Fundamentals of Food Process Engineering
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Lecture – 48
Mixing and Agitation (Contd.)

Hello everyone. Welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. We have started discussion on Mixing and Agitation in our last class and today we will continue with that.

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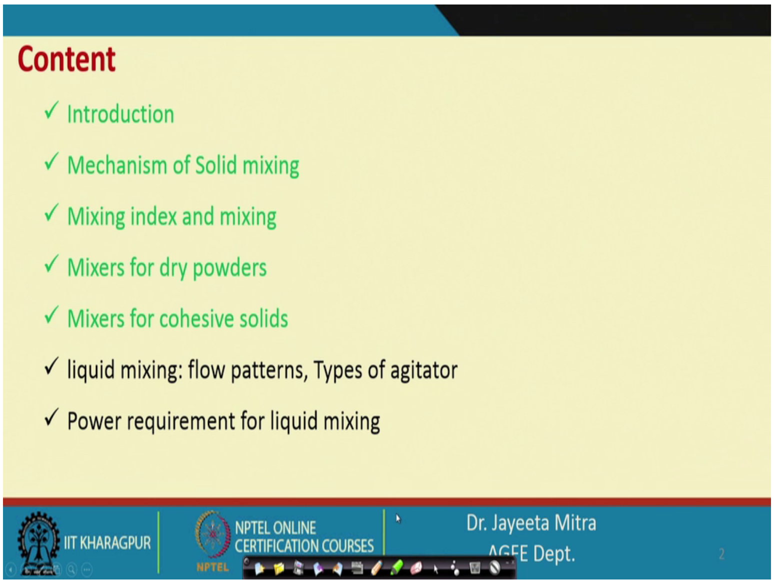

So, by now we have covered these contents: that is the basic introduction about mixing and agitation process, then the different mechanism of solid mixing and mixing index mixing process, then mixes for dry powders. We have seen that dry powder also we have seen for cohesive solids, the different kind of needles, what are the kind of different blades used for those different mechanism.

And also we have started the liquid mixing, it is flow pattern, and types of agitators. So, we will continue with this topic in a bit detail today, and also we will see; what is the power requirement for liquid mixing, ok.

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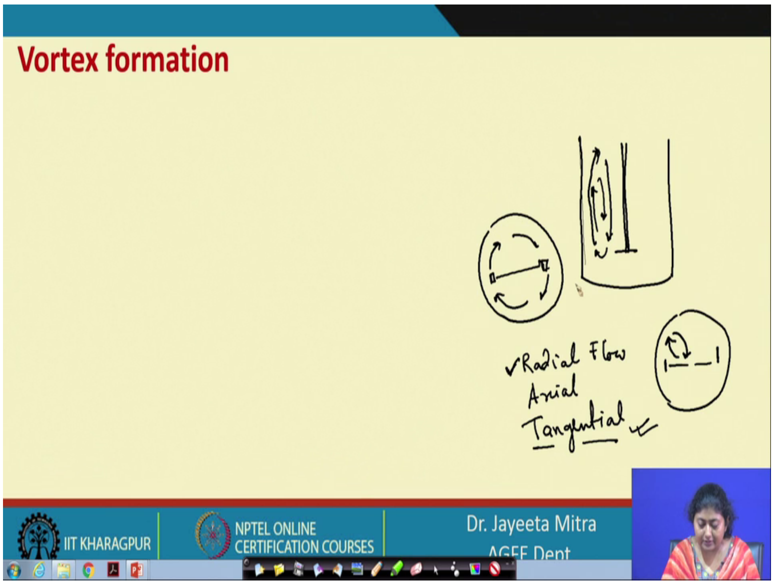

So, first let us see that we have discussed a bit of the different flow characteristics in a liquid mixing. So, if you see that we have a tank ok, we have a tank where we one to have that liquid mixing operation right. So, there is a shaft mounted in that, and we have seen that there are many kind of you know many kind of impeller different geometry of the different impeller is required depending on what kind of mixing we want, what kind of particle size, what is the viscosity of the liquid ok, and what kind of motion we want.

So, we have seen that 3 motions prevail in a particular liquid mixing. One is the radial, radial flow another is the axial, and the third one is the tangential ok. So, when the radial flow will occur, we have seen that if you see the front view ok, and your (Refer Time: 02:55) blades are like that. So, we see that this kind of motion of the fluid will be there. That is the direction of the flow will be perpendicular on the impeller ok.

And this will cause the radial mixing of the liquid right. And if we go for the axial kind of flow, in that case what will happen; that the liquid will move parallel to the shaft on which the impeller is mounted. So, then this parallel flow, this will help in mixing of the different layers of the liquid in the tank ok.

So, this will continuously help in the longitudinal or axial mixing. However, if we see the tangential flow, if these prevail in a particular kind of you know liquid mixing. So, then what will happen that, if we see the front view and this is our impeller.

So, this will initiate this kind of a tangential liquid motion, and if that happen that cause a vortex around you know the inside the inside the cylinder or the barrel where the mixing will takes place. And this creation of vortex is actually not desirable, because that will cause many unwanted phenomena happening inside the mixing, and that in a way you know hindering the proper mixing of the liquid ok.

