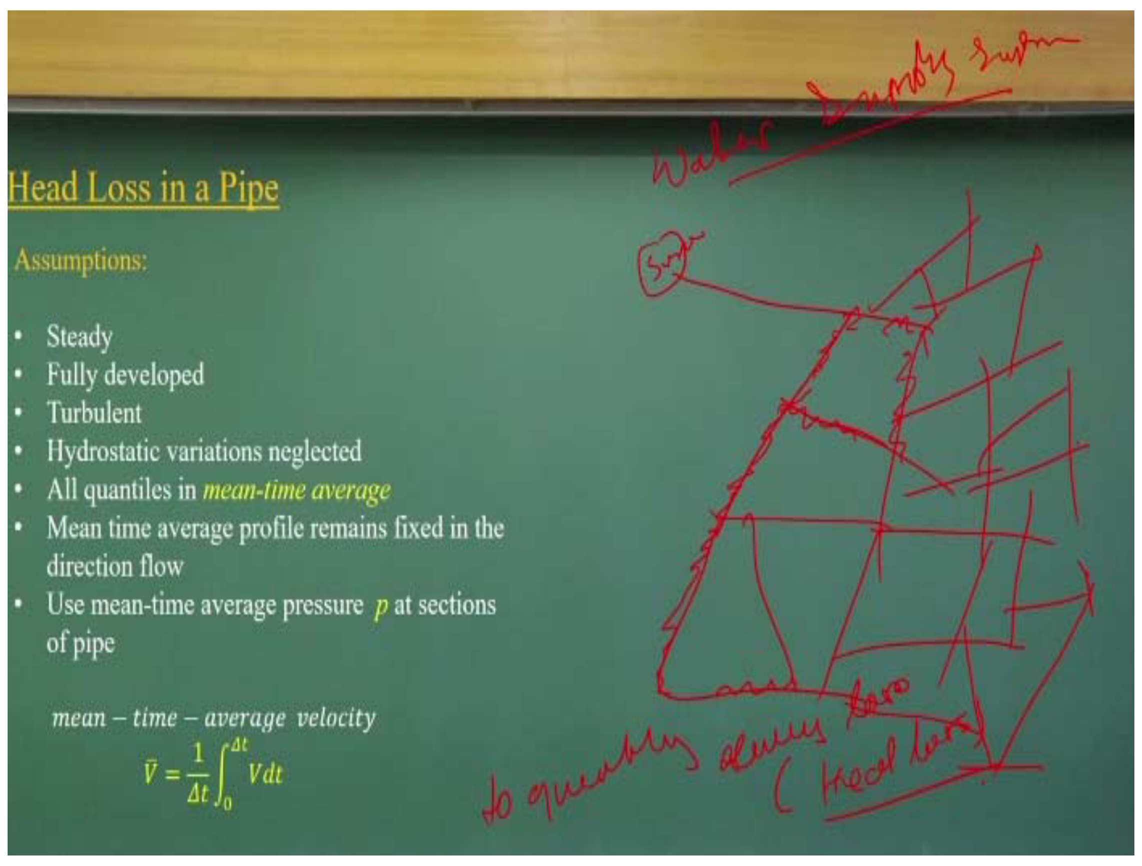

So what they did it that to design this pipe systems like for examples, we have a water supply systems, okay. So if you have a water supply systems, there could be a source and there could be the pipe network to different locations. There will be you can imagine it that can have a very complex pipe networks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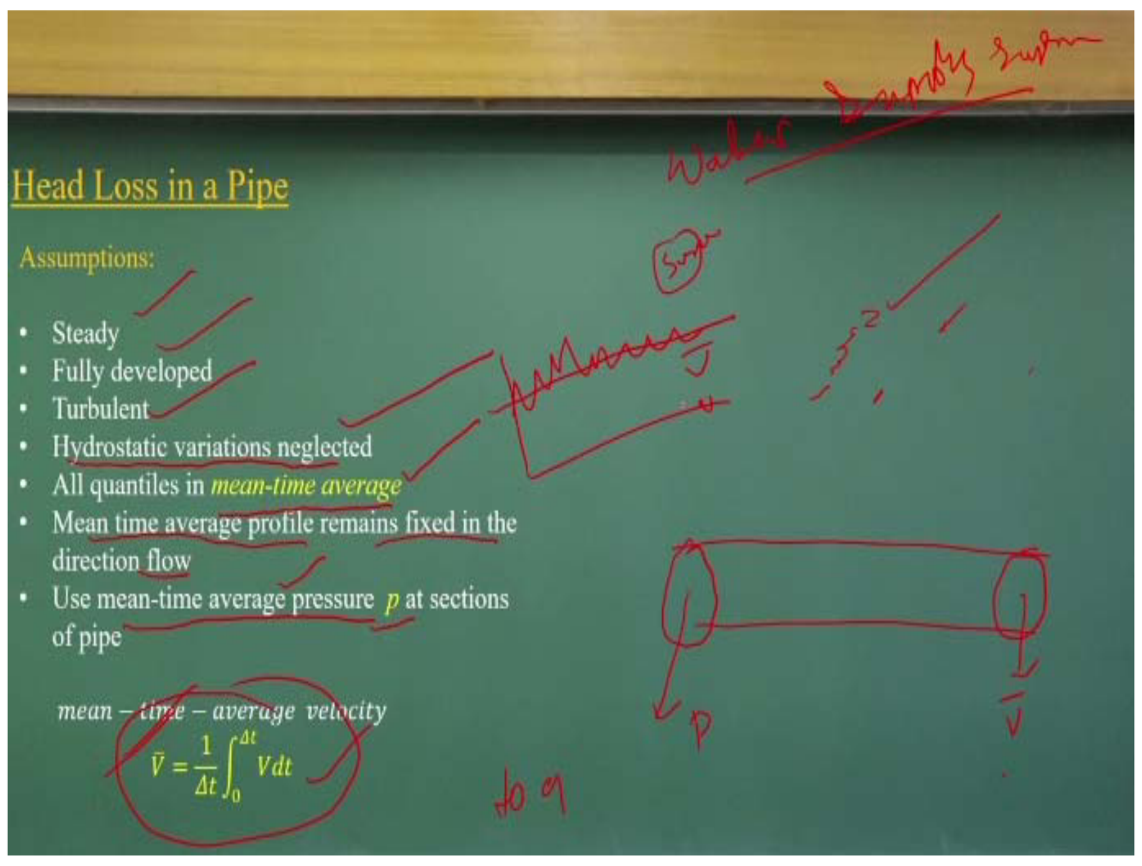

Like I have a pipe. As I have the pipe part is going through these I have to look it the average conditions the time average P and time average velocity. So we talk about the time average or mean time average pressure component. We all quantile is in terms of mean time average and mean time average profiles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

