Downstream Processing
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Lecture - 11
Pre-Treatment and Filters

We will continue on the solid-liquid separation. Before you send the slurry to the filtration process, sometimes you may have to carry out something called pretreatment; that means you need to pre-treat the slurry and then send it to the filtration process. So, there are different types of pretreatment strategies adopted.

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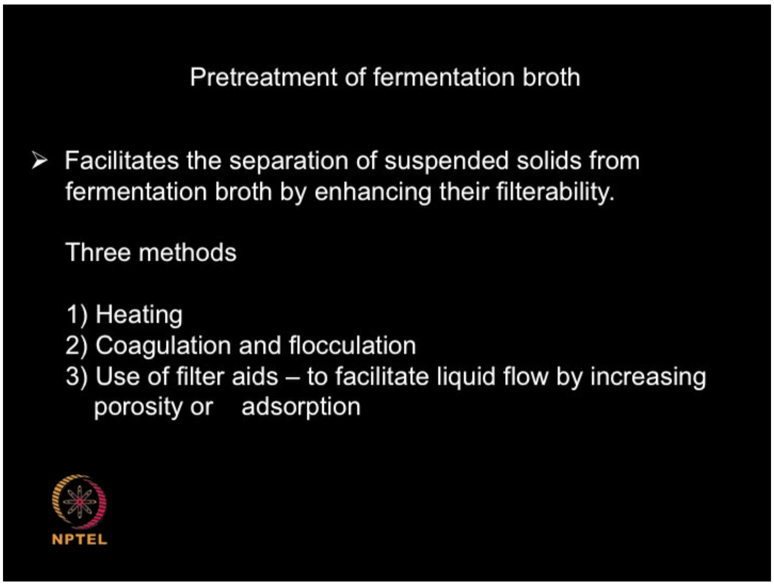

This pretreatment strategy improves the filterability of the broth, because if you recall, after the fermentation, the broth may be highly viscous; the broth will contain several types of particles – sticky particles, sand-like particles, precipitated salts, dead biomass, metabolites. So, you need to improve the filterability; otherwise, the whole material may spoil the filtration unit, as well as it will slow down the filtration process.

So, a few of the important techniques, which are adopted for improving the filterability includes heating; that means you heat the material, which you are going to filter; you adopt something called coagulation and flocculation; or, use something called filter aids. These filter aids improve the flow of the liquid through the filtration unit either by improving the porosity of the bed or doing adsorption of some of the unwanted solids, which hinders the filtration process. We will look at each one of these techniques slightly in more detail. Heating – this is a very simple method; you slightly heat the material or the liquid, which you want to filter, so that it increases the flow; that means it reduces the viscosity of the medium.

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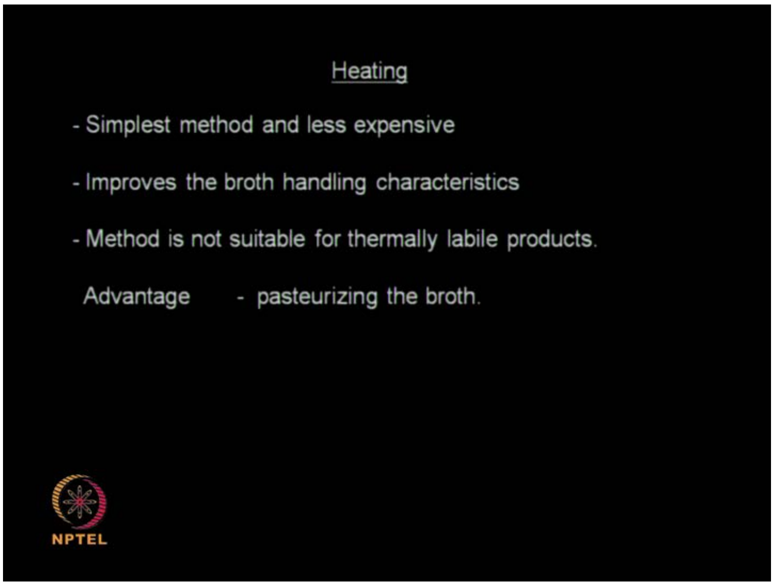

And, it also increases the handling of this particular liquid. But, it is not very suitable if you have metabolites or if you have proteins, which are thermally labile; that means the protein may loss its activity because of the heating; or, you may have some metabolites, which get denatured or deactivated because of the heating. And, sometimes when you heat, you may also lead to certain chemical reactions – unfavorable chemical reaction. So, you need to be sure that, such things do not happen when you heat the material. One advantage of heating is also it is pasteurizing the broth; that means if there are some viruses or if there are any organisms, which are pathogenic; it may kill them.