So, if we want a proper mixing we want this radial flow and axial flow so that each layer will be properly mixed. Now we will see that; what is the consequence of the vortex formation. If it is there at all what will be the cases, ok.

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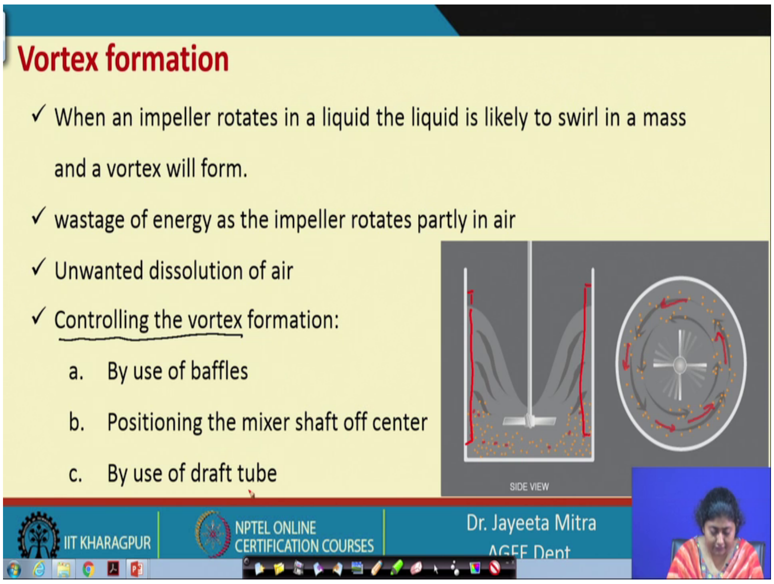

So, when an impeller rotates in a liquid, the liquid is likely to swirl in a mass and a vortex will form.

So, here you can see that, here we can see that, if this impeller is rotating around this cylindrical tank, and because of that it has tangential motion has been generated here that we can see, right. So, because of that the liquids are rotating in a layer ok, but no lateral mixing is taking place ok. If this happen, one problem is that, that proper mixing will not be there and the liquid will move around in a layer, that is one problem.

Now, the more bigger concern is that if this liquid is having particles they there are many dispersed particle will be there that we want to mix with the liquid, and that we want to make a homogenous solution. But because of this vortex formation the centrifugal force will be generated on the particles, and the particle will be thrown radially towards the wall. And eventually they will come down at the at the bottom ok.

So, because of that also there will be action of the gravity on that. And since because of centrifugal force this will be thrown away this will be hit towards the wall, and they will come at the bottom. So, deposition of the particle at the bottom will be more, as we can seen in this figure as well.

So, then there will be a distinct layer separation layer of the liquid and the solid particle will be there. So, it is against the mixing it is actually forming concentration, that is the another problem. And also the problem is since, this will form a layer, because of the centrifugal force the layer will be such that a void will be created at the center, and the liquid level will rise at the peripheral side.

So, some portion of the shaft it will rotate in a air only. It will cause no mixing phenomena properly. So, this will cause many problem in the mixing phenomena. That is why we always try to prevent this vortex formation ok. So, in a proper mixing case we will always try to prevent this vortex formation, and wastage of energy as the impeller rotates partly in air. As we can see here that the impeller is rotating partly there the liquid level has been reseed towards the periphery and the and the particles will be settled at the bottom because of this tangential motion and vortex formation.

So, unwanted dissolution of air will be there, and therefore, our requirement is how to control the vortex ok; so controlling the vortex that is the main criteria then. So, what we can do? That one phenomena is by using the baffles. So, baffles we can put here. So, around the periphery of the cylinder we can put baffles ok. And depending on the number depending on the size of the tank we can put you know 4 to 16 number of baffle generally 6 to 8 is the average which is enough to create a proper mixing ok.

So, one is by using the baffles. So, then what will happen? That this tangential force that will be hindered by those baffles, and then can convert it to the radial motion, they will try to you know circulate in a proper mixing will happen in between the 2 baffle section. So, there will be not any proper tangential motion and vortex formation. And another is the positioning the mixer shaft of center. So, that will another important design aspect you can think of while doing all such analysis in the in a mixing or designing a proper mixer for some liquid mixing operation.

And third one is the draft tube. Now you see how by positioning we can change. We have a diagram for that.

