Fundamentals Of Particle And Fluid Solid Processing
Prof. Arnab Atta
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 34
Filtration (Contd.)

Hello everyone and welcome back to the another class of Fundamentals Of Particle And Fluid Solid Processing. So, we were discussing about the fluid solid processing related to Filtration. We have discussed, the cake filtration in when we have seen the resistance of the cake and resistance including the filter media. These two scenario scenarios and we have solved two work out problems to understand the theory.

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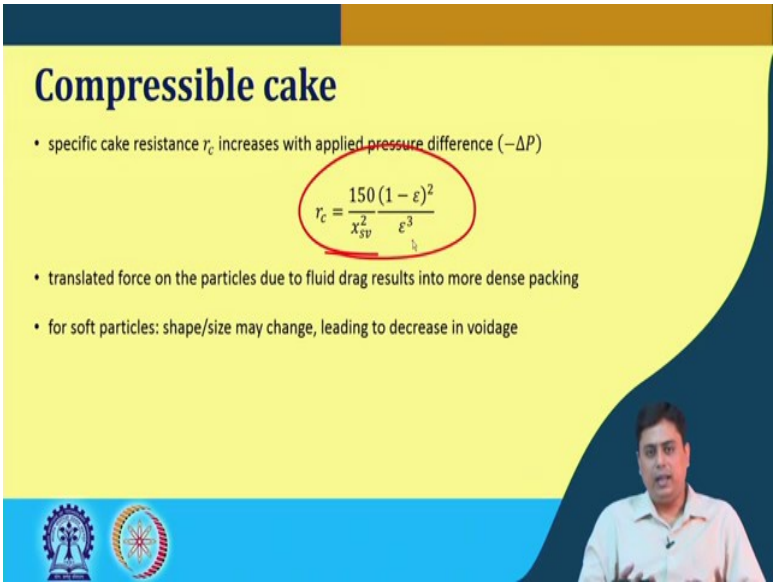

Now, mostly and in fact we have dealt only with the incompressible cake assumption that that the voidage of this deposited cake does not change with pressure or the specific the resistance becomes or remains same. So, but most of the cases it has been seen that this specific cake resistance increases with applied pressure difference.

Now, if we recall this expressions that is shown here, ok

$$r_c = \frac{150}{x_{sv}^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}$$

we can see that this specific cake resistance is basically dependent or a function of the bed voidage of the porous medium porosity. Now, the point is that when this initial cake deposition happens and after that this cake thickness increases. So, what happens? This particle drag the fluid that drag that been exerted on the particles that transmit through the way, that the bulk motion of this fluid that exerts on this particles that and when it settles this force basically propagates throughout the bed.

So, the particles that are lying exactly on the filter media, that feels a force that is the summation of all the particles that has been deposited on top of these to the upstream surface of the cake deposition layer. So, and this makes the packing more denser and as the pressure difference changes, so this becomes influenced, ok. So, this cake porosity changes with the applied pressure.

Now, in case of soft particles their shape and size may change during the deposition or under this pressure that leads to the decrease in the overall voidage of this cake. And in this cases, the problem the way that we have solved the earlier problems or that we have handed the earlier problems is not the similar. So, this kind of scenario or this kind of cake, we say that these are the compressible cake because the resistance the changes with applied pressure.