Especially if you want to pasteurize milk, heating is a very good technique. If you want to pasteurize any food products, heating is a good technique, because it kills these viruses or pathogenic organisms. But, the most important you need to keep in mind is whether the proteins or metabolites present, which would like to recover, are thermally unstable. Then, in that situation, you will not be adopting heating-like technique. Heating you can do in a batch operation or you can also do in a continuous operation. In a batch means you take the material, the broth in a large vessel and heat it; and then, cool it down and then send it to filtration; or, you may do it in a continuous tubular type of arrangement.

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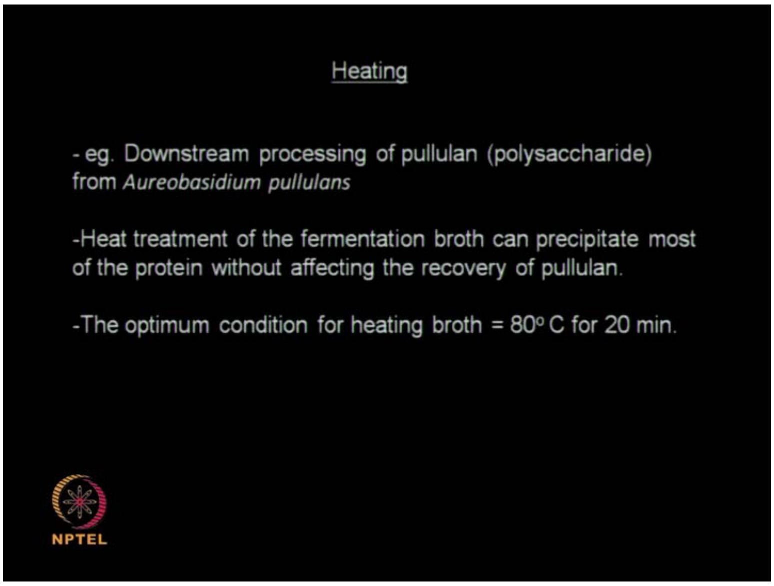

Suppose I want to process a polysaccharide like pullulan, which is fermented from a microorganism. So, when we heat it, what happens is, there are certain precipitates that happens – precipitates of the protein without affecting the pullulan. So, the proteins, which may be hindering the recovery of pullulan can be removed by this type of heating. So, when you heat, the proteins get denatured. And, when the proteins get denatured, they precipitate out. So, we can separately recover the pullulan. So, that is the main advantage of – in this particular case, heating. And, it is a very good separation process. Generally, we heat it up to 80 degree centigrade for about 20 minutes.

So, you see that, when I heat at 80 degree centigrade, most of the proteins are becoming deactivated at that particular temperature. So, whatever proteins present; once they get deactivated, the chances are they will precipitate out. So, if we have a situation, where you have an organic molecule and you have some unwanted proteins, where you are more interested in the organic molecule than heating is very good. But, if you are interested in the proteins part of it, then you are in trouble, because you cannot raise it to such large temperature; and, most of the proteins will completely get denatured.