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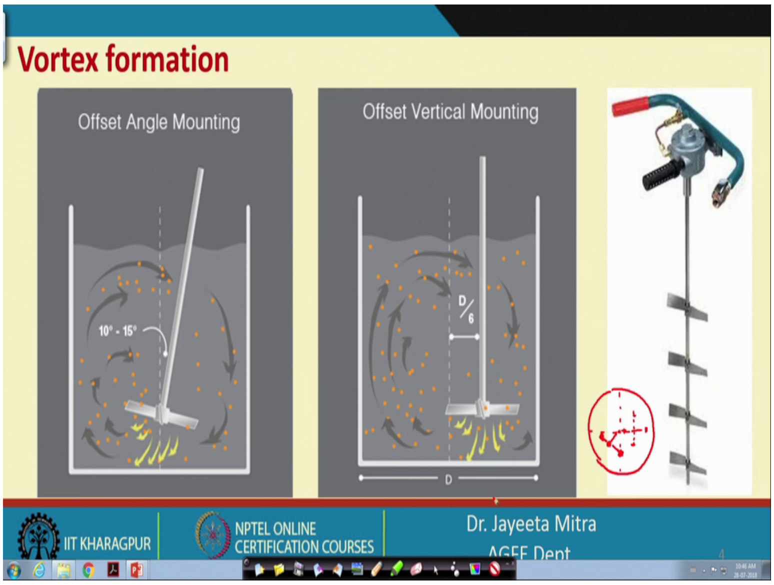

So, here if you look into it carefully, so offset angle mounting what we are doing that here we have making that shaft that is actually normally it was vertically mounted, now we made an incline with the with the central line; that is 10 to 15-degree inclination or 10 to 15 degree angle we have made. Because of that while rotating it is not creating those vortex ok. So, there will be proper mixing and some kind of axial flow will be initiated here. And other thing is we can offset the vertical mounting by some distance radially; so, this is another case.

So, if you look into the top view so, this is the center and we take the shaft here ok. So, that may be one case or may be one case that is just radially we have shifted here, and then it is rotated ok. So, in those cases there will not be proper vortex formation. And therefore, the mixing will be proper, as it can be seen by this figure and in that case the solid particle will also will be you know homogenous fashion in the whole tank.

So, these are the different configuration that we can try. Now the next thing is the utilization of draft tube.

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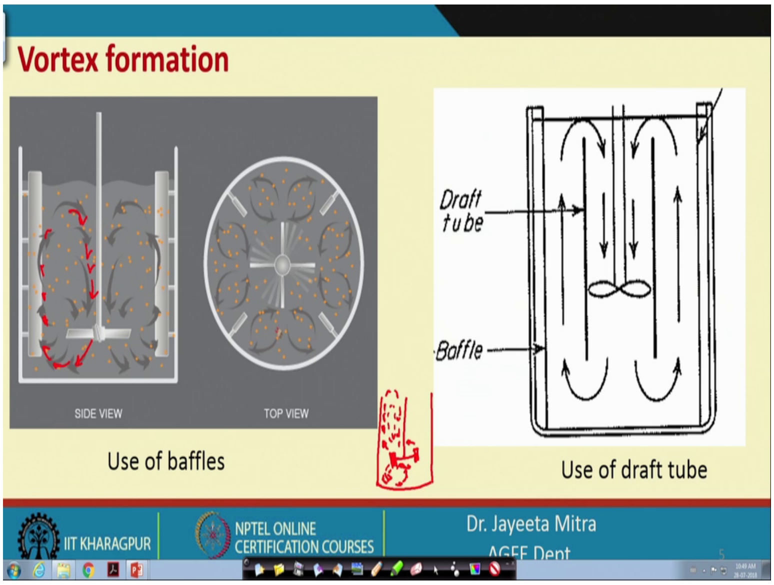

So, we will see that, yes we have a diagram for that. So, draft tube how it helps in analyzing the mixing properly. So, here what we will do? We can see a side view of baffles here and top view of that. Again we can see the draft tube in this right side diagram. First we will see what the baffles are doing. Here is an impeller mounted on a central shaft and that is rotating in a cylindrical tank. The 2 baffles we can see in the front view the 2 baffles are there.

So, at the top view the 4 baffles are clearly visible. Now while this is rotating, this will divide the whole flow into 2 segments ok. One is that it will throw the liquid in the inner side that is going towards the up ok. it may have in a reverse direction as well. I mean, it may have suppose you have a you have a tank here; where you have your impeller ok, which is rotating and there is a ok.

So, what will happen while it is rotating, it will create 2 kind of different flow, it divide the liquids into 2 kind of flow. One is the liquid will be thrown at the bottom and then again it will come radially. And another will be it is throwing the liquids in the upside and it is again coming down to the impeller, and that is why the mixing will takes place.

Here again, we can see that the liquid is thrown from the bottom side and again it is going to the up because of this baffles are there, and then it is coming down at the center section. So, it is helping in proper mixing ok. Now if you see the top view, you can see that the radial mixing radial flow is being generated because of this.

So, what will happen that, the liquid is moving in a perpendicular direction with the impeller, and that is why all the particle radially the mixing is better and the homogeneity is maintained across. Now if you see the draft tube ok, if you see the draft tube, this is the draft tube that we have placed around this is a kind of a propeller mixture is there ok.

So, propeller mixture and impeller mixture if you see the propeller mixture actually helping in the axial or longitudinal flow; while the impeller mixture is helping in the radial flow ok. So, this one was the impeller mixture, and here it is the propeller. So, what it is doing; that it is when it is rotating in the draft tube is given there. So, the liquid is coming from the bottom and it is going upward, as it is throwing longitudinally or axially.

