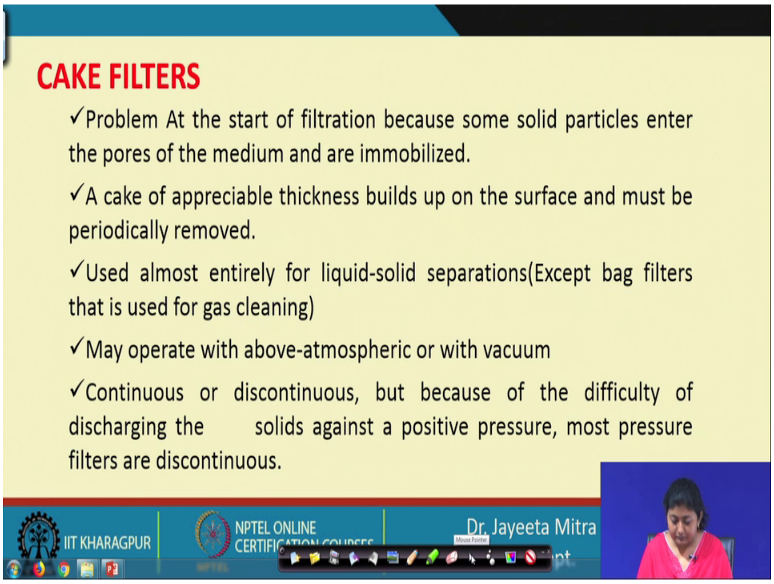
Fundamentals of Food Process Engineering
Dr. Jayeeta Mitra
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur

Lecture - 44
Mechanical Separation Techniques (Contd.)

Hello everyone. Welcome to NPTEL online certification course on Fundamentals of Food Process Engineering. In the last class, we were discussing about the filtration process and the resistance offered by the deposition of the cake from the slurry and also the resistance offered by the filter medium.

Now, today we will continue some more things in the Mechanical Separation Techniques.

(Refer Slide Time: 00:50)



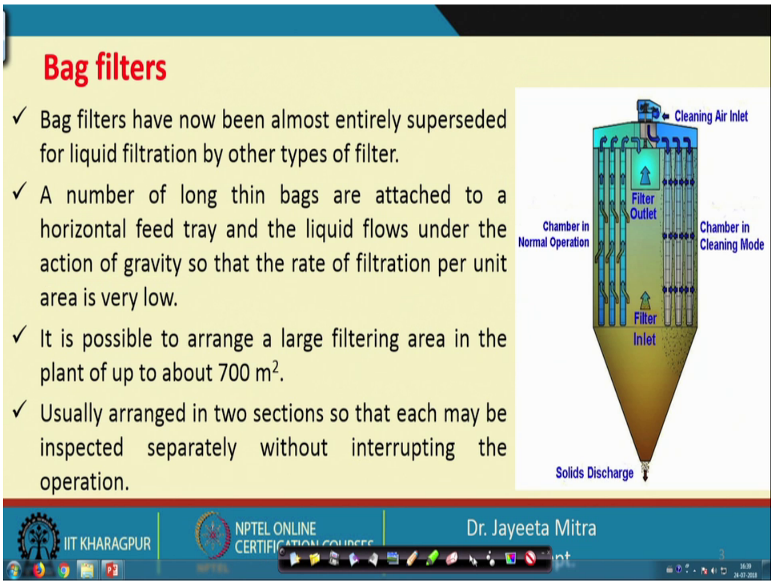
We have discussed different kind of filters; cross flow filters and dead end filters, cake filters etcetera. So, today we will continue with an the cake filters. Although it is used mostly for this kind of the slurry separation, but there are some problem that can be absorbed at the initiation of the filtration operation.

What is the problem? The problem is some solid particles some solid particles enter into the pores of the filter medium and they are immobilized and because of that they hindered the path of the liquid to flow ok. So, that there is that is one problem, we often encounter that a cake of appreciable thickness builds up on the surface and that must be periodically remove. So, that the filtration process the rate of filtration will be constant. Then this is this cake filters are used almost entirely for liquid-solid separation.

But there are some exception such as bag filters that is used for the gas cleaning and also this cake filters may operate with above atmospheric or with vacuum level. So, this is also a specific you know characteristics of this kind of filter. So, we can operate this at vacuum also and also the above atmospheric pressure.

It can be continuous or discontinuous, but because of the difficulty of discharging the solid against the positive pressure, most pressure filters are of discontinuous type.

(Refer Slide Time: 02:53)

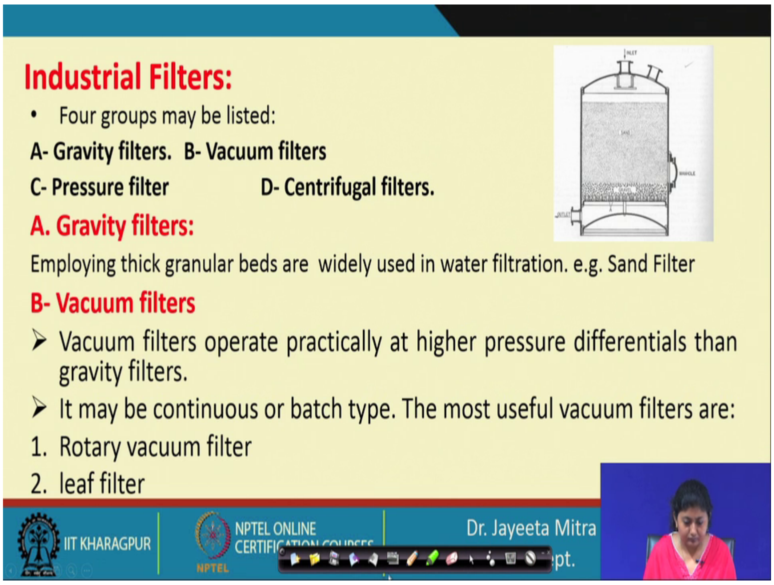


Next we will see the bag filters. So, bag filters although these are now replaced by different kind of filters which has which has you know some advanced design aspects than the bag filters. But if you look into the application of this or the operation of this bag filter, there are a number of there are number of long thin bags are attached. These are attached to a horizontal frame, horizontal feed tray and the liquid flows through this ok when the liquid is coming through this under the action of gravity so, that the rate of filtration per unit area is very low.

Because here it is coming down because of gravity we are not applying any pressure over here. So, that is why the rate is a bit slow. And it is possible to arrange a large filtering area in the plant which can be go as high as 700 meter square

And usually arranged in two sections; so, that each may be inspected separately without interpreting the interrupting the operation. So, this is how it is coming into and then the filter inlet is here ok. And the filter outlet when this liquid is going through this bag, the thin filters it is going out and then at the central location there is a filter outlet section and the solid that has been filter will be discharged from the bottom.

(Refer Slide Time: 05:01)



Now, there are industrial filters can be categorised into different groups for example, gravity filters, vacuum filters, pressure filter and centrifugal filters. Gravity filters, these are the simple one, which is employing thick granular beds and these are widely used in filtration water filtration specifically.