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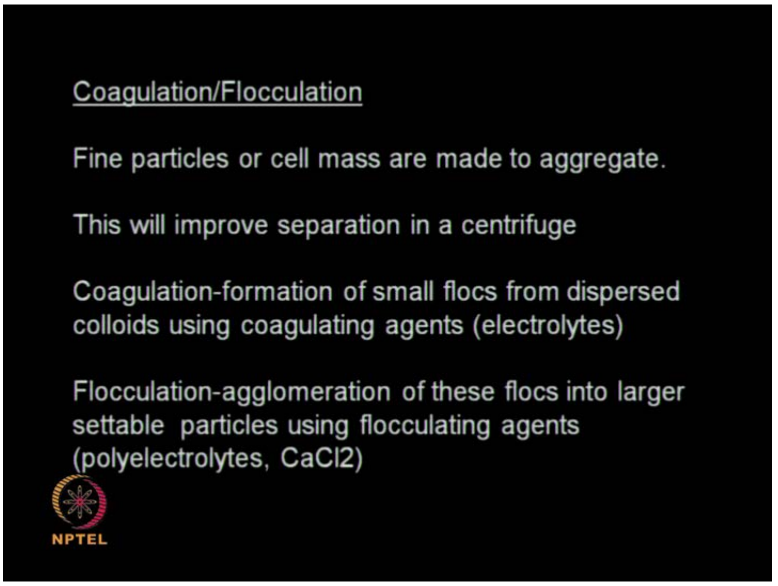

Another approach by which you could improve the filterability is the coagulation or flocculation. We talked about this in a couple of classes back – techniques called coagulation or techniques called floatation or flocculation. So, you can aggregate fine particles or cell mass. So, when you aggregate these fine particles, it becomes easier for you to separate in a centrifuge; otherwise, if they are not in a non-aggregated stage, the particle size is small; plus they are having an electrostatic repulsion. So, when you centrifuge it, they do not get separated so efficiently.

So, in a coagulation or flocculation type of approach, what you are doing is you are breaking these electrostatic repulsions – number 1, which leads these materials to come together and form aggregates. So, in coagulation, what you do is you are forming small flocs from dispersed coagulates, colloids using some coagulating agents. So, the small flocs are formed from colloids that are well-dispersed. So, you generally use something called electrolytes. So, these electrolytes affect their electrostatic charges. So, they make these colloids, which are far away from each other to sort of coagulate and form flocs. And, these flocs if they are heavy, they can start settling down; and, because the flocs have higher particle size, even in centrifugation, they can be easily separated.

The other approach is the flocculation, where you are agglomerating these flocs into larger settlable particles. So, you are again using something called a flocculating agent. So, you can use polyelectrolytes; you can use salts like calcium chloride and so on. So, coagulation, flocculation, is generally adopted if you look at a fermentation downstream; that will be the first step before you actually take it to a centrifuge or a large filtration setup. Even in for example in fermentation towards ethanol, you call something called clarification; that means there are lot of fine particles, which make the entire slurry very hazy. So, you add some coagulating or flocculating agent, which are like electrotyes or salts and allow some of the particles to coagulate and settle down; and then, you go to the filtration setup. That could be any normal bed filter or a centrifuge. So, the advantage of using a coagulation or a flocculation is to enhance or improve the filtration process.

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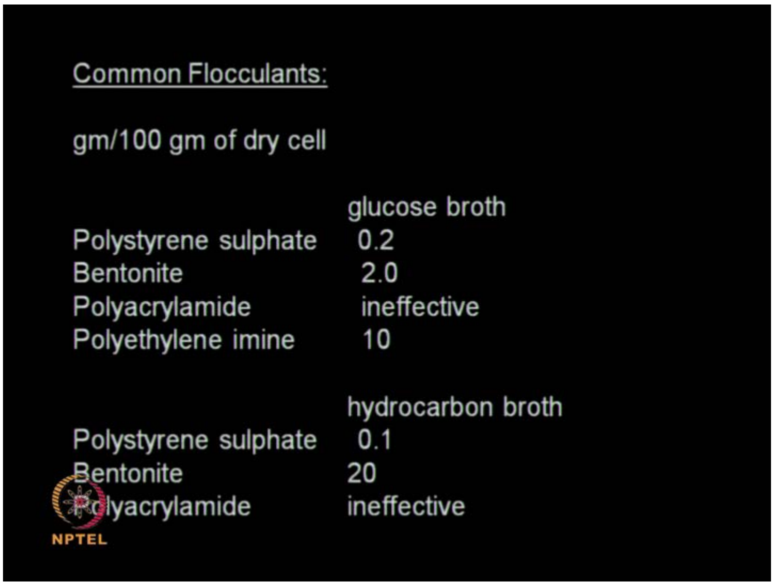