So, it is again going to the whole length of the liquid column and then it is again coming down in from the inside of the draft tube ok. So, therefore, the mixing from the whole zone mixing from the bottom to the top layer is possible, because if the draft tube would not have been there may be this liquid will go to some extent and then may drop.

So, it is helping in mixing the whole zone the liquid from the bottom layer and the top layer. So, where the highest rotation rotational movement is there and where the fluid is still whole fluid is getting mixed properly. So, it is helping in proper movement and it is hindering the formation of vortex.

So, these are the different kind of arrangements that we can think of for proper liquid mixing phenomena.

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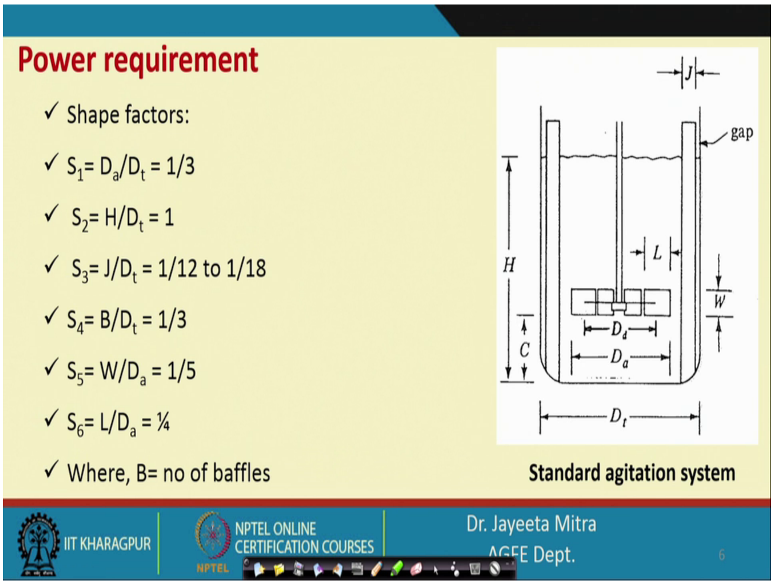

Now, next we will see that how we can analyze the power requirement in case of a liquid mixing. So, power requirement is very important aspect, because whenever we want to design any kind of a liquid mixture, our main aim will be what will be the energy requirement. What will be the energy input to the system to have the proper mixing? Ok.

So, that depends on many parameter right. So, the first obviously will be the geometry of the tank and the baffles the impeller ok. So, all these are very important. Next is; what is the liquid we are using ok. So, what is the height of the liquid column and what is the H you know density of the liquid what is the viscosity of the liquid. So, all such parameters are very important, and we can think of relating them empirically if it is not possible a direct relation. So, we can think of an empirical relation development so that we can very easily analyze the power requirement in case of the mixing.

Now, scientist have done that. They have tried to model this phenomena, model the power requirement based on several parameters, and they frame this relation in a dimensionless form that. We have often seen various analysis dimensional analysis is an important part in we have seen this in fluid mechanics as well in some operations.

So, here also we will see how the dimensionless numbers can be framed, and with that how the power number can be related in case of liquid mixing operation. So, first we will determine several shape factors. Shape factors are nothing but some ratio of the dimensional parameters of the tank and it is you know different geometry parts such as the impeller and the baffles etcetera.

So, number of those shape factors we need to know so that the whole design can be fixed. So, those numbers are one is S 1, shape factor, that is a dimensionless all these are dimensionless numbers. So, D a by D t, where D a is your diameter of the impeller and D t capital D suffix t is the diameter of the tank. And S 2 that is the height of the liquid column in a tank divided by the diameter of the tank.

So, some parameters has been fixed based on the initial analysis by different scientist. So, it has been seen that we should keep the liquid level, at least equal to D t or even higher than D t for proper mixing. So, generally we fix it equal that is H by D equal to 1, and for the other case like the impeller dia should be one third of the tan dia. Then we have S 3, shape factor S 3, that is J divided by dt; where J is the thickness of the baffles width of the baffles ok.

And that should be one twelfth or 1 by 18th compared to the compared to diameter of the tank. Then we have S 4, S 4 is B by dt, B is the number of baffles by D t ok, and S 5 this factor is W by D a. So, W is the width of the impeller blade, W by D a is the impeller dia and also we have S 6 that is L by D a.

So, length of this impeller head or impeller blade length L by D a ok. So, these are the shape factor and with that now we also look into the property of the fluid.