$$mean - time - average\ \ velocity$$

$$\bar{V} = \frac{1}{\Delta t}\int_0^{\Delta t} V dt$$

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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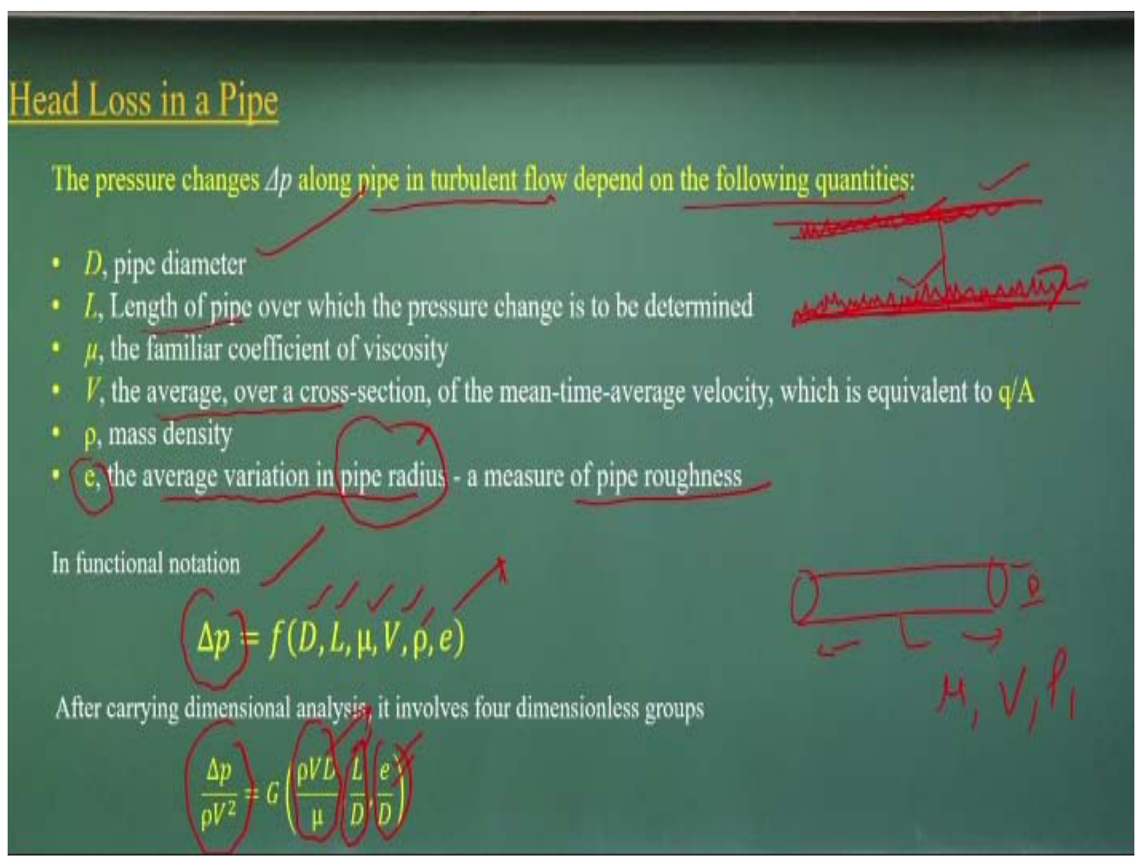

Now let us now what we are doing it first the dimensional analysis. So if there is a pressure drop along a pipe in a turbulent flow depends upon the following quantities. Pipe diameters, length of the pipe okay diameters, the length of the pipe μ is similar to the coefficient of viscosity, familiar to 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.

$$\Delta p = f(D, L, \mu, V, \rho, e)$$

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.

$$\frac{\Delta p}{\rho V^2} = G\left(\frac{\rho V D}{\mu}, \frac{L}{D}, \frac{e}{D}\right)$$

