Mechanical Unit Operations
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Lecture 25
Filtration

Welcome to the MOOCs course - Mechanical Unit Operations. In last couple of modules, we have seen flow past solid objects, especially different flow regions, stocks and Newton flow regions. Also we have seen flow through packed beds and then fluidized beds. And then for corresponding cases, we have also developed a kind of you know working principles, equations which describe this kind of processes.

How to calculate the track coefficient if it is a kind of single particle. How to calculate the pressure drop if it is a kind of flow through packed bed. And how to calculate the minimum fluidization velocity, etc or the bed extension if is a kind flow through fluidized bed. Those kind of things we have seen. We have also seen settling of kind of particles in a centrifugal field, etc.

So why we have seen because we have realised that the in many mechanical unit of pressure, it is not only solid - solid phase interacting solid liquid phases also interacts in general. So the having information or the having particles kinematics is going to be very much useful in designing or you know controlling the operating conditions of a several type of mechanical unit operations where solid fluid phases are interacting. So now what we do; from this module onwards, or from this lecture onwards we are going to apply the principles of fluid particles interaction whatever we have seen for single particles packed bed and then fluidized bed, etc.

Those principles we are going to use for some kind of realistic or mechanical fluid mechanisms. So let us start with a kind of a process filtration where we can use the principles of packed bed, whatever we have derived previously. Those principles we can apply here and then try to develop a working principle for this or filtration processes, etc. So directly before going into the principles of filtration processes, it is better to go into some basics of the filtration processes. So that is what we are going to see. So title of this lecture is the Filtration.

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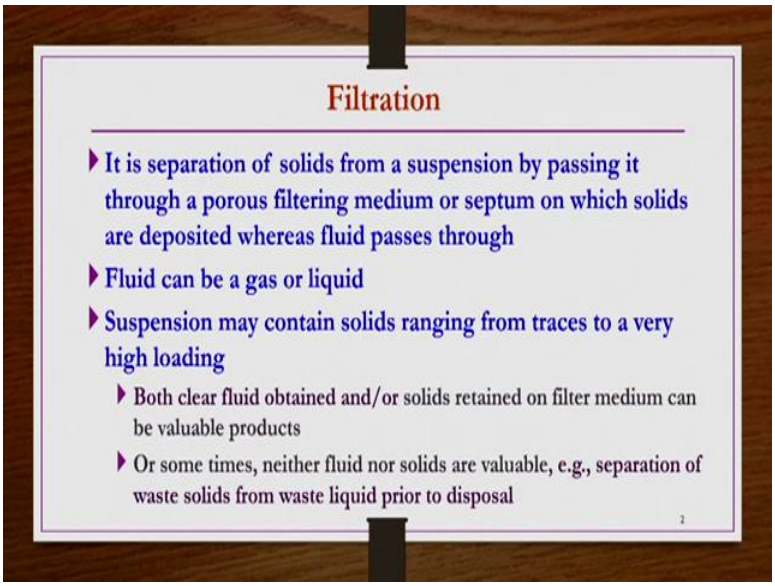

So what is filtration? It is simply in normal terminology if you wanted to say, it is kind of separation of particles from a slurry or a solution containing solids by using a kind of filter medium, so that you can have a clear or almost liquid as a kind of a filtrate. And then the solids may be retained kind of a filter medium or filtration medium.

So that is simply a filtration process but applying such simple application in industries will bring in complications in you know, design and operating of such kind of equipments. So those things we are going to see in a way. So filtration is a process where separation of solids through a suspension by passing it through a porous, filtering medium on which solids are deposited whereas the fluid passes through as a clear filtrate.

In general, this fluid can be a gas or liquid. It is not necessary that it is always a kind of a slurry from which you are separating solids. It is also sometimes the filtration process is used to separate a kind of a particle from dust laden gas, etc. So fluid can also be a gas well, not necessarily it should be liquid always in these kind of a filtration processes. Then suspension it is not necessary that suspension may be 50% of solids in general, it can have a kind of few traces also.

So whatever the slurry or dust laden gases you take for your separation of gases from your fluids; that particles may be very few traces, very few concentration like very few traces. It

can also have a kind of high loading as a kind of 40 % 50 % of given slurry something like that either of extremes are possible in general in between of these extremes anything can be possible.

So basically, these processes, these filtration processes can be used for the system where the particle are very few percentages to the particles having very high loading. And then in general when you do the separation by using this filtration process; when you separate the slurry or dust laden gases into particles and fluid also separate. Sometimes both clear fluid obtained and solids retained on filter medium can be valuable products.

Sometimes, only one of them maybe valuable product. Sometimes both may or may not be valuable product and then sometimes both of them may not be a valuable product. Something you know waste water disposal. Waste water from industry you can not dispose as it is because of the pollution control. So what you do? You do the waste water treatment and then try to separate the solids from the liquid.

Then whatever the clear or almost clear liquid you get, that you can let it go; that you can discard separately and the solids you can discard separately as per the pollution control board regulation. As per the pollution control board regulations, then you can discard liquids and solids separately if both of them are kind of not useful products.

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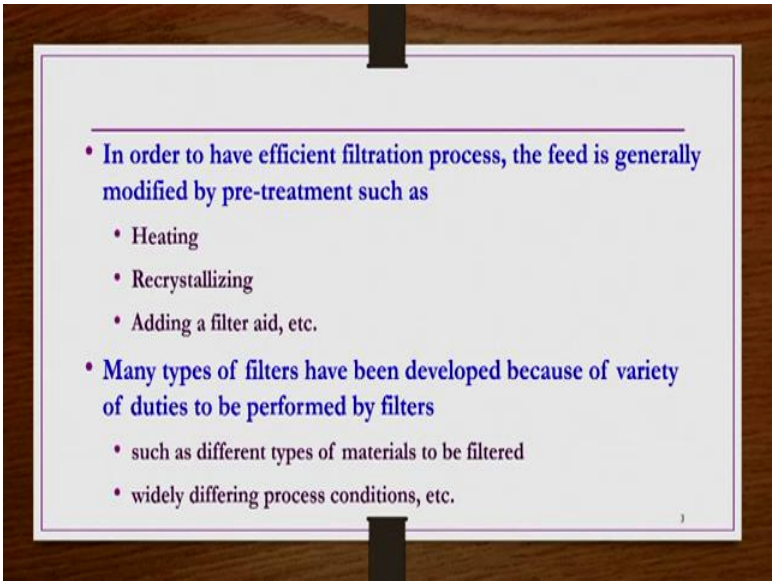

Then filtration in general is not as convenient as it looks like simple separation of solids by using a filter medium. But in general it may come across some inherent difficulties because of which filtration may not be processing conveniently or the efficiency of the process may not be sufficient. In such case, in general, some pre-treatment is carried out. Pre-treatment you know like: heating, or recrystallizing of the slurry before separation because sometimes what happens if you have a very fine kind of particles in the slurry then it may be clogging the filtration medium pores and then that maybe gradually forming a kind of impervious cake on the filter medium because of this fine particles and then further filtration may not take place.

But if you, such kind of slurry if you do, if you recrystallize it; then, this particles, this finer particles will be formed into a kind of crystals within the suspensions like that. As we have seen a kind of one a size enlargement processes. So that way once the particles will become bigger size particles then it may, this particles may not form a impervious cake kind of a thing and then filtration may not be, rate of filtration may not be diminishing with time.

So that is the reason why maybe, recrystallization may be taken as one of the ways of pre-treatment or sometimes what happens, you can add a filter aid. Filter aids are in 2 types you can add some material, some kind of filter aids to the slurry before the separation or you can have a kind of layer or a pre coating layer on the filter medium before you bring in the slurry on to the separation medium for filtration.

So either of the way, the filter medium, the filter aids are used. So adding a filter aid, etc, this kind of processes in general enhance the efficiency or the separation rate of solids from the slurries by filtration. Further, there are different types of materials to be separated in general both particles size, shape, then you know surface characteristics of the particle, etc. those many inherent details are going to affect the filtration process. Sometimes the variety of wide range of conditions may also you may also be applying for filtration. So because of such reasons many types of filters have been developed in the industry or in the literature which are often used in industry as well.