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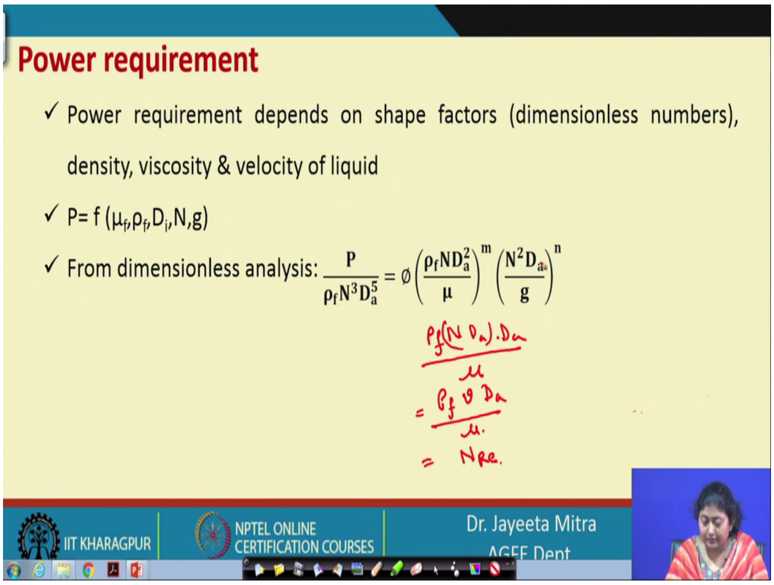

So, power requirement depends on the shape factor. Those are the dimensionless numbers, then density viscosity and also the velocity of the liquid. So, for initial calculation we have omitted the shape factor. And first we have seen that how it is being affected by the parameters such as density of the fluid, viscosity of the fluid, diameter of the tank, revolution or the speed of the movement of the impeller and the g, which is acceleration due to gravity.

So, with that we have framed the dimensionless number as power P, power requirement is a function along with the dimensionless numbers or shape factors also. So, we have created this created this dimensionless number and tried to present the power with respect to these numbers ok. What are those numbers? So, P by rho f into N cube by D a to the power 5. This is called power number in P ok. And this has been related with rho f into N into D a square by mu, and also N square into D a by g ok. Now we can see that this rho f into N into D a into D a by mu if you can write. So, rho f N into D a is velocity ok.

So, if D a since D a is the diameter of the impeller, and revolution per second is n. So, pi D n that will pi D a n that will be signifying your velocity. So, we can replace this N D a by v into D a right. So, if we do that what does it signify what does this expression tells us that it is nothing but Reynold's number ok, rho v D by mu which is nothing what Reynold's number N Re, ok.

And this is N square into D a by g, this signifies the inertia with respect to gravity which is called the Froude number ok. And this is inertia with inertia divided by the viscous force ok; that is called the Reynold's number. So, power number now can be expressed in terms of these 2 dimensionless number which are Reynold's number and Froude number.

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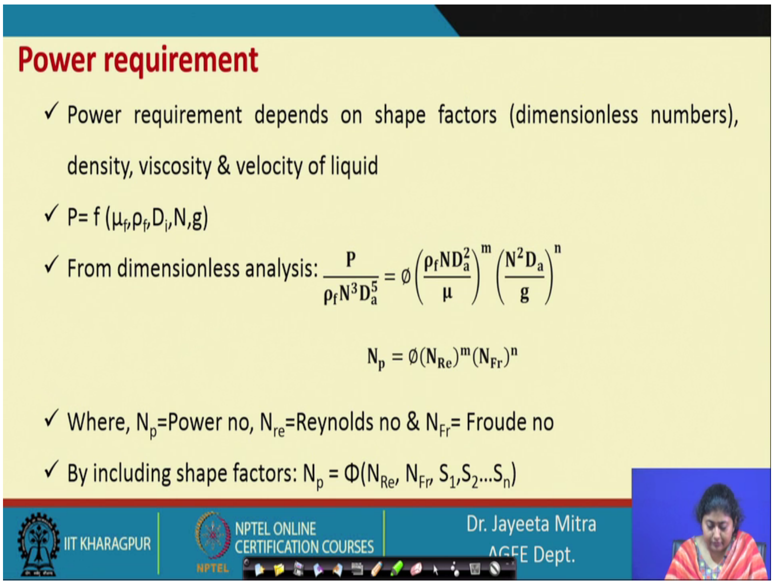

So, we can say that N P, that is power number which is the function of Reynold's number to the power, some power and Froude number to the power some factor that is N N P is the power number N Re is the Reynold's number and N Fr is the Froude number; and including the shape factor because definitely as power is depending on the fluid properties. And the impeller geometry they will also depend on the baffle and time dimension etcetera.

So, finally, we will include them because those were also the dimensionless numbers. So, N P will finally, depend on N Re into N Fr comma N Re comma N Fr comma S 1 S 2 up to S N; that is, how many dimensionless shape factors we are using. So, this is how we can correlate power with the parameters in case of a liquid mixing.