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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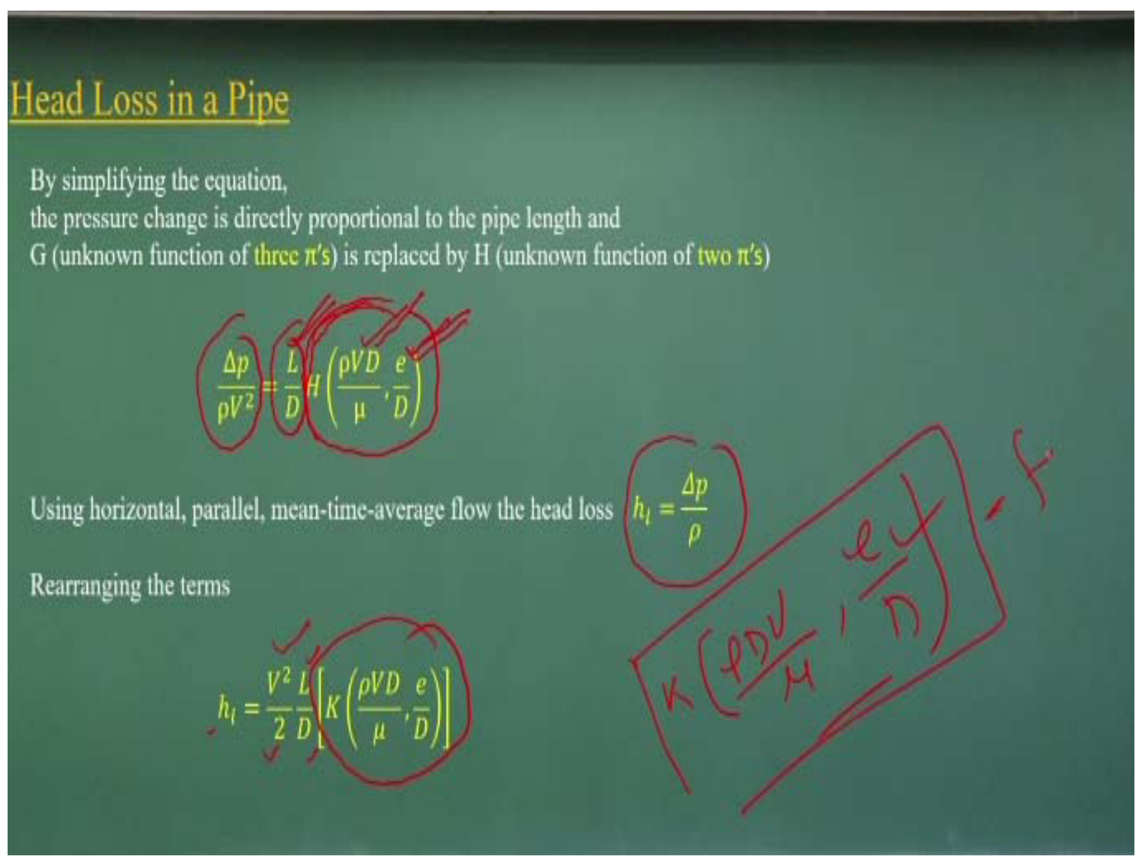

Just these equations if I further simplified it that if this

$$\frac{\Delta p}{\rho V^2} = \frac{L}{D} H\left(\frac{\rho V D}{\mu}, \frac{e}{D}\right)$$