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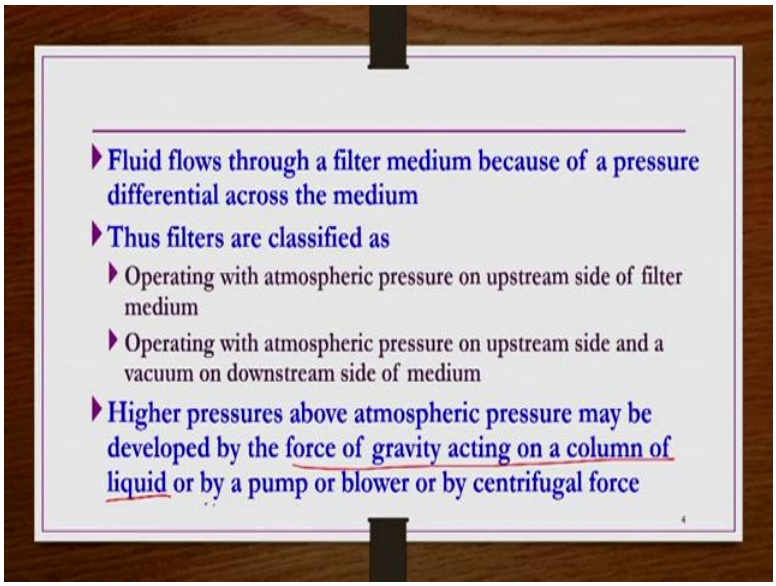

Then how the filtration takes place? Though it is a kind of simple separation, seems like a simple separation of solids from slurry by passing that slurry through a filter medium. But how this separation takes place in generally? So that takes place because of the pressure difference across the filter medium that we use.

Across the filter medium, there will be a pressure difference will develop and because of that pressure difference this operation takes place. Let us say If you have a filter medium on to which you have taken a slurry you have not applying any kind additional force, pressure force, centrifugal force or blowers etc nothing you are using. Then what happens, whatever the required ΔP is there for separation to occur, that is because of the pressure that is the column of the slurry, that liquid column or slurry column, whatever it is giving that pressure.

That pressure may be acting as a pressure, required pressure for the separation to occur. Though in such cases the filtration is not or the rate of filtration may not be sufficiently large enough. So basically whether you apply the external force or not the filtration is taking place because of the pressure difference that is developed across the filter medium. Because of that reasons the filters are in general classified as a kind of the one filers which operates with atmospheric pressure on the upstream side of the filter medium.

And the filters which operate with an atmospheric pressure on the upstream but with a vacuum at the downside of the filter medium. These two ways, one can classify the filters based on the pressure difference that have been developed across the filter medium. Sometimes having atmospheric pressure in the upstream side of the filter medium may not be sufficient to have a kind of required filtrate rate.

So in such case, in general what you need to do in general, you need to increase the pressure above the atmospheric pressure. So how you can do? That you can do simply by the force of gravity acting on a column of liquid or by using some pumps or by blowers or by similar forces.

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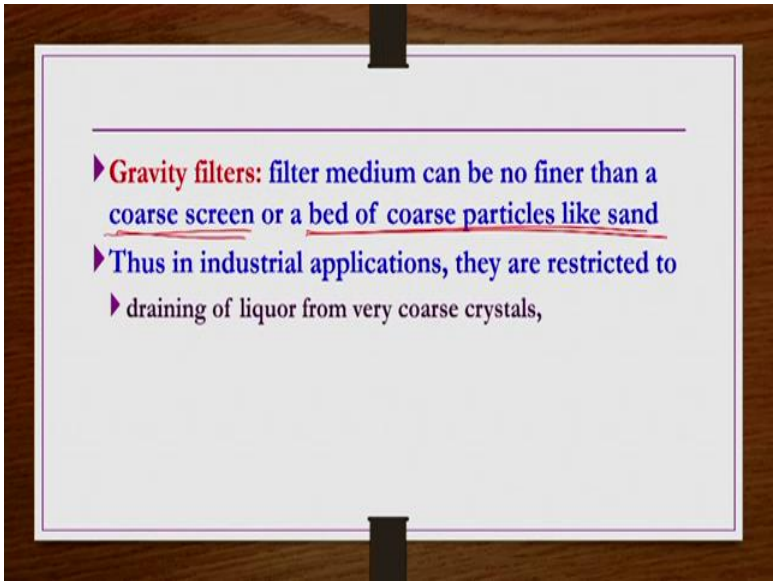

Now we see the gravity filters, in general we might have seen separation or the cleaning of water through, allowing it to pass through allowing it to passing through a kind of a bed of sand in general. So by you take a bed of sand and then you allow the liquid or the water that you wanted to be cleaned. So what you do whatever the bed of sand through which you allow the water. And then the water to pass through the bed of this sand.

So whatever the coarse particles, etc are there in the liquid or water that would be retained by the bed of sand and then clear water can be taken at the bed. That is the simplest case, one can see as a gravity filters. So in the gravity filters, filter can be no finer than a coarse screen or a bed of coarse particles or something like sand. So because of these reasons, their application in industries in generally restricted. Why because the filter medium is just a coarse grain or a kind

of coarse particles like sand where you can retain only the coarse particles are there in the solution, whatever are there. So that is because their application is limited because of this reason. So industrial applications are also restricted in general to draining of liquor from very coarse crystals or clarification of portable water or treatment of waste water, etc.

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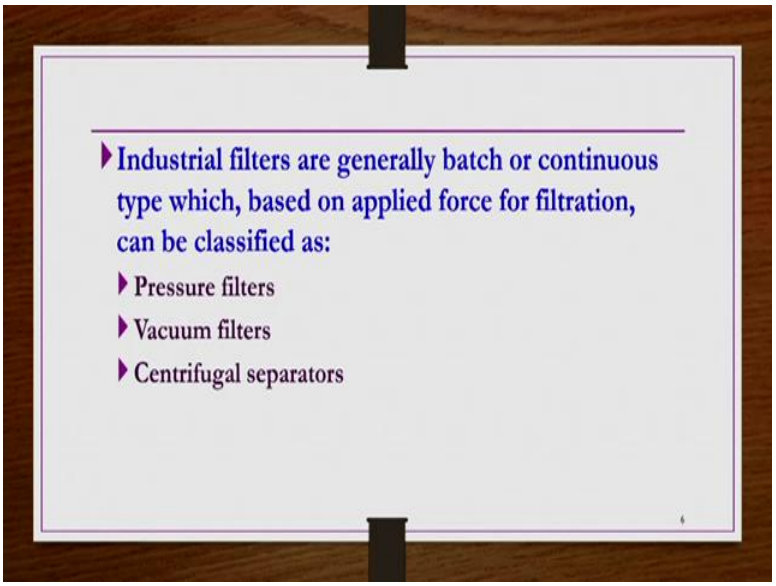

Now coming to the industrial filters. Industrial filters in general, they operate in either continuous mode or in a kind of batch mode. So but whether it is continuous mode or batch mode, the force that is applied for filtration to occur is going to play a kind of vital role on the performance or degree of this operation. So that is reason based on the force that is applied by the filtration to occur. The industrial filters are in general classified as a 3 types, one is the kind of pressure filters, another is the kind of vacuum filters and the third is the kind of centrifugal filters or centrifugal separators.

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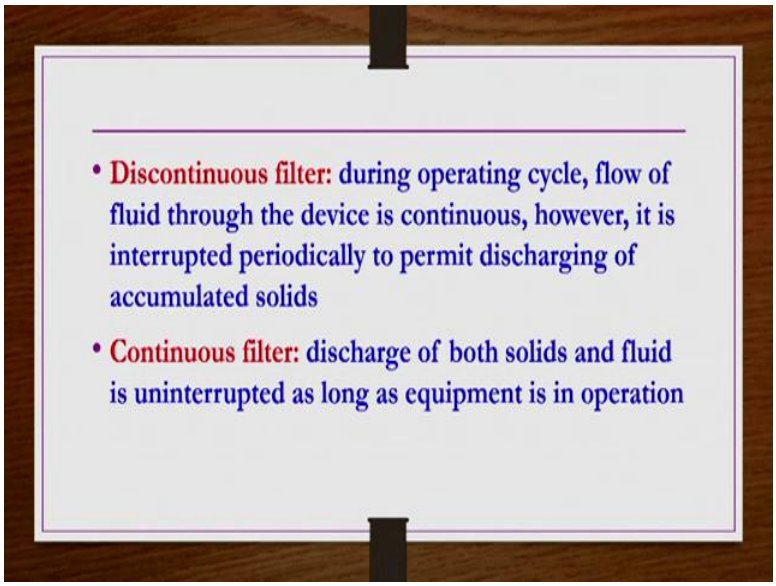

Now we see happens in batch or discontinuous filters. In general, when a filtration process is going through or the cycle is, the filtration cycle is in under operational conditions, the solids form as a kind of layers on the filter medium. And then if you do not remove them, then the in general, you know the filtrate, the flow rate of filtrate will gradually diminish or sometimes it is also possible if the particles are slimy or very fine particles then they may be forming a impervious cake.

