Aspects of Biochemical Engineering
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Lecture – 48
Transport Phenomenon in Bioprocess II

Welcome back to my course Aspects of Biochemical Engineering. Now, I was discussing the transport phenomena, which appears to be the most interesting and most important topic as per as per any chemical and biochemical processes are concerned.

Now, if you look at our biochemical process, we required the movement of the fluid and when liquid is flowing that that a through a pipeline or in a blood vessel, there is a kind of momentum transfer that we take place and in a vessel, when you have some kind of microorganism that you know also or any the when you will do any kind of stirring then this should remain in suspension. So, we come across different type of transfer phenomena; one is called that momentum transfer, another is the mass transfer, another heat transfer.

So, in the last lecture I tried to concentrate on the momentum transfer. And how you can analyze the momentum transfer; I tried to discuss how the Reynolds number plays the important role in the in case of momentum transfer. And today I want to discuss the mixing, that is the another very important aspects of the chemical and biochemical industries that how this is this transfer phenomenon plays very important role.

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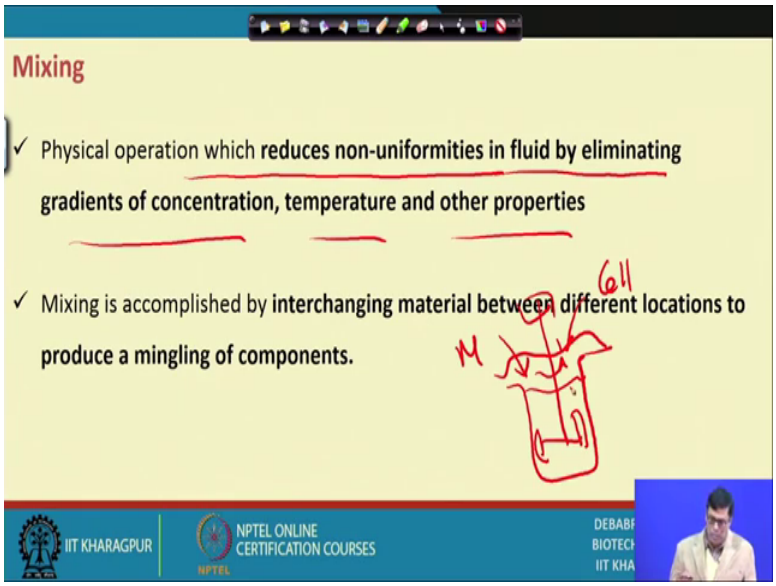

First let us know that is the; what do you mean by mixing? Mixing means that what we mean that; that which mixs the uniformity in the reaction mixture. As per example the physical operation which reduces non-uniformity in fluid by eliminating the gradient concentration, temperature and other properties.

Now, what I try to mention; suppose this is a vessel am I right? And suppose the here you put your medium and then you put your cell. Now, I told you cells are very much specific, as there they are very much specific as per environment condition is concerned, under a particular environmental condition, they give the desired product am I right um.

So, if it is; so temperature control is very important also the nutrient concentration plays in the media that also plays very important role. So, that is a mixing determined, how uniform is the is the temperature; how uniform is the concentration in the reaction mixture, so the which is very important. And mixing accomplished by the interchanging in material between the different location to produce the mingling of the components.

So, the mixing plays very important role in the chemical and biochemical industries.

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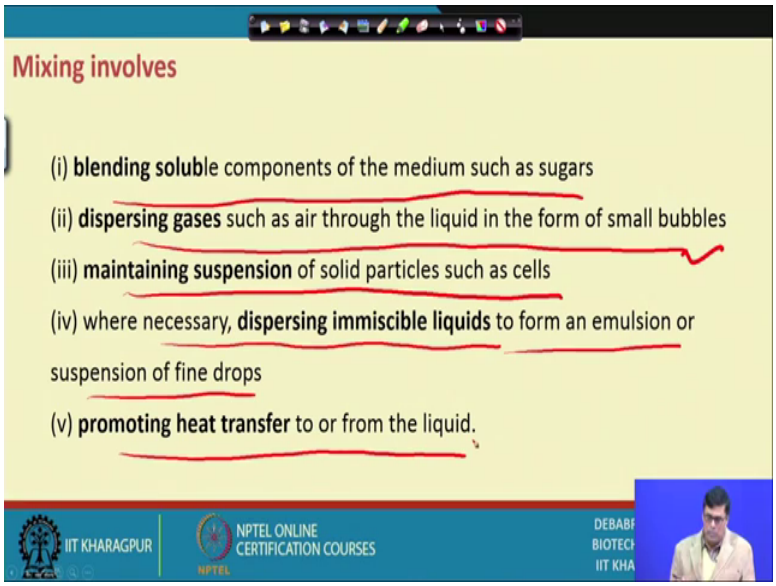

Now, mixing involve that is several things; one is blending of soluble components of the medium such as sugar. Suppose, we make a solution of sugar in the day to day life, the in our home suppose we make a want to make a solution of a sugar, we put a spoon with the help of spoon we make a solution so this also kind of mixing that we have.

Now, dispersion of gases such as air through the liquid in the form of small bubble; now I told you in case of anaerobic fermentation process, if there your main limitation is the dissolve oxygen concentration in the fermentation broth, because microorganism will take the oxygen that is dissolved in the in the fermentation liquid.

So, dispersion dispersing of gas through the air in liquid in the form of small bubbles. This is also a mixing that also kind of mixing that we have. Maintaining the suspension of the solid particles such as cell, I told you just I explain that cells, when is if you uniformly suspended in the media, then if then and only then it will freely interact with the substrate molecule and give the product and, where necessary, dispersion is in immiscible liquid to form an emulsion or suspension of fined droplets.

So, in that case what you go; what you do? We make a very fine droplets as per I can give the example that lipids as per example, they are basically insoluble in the water am I right the; so if you want to solubilize the solubilize a liquid it is very difficult to do that. So, what we can do? We can disintegrate the this flat bubbles in the final bubbles, and it can make in suspension in a which is usually done in the diary industry. And promoting

the heat transfer to and from of the liquid that heat transfer also is plays very important role.

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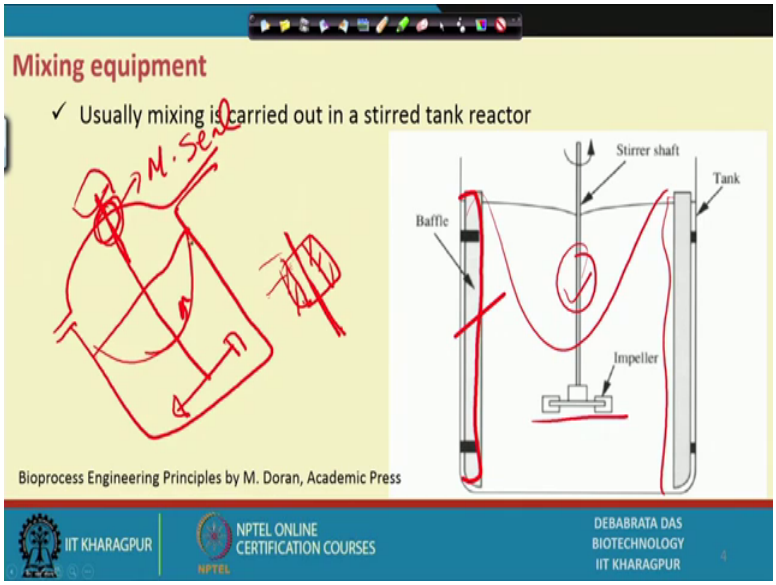

Now, and question comes, what is the mixing components we have? What are the things we required for mixing? The basic things we required a is shaft. What is what do you mean by shaft?

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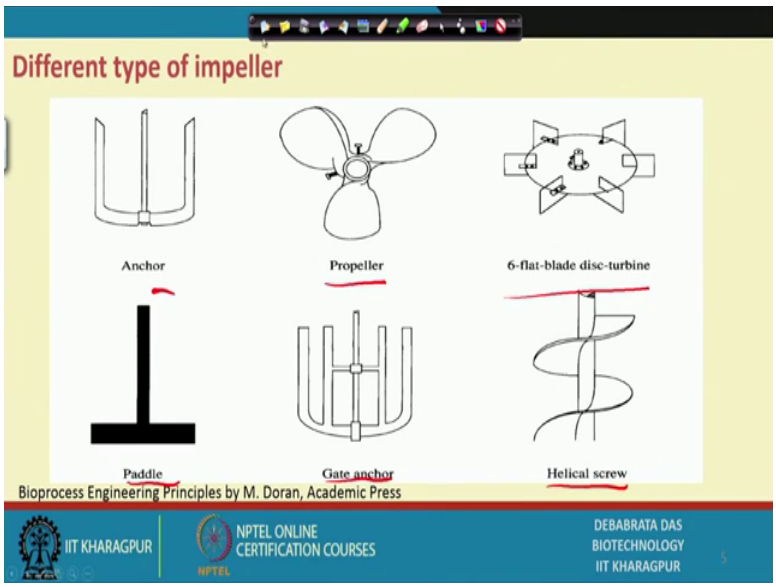

What do you mean by shaft? This is where the impeller is mounted. Now this is the shaft hang on this is this is shaft and this shaft I told you, but this shaft should be perfectly straight.