So my μ 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

$$h_l = \frac{\Delta p}{\rho}$$

Rearranging the terms

$$h_l = \frac{V^2}{2}\frac{L}{D}\left[K\left(\frac{\rho VD}{\mu}, \frac{e}{D}\right)\right]$$

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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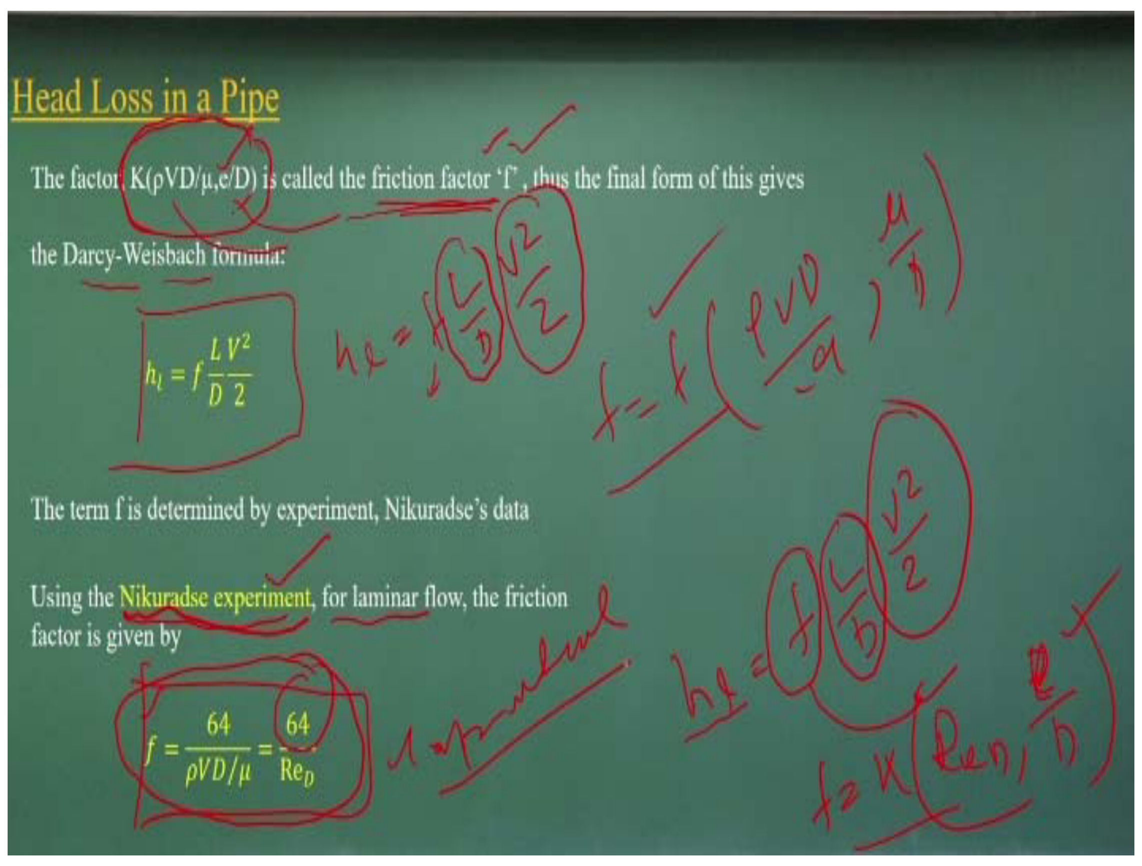