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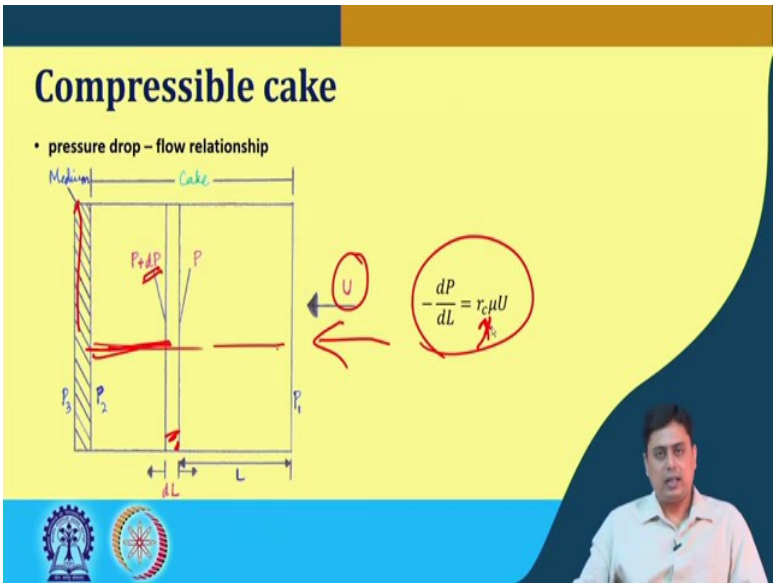

So, how do we deal such system? So, let us say we have a filter medium which is the shaded part. The flow is happening from this right side to the left side. Now, this is happening at a velocity U, we take a let us say this is the thickness of this cake that has been deposited, ok.

So, this is say the upstream surface of the cake, this is the whole length and if we consider an elemental length say dL, the pressure drop from this upstream of the cake or since the interface of the bulk liquid and the cake to this point if this we consider is the ΔP, ok, so now, in this case the differential pressure will be dP for this elemental region.

And for this case, if we assume that the flow is happening in laminar condition then

$$\frac{-dP}{dL} = r_c \mu U$$

is basically the specific resistance multiplied by viscosity and superficial velocity. Now, this specific resistance we have seen the expression.

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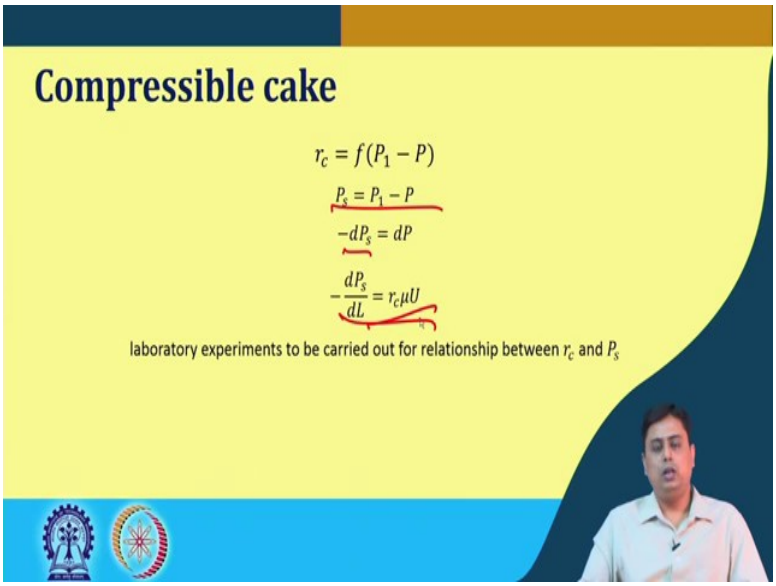

Now, this r c is a function of pressure, as this pressure increases the resistance increases because the cake becomes more denser and denser, the voidage is lesser there is less path to flow for the filtrate. Now, if you consider this scenario that

$$r_c = f(P_1 - P)$$

then we can write that

$$P_s = P_1 - P$$

$$-dP_s = dP$$

$$\frac{-dP_s}{dL} = r_c \mu U$$

Now, the point is here this r_c versus P_s this relation is not easy to find, this has to be determined by several laboratory experiments, the relation between this pressure difference and the specific cake resistance. If we have those data set we can use this expression and we can find out the relevant expression for the time required to filtrate a certain volume v of the filtrate in case of compressible cake.

So, the point that you have to remember that in case of compressible flow, this is specific resistance is varying with pressure. So, based on this idea there are there can be several experiments to perform and we can find out thus what is the relation between this r c and P s that can be used in this expression to find out what is the required time or the volume of the filleted that can be processed at a certain point of time.