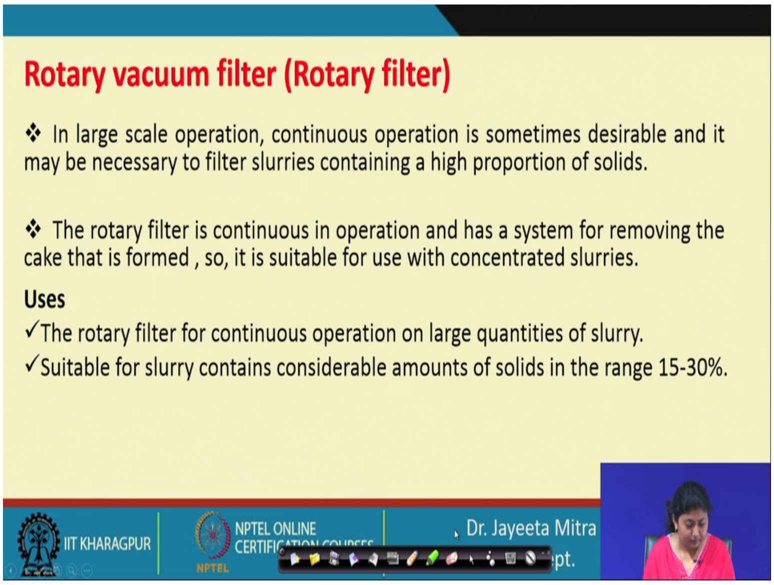
For example the sand filters. So, different you know different sizes of sand and bigger particles etcetera we start it the stack will be from the final to the coarser particle like that. So, we will have a diagram. So, the sand is there and then gradually we are having gravel or coarser particle and the inlet of water is from the top section from here and then it is coming. And then liquid the clear liquid that is that will be filtered and that will be going out from this outlet.

Another will be the vacuum filter vacuum filters operate practically at higher pressure; higher pressure differential than the gravity filters. It may be continuous or batch type.

And the most useful vacuum filters again can be categorised into two distinct types; one is the rotary vacuum filter, another is the leaf filter ok.

So, we will see one by one that how the rotary vacuum filter will perform and how the bag filter will perform.

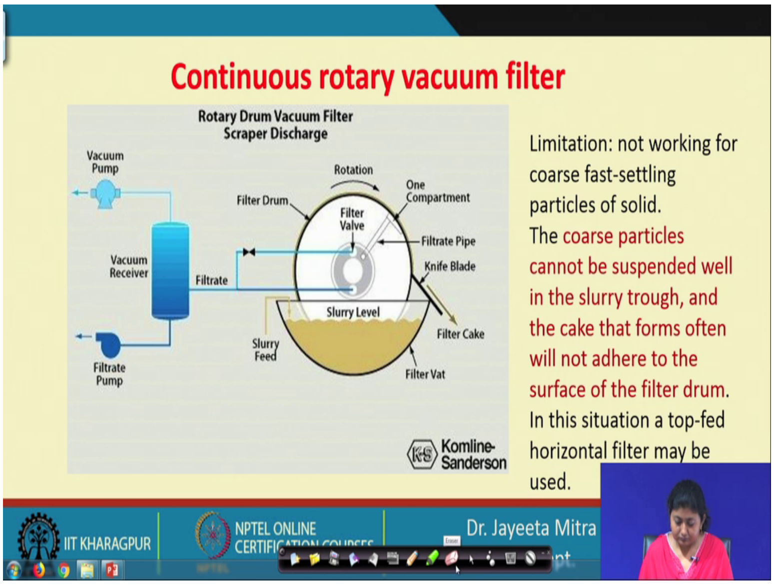
(Refer Slide Time: 06:56)



So, first we will see the rotary vacuum filter or also this is called rotary filter sometime. So, in large scale operation or continuous operation is sometime desirable and it may be necessary to filter slurries containing high profession of solid.

So, the rotary filter is a continuous systems and have a system for removing the cake that is formed over the surface of the drum. So, it is suitable for use with concentrated slurries and it can be the rotary filter for continuous operation on large scale quantities of the slurry that is one used where the large scale slurry to be filtered at a quite high rate. And the other is the suitable for slurry contains considerable amount of solid in the range of 15 to 30 percent. So, this is the range of solid that can be handled by rotary vacuum filter.

(Refer Slide Time: 08:06)



However, if you see that the continuous rotary vacuum filter design. So, the there is a drum there is a drum, which is rotating at a define speed and that speed is based on many parameter that at what rate the filtration is required, what is the concentration of the slurry, what thickness of the cake is can be deposited and can be taken out from the knife. So, considering all that we can fix the revolution of this drum, it is submerged into the slurry to certain thickness ok.

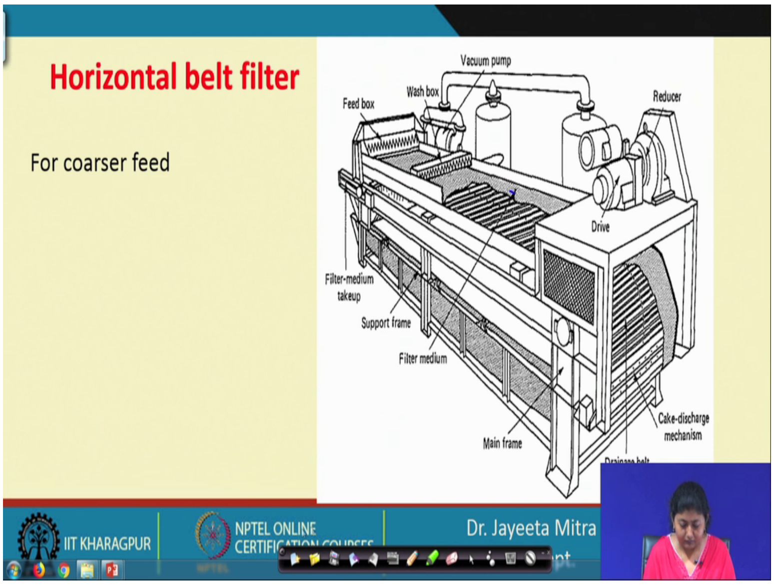
And there is a vacuum pump is there which is creating vacuum inside the inside the drum in near the section where the submerged submergence has been done. Because it is creating the negative pressure and because of that this filter process filtration process will takes place.

So, there is a filter valve slurry which is feeding continuously and this is rotating formation of the cake will be there as the filtration will proceed and the filtrate which is which because of the negative pressure because of the vacuum will come from this to this section ok. And this will collect here in in the filtrate collection channel and this will be taken out by the filtrate pump

And there is a deposition, the cake deposition over the surface and one knife is attached and its distance or gap at the surface of the drum also can be adjustable. Because we need to fix it based on the thickness, that is being deposited on the drum and it will cut that you know thick layer and that way it can remove it. So, this can operate continuously.