A few company in the world they produce only that shaft for the bioreactor, because in the bioreactor the shaft plays very important role, why; because suppose this is a this is a bioreactor and this is a vessel this is a vertical shaft and this is impeller. Now here I told you this is we have mechanical seal mechanical seal. Now these mechanical seal this is required both for the chemical and biochemical industry am I right.

Now, in the biochemical industry the mechanical seals plays very important role, the reason is that there should not be a any entrance of the air from the because since it is a moving shaft. So, there is the very possibility air can enter into the vessel and air compresses lot of different microorganism and then if it entered then whole fermentation process will be spoiled.

So, this is a special type of regulation is done. Now, that is why then and another one important thing is that; this should be perfectly straight. Now, if you are shaft is not perfectly straight, then what will happen if it is little bit angle like this, then what will happen then there will be that you know that suppose this is shaft and here we have the packing material.

Now this is all packing material that we have and this is the shaft we have. Now we are; so here if you if there is a angle there will be a friction that occurs in the mechanical field and that causes the spoiling of the mechanical seals. So, it is very a very essential. Another thing is that impeller, we have different type of impeller different type of different type of a mixing, we require different type of impellers.

Another requirement we required this is baffle, why use baffle we required; just to stop the vertex, this if you do not have this now this impeller then we will be having this kind of vertex formation in the system. Now, different type of impellers we have we have anchor, we have propeller, this is largely used in the chemical industry this is six blade flat bladed disc turbine, this is used in the fermentation industry. So, you know that paddle impeller gate anchor and the helical screw. There are different type of impeller we can use.

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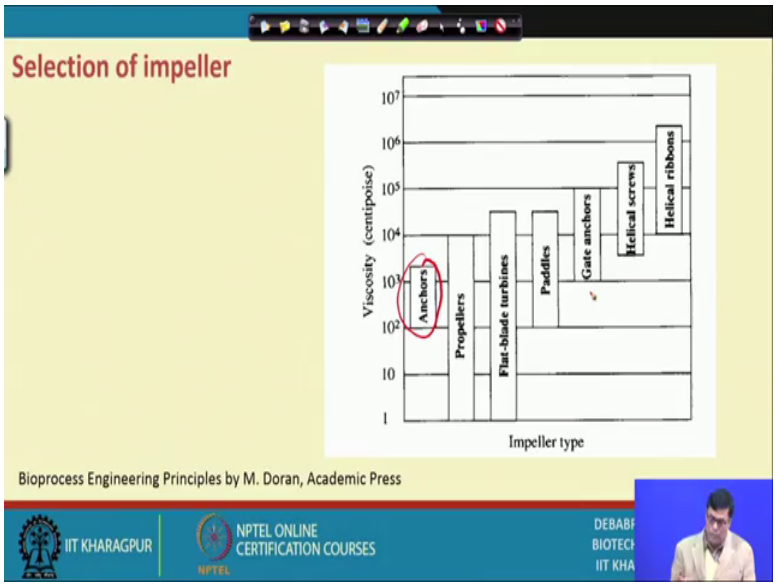

Now, if you use now viscosity plays very important role as per use of different impeller is concerned. Now, a anchor that usually lies in between 10 to the power 2 to 10 to the power 3 centipoises, then therefore, propeller is propeller, which is mostly used in the chemical industry that is 1 to 10 to the power 4 centipoise.

Now, include flat blade turbine this is mostly used in the biochemical industry, it is 1 to 10 to the power 4 paddles and other type of impellers that is also used.

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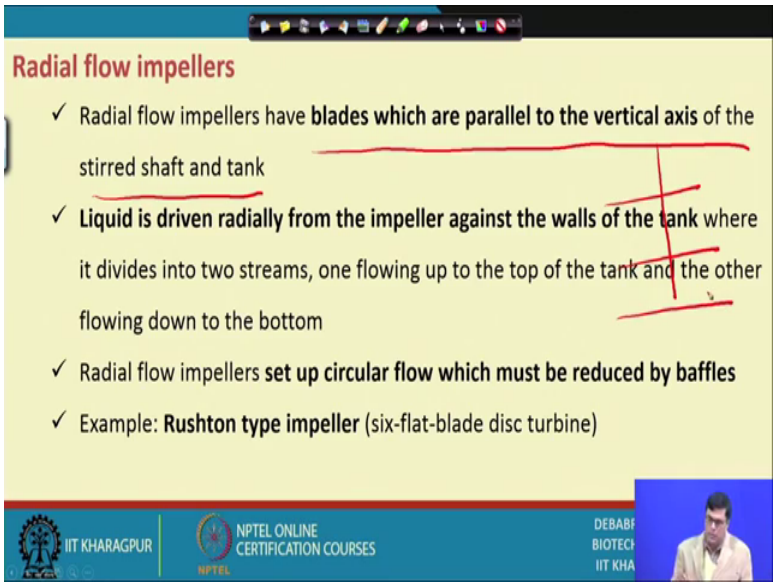

There are a different type of you know the flow patterns we have; one flow pattern we call it radial flow impellers; radial flow impellers what you mean by that?

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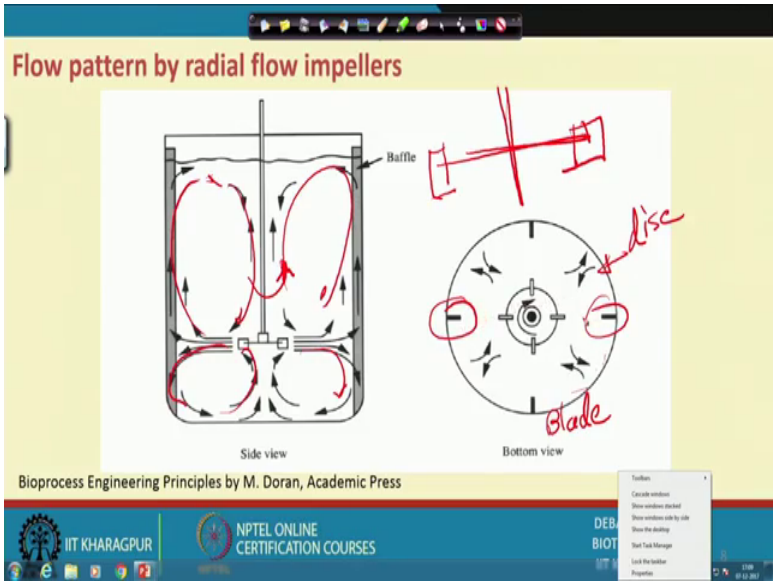

Now, this is this is actually a if you look at this particular that you know that schematic diagram you can find out what do you mean by radial flow impeller. So, when the agitator moves like this, then what will happen this cell liquid is throwing like this am I right; this is coming like this and then it rotating like this and here also it is there like this and coming like this. So, this is like this kind of flow pattern is there.

Now, if you if you take the stop view of this radial flow impeller, we will get this kind of this is the disc, this is the disc and on the disc and if you look at the side view it will be look like this. In the disc the this is the bade are mounted and this is here we have the shaft. So, these are the blade this is called blade and this is disc.

So, one experience I want to share with you that I work with (Refer Time: 10:37) biochemicals, and we observed that number of blades that you know that we must have at different height, because I can tell you that like this.