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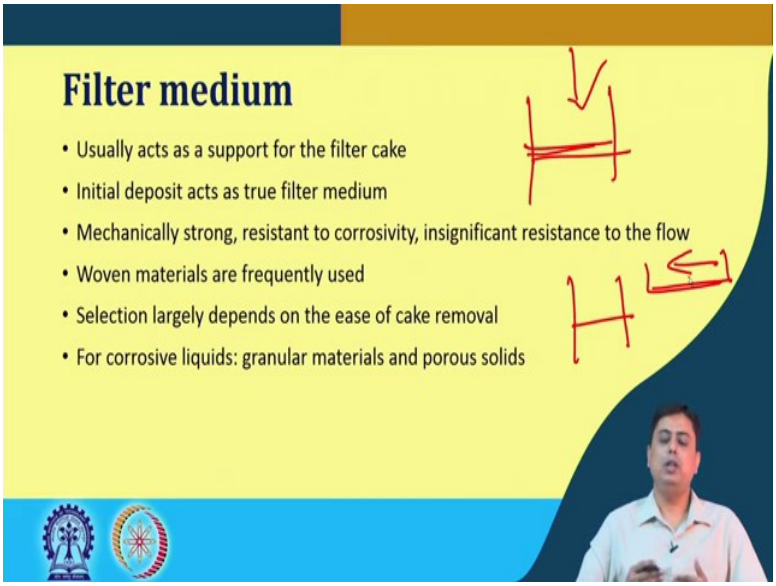

Now, we will move on to the several practices that actually happens during this filtration process that what are the suggested processes or what are the suggested criteria to follow an appropriate filtering condition. The immediate point is the filter medium that you should choose or that is chosen for a certain process. We have to remember that this filter media is basically acting as a support to the filter cake.

Now, all the discussions that we are doing or we have till now the orientation of this filtration we called as the dead end filtration which means the surface area, if this is our filter surface area the flow is happening perpendicular to that the surface that is available. The other way of filtration that we will discuss in a later stage is the cross flow filtration, so which means if you have this filter media the flow is happening parallel to the surface of the filter media.

So, in this dead end filtration, this and in cross with filtration also, we have the filter that actually acts as a support to the filter cake, the initial deposits that basically acts as a true filter media. So, which means this filter medium has to be a strong enough to with stand height throughput of the suspension as well as the weight of the cake, the impact of the particles, impact of the suspension, it should be resistant to corrosivity and ideally it should have a in significant contribution towards the resistance to flow because it is the initial deposits of the cake which will act as filter. Typical material there are used for this filtering medium is or are the woven materials.

Now, the selection of this woven materials largely depend on how easily the cake can be removed from the surface because remember in all this cases that we are discussing we consider that solid particles are the valuable product that are deposited on the surface and we can easily scrap it out, we can process those solids and we can recover the solids. So, the choice of this filter media in such cases should be such that we can easily take out that cake and wash it. For corrosive liquids, typically the granular material or porous solids are used as the filtering medium because this woven materials are typically prone to fouling as well as the corrosivity of the solution of the suspension can harm that filter medium.

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Now, during this process we have mentioned these, but let us take a deeper look into this that when this initial deposition happens this formation initial formation of this cake layer is unimportant phenomenon because it then dictates that how the filtration rate will be.

So, we mentioned that there can be two processes; one is the blocking of the pore, pore of the filter medium and the other that will sit on the surface. We broadly classified in this two processes and also it is mentioned I have mentioned that these two processes sometimes cannot be separated. Now, this blocking of pore depends on the nature of the surface structure of the filter media, it is affinity towards the particle or the suspension and the movement of the particles. This particles in suspensions are moving freely and it is having the bulk velocity of the fluid. So, to block the pore it has to be streamlined and targeted towards the pore, which is sometimes very difficult.

So, the point is that this initial cake formation process ranges between two extreme; one is the penetration of the pores by the particle, the other is the formation of bridges to prevent this entry of the pore. So, this process basically place in this two extreme range, sometimes one, sometimes other and most of the times it is the interplay between these two.