However there is some limitations, the limitation is this not working for coarse or fast settling particles of solid ok. This is not working for the coarse or fast settling particles of solid, why because of the coarse particles cannot be suspended well in the slurry trough and the cake that form often will not adhere to the surface of the filter drum. So, in this situation a top feed horizontal filter maybe used.

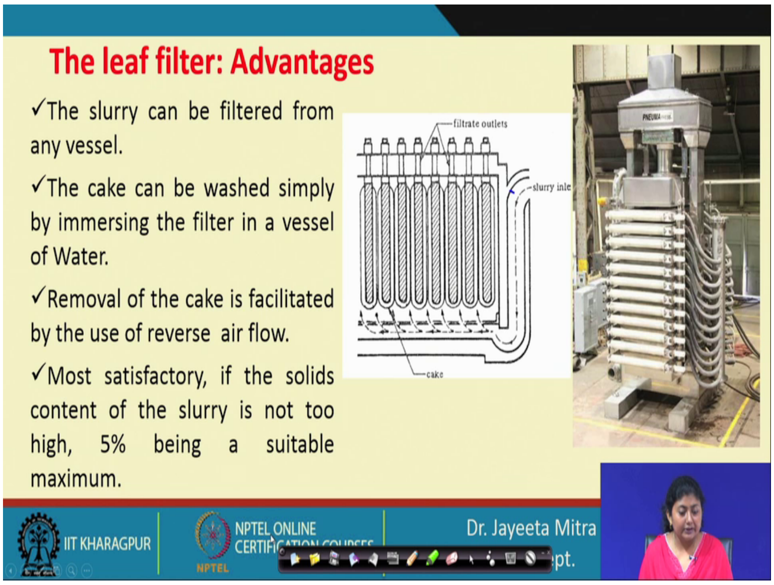
(Refer Slide Time: 11:02)



Now, so horizontal belt filter as we have mentioned that for the coarse feed, we can use this one. So, this is this looks like the diagram we have presented here where there is a mainframe and there is a filter mediuom here. These are the filter medium and there is. So, here the vacuum pump is also there, which is creating a negative pressure inside the other side of the filter medium. There is a feed box and here also the belt speed can be arranged the drive mechanism can be given to that to provide the motion to the belt ok.

And cake discharge mechanism that is also at the end. So, one section when it proceed to the other section by the time, the filtration has been done because of the negative pressure and the cake deposition at the end has been removed by some suitable mechanism or some knife or blade arrangement etcetera. So, this can be used for the coarser feed and since it is not as I said that because, of the coarser particle it is not sticking as a cake most of the time. So, that deposition can be discarded at the end.

(Refer Slide Time: 12:27)

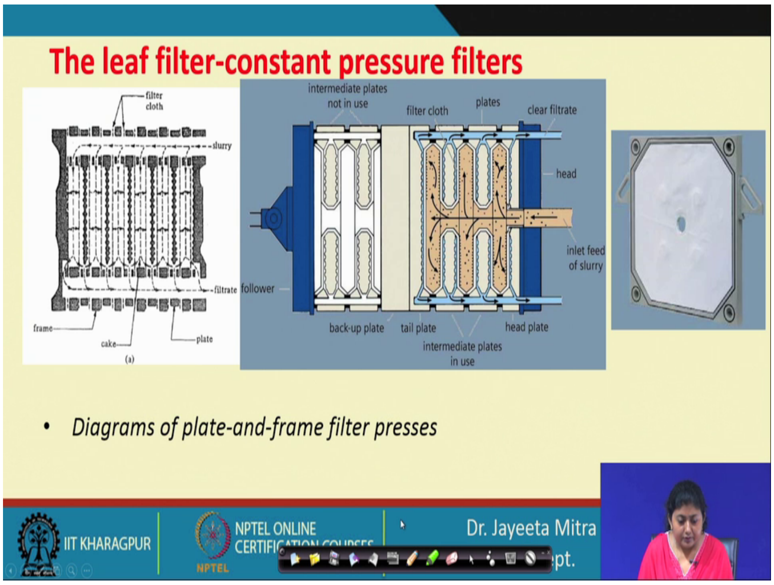


Then coming to the leaf filter- so, the leaf filter the various arrangements can be observed like this. This is the typical sketch and this is the exact a small prototype of the leaf filter where we can see that the slurry inlet section is there and it goes to each and every leaf ok. And in between there is a filter media. So, when the slurry this can be filtered from any of this vessels, the cake can be wash simply by immersing the filter in a vessel of water.

Removal of the cake is facilitated by the use of reverse air flow and more satisfactory if the solid content of the slurry is not too high that is 5 percent being a suitable maximum. So, we can see that whether in case of a rotary drum, we can handle slightly higher concentration, but in this case we cannot go as I cannot go for a higher concentration more than 5 percent solid concentration ok.

So, when the slurry comes into it, there is a leaf individual leaf and this is the section where the filter outlet is there. So, when it comes here it is going through this medium and then it comes to the section and the filtrate is going out or to be collected as per requirement ok.

(Refer Slide Time: 14:16).



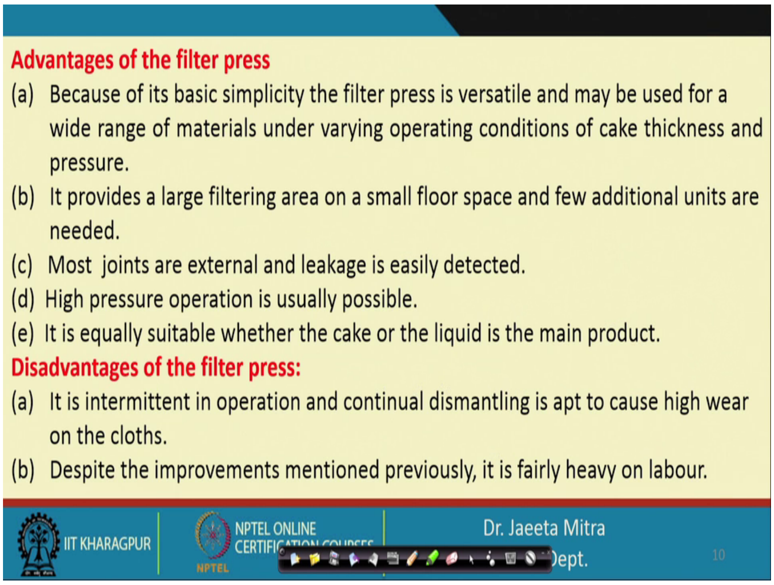
So, leaf filter which we can also call it we calling the constant pressure filter because here the difference pressure difference across which the filtration takes place that is constant and we can increase or decrease the number of leaf or the plates that we are using. This is also based on the capacity of the plant we can upscale or downscale as per requirement.

So, there is a frame. There is a frame with then, we have with that plates. So, between two frame one plate is attached ok. Every two frame there is one plate and when the slurry comes into the filter medium ok. So, it is entered into the section and then whatever filtration, clear filtration will have through the filter medium; it will collect in a channel and the filtrate will collected from the other section.

There is a filter cloth between every filter and the plates ok. So, every plate between every plate and filter there is a filter cloth. So, there is we can see that when some plates are operative, we can have some backup plate. When the capacity increases, we can make it you know workable and if it is not required, we can fix it like that.