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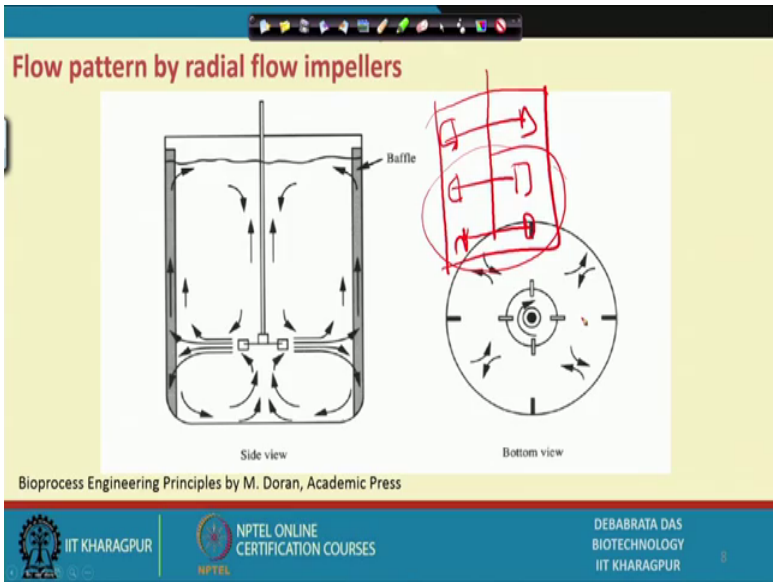

Suppose the you when you use the very large fermenter. So, you have very high height, then naturally if you put one impeller at the bottom it may concentrate mostly one particular zone, it will not be effective throughout the medium.

So, you have to have different impeller at different heights, there will be parallelly mounted like this. So, that you can have proper mixing now question come that what should be the configuration of these blade; that in the disc that whether it is it is a 4, 4, 4 or 5, 5, 5, or 6, 6, 6 or 7, 7, 7 or there will be 4, 5, 6 like this.

Now, we have find that you know that in the industry this number of blades, since that blades causes lot of friction and number of blades very important role for the vibration of the reactor. And that we shall have to find out experimentally, what combination will be most suitable for these particular fermentation process, that we can find out we determined experimentally.

So, let me tell more details about the radial flow impeller. Radial impeller have the blades, which are parallel to the vertical axis of the shaft and the tanks. I just explain vertical means, this is the vertical this is at different vertical position your impeller are mounted. The liquid is driven radially from the impeller against the wall of the tank, that I have just shown you how it rotates like this; how it rotates like this; that I have shown you.

Radial flow impeller sets up circular flow which must be reduced by the baffle; that you know that kind of movement will be it reduced by the baffles and why the baffles is required? We want to make the maintain the uniformity the height of the liquid and if you do not use the baffle, then we have a vertex formation. The example of the radial flow impeller is the Rushton type of a impeller with the six-blade disc turbine. I showed you what is disc and what is the blade; flat blade that you have.

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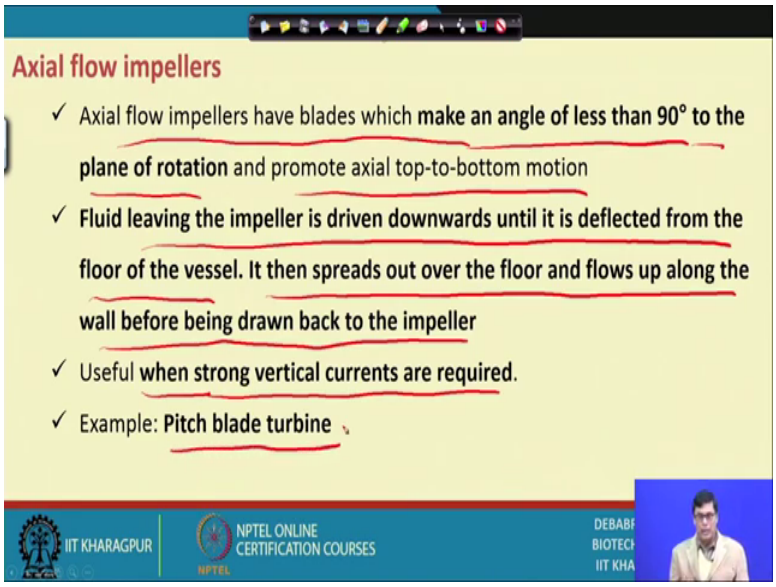

Now, another thing that we have, what you call axial flow impeller; now, let us see how it looks; axial flow impeller; so you can you can easily find out there is a pattern it is little bit different as compared to radial flow impeller, here you find there is a angle.

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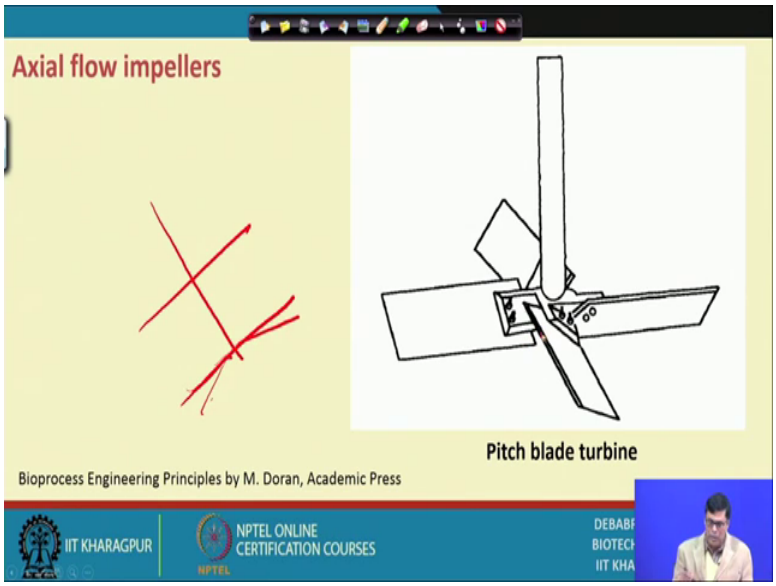

Now in case of previous thing it was perpendicular with this am I right. Now, here it is not the shaft; this blades are not in the perpendicular, it is kind of angle they are maintaining like this [FL] angle in there been maintaining like this.

So, some kind of angle is there; and if you look at the flow pattern which little bit different as compared to radial.

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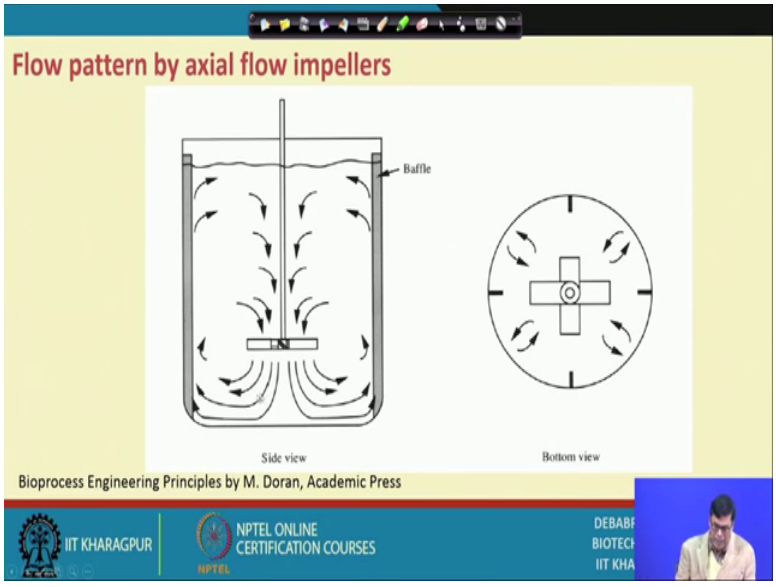

So, here it is like this; this goes like this and it has goes like this like this. Now, if you look at that radial flow, it has it is something different it is a it; bottom one concentrated

the bottom part and this one concentrated on the topper upper part, but here it is not like this, here you see that here it is governed by the whole things it is like this pattern is little bit different and here also you have shown that.

Now, let us say let us do little more analysis the at the axial flow impeller have blades, which make an angle less than 90 degree to the plane of rotation and promote the axial top to bottom motion that I have shown you it is top to bottom motion is there. Fluid leaving the impeller is driven downward until it is the deflected from the floor of the vessel.

And then spreads over the floor and flow of along the wall before being drown back to the impeller. I have shown you this, and when this is useful when strong vertical current are required. The example is pitch blade turbine.