So because of which the further filtration may not take place. So for that this filtration cake has to be separated periodically. So if you stop the filtration cycle, so that you can separate this you know the filter cake whatever is formed on the filter medium. Then such kind of processes are known as the batch or discontinuous filtration process. In which, during operating cycle, flow of fluid through the device is continuous.

However, it is periodically interrupted so that to permit discharging of accumulated solids. But in the continuous filtration process, what happens not only this flow of filtrate is continuous but the, whatever the cake form is there, discharging of that cake is also continuous, during the operation of the cycle. So you will not stop the process intermittently just for the cleaning the in order to discharge the solid cake, whatever is formed. So the continuous filtration, discharge of both solids and then fluid is in general uninterrupted as long as equipment is in operation.

So this is the difference between continuous and batch filtration processes. So there are many filtration equipment are there which operate either batch wise or continuous. There are also some equipment that operate both in continuous and batch mode.

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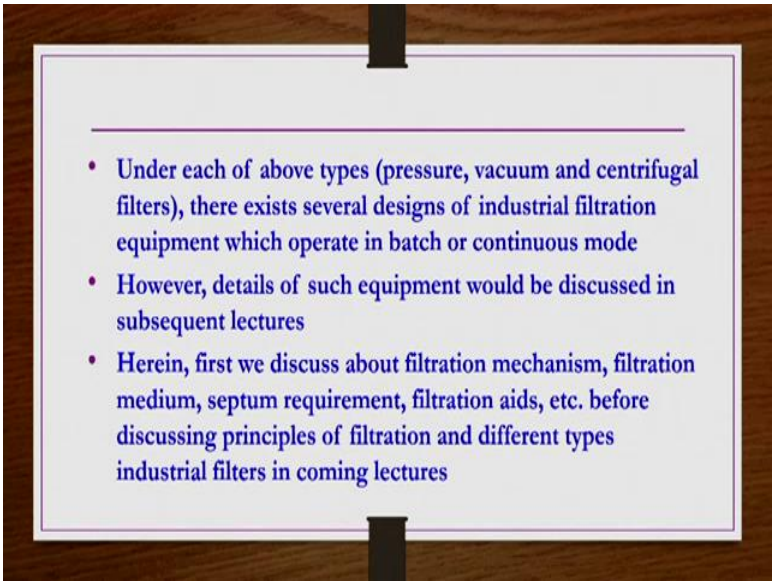

So under each of the 3 types of filters that is based on the force applied for separation to occur, that is we have the pressure filters, vacuum filters and centrifugal filters. There exists several designs of industrial filtration equipment which may operate in continuous or batch mode. However the details of such equipment, we are going to study in the subsequent lectures. We are not going to go through those industrial equipment right through because before going into the details of filtration TD or principle of filtration and industrial equipment used for the filtration, it is much more important to know some basics about the filtration mechanism, filtration aid or requirement of the filtration medium or filtration septum.

Whatever used what are the required means what are the filtration aids, etc are available. Those information, general information things are kind of essential. So first we go and see those details before going into the principles of filtration processes and equipment used for the filtration processes.

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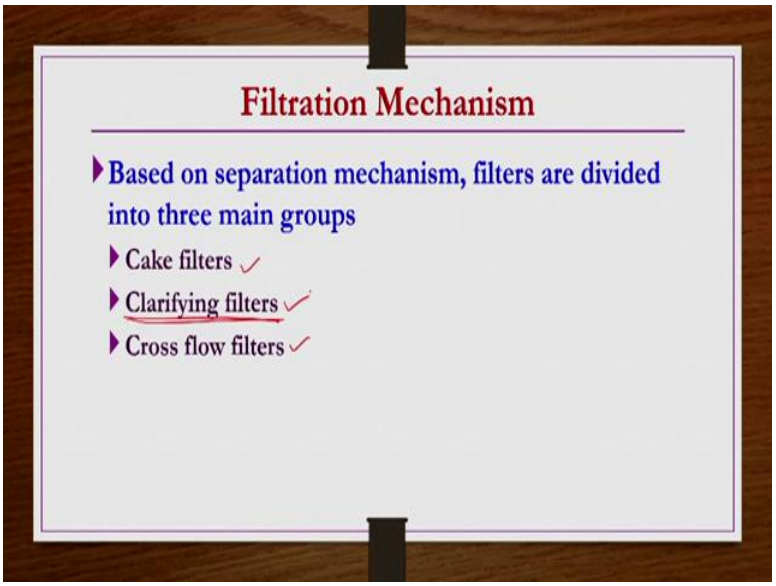

So now based on the filtration mechanism the mechanism that has been used for filtration: the filters are in general classified into 3 types. One is the cake filters, another is the clarifying filters and the third one is the cross flow filters. We see a few details of each of them right now. And then we see the details of each of them in subsequent lectures. So principles of cake filters and then principles of cross flow filters we are going to later on. But at the end of the lecture we will be discussing principles of clarifying filters.

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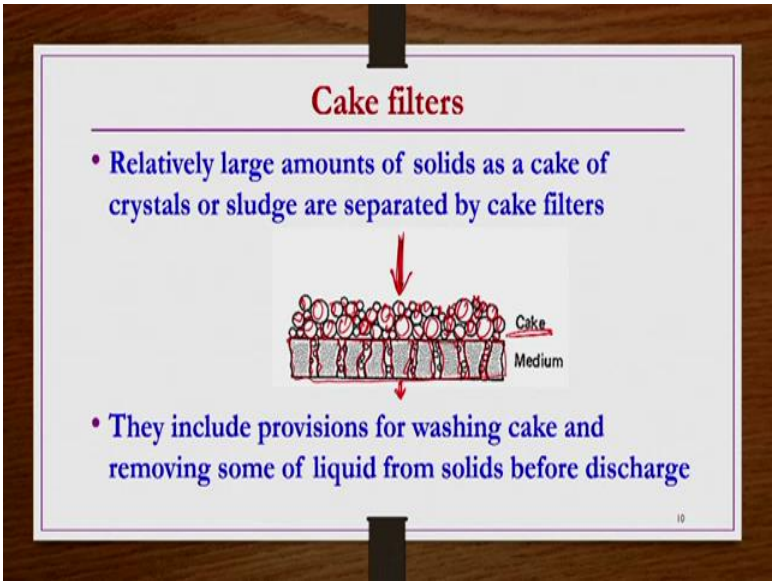

So what happens in cake filters? Cake filters in general, relatively large amounts of solids as a cake of crystal or sludge are separated by cake filters where schematically if you see, you have a kind of filter medium like this, which may be having a kind of a porous structure, not necessarily a kind of a linear or channel kind of structure as shown here. But there may be a kind of interconnection of porous structure may also possible. So on to this filter medium, the slurry is allowed to, through this filter medium, slurry is allowed to pass through a kind of a direction normal to the filter surface. Normal to the filter surface, the slurry is allowed to pass through this filter medium.

So that clear liquid or filtrate may be collected at the bottom. It may be clear or almost clear, not necessarily that it should be completely free from particles. There will definitely be a few particles in general because this are used as a larger amount of solids as a cake crystals or sludge. So whatever the particles, the bigger particles are there or intermittent particles are there in the slurry they will be forming a cake on the surface of the filter medium.