This is new definitions we put it that this constant, it is not a constant, it varies with respect to the Reynolds numbers with respect to the ratio of roughness height and the diameters which we call a constant, the friction factors. Because for particular flow systems, you know the Reynolds numbers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

$$h_l = f\frac{L}{D}\frac{V^2}{2}$$

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 $f\frac{L}{D}\frac{V^2}{2}$ is the kinetic energy per unit mass. $\frac{L}{D}$ 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.

$$f = \frac{64}{\rho V D/\mu} = \frac{64}{\mathrm{Re}_D}$$

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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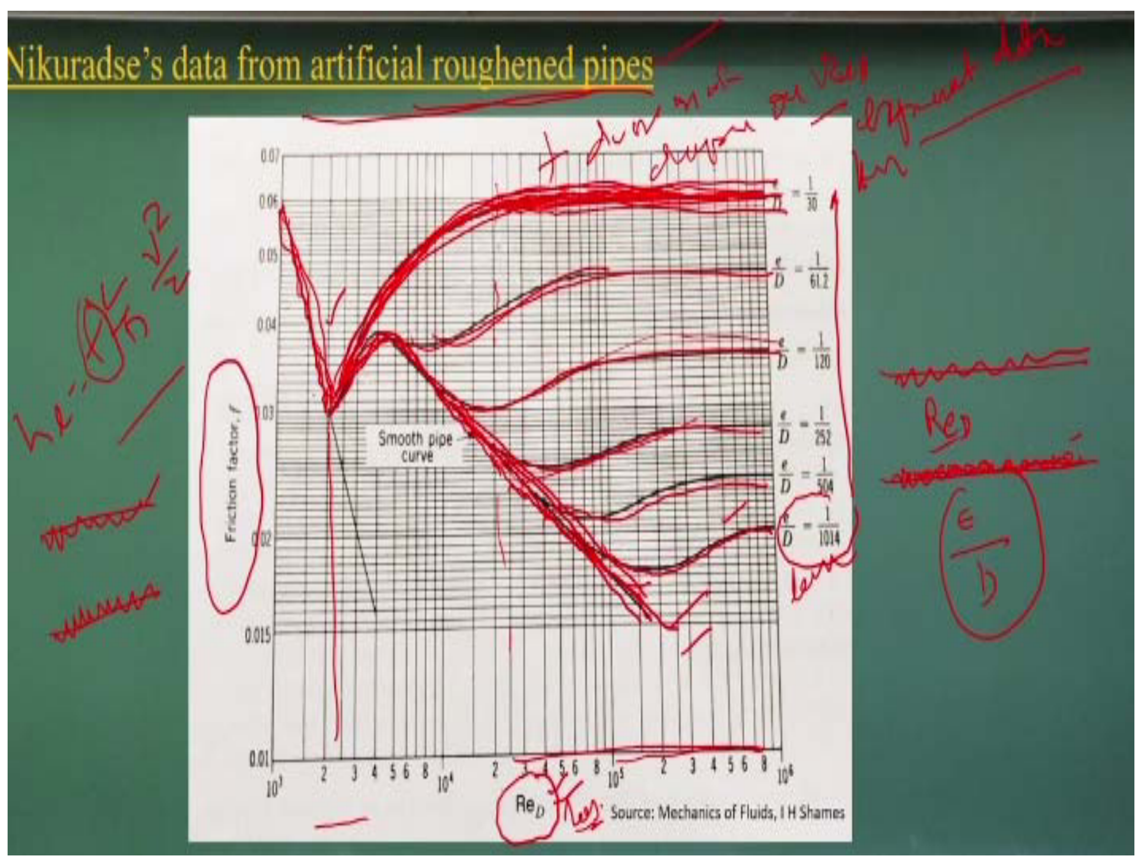