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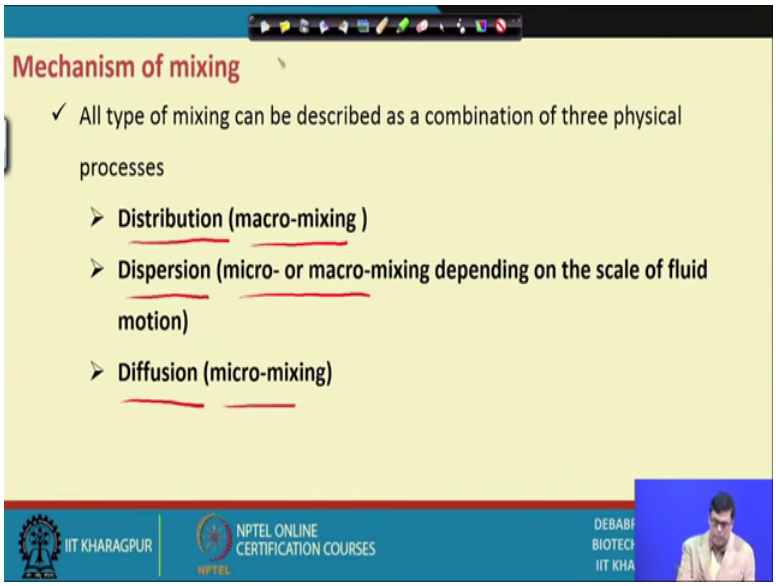

The mechanism of mixing; now what are the mechanism of mixing? Mechanism is mixing is the three: one is distribution dispersion, and their diffusion. Distribution we consider is the macromixing and dispersion it includes both micro and maximum unit depending on the scale of fluid motion and diffusion you consider as the of micro mixing. Let us see that what do you mean by that.

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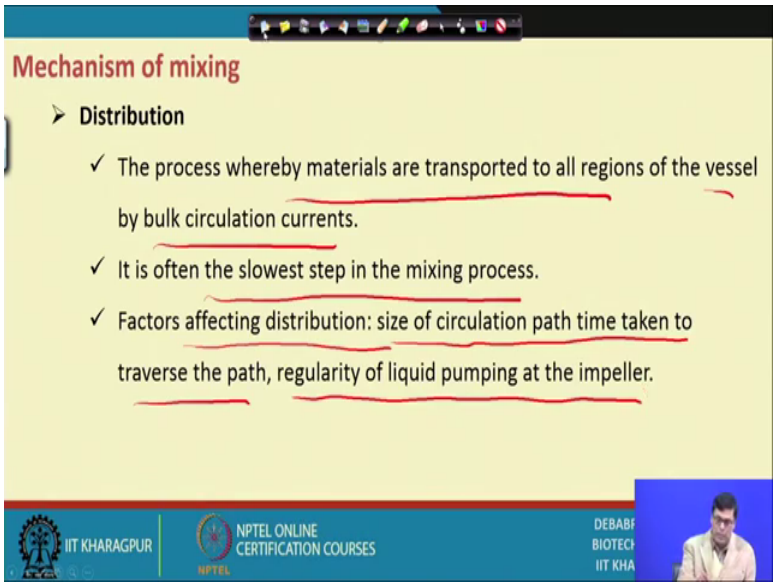

Now, distribution will be the distributed; that means, what you mean; the process whereby materials are transported to all region of the vessel by bulk circulation pattern. We are circulating by you know may be we are circulating the in a manner it is circulated at different part of the vessel, and it is often the slowest step of the mixing process.

And factors affecting the distribution size of the circulation path taken to the traverse path, and regularity of the liquid pumping at the impellers. So, this depends on the this two factors. Now important is the dispersion.

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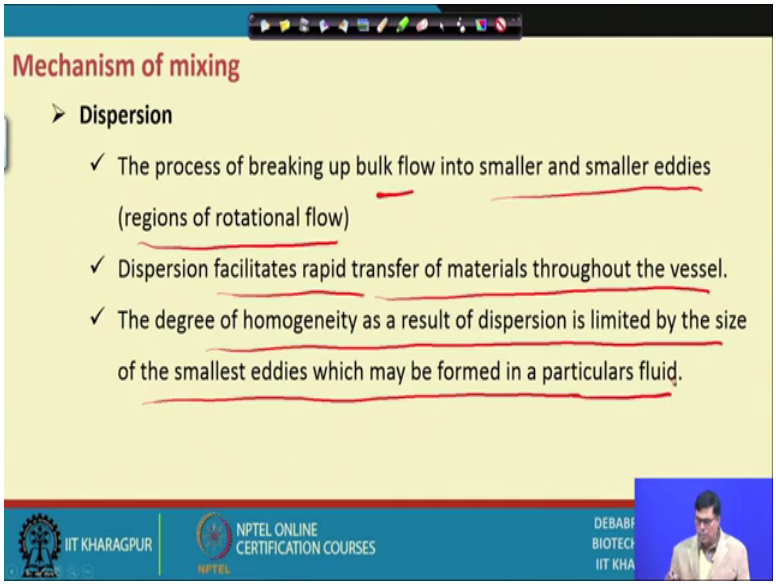

Dispersion is that the process are breaking the fluid flow if this smaller and smaller eddies. I have shown you only eddies, how eddies are created; region of rotational flow. The dispersion facility facilitates the rapid transfer of material through the vessel, throughout the vessel. And degree of homogeneity as a result of dispersion is limited by the size of the smallest eddies where which may be form in a particular fluids.

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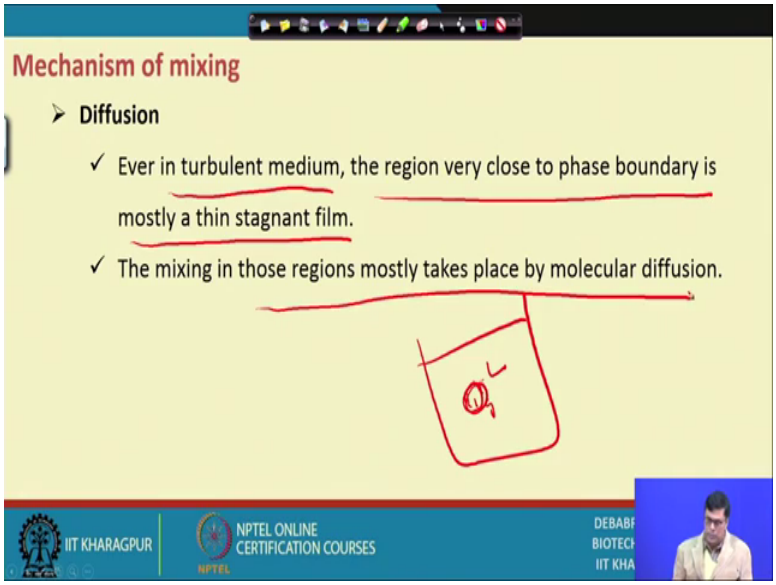

Next is the diffusion, a ever in turbulence medium, that the region very close to the phase boundary is mostly by the thin layer. I can I can tell you, suppose this a liquid and there is a bubble here, then there. So, here you have two boundaries am I right this is liquid and here is a gas layer.

So, diffusion that takes place across the mixing, those region mostly take place to the molecular diffusion. I can give the example of how oxygen is diffused in the fermentation medium from the here for anaerobic fermentation process, particular in case of surface culture.

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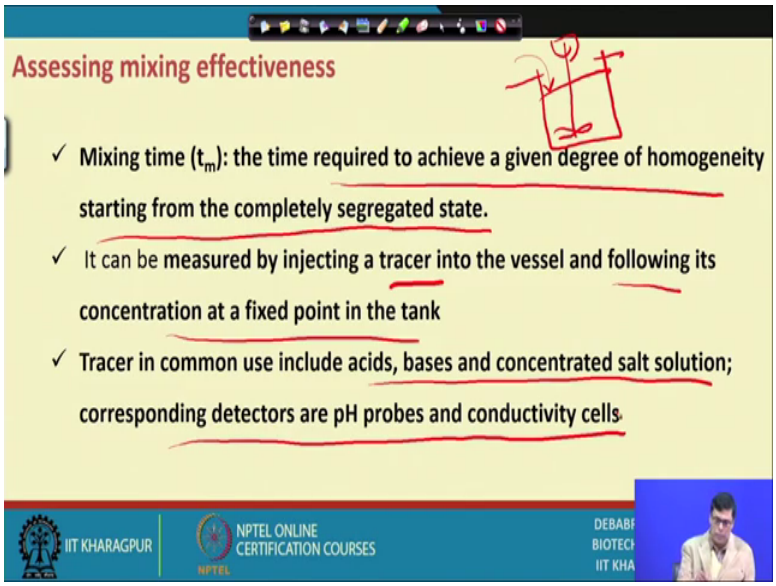

Now, mixing time who how you determine the mixing time is the time required to achieve given degree of homogeneity starting from the completely segregated state; that means, suppose this is this is a this is a liquid, and you put some material here. Now question come mixing time is the how quickly it is disperse into the medium; that means, how that time required for the homogeneity of the of the reaction mixture.