So, the common flocculants that are used when there are large number of flocculants, which are used actually. And, the common flocculants is what I am going to tell you. And, it also depends upon the type of broth. So, if suppose you have a glucose-based broth, we may use some salts like polystyrene sulphate, bentonite – bentonite is a clay; polyacrylamide – this is the polymeric material; polyethylene imine, and so on. So, this one tells you how much is the quantity of these flocculants used per 100 grams of dry cell; in which a hydrocarbon-based broth; then, again you can use polystyrene sulphate or bentonite or polyacrylamide. But, then you see that, a polystyrene sulphate quantity changes depending upon the type of broth; bentonite quantity changes depending upon the type of broth. And, here polyacrylamide is not very effective whether it is a glucose broth or whether it is a hydrocarbon broth.

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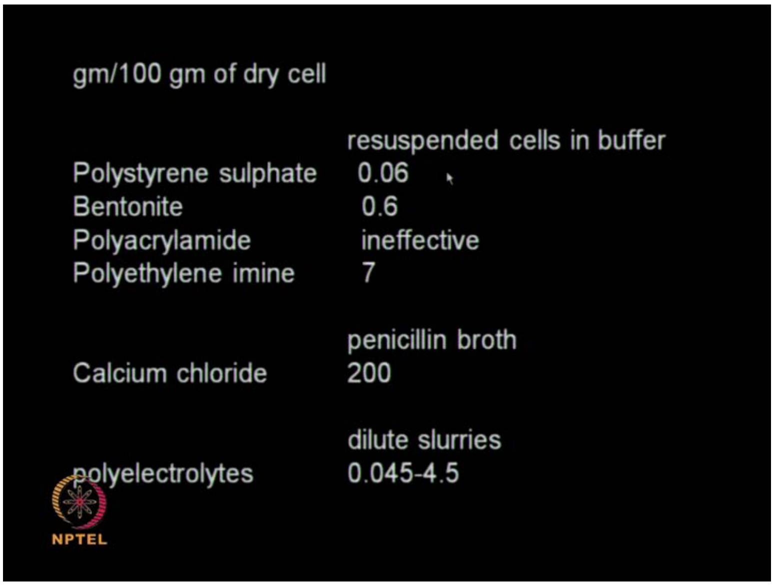

So, if it is a cell – resuspended cells in a buffer; you see that, again the quantity of polystyrene sulphate and bentonite changes. But, polyacrylamide is ineffective; which a penicillin and an antibiotic-based broth; then, we can use calcium chloride. And, if it is a dilute slurry, we can use polyelectrolytes. Generally, polyacrylamide is very good for water treatment plants. Now, we have a very fine suspended particles; it leads to nice flocs by using polyacrylamide type of material. The third approach by which you can do pretreatment, is use of filter aids.

These filter aids enhance the filterability of the fermentation broth. These are materials you separately add and then you perform the filtration process. So, when you do that, this material sometimes adsorbs some of the impurities present in the broth or it also improves the filterability; that means it increases the porosity of the bed. Suppose if the cake is compressible; what happens? The cake compacts on the top of the bed; and hence, the flow of the liquid slowly starts going down and down; and finally, there is absolutely no flow. So, what you do; by adding a filter aid, we can increase the porosity; thereby preventing the compacting nature of the solids.