Now, the specific resistance of cake, it is typically assume to be dependent on the amount of deposit and it works this assumption works pretty nicely, because after several experiments it has been proved that this special specific resistance to the filter cake is actually dependent on the amount of the deposit that is having on the top of the filter medium. But having said that

influence of pore and particle size distribution is also important because what can happen that the multiple particle can go into a single pore or an only one pore.

So, in that case what happens, the resistance increases in stages that earlier what was happening that one pore was blocking by one particle and then the successive particles where filling the other pores, so the resistances were increasing smoothly. But in if there is this pore and the particle size distributions in such a way that the multiple particles can go into one pore, then you can think of preferential deposition of the particles and in that case you can have a resistance of the cake that increases in a steps.

But practically some pores will never be completely blocked and some pores will be half or poorly blocked or partially blocked, so the cake will have lower resistances in those areas of this partially blocked or completely open pores filter pores.

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Now, particle concentration in the suspension has significant influence on this cake resistance or the filtration rate, in the overview of the introductions we have mentioned this, but let us see why that happens. The reason is that when there is the higher concentration of particles, the distance between two particles are very close, ok. So, in order to streamline this particles towards the pores to block those pores is difficult.

So, what happens? This particles of high concentration evenly distributes over the this filter media and the blocking of this pores this tendency goes down. So, that results in the cakes of

lower resistances. And quiet naturally, since it is not blocking the pores, it is not going into the pores the particle inter particle bridges are formed and that deposits on the surface. It is not going into the pores that is not in the mode of the deep bed filtration. Also sometimes, with the concentrated suspension what happens?

In concentrate suspensions the size ranges are not very wide, there is a narrow size distribution of the particles which means that this particles if those are settling rapidly or the sedimentation rate is higher, then that would be the same rate of particle sedimentations because the size range is narrower, all the particles will try to sediment at a certain or at a similar time which means there will be rapid buildup of cake if the filters surface is facing upward direction; that means, the particles are settling and it is settling all at a time, approximately at a time.

So, there will be a rapid buildup of the particles on this filter surface, compared to if that is having a downward face because then their particles are segmenting basically. So, in that case only the smaller particle in that narrower range will come closer to the surface or will sit on the surface and you have a enhanced rate of filtration in case of downward facing filter because here the cake thickness is lower. But in case of dilute suspension, the large particles will settle faster. Now, we know by stokes law the terminal velocity, and if the larger particles sits faster you can think or you can imagine that the cake will consist of these larger particles which has a larger voidage and it will create a low resistance cake.

So, in case of this dilute suspension now, consider the scenario of downward facing filter surface. Now, in that case what will happen? The fine particles will come closer to the or will sit on this filter surface, will stick to the filter surface. So, there will be preferential deposition of fine particle on the case of downward facing filter surface. So, in this case, the cake resistance will be much larger than the upward facing surface. So, the orientation of filter surface of the filter medium in such cases is critical or has to be considered considering your particle concentration in the suspension or in the slurry. So, during this practice of filtration these things have to be kept in mind.

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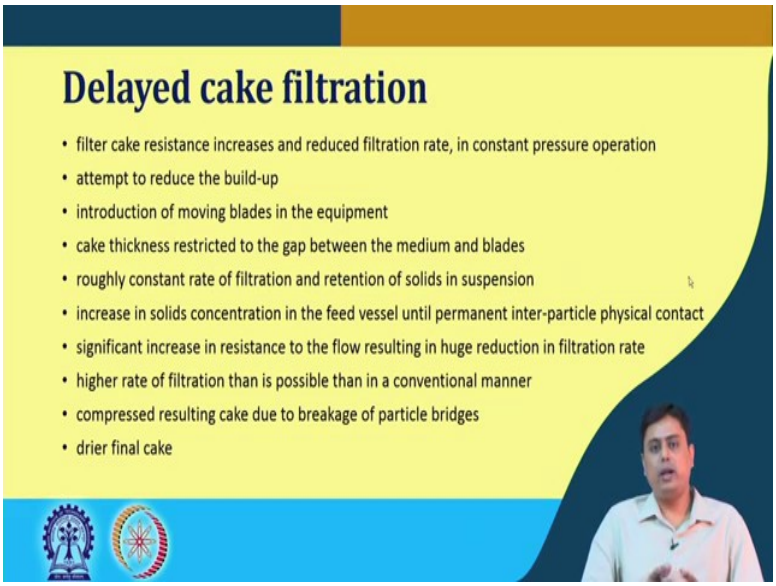