Now we will talk about the Nikuradse's data for artificial roughened pipes which he conducted a series of experiments and this x axis if you look it is a Reynolds numbers and the y axis is a friction factors, the Reynolds numbers in a log scale okay. So if you can look it these Reynolds numbers in the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

$$h_l = f \frac{L}{D} \frac{V^2}{2}$$

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

$$h_l = f \frac{L}{D} \frac{V^2}{2}$$

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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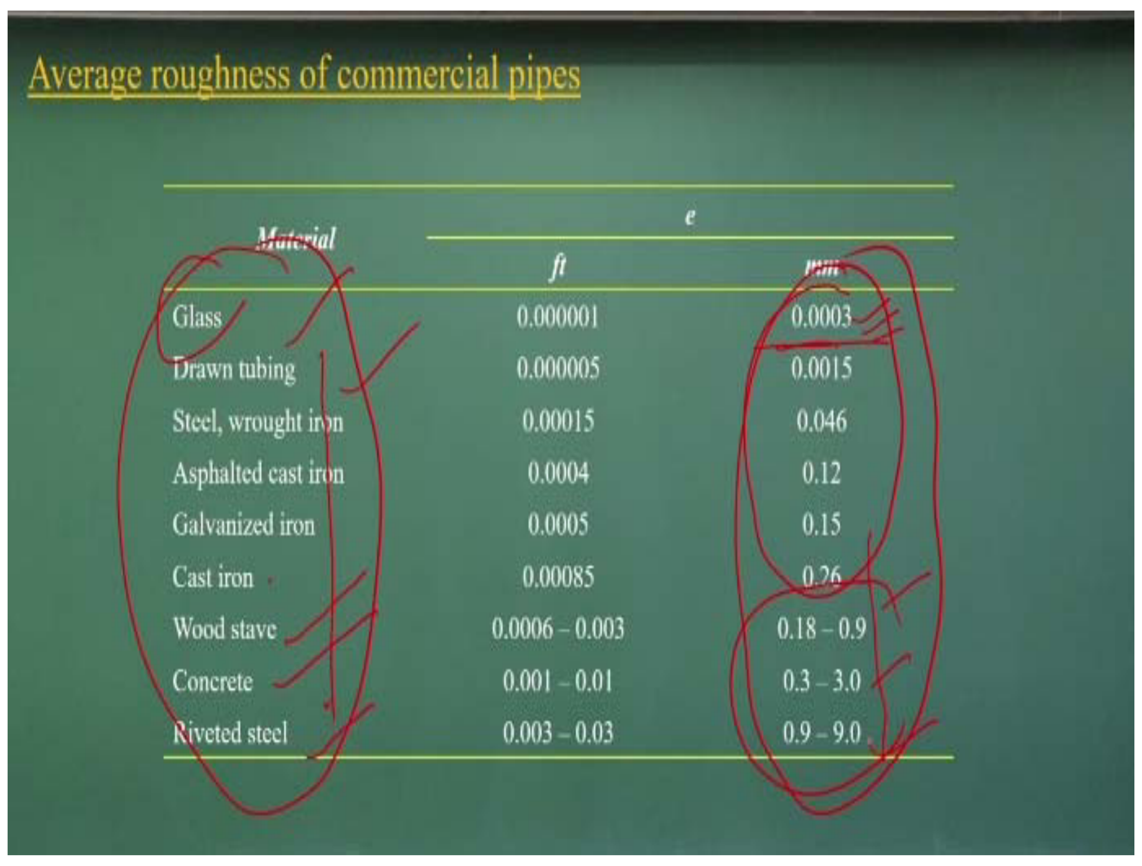