And the operation is same this is just clear picture and this is how the plates look like, if you take a cross section. So, this kind of channel will be there because this is the inlet channel and it spread across the whole leaf or the plate. From this section we feed the inlet ok. The cleaning is also bit easy, we can dismantle this a whole frame and plate assembly and we can clean it effectively. So, this is the leaf filter ok.

(Refer Slide Time: 16:47)

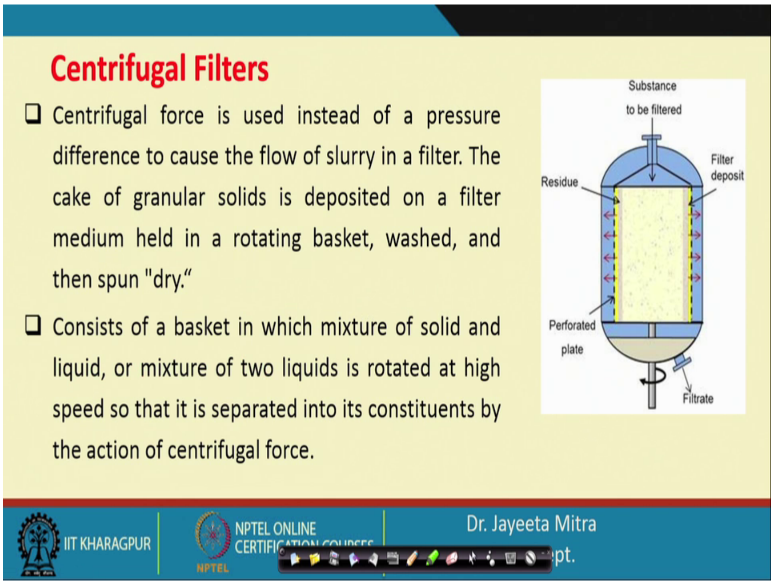


So, the advantage of the filter press; if you see because of its basic simplicity the filter press is versatile and may be used for a wide range of material under varying operating condition of cake thickness and the pressure. So, various pressure differential can be created across the across the you know filter filter medium and then this different for the for different material also this can be used. It provides a large filtering area on a small floor space and few additional units are needed ok.

So, because, we are stacking more and more plates on a horizontal area most joints are external and leakage is easily detected. High pressure operation is usually possible and it is equally suitable whether the cake or the liquid is the main product.

Now, there is some disadvantage associated with it this method as well. It is intermittent in operation and continual dismantling is apt to cause high wear on the cloths. And despite the improvement mentioned previously, it is fairly heavy on labour. So, although some modification has been done, but high labour in intensive method it is. So, these are the disadvantages.

(Refer Slide Time: 18:22)



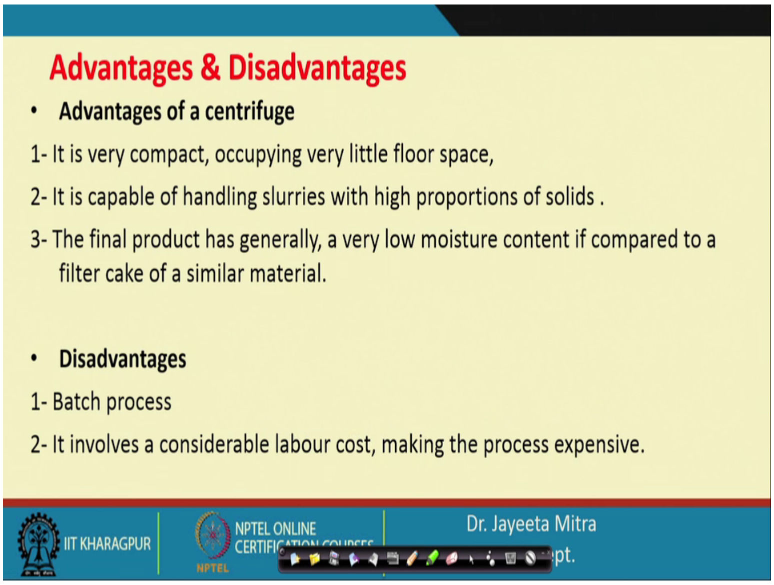
Now, the in the filters the last category is the centrifugal filters. So, we normally create a pressure drop across which the filtration can take place. Now instead of the pressure drop in centrifugal filtration we are using the centrifugal force ok. So, based on centrifugal force, we try to channelize or try to throw the slurry towards the filter towards the perforated filter medium or filter cloth and then it will you know the filtration will take place ok. So, instead of a pressure force centrifugal force is used here to call the flow of slurry in a filter.

The cake of granular solid that is being deposited in the inner layer of the perforated plate ok so, on the perforated plate, there will be there will be a residue and there will be a deposition also. So, granular solid is deposited on the filter medium held in a rotating basket so; obviously, this have to be rotating, this have to be a cylindrical or this barrel kind of system and it is rotating continuously.

So, that the centrifugal force can be utilised for filtration, this can be washed easily and then we can burn it dry. This consist of a basket in which the measure of the solid and liquid or mixture of two liquids is rotated at a high speed and that is separated into its constituent by the action of centrifugal force. So, whether the solid or liquid we are taking or two different density liquids we are taking ok; so, in that case if it may be a liquid liquid mixture or solid and liquid mixture.

So, mostly filtration we do when there is any even if it is low, but some concentration of solid should be there. So, that will be that will be deposited on the filter medium and the clear filtered will be taken out. So, this is very effective because in some cases when the you know, the pressure difference we cannot create enough to cause this cause this filtration that time we can use this one so, that we can get a higher higher force to call the filtration.

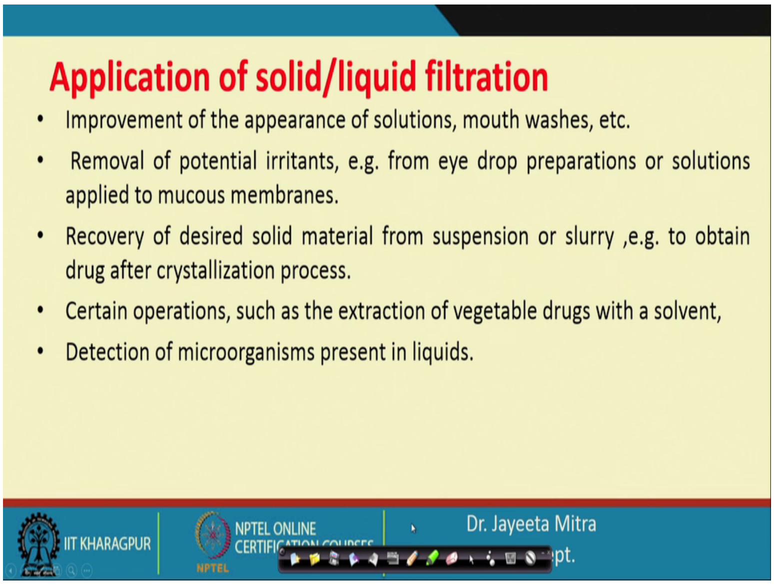
(Refer Slide Time: 21:21)



Then advantage and disadvantage- so, advantage of a centrifuge it is very compact occupying very little floor space. It is capable of handling slurries with high proportion of solid and the final product has generally a very low moisture content, if compared to a filter cake of similar material. So, because of the centrifugal force its constantly you know having the having the higher pressure differential and the moisture will be total most of the moisture of the cake has been separated and as going as a filtrate.