Now, it can be measured by injecting a tracer and tracer might be anything it might be acid solution; may be alkali solution; may be color anything we can have and or may be any salt solution and following it is concentration with the fixed point of tank. And your monitoring difference might be at several in case of acid or alkali you should have pH in case sodium chloride you add you a use the conductivity detector, in case of color we can have some colorimetric estimation process that we have.

The tracer is commonly used the acid, base and concentrated salt solution corresponding detector is pH probe and conductivity cells.

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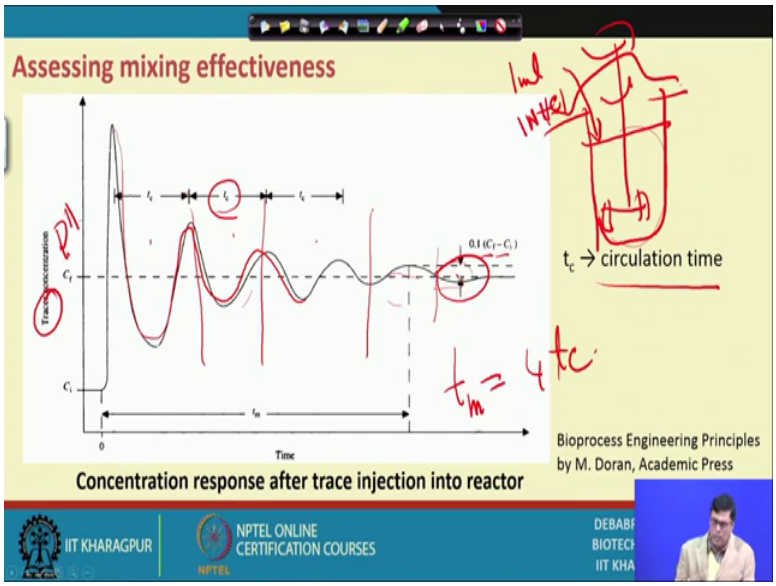

Now, how the mixing take place; let us let us let us give the example. Suppose this is the vessel and this is the starter that we have, this liquid; now when suppose I am putting 1 millimeter of one normal is cell solution let us take the example.

Now, when you add this acid here, then what will the immediately it will not be uniformly mixed. So, what will happen if we consider here concentration of the acid a or you know pH suppose you consider here pH you will find pH we will that that you know that or you know your yes acid that concentration will keep on at a different it will be keep on increasing decreasing increasing decreasing in the media and finally, a you will find the homogeneity in the reaction mixture.

So, you have. So, many wave type of characteristics that you will find and after several wave you will find that you know uniformity in the in the in the in the in the reaction mixture that you know final concentration minus in a initial concentration that you can find out. So, what I want to name that here these this curve this is the web that we have this time between this two peaks we consider as, because if you considered this two peaks we consider T c, and what is T c is the circulation time.

And actually that we have observed t m mixing time equal to 4 into t c. This is usually the case that we have four a such you know we can you see the here how many ts 1 2 3 and we consider another thing is more or less is considered a 5 also some time may be applicable.

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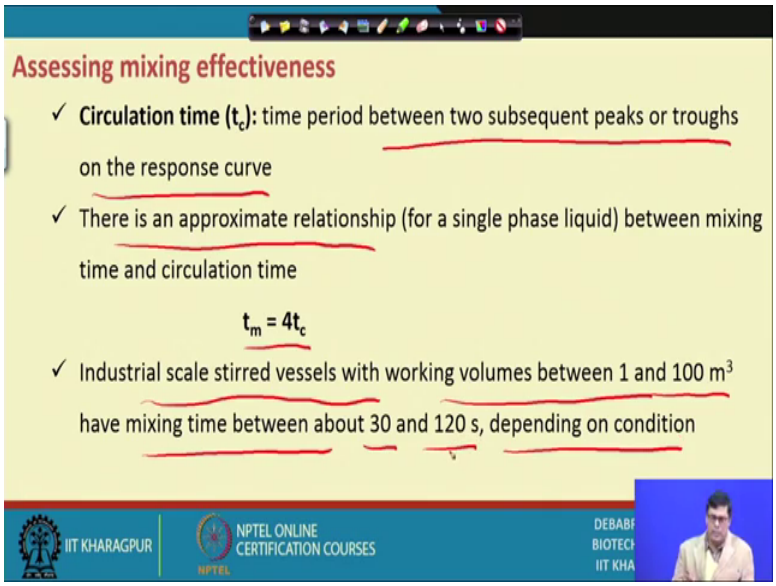

So, circulation time how you define the time period between the two subsequent peak of the response curve. And there is a approximate relationship that t m is equal to 4 t c. Industrial scale vessel working volume in between a 1 to 100 cubic meter mixing time varies in between 30 to 120 second depending on the conditions.

So, this is the 1 to 100 cubic meter reactor, if we have this mixing time is coming over 30 to 120 seconds.

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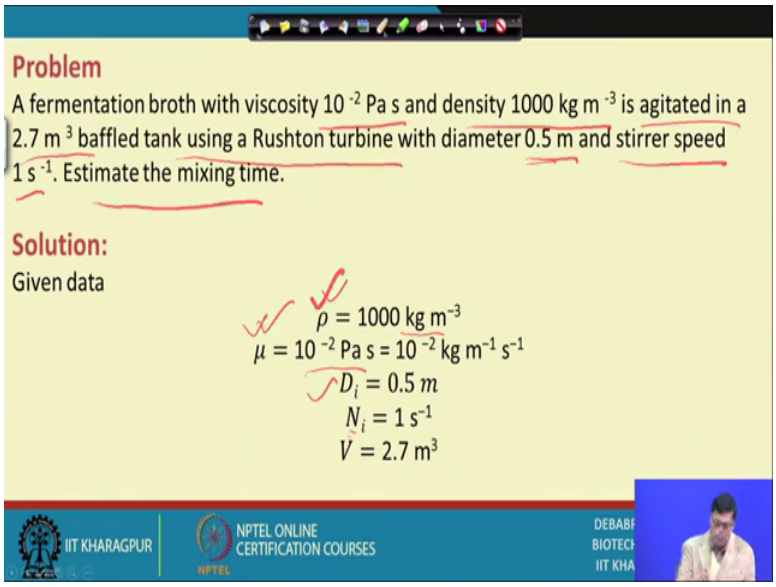

Now let us let us try to solve the mixing time that in case of we have seen in case of Rushton turbine can be estimated by the following equation.

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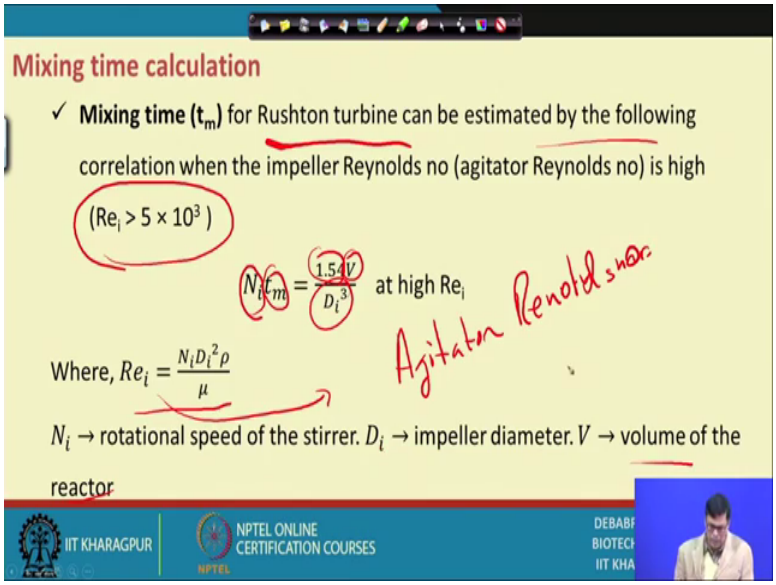

And this is applicable when Reynolds number is more than 5 into 10 to the power 3. Then this is the rotational speed of the agitated this is the mixing time equal to 1.54 volume of the volume of the layer reactor and Di is the diameter of the impeller. And Reynolds number is equal to D; this is this is called this is not the normal Reynolds number this is called agitator Reynolds number ok. This we call agitated Reynolds number.