So that is the reason these filtration processes are known as the cake filters. So if these cakes are removed from the filter medium by the interrupting the process, then that process we can call it as kind of batch process. But if you have a mechanism in your design such a way that this cake is periodically you know, continuously it is removed as it is formed and the solid object by scrapping it by a knife or like that. Then such kind of a process is known as a continuous process where the collection of filtrate as well as the discharging of the solids is continuously taking place.

However, we are going to see those details later on in the equipment part anyway. Here, they include provisions for washing cake and removing some of liquids from solid before discharge. We see more details of these cake filters later on, especially their working principles, etc and that what kind of equipment, that we have industrial equipment we have which operate you know where the cake formation is a kind of primary important thing. Those kind of things we are going to see in subsequent lectures anyway.

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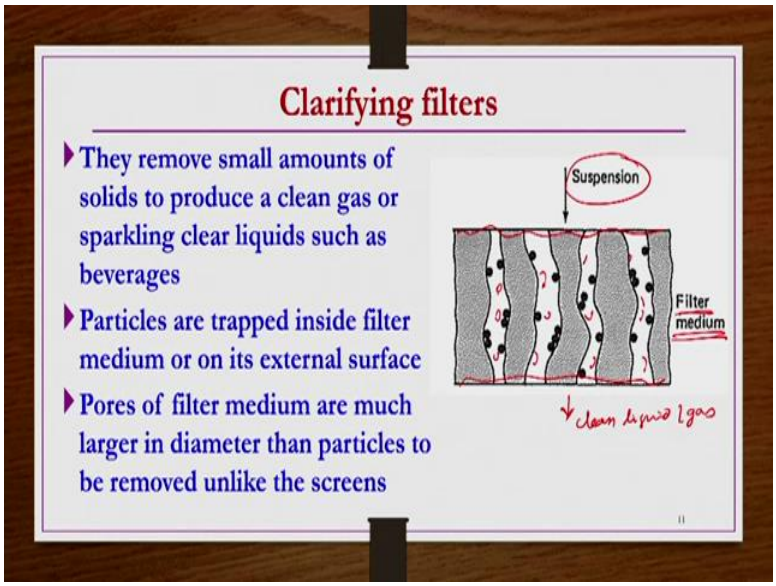

The next one is the clarify filters. Clarifying filters in general they remove small amount of solids to produce a clean gas or sparkling clear liquid such as beverages. So if the cake filtration is separating large amounts of coarse particle, clarifying filters are separating small amount of particles which are there in gases as dust laden gases or in some beverages, liquids then those small amount of particles so then those small amount of particles can be removed by this clarifying filters. So particles are in general trapped inside filter medium or on its external surface.

So basically this filter medium here, you know, it is not like a simple filter cloth that is used in the cake filtration, etc. Filter medium that are used for clarifying filters in general a kind of pack or pad which is filled with cotton or cellulose pulp or glass fibres etc. They are a kind of bed, deep bed in general. So whatever the suspension which is having small amount of solids or gas which is carrying a few amount of solids which are allowed to interact with this bed or the pack of this cotton or cellulose pulp or glass fibres in such a way that you know these particles are trapped when they interact when they strike on the surface of this you know filter medium.

They will be sticking to this surface or they may be partially blocking the porous structure of the pack whatever we have. And then leaving behind almost a clean liquid or a kind of gas if you are using the sliding gases. So this is the in general principles here. So what we can see here in general the pore structure, the pore structure of this bed, or the filter medium, which is a bed,

kind of a bed, it is a kind pack of cellulose pulp or glass fibres or cotton structure, etc. So the porous structure or the pores maybe in general much larger than the particles size.

Whereas in the screens what happens you know the apertures should be of size smaller size so that the particles are retained on the screen. But here it is not like that. It is like you know the porous structure, the pores may be much larger than the particle size and the you know particles when come and strike on the surface, the particles will be trapped on the surface and later on they will be removed. So that is the process, that is the principles of clarifying filter. Anyway, so pores of filter medium are much larger in diameter than particles to be removed unlike the screens in general.

So this is the basic thing about what is happening in clarifying filters. So here impingement is the kind of process which is causing a kind of causing the separation. It is not the porous structure that is causing the separation to occur. The porous structure is there just, which will allow the clean liquid or clean gas to pass through by the particles which are striking on the surface of this beds, they will definitely be, you know be sticking to the surface because these particles anyway, the small amount.

We use this clarifying filters for the cases where the liquids or the gases containing only small amount of solids. So the small amount of solids will striking on to the surface of the filter medium and sticking on to the surface of the filter medium or they maybe that will be partially blocking the pores. But they will not be able to pass through the deep bed of this filter medium which is you know generally pack of cotton or cellulose pulp or glass fibres. So what is the difference between the cake filters and clarifying filters? Cake filters are in general used to separate large amounts of coarse particles. Whereas clarifying filters are in general used to separate small amount of fine particles, smaller particles.

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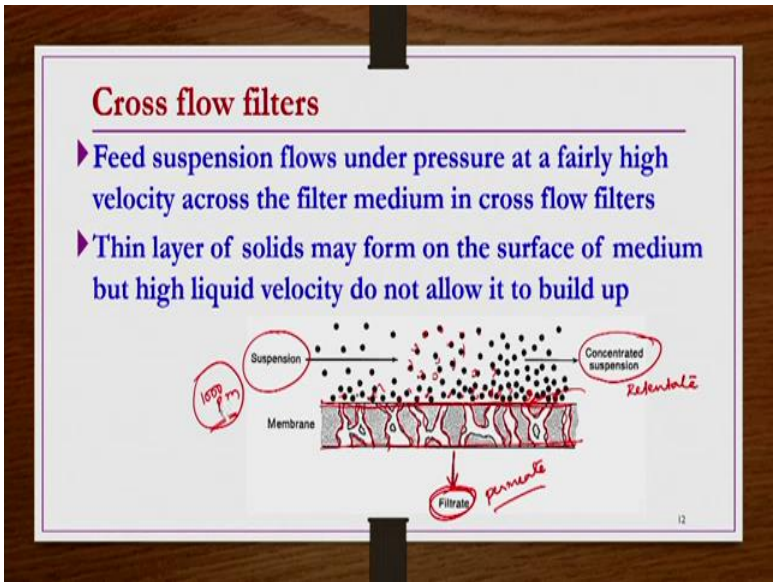

Then on the other hand, cross flow filters, we have a kind of you know cake filters the flow, the slurry is allowed to pass through the filter surface in a normal direction. If this is the filter surface, in the normal direction, the slurry is allowed to pass through so that the liquid is coming through the bottom and the solids are retained. But in the case of cross flow filters, the slurry or the liquid that is containing the solids is coming at high speed across the filter surface like this.

Across the filter surface like this so whatever the particles are there are deposited on the surface and then clearly a liquid is coming out from the bottom, as in general in a kind of a membrane processes, in the kind of membrane processes only. So when these particles are forming the depositing on the surface. They also have a kind of tendency to form a kind of cake, something like that.

But they high, relatively high velocity fluid, whatever it is coming that will be carrying these particles to move in the direction to move forward in the flow direction. So that surface is not accumulated by the particles, though there will be a kind of layer of particle forming a kind of concentration polarization kind of a thing will form also but they will not allow to form a kind of cake. There will be a layer of particles deposited but they will not be high speed liquid that is coming at high speed, that will not allow the solid to kind of accumulate. They will only be free

layers which is also kind of known as concentration polarization. That is what happens in cross flow filters.

So fed suspension flows under pressure at a fairly high velocity across the filter medium in cross flow filters. And thin layer of solids may form on the surface of medium but high velocity do allow it to build up like a cake like this. So let us say we have a kind of membrane surface or the filter medium now here in our terminology. It is nothing but membrane which may have a kind of continuous pores without any interlocking. There may be interconnecting force something like this, I have shown here.

So all kind of force are possible in general in membrane surface. So what happens here, onto the surface, membrane surface we allow a kind of suspension which is carrying, which is having particles to flow across the filter medium surface at relatively high velocity. So that you know particles in general would be deposited on this surfaces, the surface of the membrane and then a clear filtrate in general will be collected at the bottom. So these particles though they are depositing on the surface, the high speed of slurry or the liquid which is a kind of filtered from which we are separating particles.