Disadvantage is that its a batch process and it involves a considerable labour cost making the process expensive because we need to dismantle it and then, clean it properly; if all the deposition in the surface and then again assemble and then we can use it. So, that is why it is a labour intensive method.

(Refer Slide Time: 22:25)



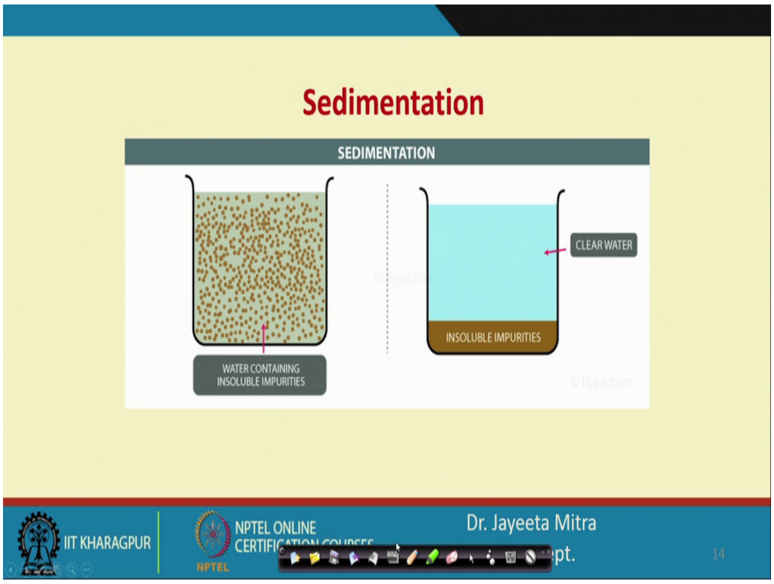
Application of solid or liquid filtration, it is used mainly in the improvement of the appearance of texture or you know to get a good appearance of a solution. For example, if we are taking some fruit juices and there is some suspended particle and that may not be liked by the consumer or some you know the fraction of seed etcetera is there. So, we need to make it a clarified juice; so, we filter it and to get a good clear solution ok.

So, improvement in the appearance of solution that is one, then mouthwashes etcetera. Then another thing is removal of potential irritants. For example, from the eye drop preparation or solution applied to mucous membrane ok. So, whatever the irritant are there that is being filtered by this application.

Then recovery of desired solid materials from suspension or slurry because sometimes dissolved material is of interest not only the filtrate. So, in that case, if we apply heat for removal of the water and then we want to get that material; it may not work because some time the heat sensitive materials are there. So, filtration is very easy and low cost method for that matter when we want to desired the solid material from the suspension or slurry. And we can we can use it for the crystallisation process also to recovery of the crystallisation crystals.

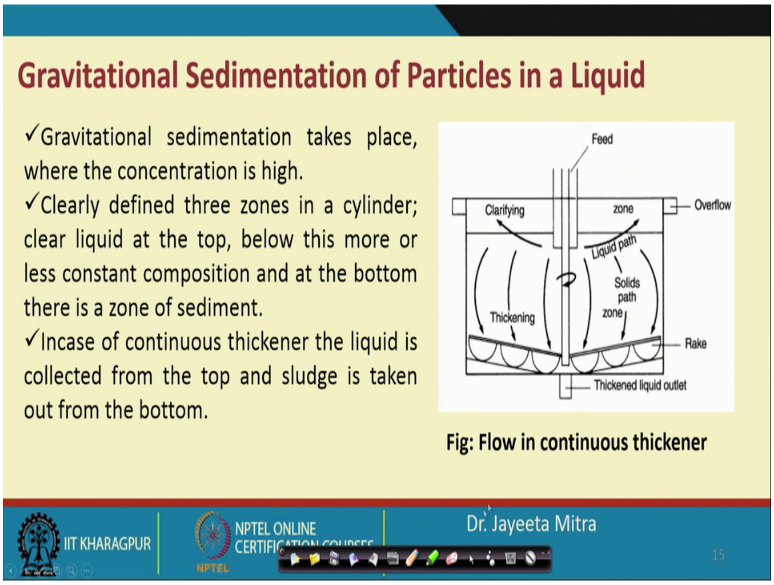
Then certain operations such as extraction of vegetable drugs with the solvent the detection of microorganism present in the liquids. So, when we want to extract the solvent, sometime we make a miserly of the product from which we are extracting the you know. Essential components or extraction and then we mix it with a solvent and then go for filtration. So, that we can get the component extracted in the solvent. So, these are the common application where filtration is being used.

(Refer Slide Time: 25:01)



Now, coming to the sedimentation - sedimentation is very easy method and most commonly used in the you know separation mechanical separation processes. And if we keep the material for some longer time for a suspension or solution we keep it for a longer time, we may get three distinct layer in it first layer will give you a clear filtrate ok. The upper layer will give you a clear filtrate and then at the middle you may observe uniform composition layer ok. You may get a uniform composition layer that there still the particles are about to settle, which will be settle if you keep it for a further longer period and at the bottom, you will get the heavy deposition of the insoluble impurities ok.

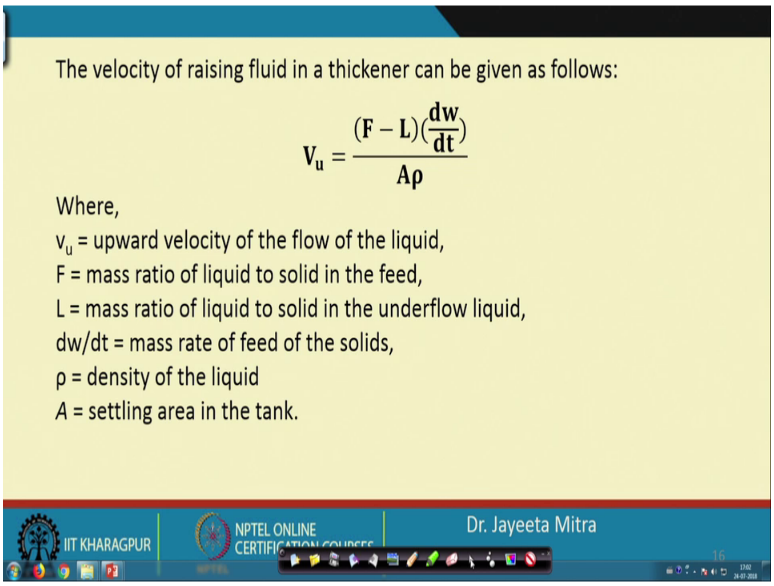
(Refer Slide Time: 26:11)



So, sedimentation generally occurs because of the gravitational motion and this most commonly performed when the concentration is high. So, this is as I said that three for clarification of many material, we can we can use this method where the bigger particles or higher concentration of the solid will be settle down at the bottom because of the gravity flow.