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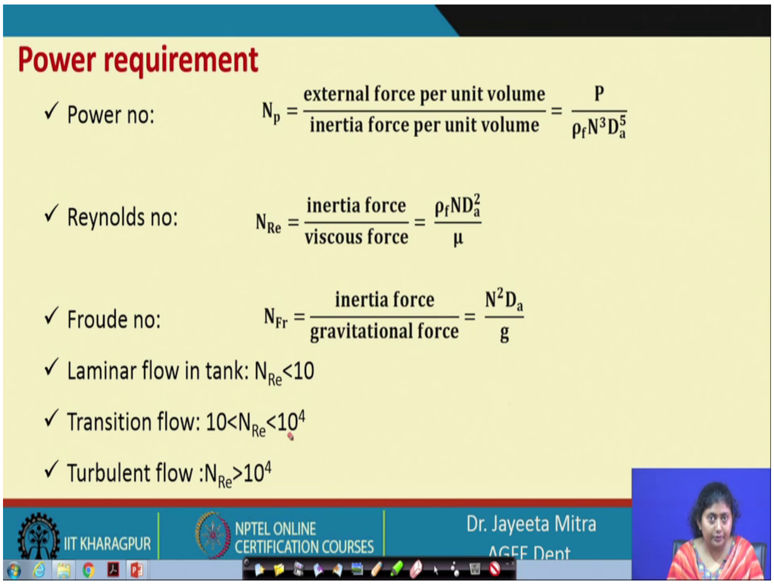

So, power number N P is external force per unit volume divided by the inertia force per unit volume; that is, P by rho f into N q D a to the power 5. Reynold's number N Re that signifies inertia force divided by viscous force, and the expression is rho f N D a square by mu. N is a revolution per second D a is the impeller diameter rho f is the density of the fluid and mu is the viscosity of the fluid.

Froude number, Froude number is inertia force divided by gravitational force and explain as N square D a by g. And also in this particular case of mixing inside a tank, the laminar flow we can consider when the N Re will be less than 10 ok. So, N Re so in this case we have seen the value of N Re is rho f into here we have given that N into D a square by mu. So, N Re will be less than 10, then we will consider the laminar flow or viscous flow and transition flow will be considered when N Re ranges from 10 to 10 to the power 4.

And beyond 10 to the power 4 we will consider the flow and turbulent flow.

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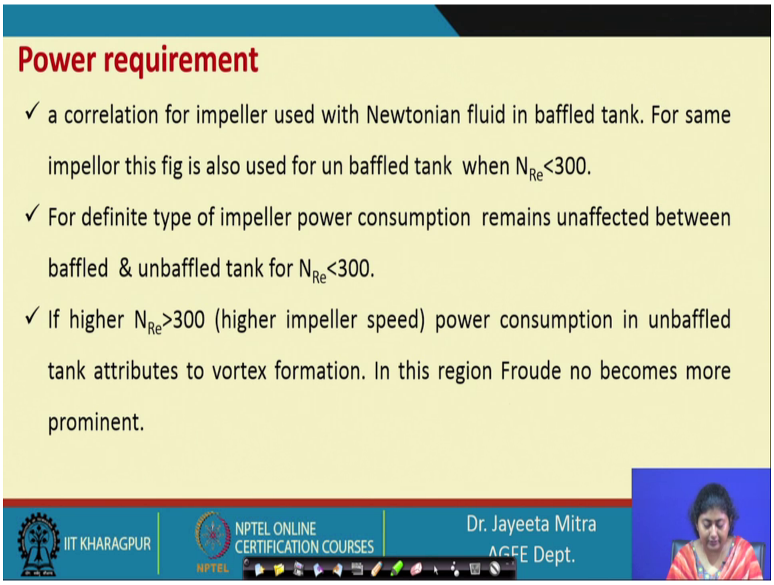

Now, a correlation for impeller used with Newtonian fluid in a baffled tank. So, that we need to develop now the correlation for impeller used with Newtonian fluid in the baffle tank. For same impeller, this figure is also used for an unbaffled tank when N Re is less than 300.

So, we will see that what kind of correlation is has been developed already, and where that can be applied. For definite type of impeller power consumption remains unaffected between, baffle and unbaffled tank for N Re less than 300. So, we are getting some condition, first condition is that the correlation for impeller used in the Newtonian fluid in a baffled tank this correlation. We are having we have some plot related to this.

And the same impeller this figure is also used for an unbaffled tank, when the N Re is less than 300 ok. And definite type of impeller power consumption remain unaffected between baffle and unbaffled for N Re less than 300, and for higher N Re value than 300. So, power consumption in unbaffled tank attributes to vortex formation in this region Froude number becomes more prominent.

So, what happens that when the speed of the impeller increases, and if the tank is unbaffled then the vortex formation will be there ok. So, vortex formation will be there and we know that if vortex is formation is there the solid particles will because of the centrifugal force they will be thrown towards the periphery, and then they will come down to the bottom and then the gravitational force will be different as it was in case of a homogenous mixture.

So, then the Froude number will be prominent. That is why for this kind of analysis when we go for higher speed, we need to very clearly know that what are the what are the you know dimensionless number change in that case so that we can assess the exact power requirement.