The high speed will not allow these particles to form a kind of cake etc. Though there will be a kind of layer formation cannot be avoided in general. And thus such kind of layer of particles formed on the surface is known add a concentration polarization in membranes terminology anyway. So the difference between the previous two methods and this method of filtration is you know here we get a clear, almost clear filtrate, with almost free from solids as a one phase. But other phase, you will not get a kind of a separate phase as a kind of solids.

You will get a kind of a concentrated suspension. So which is known as a retentate. So filtrate is also known as a permeate. Permeate is a kind of almost clear or almost clear liquid without any kind of solids. So once you get this permeate out continuously, the solution that is retained on the membrane surface is in general a kind of a concentrated suspension. So rather getting to separate phases as a kind of complete separation, here you get only one phase, almost pure phase like a liquid phase as a almost pure almost clear permeate.

Whereas this remaining one is a kind of a concentrated suspension. Let us say if you have a suspension, feed suspension something like 100 ppm solution, then permeate you may get something like you know having 1 ppm or less than 1 ppm solution. Whereas this retentate may be having 10^5 ppm or even higher concentrated suspension you may get, which is known as a kind of retentate. So this numbers are just to indicate you to show these things but not necessarily they have a kind of a real connection with the real situation, realistic problems.

Here we can see, feed is 100 ppm and retentate may be having 10^5 or 10^{10} ppm also possibly, not necessarily depending on the application. Whereas filtrate or clear permeate we try to have, you know a liquid which is having almost no solids that is less than 1 ppm or less than that. So these numbers are just too explain. Not necessarily they represent the true picture of membrane separation process in general.

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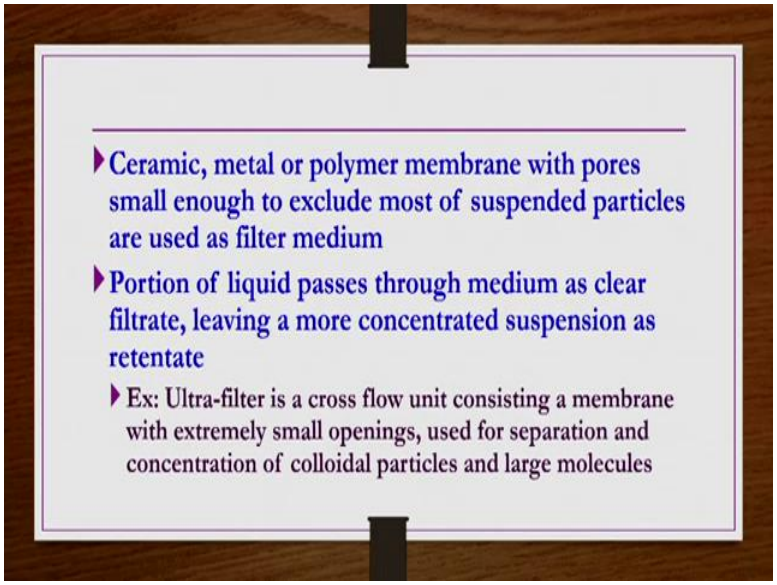

So what kind of membranes in general used for this cross flow filtration. In general, they are ceramic, metal, or polymeric membranes are used with pores small enough to exclude suspended particles. So such kind of membrane are in general used as filter medium under cross flow filters. And then portion of liquid passes through medium as a clear filtrate leaving a more concentrate suspension as retentate. Example, in ultra-filtration, whatever the membrane is there that is ultra filter. And then this ultra filter is a crossflow unit consisting a membrane with

extremely small openings, used for separation and concentration of colloidal particles and large molecules.

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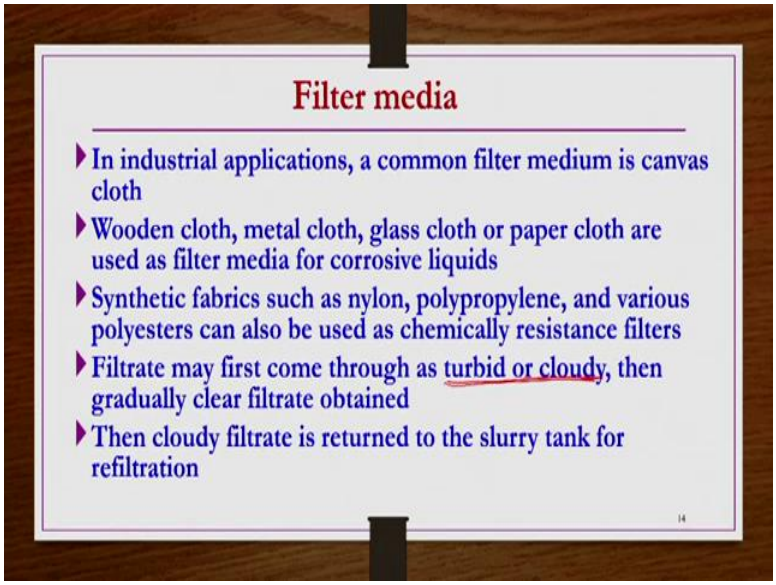

Then filter media. What kind of filter media one should use in general? For industrial applications most of the industrial applications a common filter medium is Canvas cloth but if the slurry is kind of corrosive or the liquid which you are treating separation of the solids from the liquid. If that is a kind of corrosive then in general wooden cloth, metal cloth, glass cloth or paper cloths are used as a filter media for such kind of corrosive liquid. Sometimes you need a kind of chemically resistant filter medium.

For few applications so then in such cases synthetic fabrics such as nylon, polypropylene or types of various polyesters can be used as chemically resistance filters. Filtrate may first come through in general as a kind of turbid or cloudy liquid but after initial stage then we start getting almost a kind of clear filtrate. So what we do is this initial turbid or cloudy filtrate that we get that we send back then cloudy filtrate is returned to the slurry tank for re-filtration.

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Then requirements of septum, septum or filter medium that we are in the kind of very much essential in the filtration process. There should be some kind of minimum duties that septum or filter medium should do. What are those requirements that you are expecting that filter medium or septum to fulfil for a given filtration process? Basically the most important one is to retain solids to be filtered and provide acceptable clean filtrate. Acceptable clean filter rate there are some kind of process where the volumetric flow rate of filtrate selected is in general very small. Something like you know 10^{-3} m^3 /min something like that.

Such a kind of small filtrate, so if the filtrate the volumetric flow is such small operation cannot be the kind of feasible at industrial scale in general. So because of that one it is the filter medium for septum whatever be used not necessarily just you know retaining solids but they should also provide acceptable clear filtrate and they should not plug for blind in general. Otherwise you know the filtration process may be disturbed. The septum should be chemically resistant and strong enough physically to withstand sometimes process conditions applied for the required separation processes.

Sometimes you may be applying the palms or blowers or centrifugal force in such a way that the ΔP that it is been generated that may be in general be very high. That is required for given separation in general sometimes. Then whatever the septum that you take that should be physically strong to with stand such kind of high pressure for filtration as well. Though very

high pressures are not a kind of economically feasible anyway and then should permit cake formed to discharge cleanly and completely and should not be prohibitively expensive.

They should not be very expensive because you know if they are expensive then the overall process cost is going to increase anyway. So then filter aids sometimes filtration process may not happening or occurring to the expected level so then one can use filter aids. This filter aids can be used in two ways. One is adding some kind of external material external inert material to the slurry before filtration that is in process. Other process is adding or forming a pre coat layer on a filter medium before the start of the filtration process. Either of them are possible.

