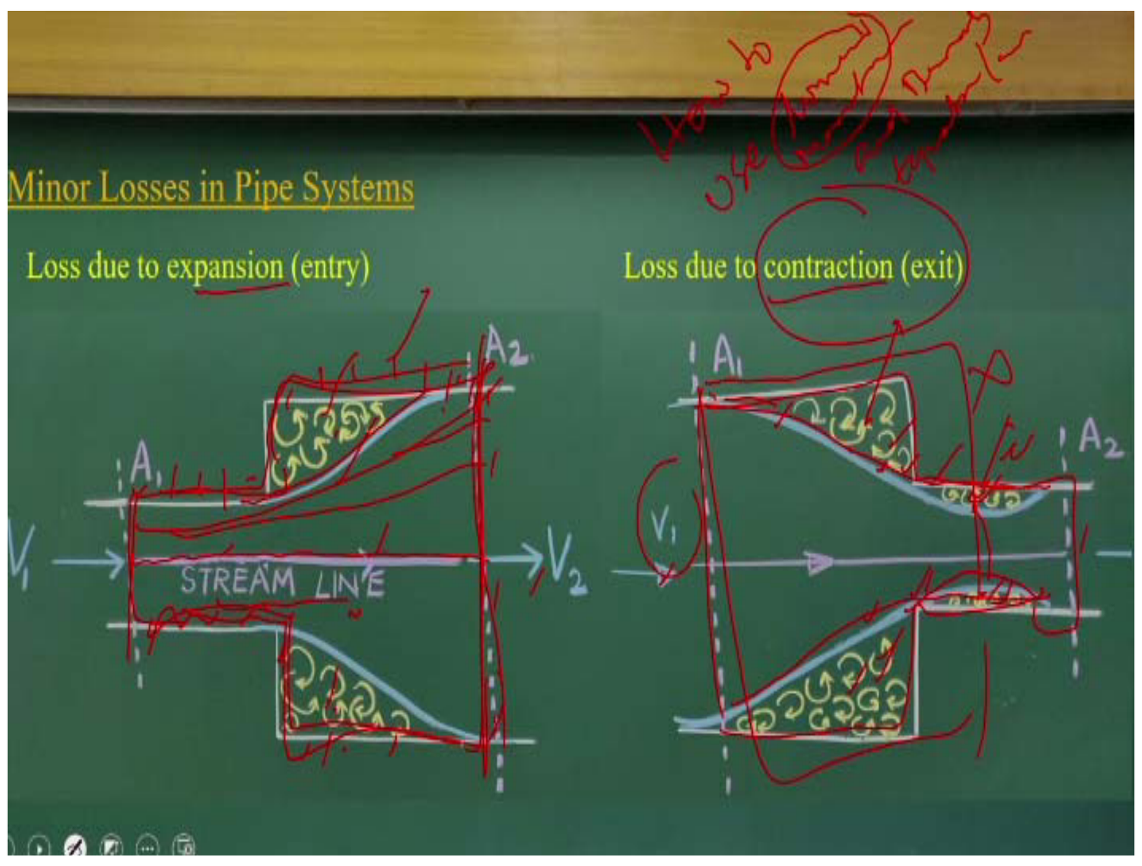

But interestingly let us go for that is two systems okay, which I intentionally putting to you that just look at these figures. One is expansions another is contractions. The flow is comes from this side and goes like this side. In this case also flow goes like this. Now if you look at the steamlines, which is just closer to the wall, in this case, it happens like this. We already discuss it, but if you have a contractions, then what it happens it. There will be vortex zones here. There will be vortex zones here.

So you can understand it that more energy losses will happen when you will have a contractions okay, when you will have the contractions. But in case of expansions the vortex zones are the less. So energy losses in this case which will be much higher as compared to the expansion zones because of the vortex formations.

But if you can make it a the shape of like this okay gradually variations or gradually expanding it then you can avoid the energy losses what is going to happen because of this vortex in a similar way like this. But exactly to have this shape is very difficult okay and as this in a pipe flow we do not get a constant velocity there is a fluctuating velocity there is like the flow varies it.

Because water demand is varies from the winter to monsoon to the summer season. So we vary the waters to design exactly the face of what will be the shape of the outer streamlines are very difficult the mostly we take a trade off between that and you try to make it as closer as possible to have a less energy losses because of this part. I just highlighting here to show you streamlines okay to tell it.

Now if you look it I am just talking about how to use linear momentum and Bernoulli's equations which is energy equations. So to apply this energy equations what I should do it, I take a streamline. Along the streamline I should apply the Bernoulli's. So most appropriate streamline is this ones, you take it this. Because this is a horizontal streamlines so we can just know the pressure and velocity, pressure and the velocity and modify the Bernoulli's equations, apply over this ones.

Not here are there okay. Similar way if I am to apply the linear momentum equations or other mass of conservations I should consider the control volume is much bigger than affected area so that I can get it, this effect should not be there. So I can use this control volume to apply the mass conservation equations or linear momentum. Exactly same way I can use this control volume still up to this spot, apply it.

Please do not take the control volume like this, which is totally wrong. Because you do not know it this zone what is happened it. So when you take the appropriate control volume we should take it. That means you should look it the control volume, where the streamlines are the parallel, streamlines are parallel. In this region the streamlines are not the parallels.

So you try to avoid to draw the outward streamlines, find out the reasons where there are not supposed to have the streamlines having any curvatures, the more or less the parallels. Like this case I draw the streamlines all will be the parallel by the time we reach it here. These regions I can consider this part and this part anyway, it is not a difficult for us, because there is no flow boundary conditions.

So to take a appropriate the control volumes, we should have a knowledge of how the flow happens it, how the flow behaviors are happens it, where the vortex is happening, where the flow lines the streamlines are parallel, you consider that by visualizing this flow like this or this. Then you try to look it. So what I do encourage you to that whenever you get a problems you try to draw the streamlines and find out where is the locations we can have a vortex formations.