And in case of a continuous thickener, the liquid is collected from the top and sludge is taken from the bottom. Because the upper liquid which is you know the clear liquid or clarified liquid will be at the top, so that is collected and the sludge is collected from the bottom.

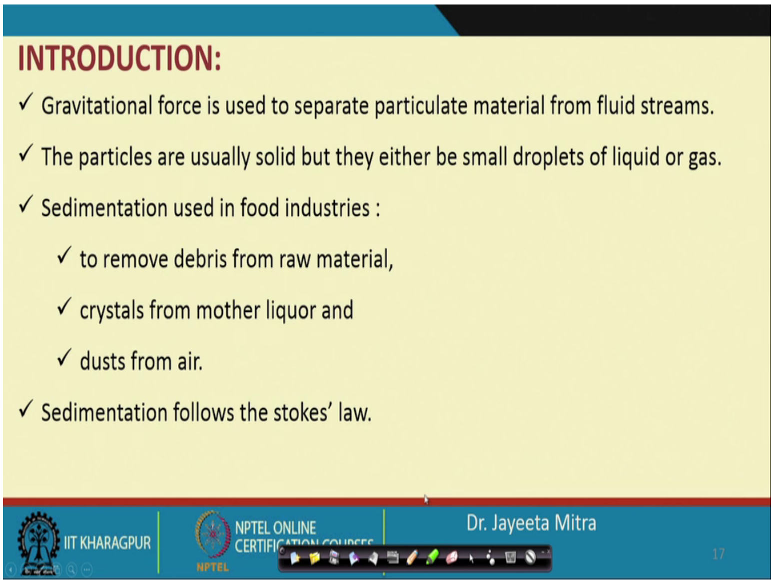
(Refer Slide Time: 26:58)



Now, the velocity of raising the fluid in a thickener can be given as follows V u that will be equal to capital F minus L into dw by dt by A into rho. So, this V u is the upward velocity of the flow of the liquid, capital F is the mass ratio of the liquid to solid in the feed; that means, when we are putting the slurry into the thickening thickener ok

So, then, what will be the concentration of the liquid to solid? And then when we are getting the L, L means the mass ratio of the liquid to solid in the underflow liquid; dw by dt is the mass rate of feed of the solid and rho is the density of the liquid A is the settling area in the tank.

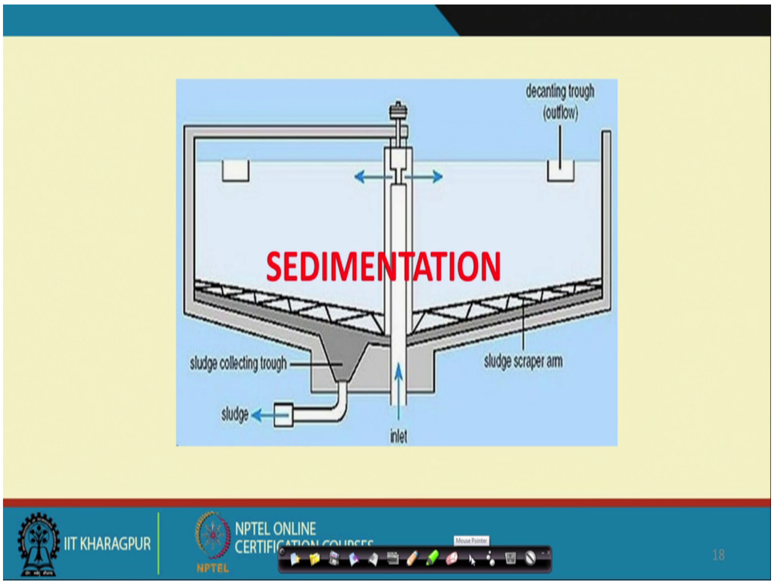
(Refer Slide Time: 28:10)



So, in the sedimentation the gravitational force is used to separate the particulate material from the fluid streams; obviously, and the particles are usually solid, but they either be small droplets of the liquid or gas. So, generally solid particle we handle, but maybe some liquid particles also will be settle.

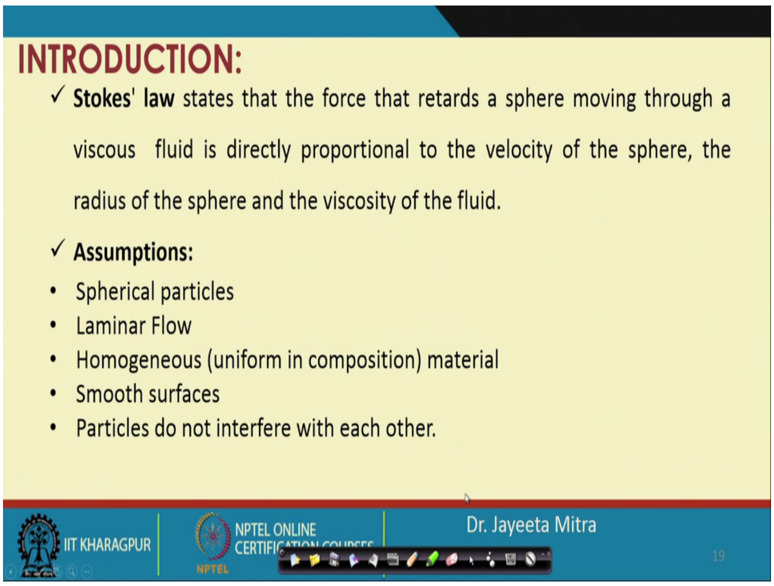
Sedimentation used in food industries to remove the debris from the raw material, then to separate the crystal from the mother liquor and dust from the air. And sedimentation that the principle of how we calculate the velocity that follows from the stokes' law.

(Refer Slide Time: 28:59).



So, if we see this kind of a arrangement is normally done where the where the slurry is fed from the bottom this is the inlet section and then it is spread continuously in the whole system or the tank. And then when the sedimentation will takes place that is the higher concentration of the solid particle will settle down at the bottom, the sludge collection trough is there and from where this is collected and the decantation or the outflow or the clear liquid that can be collected from the top. There is a also sludge scrapper arm is provided.