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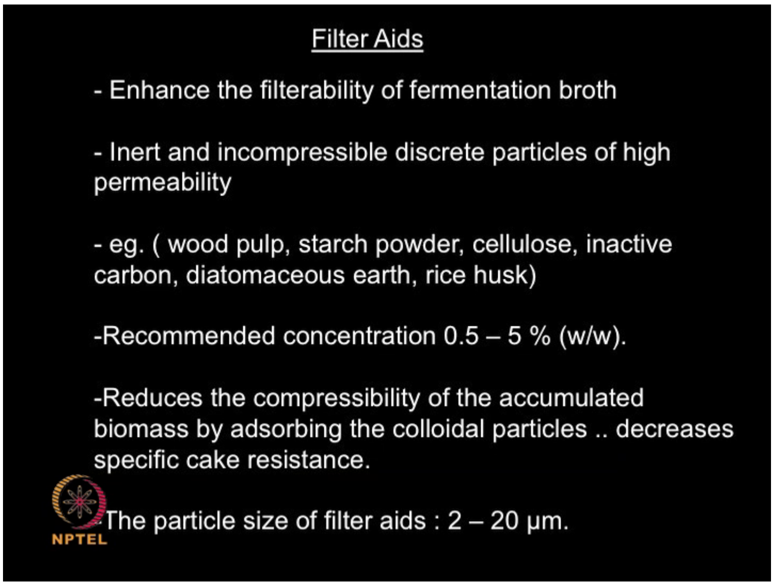

Generally, you add materials like starch powder, cellulose, inactive carbon, diatomaceous earth, rice husk, starch. So, these are the materials, which does not get compacted at pressure. Generally, the concentration varies depending upon the type of solids you are trying to remove from the fermentation broth. So, the quantity may change between 0.5 to 5 percent weight by weight. So, basically, what does it do? It reduces the compressibility of the biomass; it reduces the specific cake resistance. So, if you remember, specific cake resistance in Darcy's law comes in and it has a very very important bearing on the flow of the liquid as well as the rate of filtration. So, it decreases the specific cake resistance. Generally, the particle size of these filter aids are between 2 to 20 microns.

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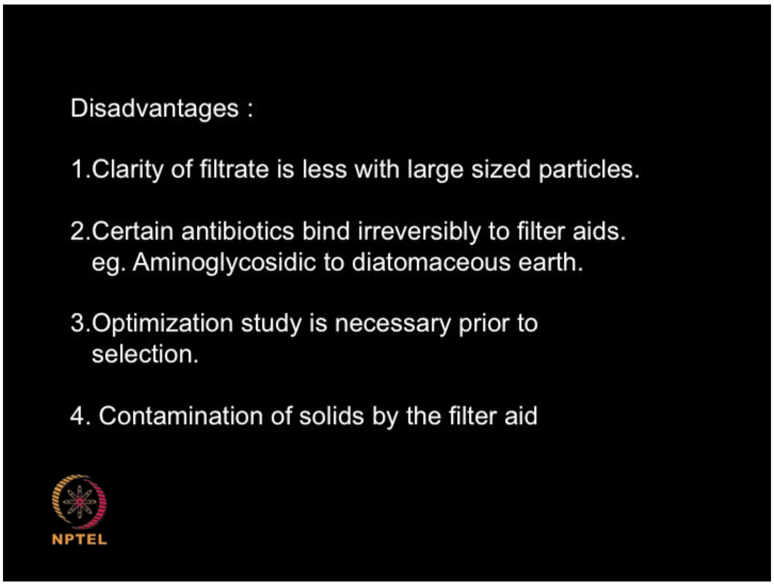

So, there are some disadvantages in use of filter aids. If there are advantages, there are always disadvantages any process you select. So, the disadvantage is the clarity of filtrate is less when you use large sized particles. If you have antibiotics, these antibiotics may irreversibly bind to the filter aids and then you will not be able to recover the antibiotics. If that is the desired product, you are using the product in the filter aids. For example, aminoglycosidic antibiotics – they may bind irreversibly to diatomaceous earth. So, you are losing the product. So, the yield goes down.

So, you need to also do some optimization study; how much of filter aid I need to add; what should be the particle size of the filter aid; and, so on actually. Number 4 – it contaminates the solids. So, if I am interested in the solids, then I have filter aid also mixed with the solids. Then, how do I then remove the filter aid from the solid? That becomes an issue. If I am interested in the liquid part of the slurry, then there is no problem. But, if I am interested in the solid part like especially in cell harvesting, where I am interested in the cells, not on the liquid part; then, I am in real trouble, because filter aids also will be there and it is very very difficult or impossible to remove the filter aid from the solid cells. So, you need to consider all these aspects before deciding on the type of filter aid you would like to select as well as the particle size of the filter aid actually.