Now we have the tabulative values of the pipe. If you look it from the glass to the concrete this as you know it glass will be as smooth as but still it have a in terms of millimeters you have the dimensions but when you go for concrete will have a dimensions if you can look it okay. So you just look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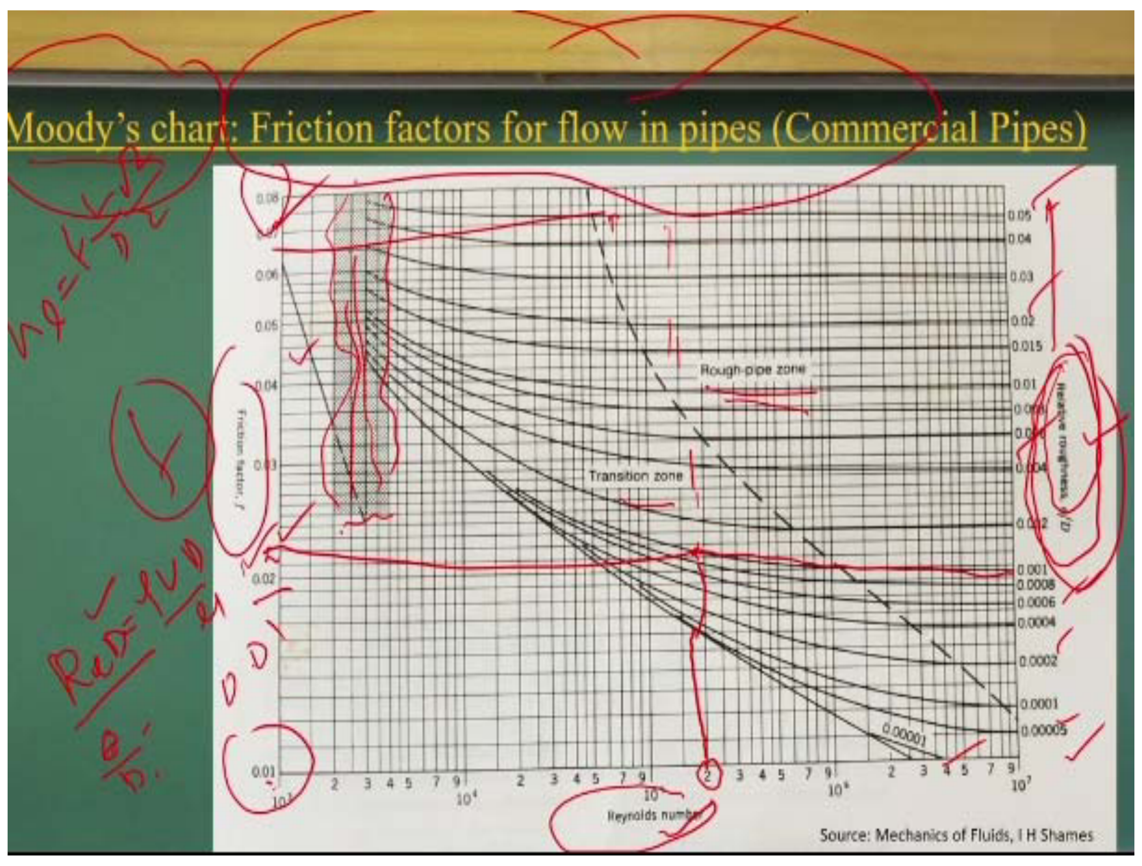