So, there is a problem no; that how let us see how we can solve this problem. A fermentation broth with viscosity 10 to the power minus 2 Pascal second and density 1000 kg per cubic meter is agitated in a 2.7 cubic meter of baffle tank using Rushton turbine with diameter 0.5 meter and stirrer speed is one this second inverse. Estimate the mixing time now how we can solve that.

Now, I told you that when we try to solve any problem please note down the what are the data is supplied. So, we have the density is given, viscosity is given, and viscosity now whenever you have this kind of data try to convert into the same unit this is the si unit. So, you convert into the si unit then this is diameter of the impeller we consider as 0.5 meter and Ni 1 to second inverse and V is 2.7 cubic meter.

Now, first we shall have to find out the Reynolds number.

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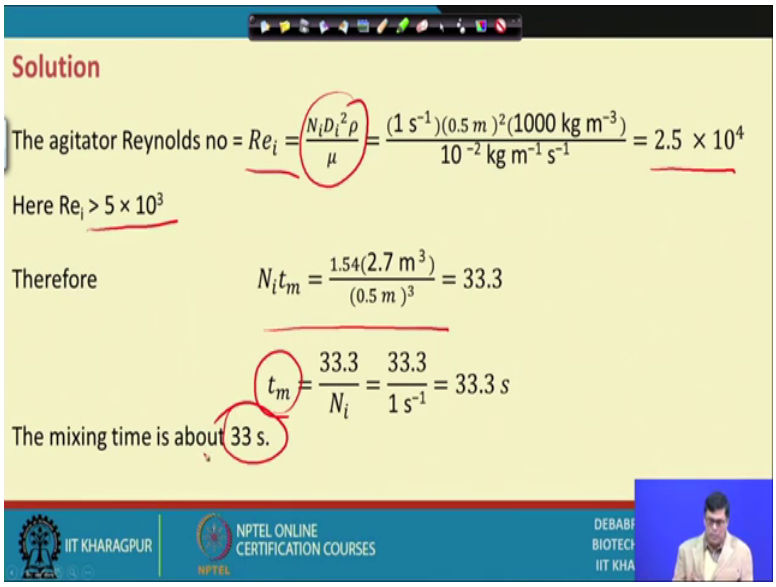

We can find out this equation, this is 0.5 is the diameter of the impeller, then it is coming about 2.5 into 10 to the power 4. Now, this indicate this is more than 5 into 10 to the power 3. So, this equation is implies. So, since the this equation imply we put all the value here. So, just to calculate the mixing time and mixing time is coming about 33 seconds. So, we can easily solve the problem.

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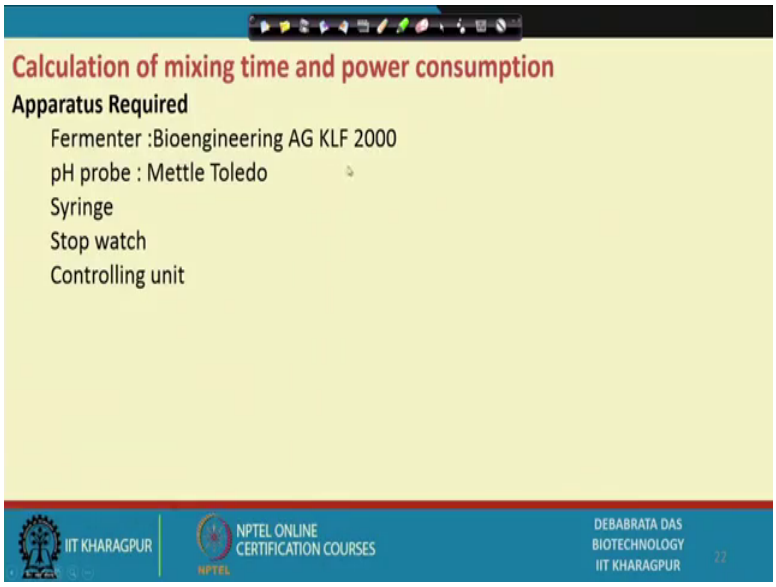

Next thing I want to share with you, that we guide out some kind of experiment in our lab, and just to find out that how to how to calculate the mixing time and how it correlated with power run by the agitator and the Reynolds number. Now we use the bioengineering AG fermenter and the pH probe; I told you whenever you do that you have to use some kind of monitoring device, and pH probe is required, then other things requires syringe, stop watch and other controlling unit.

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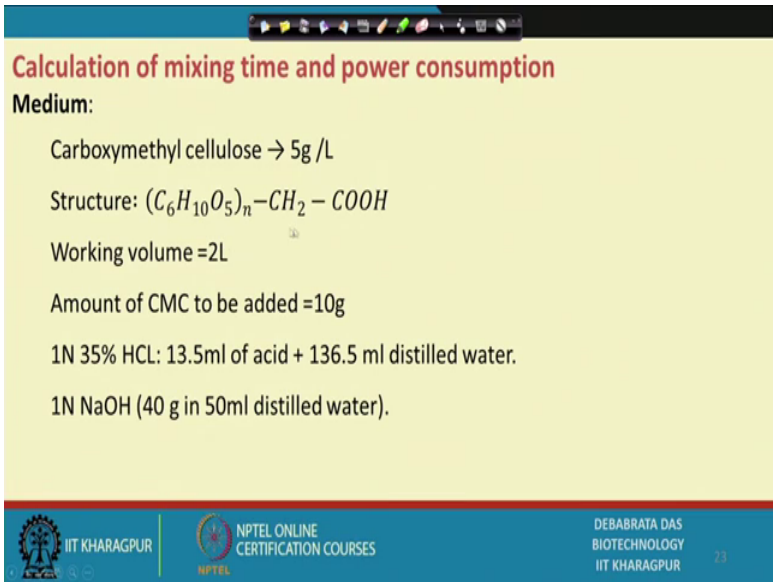

Now, here we use the CMC solution CMC carboxy methyl cellulose, and why carboxyl methyl cellulose? Because carboxyl methyl cellulose though it is insoluble in water as normal temperature, but if you heat it with constant stirring it will become soluble, but when we cool it down then, characteristics of the CMC solution will be same as the characteristics of the fermentation broth.

And another important factor is that, when you add acid or alkali, then what is happening; that there will be not be change in the chemical structure of the CMC. So, this is the; this is how the how the CMC is defined this is the polymer of the cellulose C 6 H 10 O 5 n and this is the methyl group and this is the carboxylic acid group.

Now, we working volume is to 2 liter and we take 10 gram of CMC solution and we also prepared one normal HCL and one normal this CMC solution.

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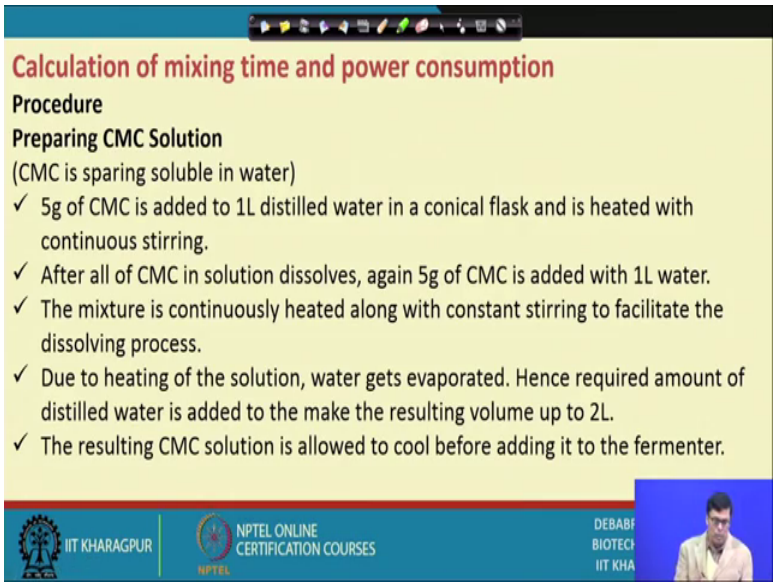

Now, this is the methodology how you can prepare through a CMC solution; I am not going in details.