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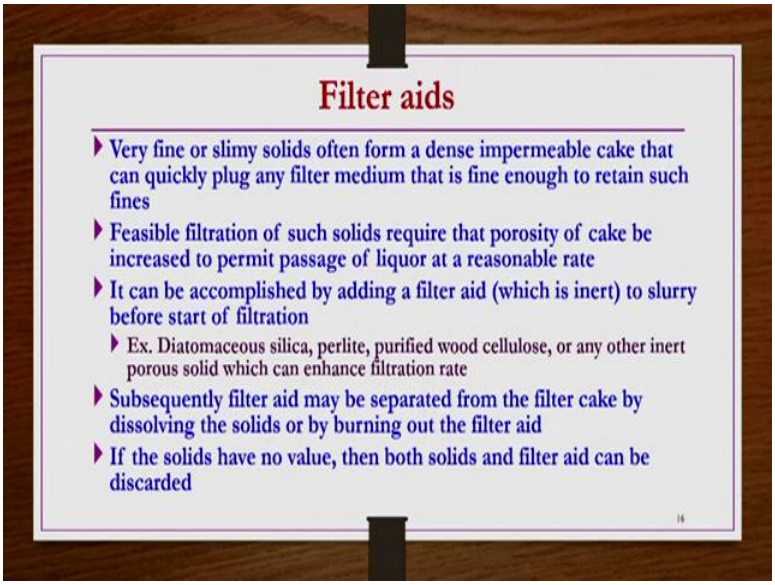

In general, very fine or slim solids often form a dense impermeable cake that can quickly plug any filter medium that is fine enough to retain such fines. Under such conditions feasible filtration of such solids required that porosity of cake be increased to permit passage of liquor at a reasonable rate. So how that can be done? that can be done by adding a filter aid which is in general inert to slurry before the start of filtration process. So some examples of such filter aid are diatomaceous silica, paralite purified wood cellulose or any other in a porous solid which can enhance filtration rate.

Subsequently filter aid may be separated from the filter cake by dissolving the solid or by burning out the filter aid. If both solids and the filter aid they are of no use, then both of them

can be discarded together. You do not need to separate filter aid if you are solids are a kind of important product then you have to separate the filter aid from the solids that are being retained. If the solids are not important for any kind of application further if they are simply to be discarded, then both the filter rate and the solid can be discarded together.

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So the other way of filter aid is forming a pre coating layer on a kind of medium. So depositing a layer of aid on the filter medium before filtration is an alternative way of applying a filter aid pre coat layer is in general thin in batch process. But if the filtration process is a kind of continuous process then layer of pre coat is thick and then gradually becomes thicker and thicker as the filtration process progresses. However, the top of the layer is continually scrapped of by an advancing knife to expose a fresh filtering surface continuous process because in continuous process we cannot afford to stop the process for clearing the Scape.

So you have a kind of advanced knife scrap of this solid cakes that are formed in the solid filter medium to expose fresh filtering surface for further separation of slurry. Pre coat layer prevent gelatinous solids from plugging the filter medium and give a clear filtrate almost. Pre coat obviously is a part of the filter medium it is not a part of the cake. It is a part of the filter medium because this pre coat we are a giving on to the as a kind of coating onto the filter medium. So it is a part of filter medium rather than of the cake.

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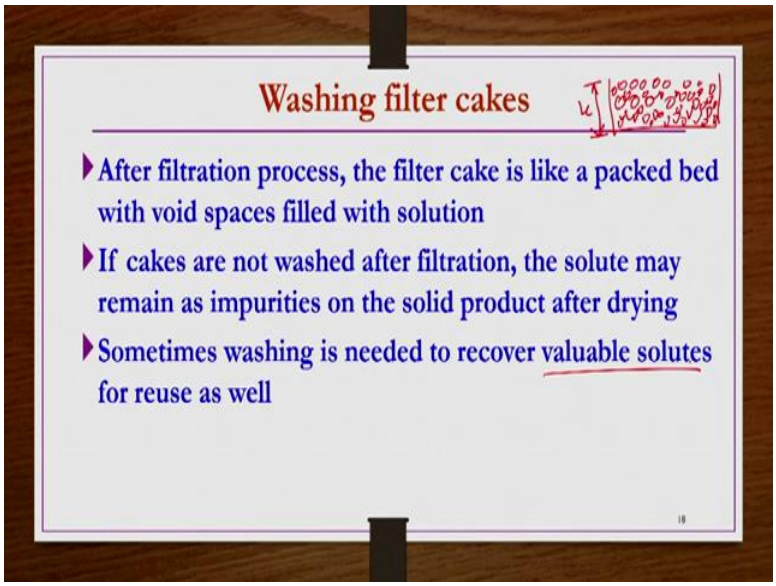

Now washing of filter cakes. Washing of filter cakes is also kind of very much important even if the solids are not important for application point of view because of pollution control board regulation also.

Sometimes this washing of cake is a kind of very much essential. what happens after filtration process is that the filter cake is like a packed Bed with void spaces filled with solutions whatever the cake that we have in general, let us say after the filtration whatever the cake that is formed it is having this kind of packed bed structure in general. So this may be cake maybe having a finite size L_c in general. So here in general these are the particles but this is in a bed form so whatever the Porous structure is there that is being occupied by the solution.

So you need to watch this because of either importance of the solids or because of the any other reasons like you know pollution control reasons or any other specific to given application. So if cakes are not washed after filtration what happened the solute may be retained as impurities on the solid product after drying. So sometimes washing is needed to recover valuable solutes so that they can be used or reused as well.

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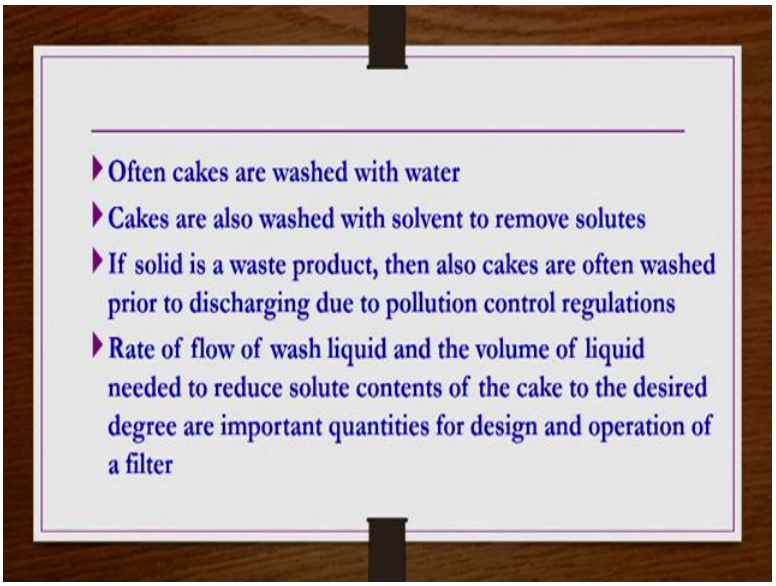

So often cakes are washed with water in general. Some cakes also washed with solvents to remove solutes. If solid is a waste product then also cakes are often washed prior to discharging due to pollution control regulations. Further the rate of volume of washed liquid that is volumetric flow rate of wash liquid that is used along with the volume of the wash liquid are a kind of important to design parameters as well as the important parameter for a controlling the operation of the filter. So how much liquid should be used for a given washing of a cake and then what volumetric flow rate this liquid should be used are going to be two important parameters for washing of filter cakes.

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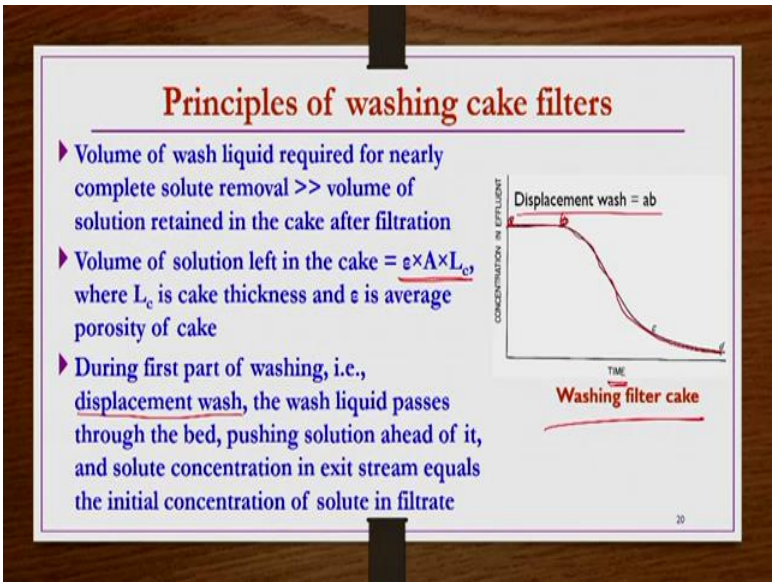

So let us see principles of washing cake filters. In general, as I already mentioned this wet cake is having mostly solids but the void spaces are in generally occupied by the solution. So volume of wash liquid that is required to take of the solution or completely nearly remove the solute that is going to be much more higher than the volume of solution retained in that cake after filtration. That is volume of wash liquid required for nearly complete solute more is in general much more higher than the volume of solution retained in the cake after filtration. Let us if L_c is cake thickness and then epsilon is average porosity of cake which you want to wash and then a is the cross sectional area of the cake then $\varepsilon A L_c$ is the volume of solution left in the cake.