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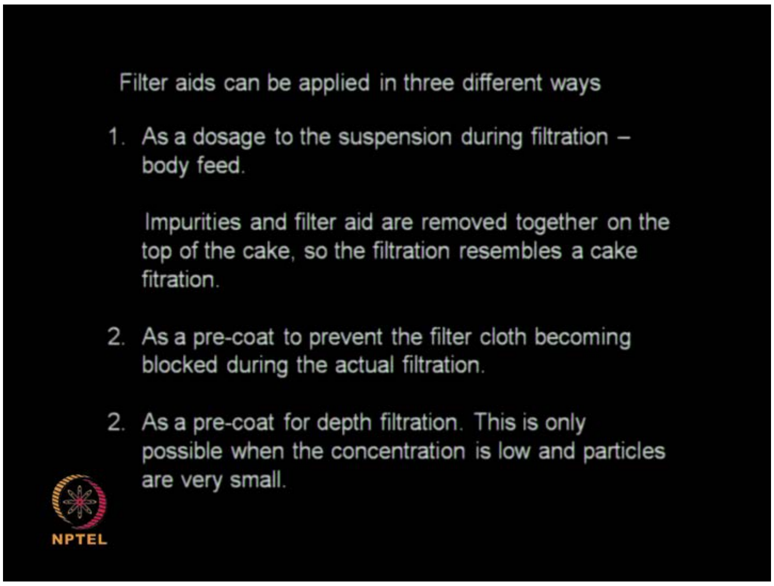

So, they can be applied in different ways these filter aids like I can add this filter aid as a dosage to the suspension during the filtration process actually. So, what happens is the impurities, that is, the solids that are settling down on top of the filtration aid and the filter aid settle; so, they can be removed together. So, it is like a filtration process, where I have the cake as well as the filter aid; I am retarding the flow of the liquid. Second approach is I can use it as a pre-coat; that means initially, I will just pass filter aid. So, the filter aid initially settles on top of the filter cloth or filter medium. And then, the biomass or the solids start settling down top of that. So, the filtrate does not go and block the holes in the filter cloth or filter medium. So, that is called a pre-coating. So, you can do it that way; that is, doing the pre-coating process.

If you are doing depth filtration; so, again you can use it as a pre-coat. This can be done if the concentration is low as well as the particle sizes are very small, because is the particle sizes are very large in depth filtration, the filtrate will not reach to the bottom of the filtration unit. So, filter aid can be used or applied in three different ways during the filtration process. So, the first approach is you add it as the dosage will the slurry. So, the solids in the slurry as well as the filter aid will settle on top of it and they form a mixed bed, because the filter aid does not get compacted; the porosity of the bed is very high. So, the liquid flows nicely. The second approach is the pre-coating of the filtration unit; that means the filter aid goes and settles on top of the filter medium initially. So, the solids will not go and close the pores; or whether the solids will not block the pores, thereby maintaining the flow rate. The third approach is if you are using depth filtration, again you can use the filter aid as a pre-coat. But, here you need to keep in mind that, the particle size of the filter aid has to be small, so that they travel right down to the bottom of the filtration unit.

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Properties of filter aids

Property	filter aids			
	RHA	DE	Perlite	Cellulose
Permeability	0.05-2	0.05-30	0.4-6	0.4-12
Median pore size, microns	0.5-10	1.1-30	7-16	-
compactability	Low	Low	medium	high
Trace metal contamination	Low	Moderate	moderate	low
Silicosis concern	Low	Low to High	Low	None

What are the properties of these filter aids? They have to have certain important properties. There are different types of filter aid and they have different permeability values just fit for different pore sizes in microns; they have different values of compactibility or compressibility as we call it. And, they have different levels of trace metal contamination and they can lead to silicosis.

So, if you are looking at compatibility, cellulose have higher compactibilities; whereas, perlite like material has medium compatibility. If you are looking at contamination present in these filter aids, you can see that, again cellulose has lowest contamination. Again if you are interested in the particle size, then you see a large variation in the particle size. And, the permeability values also changes quite a lot starting from very very low values of permeability going up to almost a factor of 1000.