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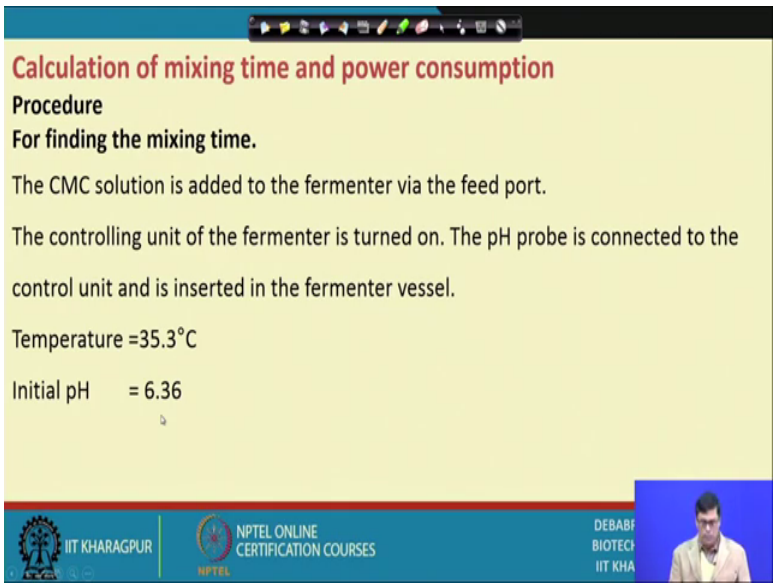

Now that for finding out mixing time, we put the CMC solution and they will maintain the temperature at 35.3 degree centigrade with the initial pH of 6.36.

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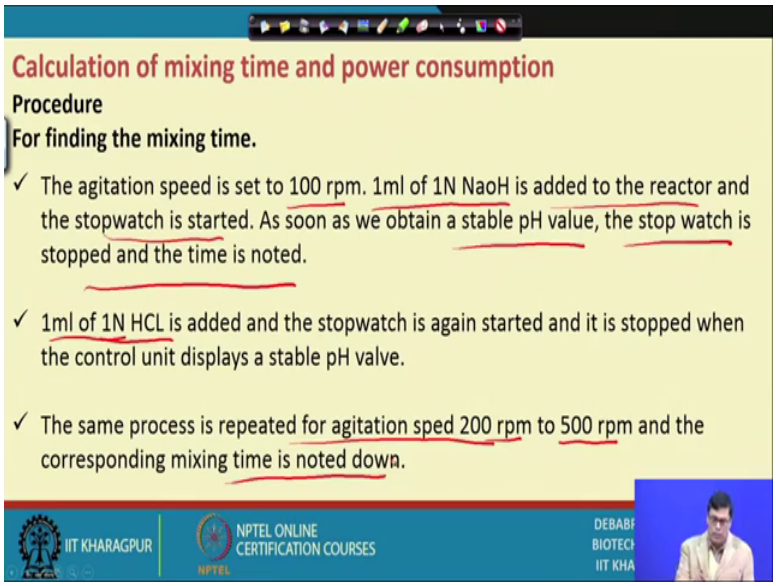

Then what we have done that you know agitation speed; we control the agitation speed at different level first we consider 100, then 1 milliliter of 1 normal NaoH solution is added to the reactor and stop watch is started. We as soon as we add we will we put on our stop watch, then and find out how long it takes to maintain to have the uniform pH.

So, this to obtain the stable pH the stop watch is stopped and time is noted. Similarly, we can we can take we can add 1 milliliter of 1 normal HCL solution and we can also monitor the time required for having the constant pH that we can easily find out. The same process is repeated in case of stirrer with 200 rpm 500 rpm and the corresponding mixing time is noted down.

So, this we can we carried out in the lab. Then this is the table that we prepared.

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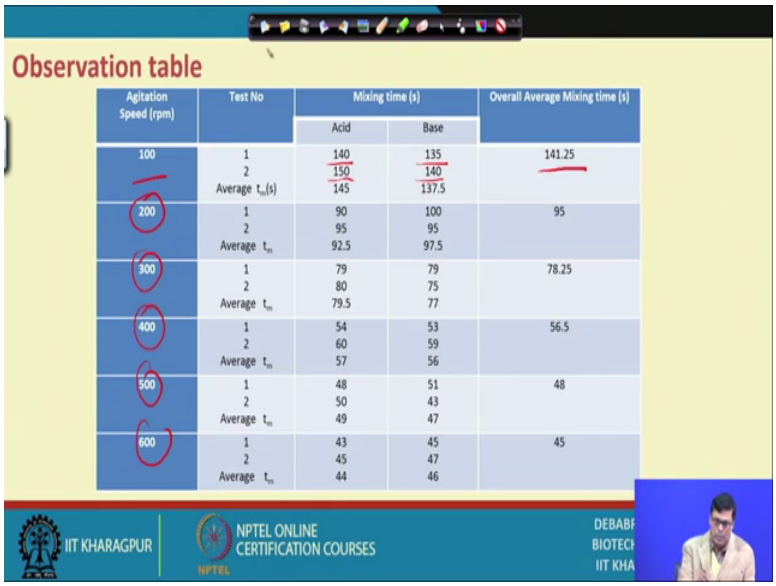

You see that 100 rpm we have test 1 and test 2; we have we this is initial take 140 no 40 seconds to have the uniform pH and when a when a, but when you use the base it take a 135 seconds. And in second case when you use one acid 150 seconds and it is a same case it is 140 seconds.

So, we take a average of this and we find the mixing time this similarly, we can find out the value; at 200, 300, 400, 500 and 600 rpm.

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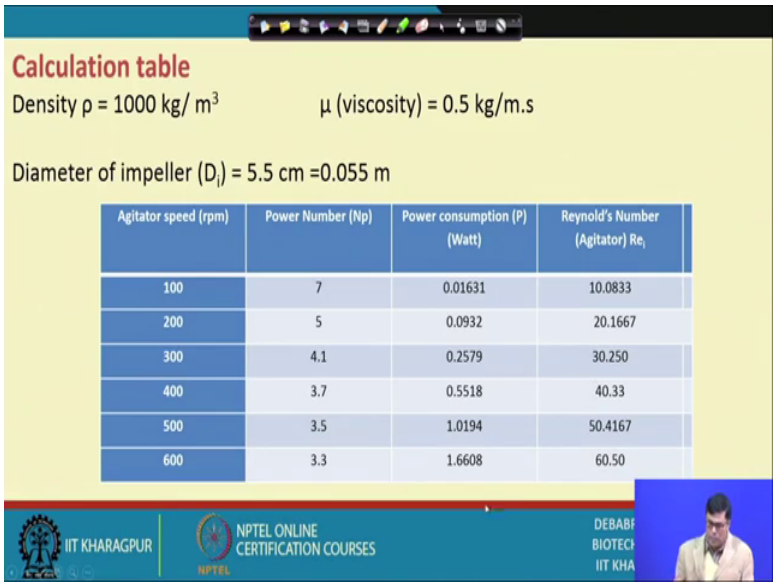

Now, we prepare a table like this at different rpm, what is the power number? What is the; what is the that power consumption by the agitated and Reynolds number?

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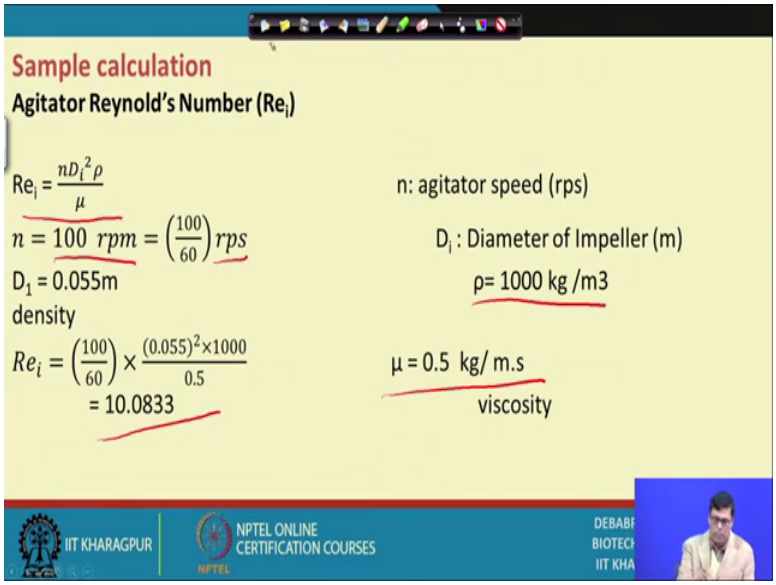

The question come how you did it; that Reynolds number if you look at the Reynolds number, how you calculate; you do the agitated Reynolds number in a rpm is that you know 100 rpm we can write this is the rps. So, 100 by 60 is the rps per second and Di is 0.005 millimeter, and then we can find out the Reynolds number is this. And then we find out the there we know the rho value is a 1000 kg per cubic meter and viscosity is 0.5 kg per meter per second. So, Re value can be easily calculate.