So whatever the volume of wash liquid is there that is going to be much more higher than the value of this $\varepsilon A L_c$. During first part of washing there are several stages in washing first stage is known as the displacement to wash where the wash liquid passes through the bed and then just pushing the solution ahead of it and solute concentration in exit stream is equals the initial concentration of solute in filtrate in general. Pictorially if you see let us say washing filter cake so effluent concentration with respect to time if you see; this initial period is period a and from this location to b location whatever the concentration you can see is almost constant and then it is almost constant and then equals to do whatever the initial concentration of the solute in the filtrate.

This level is known as displacement wash. In this region what happens whatever the liquid is there wash liquid that you use that will simply push the solution that is retained in the porous structure of the cake and then that solution moves out. So then that solution that moves out then the effluent in the effluent the concentration of the solids is almost in the initial concentration of the solute filtrate. Once it is crossed here so abruptly the concentration of the concentration in effluent that abruptly drops to 0 almost like this.

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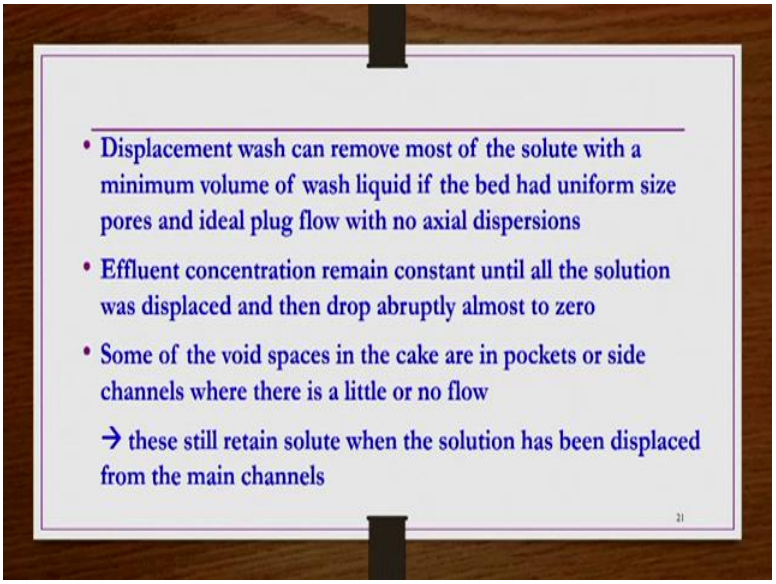

So displacement wash can remove most of the solute with a minimum volume of wash liquid if the bed had uniform size and ideal plug flow with no axial dispersions. then effluent concentration remain constant until all the solution was displaced by the wash liquid and then drop abruptly almost to 0 as I have shown in the picture. Sometimes the white spaces in the cake or in pockets or in side channels where there is little or no flow is occurring. So removing the solution from there is kind of difficult. So these still retain solute when the solution has been displaced from the main channels, because in those pockets you know side channels there is little or no flow. So it is not possible to remove them simply by placement wash.

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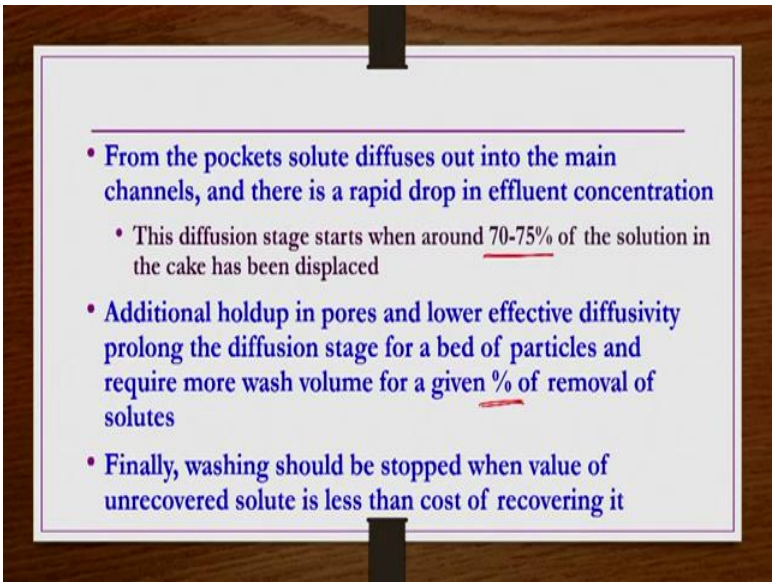

From the pockets what happen solution diffuses out into the main channels. So once what happens in from these pockets you know because of the concentration difference once the wash liquid is displacing the solution that is present in the void spaces, so whatever the solute that are there in the pockets or side channels they will be finding a kind of concentration difference. There concentration is high in these pockets channels where as their concentration is very less in the kind of main channels or main void spaces from where the solution has already been displaced with wash liquid.

So there in the void spaces you have the wash liquid. Wash liquids are almost having no solute. So in the pocket or the side channels whatever the solute are there they experience a kind of concentration difference and then because of that concentration difference diffusion will start occurring and because of the diffusion those particles which are there in the pockets or side channels they will come into the main channels and then they will be carried away along with the wash liquid.

From the pocket dissolute diffuses into the main channel and there is a rapid drop in effluent concentration because there is only a few particles remaining in the pockets and then side channels. This diffusion stage in general starts when around 70 to 75 % of the solution in the cake has been displaced by the wash liquid just buy the displacement stage. Additional hold up

in pores and lower effective diffusivity prolong the diffusion stage for a better particles and require more wash volume for a given percentage of removal of solutes.

So from this point onwards one should be very useful whether further washing cake is required or not because from here it is going to take a more wash volume for a small percentage of removal of solutions because majority of the solutes have already been removed. There are only few solutes are there. So one has to do to a trade-off such that you know the washing should not be going to be more costly compared to the value of the solutes that you are going to recover. So washing should be stopped when the value of an unrecovered solute is less than the cost of the recovering it. So this is about the principle of washing filter cakes.

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Now we see a few things about clarifying filters. Clarifying filters as I said it is a kind of impingement of particles and the filter medium and then filter medium used for this clarifying filters are in general the kind of packed or pads which are filled with cotton, cellulose pulp or glass fibres etc they are kind of deep bed. When the slurry containing small amount solids or dust laden gases come and interact with this pad of Glass fibres or cellulose etc, the particles will stick on to the surface and then the clear, the clean gas or liquid will pass through the filter medium.

These particles may be separately removed later on. So in the clarifying filters these remove small amount of solid or liquid droplets from either liquids or gases. So usually they are used when the concentration are only a few traces of solid are present or small amount of solids are present in the liquid or gases then only we use this clarifying filters. Separation occurs as particles are trapped inside filter medium on its surface and in general they differ from screening such a way that pores in filter medium are larger as I already discussed in one of the previous slides and this filter medium is a kind of bed of cotton or glass fibre etc.

Show the Porous structure of this bed in general is larger than the particles but however the separation is taking place when particles are coming and hitting surface by impingement. They stick to the surface and then liquid can be passing through clearly. Whereas in screens you know the aperture opening has to be smaller than the particle size so that particles can be retained on the screen. So that is the difference between in general screens and clarifying filters. This whatever the clarifying filters the pores are there whatever the pores are they may be much larger than the particles to be removed.

However, despite the size separation takes place almost complete separation takes place because of the deep bed of this pack of this filter medium that we use. In this filters particles are caught by surface forces and immobilized on the surfaces or within the flow channels and they reduce effective diameter of channels but usually do not block them completely.