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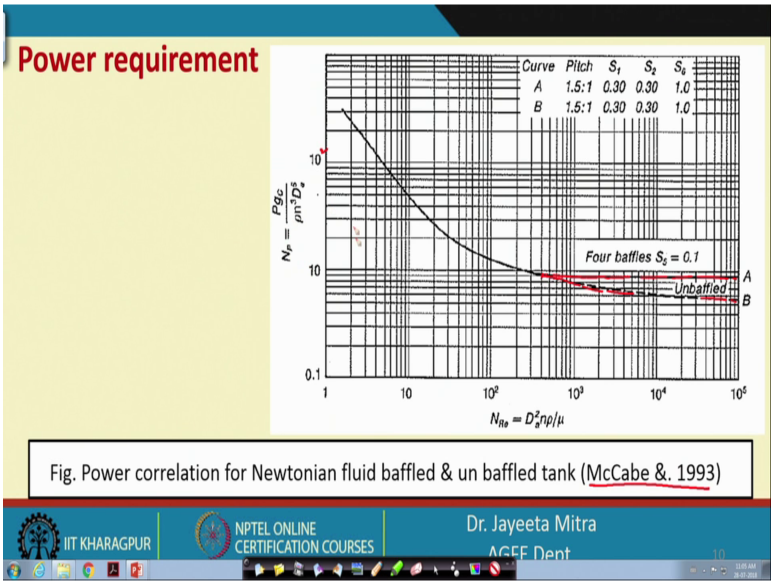

So, here is a power correlation for Newtonian fluid in a baffled and unbaffled tank. This has been sourced from McBeth Smith book of unit operations in chemical engineering. So, here we can see that we have plotted this N Re Reynold's number with respect to this power number N P in a log scale.

So, so here as we are increasing in the in the extraction the Reynold's number is increasing, and initially for the for 2 baffled and unbaffled initially, we are getting that up to 300 this plot is seen ok; that means, there is no change in the power number for different kind of unbaffled, and baffled tank and beyond that there is a 2 distinct demarcation will be one is for the one is for the baffled and another is for the unbaffled.

So, whenever we want to calculate this power requirement, first we will see what is the Reynold's number in that particular fluid case, for that we need to know the diameter of the impeller, the density of the fluid, viscosity of the fluid and also the rotation or revolution of the impeller in the fluid per second. So, once we got the N Re, then we will plot it and find what will be the N P value and whether it is a baffled or unbaffled that also we need to see.

So, based on that we can calculate what is the N P, and N P is a direct relationship with the power requirement.

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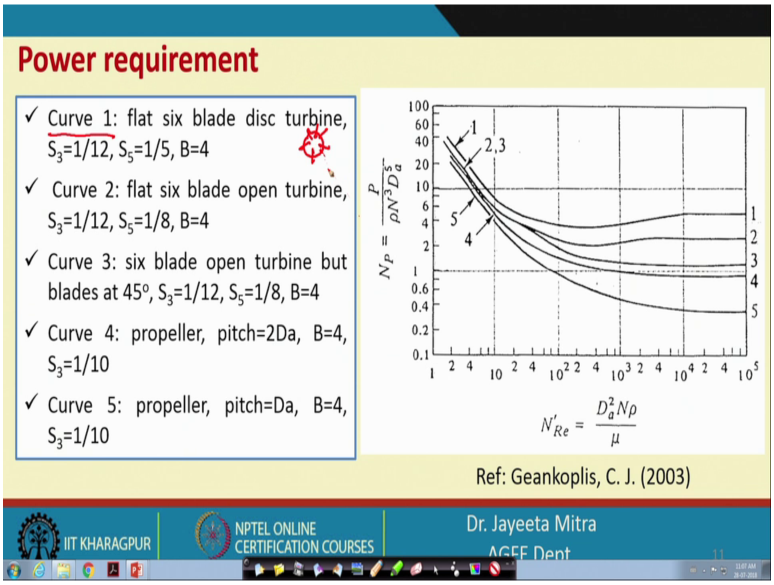

So, from that we can calculate the power requirement. So, again there are certain different kind of you know different kind of lines we can see here. So, these are again the power correlation with N Re, but the difference is that here the different kind of impeller has been tested, and empirically these data has been plot and this particular kind of expression has been generated.

So, what we can see here is that, curve one this is for flat 6 blade disc turbine ok. So, there is a flat, there is a flat 6 blades turbine will be there. So, 1, 2, 3, 4, 5, six; this kind of a flat disc turbine is there. In that case what is the parameter that we need to know, the parameter when S 3 the shape factor is 1 by 12 and S 5 is 1 by 5, number of baffle is 4.

All this S 1, S 2, S 5 these are already given to you that the ratio of some geometric parameter of the tank and impeller. So, for this one the first curve the first curve will be ok. So, as it is changing we can see. So, this difference is more visible the power number difference is more visible, when the Reynold's number is in the lamina region, when it becomes in the turbulent region. So, there is not much change.

We can see that in the turbulent region, that is almost equal constant power number we are getting. Curve 2 which is for the flat 6 blade open turbine ok. So, this is curve 2, again this is also showing the same trend that almost near to you know turbulent region, they are showing the constant power constant N P value. Fluctuation in the transition region is a little bit, and the highest change we can observe in the viscous or laminar region.

Curve 3 is a 6 blade open turbine, but blades at 45-degree angle, ok. So, in that case we are getting again this is the third plot. However, the trend is same, that is in the turbulent region we are getting constant N P. And similarly curve 4 which is for the propeller pitch propeller we know that this kind of this kind of you know mixing will be in the actual direction mode pitch is given 2 into D a baffle number 4.