Now this Moody chart compiles for conducting series of experiment in using commercial pipes or artificially roughened pipe. So again plotting with the Reynolds numbers and the friction factors. This side is friction factors. Again I am writing f equal to

$$h_l = f\frac{L}{D}\frac{V^2}{2}$$

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 $\frac{e}{D}$. 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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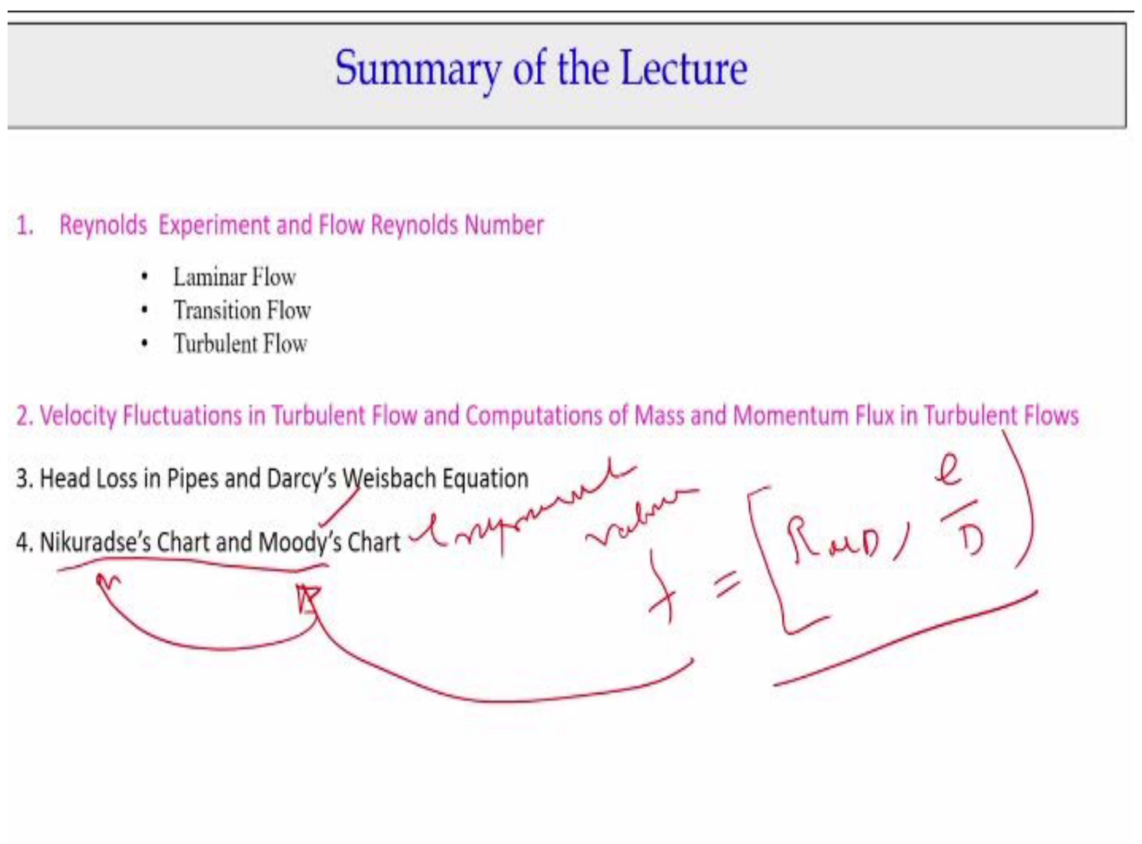

With this let me conclude today's first we discussed about the Reynolds experiments, how the three different type of flows, they are laminar flow, transitions and turbulent flow. We also discussed the virtual fluid balls how we can compute the mass and momentum flux. In turbulent flows the head losses 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 $\frac{e}{D}$ 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.