Now, in order to attempt to reduce this cake buildup because now we know this filter cake resistance increases and the filtration rate reduces which is not desired and that this happens particularly in case of constant pressure operation. So, there are attempts to reduce this buildup this cake thickness and that has lead to the introduction of moving blades in the equipment near to the filter medium. So, that it scraps those cake that is happening or that is depositing after certain thickness that has been deposited. So, this cake thickness then is restricted to the gap depth between the medium and the blade surface.

So, you give a certain depth or certain clearance between the blade and this filter media and that would be the thickness of the cake that you wanted it to deposit. So, in such cases roughly constant rate of filtration can be achieved and then this cake that is now remove after scrapping retains in the suspension. So, what happens? This width time since these solids which where depositing as cake is now retained in the suspension the concentration in the suspension increases with time or in the feed vessel until a situation appear where there is physical contact between the particles, there is no space to move those particle. Now, that leads to the significant increase in the flow resistance and huge reduction in filtration rate.

So, by this way you can have a higher rate of filtration, the overall rate can be higher than the conventional manner, but after a certain point as it has been mentioned that the significant increase in this resistance of flow will be seen and suddenly this filtration rate will be 0. Now, such a way by delaying this caked deposition of or having the cake deposition of certain

thickness, the results are that it creates a compressed resulting cake due to the breakage of particle bridges by the blades of this moving blades.

And since, this suspensions are having concerned or getting more and more concentrated and we are having this cake of certain of let us say a controlled thickness we can have more drier final cake in such case. It is becoming compressed as well as since it is becoming compressed the filtrate that were there loosely inside the pores will becoming more and more drier.

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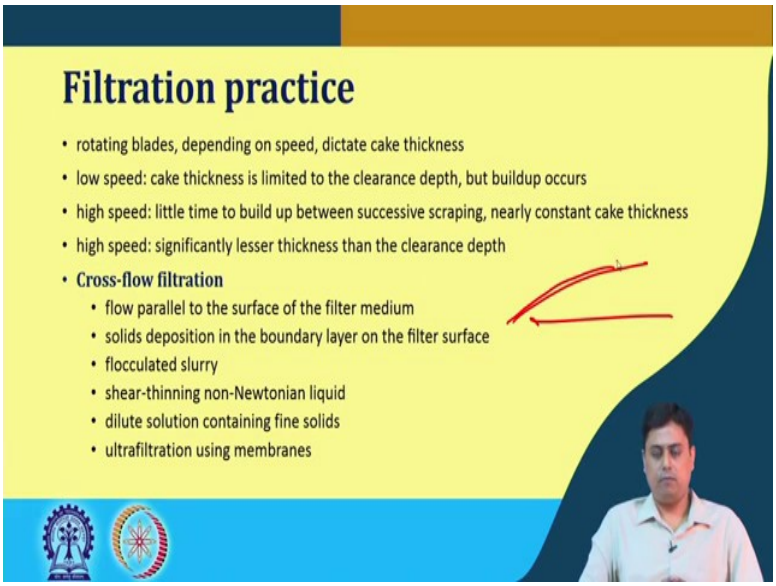

Now, if this blades are of rotating in nature or means if that is inside their inside the equipment if there are rotating blades or rotating scrappers. Now, depending on the speed of those blades, cake thickness different cake thicknesses are assumed or different types of cakes basically are assumed. For example, when there are low speeds the cake thickness is limited to the clearance depth, but the depth actually this build up occurs again when that scrap is gone and the time interval in between the another blades or that same blades comes after a certain interval to scrap those cake. Now, in that time interval the cake buildup can happen, so that means, the resistance will vary if that moving at a low speed.