So, this is a curve 4 and finally, propeller where pitch is equal to D a and bafflle is 4. So, there we are getting the curve 5. So, all 5 will look into what kind of impeller is attached to the shaft. And then we can design that what will be the N P value.

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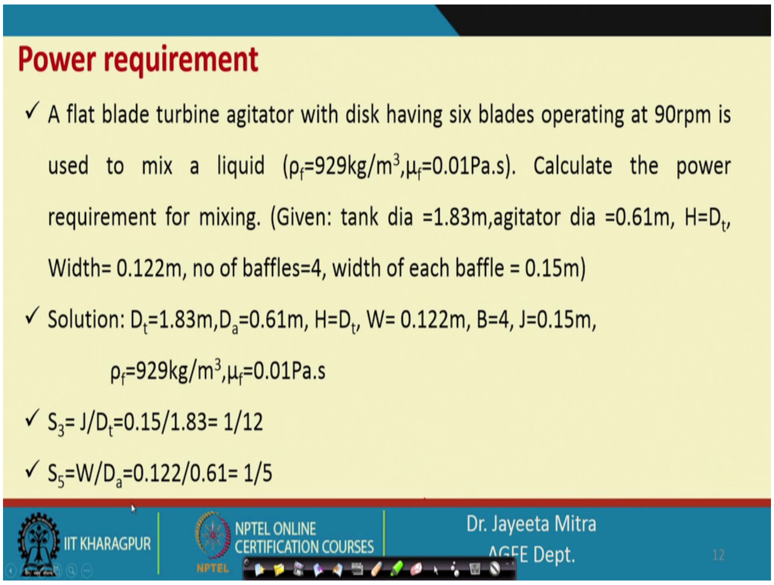

So, there is a problem a flat blade turbine agitator with disk having 6 blade operating at 90 rpm is used to mix a liquid for which the density is 929 kg per meter cube viscosity is

0.01 Pascal second. Calculate the power requirement for mixing. And what is given to us? Given is the tank dia D 1.83 meter agitated dia D a 0.61 meter. H that is the liquid height is equal to D t, width is 0.122 meter.

Number of baffle is 4 and width of each baffle is given. So, this is width of the impeller width of the baffle and number of baffle. Now what will be that first we will see; what are the value of those parameter. And then we will calculate the shape factor right. So, S 3 that is equal to J by D t; and J is given as width of each baffle is 0.15 by 1.83. So, 1 by 12 we are getting.

And S 5 that we are getting W by D a; that is 0.122 width of the impeller by D a; so 1 by 5.

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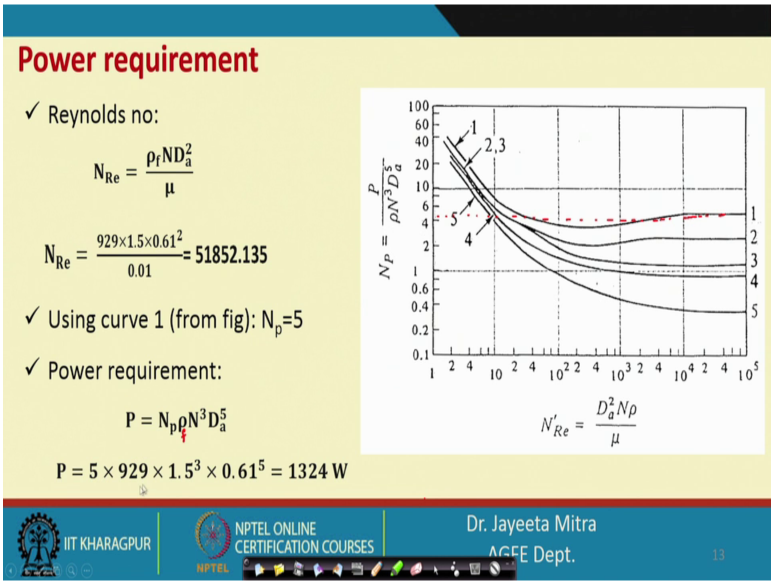

Now, for this first we will calculate the Reynold's number. So, Reynold's number row f into N D a square by mu, that we are getting, 929 is the density, 15 is the rotation per second revolution per second, 0.61 is D a, viscosity 0.01 Pascal second. So, Reynold's number we are getting this one.

So now, this is 51,852.135 if we look into here. So, it is coming in the turbulent region ok. So, then using the curve one, because it has been stated that 6 blade flat disc. So, curve one we will take, and for this value, 51 something like this. So, we will get the we will get the value of power number, we will get the value of corresponding power number from this.

And we are getting N P as 5. So, power requirement will be following this formula power requirement equal to N P into rho f into N cube into D a rho or rho f whatever this is the same. This is rho f that is density of the fluid, N cube into D a to the power 5. Now all such values are known to us. So, we will put it in P as 5 929 is the density 15 cube into 0.61 square. So, 1324 what is the answer right.

So, we will stop here. And we will continue in the next class.

Thank you.