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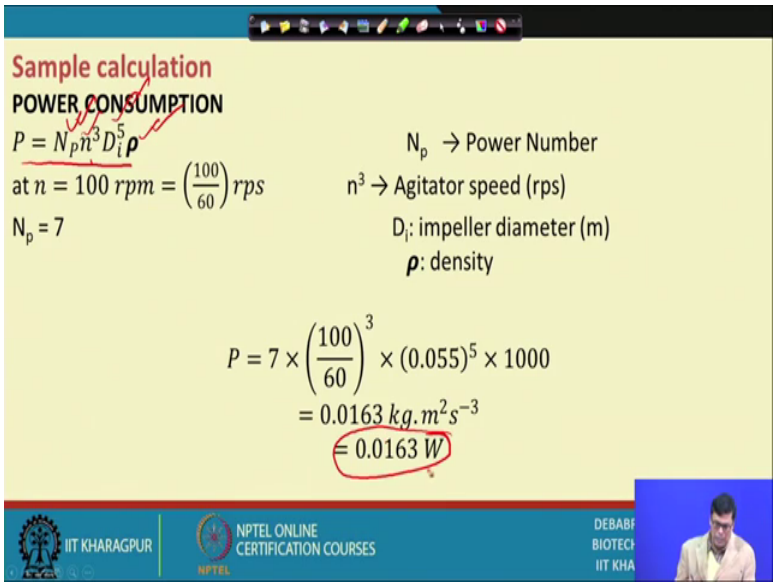

Now, similarly we can calculate also the power drown by the agitator, how you will; how can you do that power drown by the agitator is a Np; Np is the power number N the if the rotational speed of the stirrer, Di is the diameter of the impeller and rho is the density of the liquid. So, everything is known we put the value we can find out the what is the power drown by the agitator.

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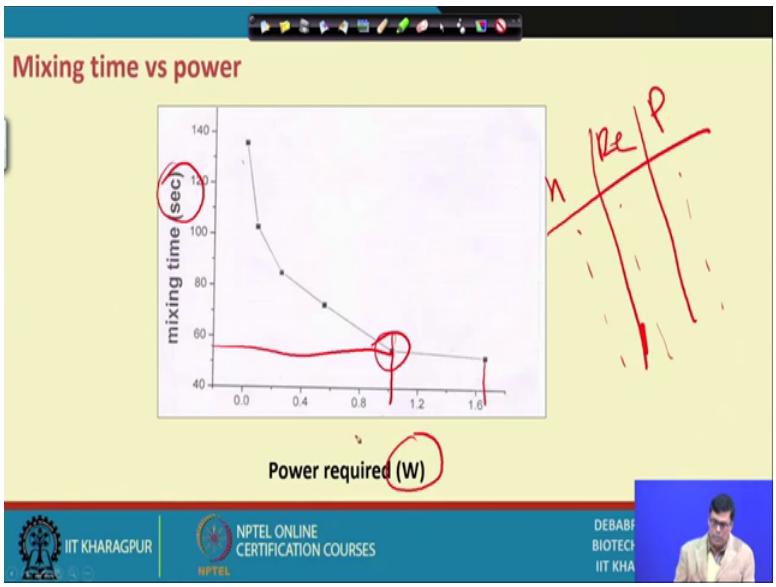

So, we can easily calculate.

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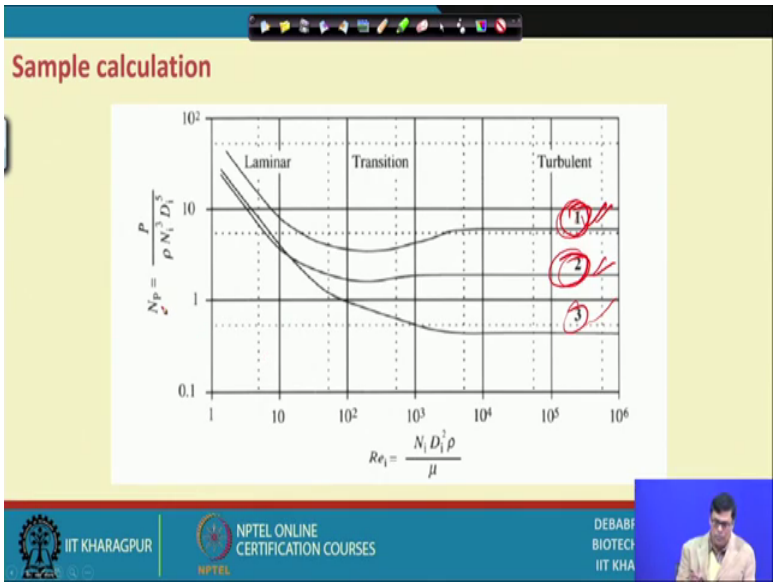

Now here I want to show you that that different region we have; we have laminar flow, we have transition flow, we have turbulent flow. The turbulent flow I told you it is lying in between 10 to the power 4 onwards, but in between approximately the 10 to the power 2 to 10 to the power 4, we have transition phase and laminar flow is the usually the Reynolds number 1 to 10 to the power 2.

So, this is the reason that we have the different type of impellers, they have different type of probe pattern, this is different type of impeller is applied. Let us assume that if this is t this is the that a that is the probe this it may be applicable for if a one might be applicable for propeller another for impeller may be another parallel type of thing.

So, as for our requirement we shall have to find out ok, if you know the Reynolds number we can correspondingly we can find out the power number. Then we can calculate in this equation, I have show you the calculation we can find out; so what we can find out in the table; we can we have the table we have n value, and we have Re value, that n is the rotation of Reynolds number and then this power drown by the agitator. We can have different values here.

So, what we can do we can make a; we can draw a curve this is power drown by the agitator and the this is the mixing time required. The if you draw we will find this; The why this curve is the important; the reason is that we try to find out and what is the minimum power required to have the minimum that mixing time. The maximum that that

this is the value there here you see if in after this, if you increase the power of the agitator it is not going to decrease the mixing time significantly.

So, we shall have to for design purpose we shall have to consider we can assume this kind of power is required for proper mixing of the; of a particular vessels.

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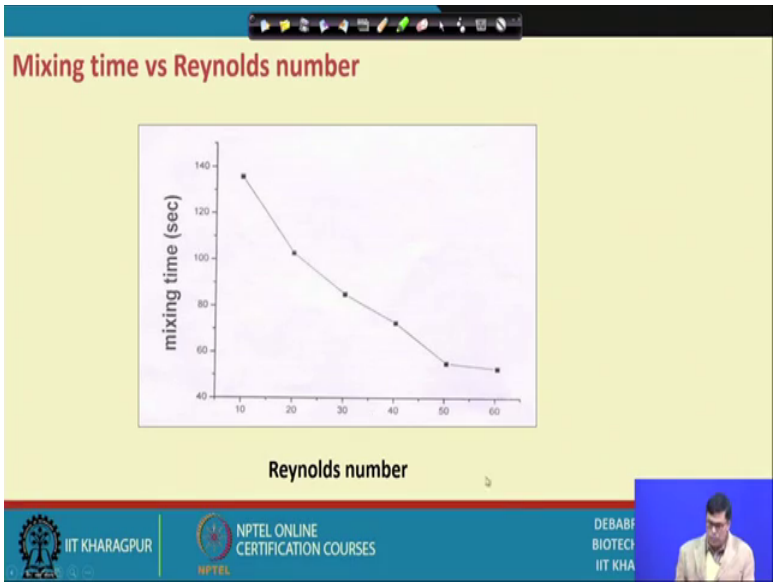

Now, here there is the another coalition of the Reynolds number and mixing time that also we can draw.

So, in this particular presentation, I try to discuss the how the mixing that involve the transportation of the fluid, because this how the different material they flow in the that mix in the system, because main purpose of mixing to mixing the homogeneity in the reaction mixture particularly it is essential when any fermentation process, because we know the our microorganisms are very sensitive with respect to the environmental parameters with respect to sub state concentration.

So, um; so, this now we try to find out how the mixing time we can determine the mixing time is the time required to make the homogeneity in the reaction mixture. And I told you this is equal to t m equal to 4 t c and a and the and also we try to find out the mixing time in a particular fermentation process. And finally, we discuss some kind of experimental trail that we have carried out in the lab, and how we how we correlate with the power

drown by the agitator and which is very much essential for designing any fermentation process.

Thank you.