But in case of high speed, there is a little I mean very little time or lesser time for this buildup to happen. It continuously removing the excess cake thickness beyond the depth of this distance between that filter media and the blade. So, in high speed we have actually the constant cake thickness with time and here we achieve a significantly lesser thickness than the clearance depth also because once this is rotating at a very high speed, near the blade

there are the wakes that are formed in the suspensions, the turbulence that local turbulence that is formed.

So, basically if the thickness of the cake is not exactly to the thickness of the gap that has been provided between the blade and the filter media. There is a optimization between this force that helps to stick to the surface or that upper surface of the cake and the convective motion of the suspension near the blade. So, in order to reduce this cake deposition, the other way is the cross flow filtration that we have mention at the beginning. In cross flow filtration what happens? The flow is happening parallel to the surface of the filter media. So, how the solids can build up?

Now, if you think of the scenario that there was a flat plate and the flow was happening, the flow over flat plate. There was the development of boundary layer where the velocity is very low, it is the viscous effect only. So, which means if that is the only viscous effect is there, the sedimentation of the particles will happen and will form layer of cake in that boundary layer and this thickness is very low, which means you can have a constant rate of filtration for a longer time.

Such scenario is helpful when there is flocculated slurries or and in fact, there are shear thinning non-Newtonian liquids that we are handling, the scenarios where dilute solutions containing fine solids because that those fine solids basically block the pore. It goes inside the pores. The examples are like ultra filtration using membranes during say the water purifications. In this case, the cross flow rate is in fact several times higher than the dead end filtration rate, the flow rate. The inflow rate or the feed rate in such cases to have a certain rate or a fixed rate of filtration is in order of magnitude difference in the inflow rate of the flow feed.

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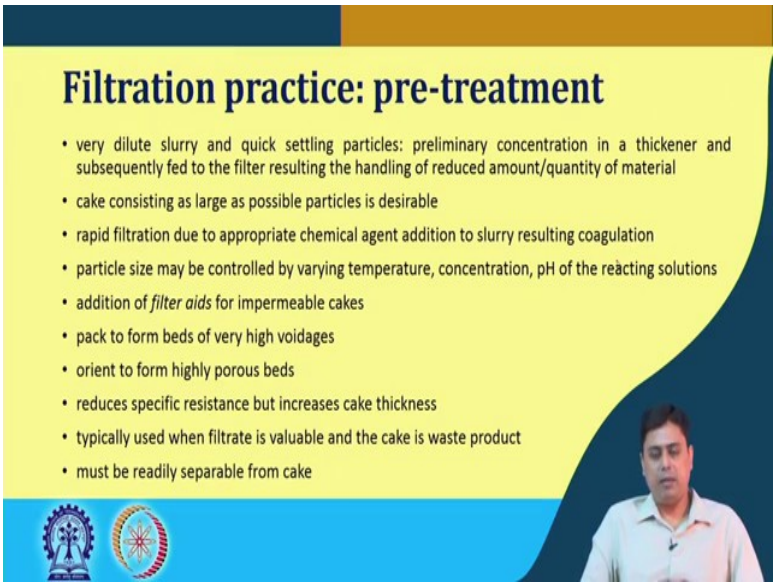

So, we have mentioned there is pretreatment whenever that is required. So, when there is a very dilute slurry and quick settling particles are there, then it is logical and in fact the pre-treatment happens in a thickener to concentrate that solution of the suspension, then what happens? You can handle a reduced amount of the slurry.

If the cake is of larger particles, that we have now known that is desirable. So, in order to make such cake, chemical agents are added or additives are added in the suspension, so that the slurry becomes coagulant, the coagulation can happen. And ones that happen, the particles get bigger then bigger that deposits it creates a low resistant cake. Also, if this is happening by precipitation the reactions, the particle size also can be controlled by temperature, concentration, the pH of the solutions.