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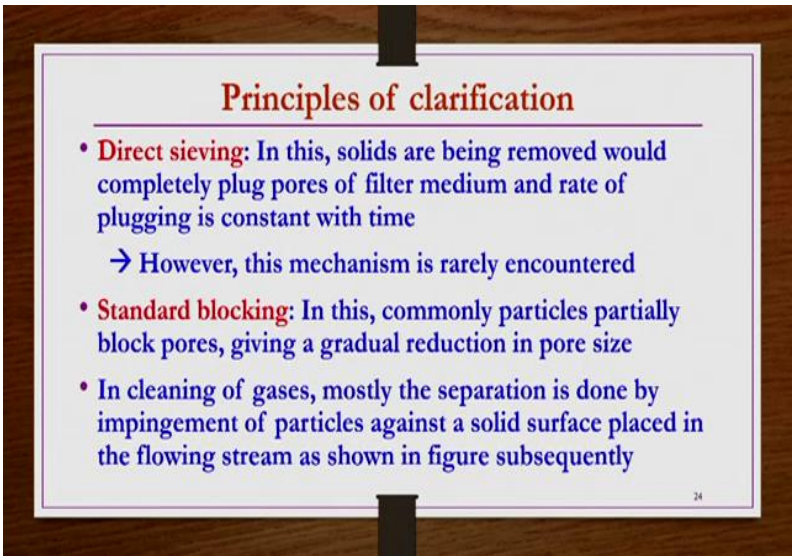

So there are some principles of clarification that we can see here. Direct sieving is the one. In this solids are being removed would completely plug process of filter medium and rate of plugging is constant with time but in general such kind of completely plugging the pores structure of the filter medium is not experienced which is a very rarely encountered in general.

Standard blocking where commonly particles partially blocked the pores giving a gradual reduction in the pore size and then in cleaning of gases mostly the Separation is done by impingement of particles against a solid surface placed in the flowing stream as shown in a figure here.

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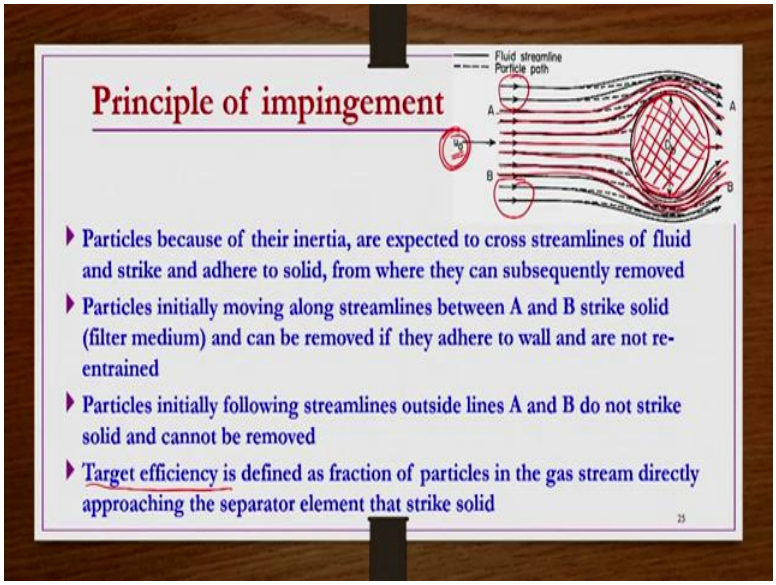

So we discussing principles of impingement here pictorially we can see here. So now let us say this is a kind of a surface filter medium this is a kind of filter medium which is kind of pack of cotton or glass fibre or cellulose pulp etc. So now here a fluid carrying particles coming with the velocity u_0, the fluid will have a kind of streamlines like this solid lines shown here like this.

The solid lines whatever are shown are a kind of in general stream lines that you find in general like this we have like this when a fluid is flowing in across a object like this. Now object I have taken kind of a circular one here for easy understanding but the what is to be observed is that you know velocity u_0 velocity is there. That is for the particles and then this liquid whatever is there or the dust laden gases whatever there so then because of the inertia of the particles they

deviate from the streamlines. Part lines of particles in general deviate from the streamlines as shown in the kind of lines here because the inertia is higher in comparison to fluids a gas or liquid.

So then because of this inertial higher inertia these particles strike on to the surface of this filter medium and being separated. So initially whatever particles you know whatever these things like this between A B line are there. so whatever the particles are there they will be striking on to the surface and then maybe separated and then they do not need to be separated. Whereas the gases or the particle laden gases which are moving this A and B locations, they may not be separated. They are not having a kind of interaction with a kind of filter medium here.

So particles because of their inertia are expected to cross streamlines of fluid and strike and adhere to solid from where they can subsequently be removed. Particles initially moving along streamlines between A and B strike solid filter medium and can be removed if they adhere to wall and then are not re-entrained again because they are already separated. Particles initially following streamlines outside lines A and B do not strike solid and cannot be removed. Show the efficiency is a kind of factor. So the target efficiency is defined as fraction of particles in the gas stream directly approaching the separator element that strike the solid and being striking on the surface of this filter medium.

So only those fraction of solids which are striking onto the filter medium that fraction of solid material is known as target efficiency because the particles which are not striking to the filter medium they are not being separated. So that is the basic way for the best possible way to define the target efficiency for this kind of filter medium. So what is the target efficiency? it is the fraction of particles in the gas stream directly approaching the separator element that strike the solid and being adhered to the solid surface or filter medium which can be separated subsequently or removed subsequently.

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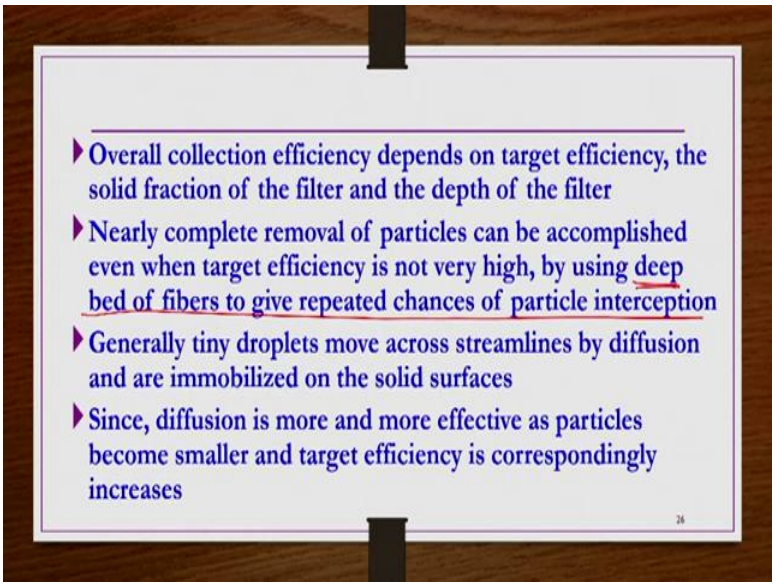

But overall collection efficiency is different from the target efficiency and this overall collection efficiency depends on different things. One is that target efficiency the other one is the solid fraction of the filter and the depth of the filter bed that has been used. So even when target efficiency is not very high nearly complete removal of particles can be accomplished by using Deep bed of fibres to give repeated chances of particle interception. What we have this filter medium as a kind of as I mentioned they are pack or kind of pad with cotton or glass fibre or cellulose pulp etc.

If this pad if you can have a gain a deeper one deep bed pad if you have then it is possible that you know repeated interception of these particles with the filter medium takes place and then separation efficiency will increase. So generally, tiny droplets move across streamlines by diffusion and are immobilized on the solid surfaces. And since diffusion is more and more effective as particles become smaller target efficiency correspondingly increases. This is about some basic principles of the clarifying filters. In the next lecture we will be discussing the working principles of cake filters.

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The reference for this lecture is McCabe, Smith and Harriot that is the textbook unit operations of Chemical Engineering by McCabe, Smith and Harriot. that is the reference book that I have used for preparation of this entire lecture. However, some details can also be found in about the filtration and this other reference books like unit operations of particulate solids theory and practice by Ortega-Rivas. Then Coulsen and Richardson chemical engineering 2nd volume by Richardson and Harker. Then transport processes and unit operations by Geankoplis. Then Unit operations by Brown et Al and finally introduction to chemical engineering by Banchero and Badger. Thank you.