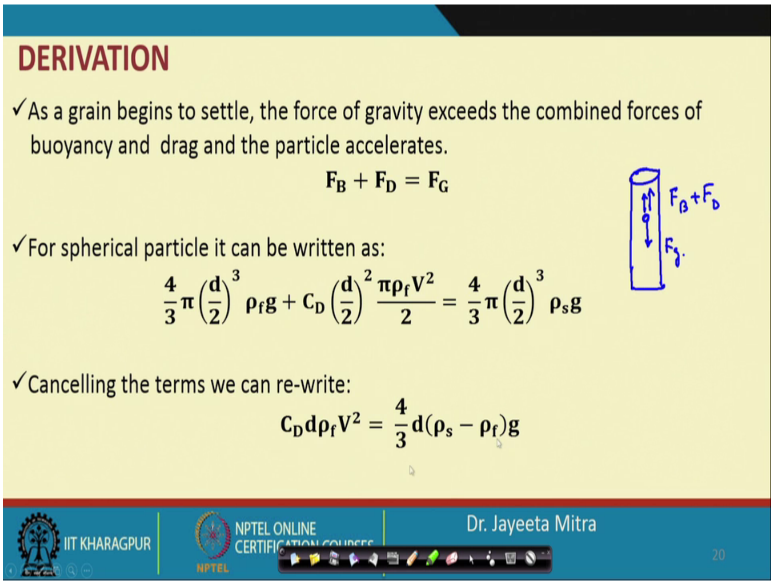
(Refer Slide Time: 29:50)



Now, then we will see then how using the Stokes' law, we can calculate the you know velocity, settling velocity. So, stokes law states that the force that retard a sphere moving through viscous fluid is directly proportional to the velocity of the sphere and the radius of the sphere and the viscosity of the fluid ok.

And for that we have certain assumption that, we have assumed that the particles those are you know suspended in the material. So, those are of spherical shape and we also assume that the fluid is flowing in a laminar flow and the composition is uniform, the composition of the material is uniform composition of the solid particle. And also of the fluid that is uniform and the particle surface are smooth that that is also one assumption particle do not interfere with each other ok. So, these are the basic assumptions that we take while doing the you know doing the derivation of mathematical expression to express the settling of a sedimentation or settling up a particle using stokes law.

(Refer Slide Time: 31:18)



So, as the grain begins to settle or the particle begins to settle what are the forces that will act on that body. So, obviously, first thing is the gravity because it is falling at the bottom because of the gravity force only. However, there will be buoyancy force and drag force also.

So, the force of gravity that exceed the combine force of buoyancy and drag, then only the particle will begin to settle ok. So, when it tries to fall, the opposite force that the liquid you know exert on the particle that is the drag and buoyancy also that is acting on the upward ok.

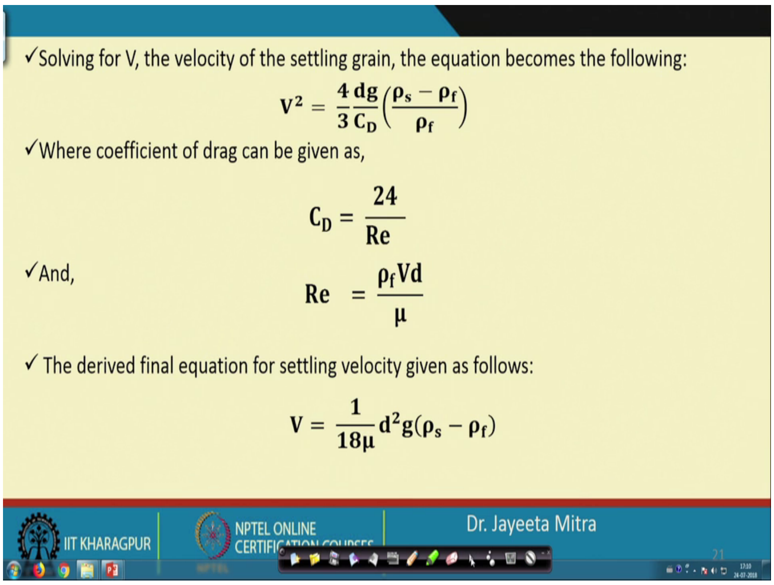
So, if we consider like a cylindrical a cylindrical channel is there where a particle we have taken and that is falling; so, the force the two force that is acting on it upward direction that is F B buoyancy force and F D and here F G that is the gravitational forces acting. So, when the gravitational force is at least equal or greater than this will be settle. So, we will balance this or we equate this with the buoyancy force and drag force.

So, for spherical particle we can write this as first is the gravitational force that is 4 by 3 pi r cube 4 by 3 pi r cube that is the volume into rho s, the density of the solid in to g ok, gravitational force. And here we have buoyancy that is 4 by 3 pi into r cube into rho f where this is the density of the fluid into g ok.

So, the buoyancy is because whatever mass is it has been at replace or displaced that has been you know exerting and upward directional force on the particle plus this is the drag force C D into r square pi rho f in to V square by 2.

So, pi r square this is the projected area of the particle and rho f is the density of the fluid, V square by 2; this is the velocity and. So, when we equate this when we equate this, we can find an expression of velocity that is our ultimate aim. So, we can write c d into d in rho f into V square that is equal to 4 by 3 d rho s minus rho f into g; rho s and rho f is the density of the solid particle and density of the fluid respectively.

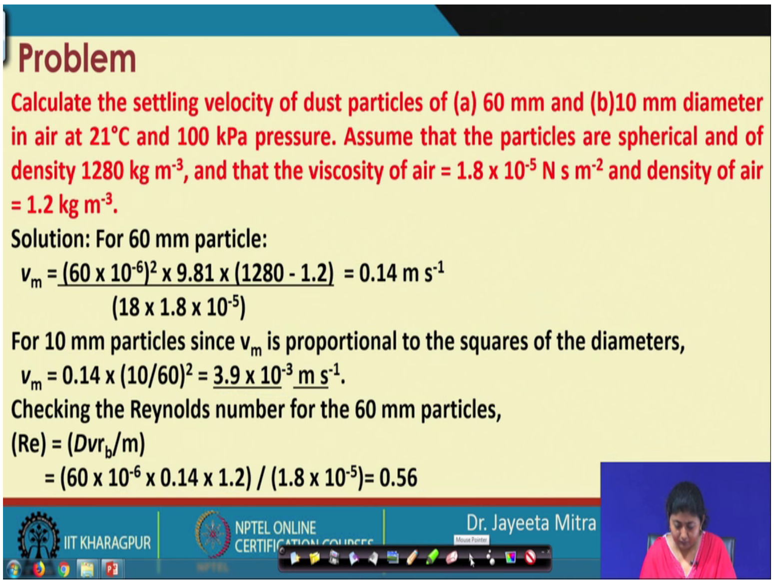
(Refer Slide Time: 34:39)



So, if we get the expression of a velocity here, we are getting V square equal to 4 by 3 d into g by C D into rho s minus rho f by rho f; C D is drag coefficient. So, this value is 24 by an R e 24 by Reynolds number. So, we will use that that one and an re again rho V d by mu. So, rho is rho of the fluid it will be. So, we will put this value of C D here in the this equation.

And finally, we will get the expression of velocity that is the settling velocity of the particle that is 1 by 18 mu d square g rho s minus rho f; mu is the viscosity of the fluid, g is acceleration due to gravity, rho s and rho f is the density of the solid and fluid ok.

(Refer Slide Time: 35:38).



So, let us see one problem. Calculate the settling velocity of dust particle of a 60 mm and of 10 mm diameter in air at 21 degree Celsius and 100 kilopascal pressure. Assume that the particles are spherical and of the density 1280 kg per meter cube and the viscosity of the air is 1.8 into 10 to the power minus 5 Newton second per meter square. Density of the air is 1.2 kg per meter cube.