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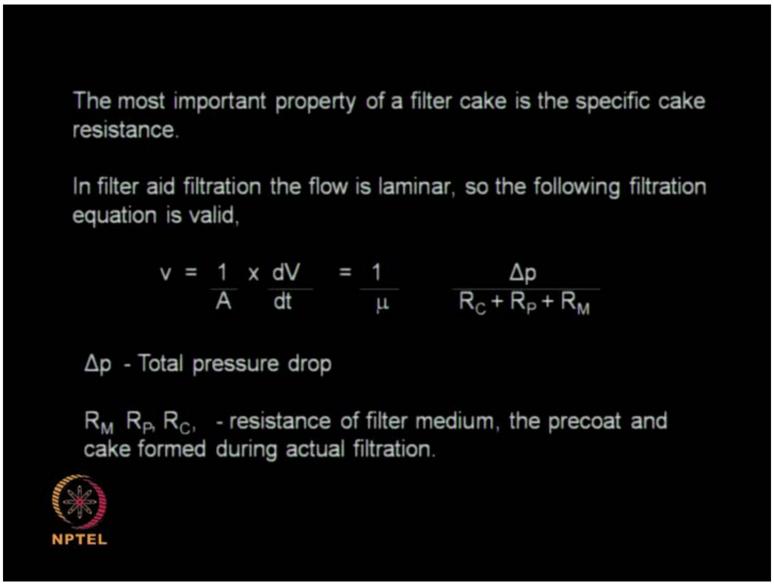

The most important property as we remember in the Darcy's law is the specific cake resistance of the cake or permeability of the cake. So, the permeability is inverse to the specific cake resistance. So, we talked about different types of models. In the first model, when we assume that, the filter medium does not offer resistance, we just had the properties of the cake; that means specific cake resistance. And then, later looked at a model, where we said the filter medium also offers some resistance. Now, in the third situation, you may have a situation, where the filter aid or pre-coat also can offer some resistance to the flow of the liquid. So, the velocity of the flow of the liquid is equal to 1 by area of the filtration multiplied by the volume that needs to be filtered and the time. So, this gives you the rate of filtration; this gives you the velocity; and, here you have the area.

Now, this is related to the pressure; that is, the pressure that you are applying, viscosity of the fluid and various resistances. There are three resistances now. So, there is resistance offered by the cake – number 1; there is resistance offered by the pre-coat or the filter aid; and, the resistance offered by the medium; that means filter cloth or stainless steel filter or ceramic filter. So, all these three may be offering resistance at various degrees. So, you need to keep that in mind. So, cake may be offering maximum resistance; and then, you may have the filter medium offering resistance; and finally, the pre-coat may be offering resistance. So, if you know all these values, we can introduce all these here and then we can integrate this equation and calculate the time required for filtering certain volume of slurry just like we did in the previous cases, if you recall all those things actually.

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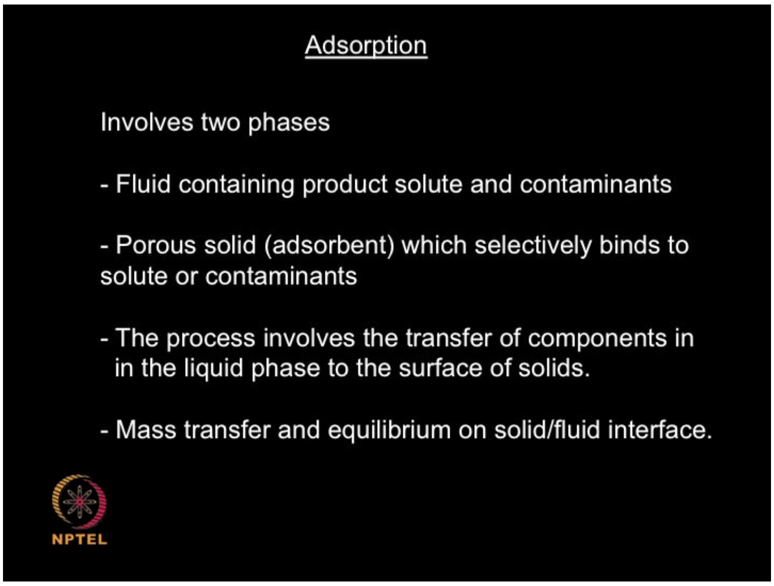