There are also examples or practice of adding filter aids, when the cake becomes impermeable which means hard to flow inside the cake. Now, such characteristics of the cake is not desirable, it has to be porous in nature so that the filtration can happen. Now, this filter aids has a basic property that can form a bed of very high voidage, so it is mixed with the suspension as a pre treatment and then the whole suspension plus the additive or the filter aids are flown to the membrane. So, it reduces the specific resistance, but the cake thickness increases. It creates a pack bed of higher voidage, but the pack bed height increases. So, there is an optimum amount of additives or filtrates that needs to be added.

Now, definitely the economical perspective has to be there that how much is economic, but at the same time it has to be taken care that if this filtrate this filter aids are easily separable from the cake or not, because this is the cake that we are collecting and from refining as our product, valuable product. So, it has to be easily separable from the cake.

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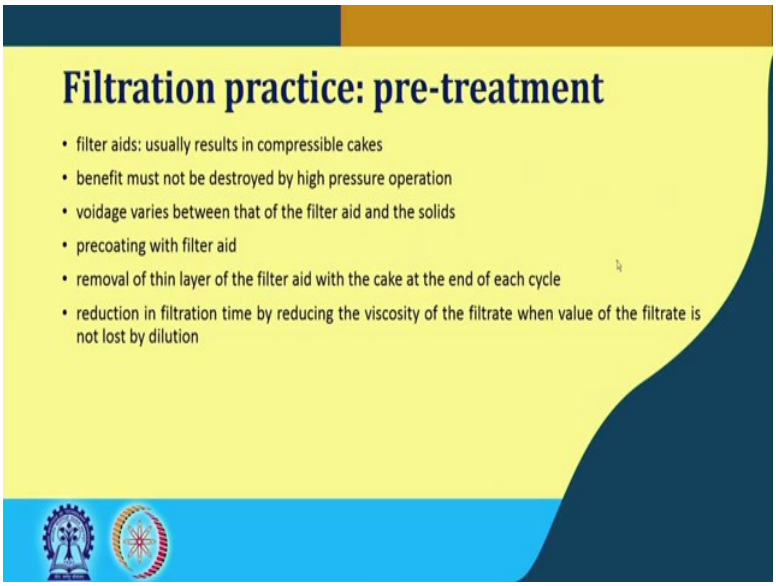

This usually results in compressible cake because as there are high voidages. So, if you apply high pressure this voidage is changing or changes. So, the benefit of adding this filter aids must not be destroyed by high pressure operation and the bed voidage is typically varies between the two extreme of bed voidage is created by the filter aid and by the only solids. In this ways this bed voidage is varies. Several ex-researchers have shown that by adding this filter aids the bed voidage can be achieved as 0.85. Sometimes the filter media is pre coated with this filter aids, so that from the initial deposit itself there is the higher voidage and lesser resistance for the filtration, but the filtration is happening at a constant rate.

During the removal, a thin layer of filter aid is also scrapped with the cake at the end of each cycle. These are the practices; these are the practices. And also, at the beginning we mention that the reduction in filtration time can be achieved by reducing the viscosity of the filtrate when the value of filter aid is not lost by dilution. In such case we can try to dilute the suspension to reduce its viscosity and have the filtration, but in that case you have to keep in mind that the value of filtrate is not lost.

So, these are typically the filtration process and of course, after filtration there is the washing process that we have already discussed. In washing process particularly in case of compressible cake the channeling phenomena can occur, because you can think the compressible cakes is having a nature that changes with pressure. So, during this operation, it will try to flow through a less resistance zone and once you can find that then that zone increases with time and with flow. And this is called the channeling, the preferential path for the flow that will happen in such cases. This can be prevented by operating the washing at a lower pressure drop, so that this change does not happen. This change in porosity of the expansion of the bed does not happen. So, these are the practices in filtration pre and post-process stuffs.

With this, I will conclude today's talk and in the next class we will see different types of filters and its selection criteria.

With this, thank you for your attention.