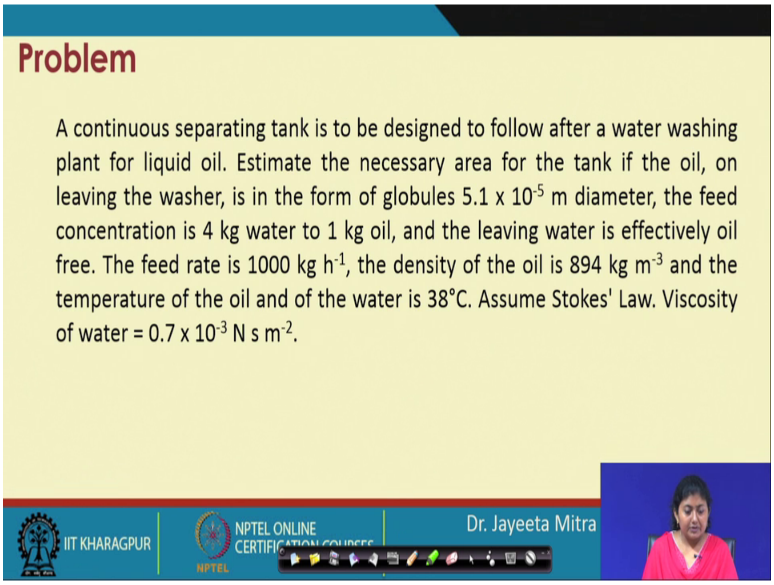
So, with this data, first we try to see that what will be the velocity of two different particle dia 60 mm and 10 mm. So, for first case 60 mm that is the d square into g. So, this is 60 m d square into g into rho s minus rho f density difference that is equal to divided by 18 mu; mu value is given 1.8 into 10 to the power minus 5. So, we are getting 0.14 meter per second ok. This is 60 mm. So, we have converted to meter this is 9.81 and 1280 kg per meter cube. This is also 1.2 kg per meter cube for air.

Now, for 10 mm particle since V m is proportional to the square of the diameter. So, we can use this directly using 10 mm and all the value or simply we can calculate from this because the ratio of these two will be same when all other parameter; that means, the density of solid and the and the fluid viscosity and everything are same. So, V m can be easily calculated as 0.14 into 10 by 60 square that is 3.9 into 10 to the power minus 3 meter per second.

So, then checking the Reynolds number for the 60 mm particle; what will be the Reynolds number? Rho V d by mu. So, rho is 1.2 because it is density of the fluid we need to take. So, 1.2 kg per meter cube, this one; then velocity of that 60 mm particle that is 0.14 meter per second and then d is 60 in to 10 to the power 60 mm is there. So, so, it will be 60 mm. So, 60 into 10 to the power minus 3 and ok

So, here it will be mm to meter. So, 60 into 10 to the power minus 3, it will be and divided by 1.8 into 10 to the power minus 5. This is the value of mu that is given ok. So, here we will we will have this value some; so, around 560 will be the value. And so, this is how we can solve if the particle diameter is given and the density of the fluid whether it is air or whether it is some liquid water or something that is given. So, using this equation we can calculate it.

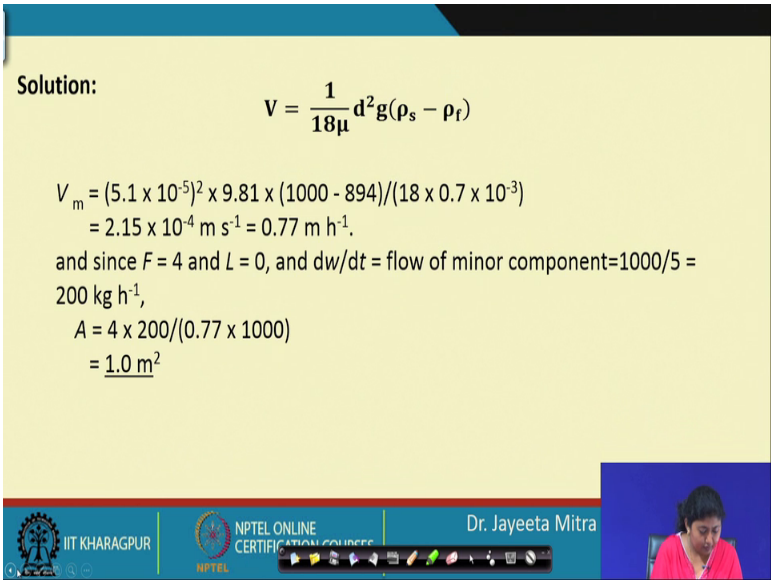
(Refer Slide Time: 39:57)



So, another problem is a continuous separating tank is to be design to follow after a water washing plant for liquid oil. Estimate the necessary area for the tank if the oil, on leaving the washer is in the form of globules of 5.1 into 10 to the power minus 5 meter diameter. The feed concentration is 4 kg water to 1 kg oil and the leaving water is effectively oil free.

Because it has to be it has to be separated properly. So, it will be oil free and the feed rate is 1000 kg per hour. The density of the oil is 894 kg per meter cube and the temperature of the oil and the water is 38 degree Celsius. Assume Stokes law viscosity of the water is given as 0.7 into 10 to power minus 2 Newton second per meter square.

(Refer Slide Time: 41:02)



So, what we will do? Again we will use this equation V equal to 1 by 18 mu into d square g into rho s minus rho f. So, d is the diameter of the particle here. So, V m will be 5.1 into 10 to the power minus 5, this is the particle size given square into 9.81 into 1000 minus 894. So, because it is water and oil ok.

So, what was given 1000 kg. The feed rate is this one and ok, the density of the oil is given as this one and density of water is taken like that ok. So, divided by 18 mu. So, we are getting the velocity 2.15 into 10 to the power minus four meter per second or meter per hour, we can convert it.

Now it is given that the ratio of that is the ratio of the, see concentration ratio of the oil in the feed that is 4 kg of water 1 kg oil and when it is leaving there is no oil. So, ratio of the solid to liquid if we consider that way or if we can consider here the concentration of the oil that has to be separated in the total feed stream or the or the oil is to water and in the exit also the oil is to water.

So, then we can take F is equal to 4 and L equal to 0 because there is no oil. So, here it is 4 is to 1 and there is there is 0, L will be 0 dw by dt is the flow of minor component. So, 1000 divided by 5 because the total is entering the total feed is entering in that 4 parts is of water and 1 part is of oil, together if 1000 kg per hour is the rate.

So, the rate of minor component will be 200 kg per hour and the area is 4 into 200 divided by 0.77. This is the velocity and this is the density. So, 4 area will be 4 times this 200 because the mass flow rate if you want to calculate, 200 will be for one fraction.

So, 4 fraction is that is that constitute the water steam that is coming. So, 4 into 200 divided by 0.77 into 1000; the area we are getting 1 meter square ok. So, we will stop here and we will continue in the next class.

Thank you.