Another technique by which we can remove some of the solids present in the slurry, which prevents the filtration process is by adsorption. Sometimes as I said, the filter aid itself does this adsorption process; that means some of the unwanted material can get adsorbed on filter aid. After all we are adding a pretreated or processed clay or cellulosic material or wood chips or carbon and so on.

So, they have certain surface area, which can aid in the adsorption of some unwanted materials. So, adsorption is another approach by which we can improve the filtration process. So, there are two phases. In any adsorption process we have, it is a multiphase process. You have the fluid containing the solute and other contaminants; that is, fluid means the slurry. And then, other – the adsorbent, that is, these porous solid, which selectively adsorbs a contaminant or a solute. So, what happens is during this process of adsorption, the components from the liquid gets transferred and gets attached to the pore adsorbent or the porous solids.

So, there is something called mass transfer; and, there is something called equilibrium. So, the adsorbent cannot adsorb all the solute and the adsorption process depends upon the equilibrium concentration. So, each solid has certain capacity; beyond which it cannot adsorb the contaminant or the solute – number 1. Number 2 – the mass transfer determines the rate of adsorption. So, the mass transfer determines how fast or how slow the adsorption process is. And, the equilibrium concentration determines how much I can adsorb. So, depending upon the concentration of solute in the slurry and how much of solute I want to remove from the slurry before I resort to filtration, I will decide on the quantity of the adsorbent.

And, depending upon the mass transfer, I will determine how long I will perform the adsorption process. So, depending upon the mass transfer, if the mass transfer is very fast, I will perform the adsorption very fast. If the mass transfer rate is very slow, the adsorption also will be very slow. So, I need to give sufficient time for the solute to get adsorbed. And, depending upon the equilibrium concentration, I will decide how much of solid I need to add into the slurry. So, the mass transfer and the equilibrium determines the thermodynamics and the kinetics of the process. Mass transfer determines the kinetics; equilibrium determines the thermodynamics.

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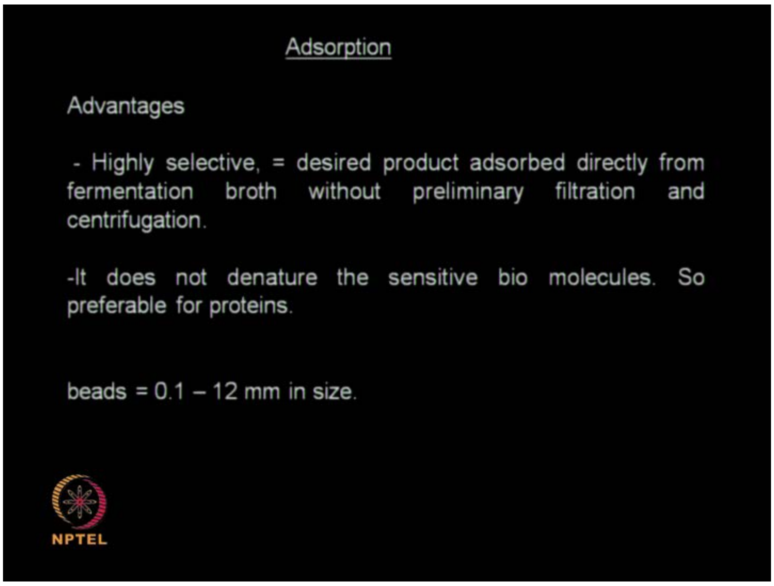

So, adsorption is a very selective process. We will talk about adsorption later on in more detail. We will look at different types of adsorption processes; we will do some problems on adsorption. But, as you know, adsorption can be very very selective; only the desired product can be adsorbed directly from the fermentation broth; we do not need to do preliminary filtration. So, we can do adsorption and then we can do the preliminary. And, it generally does not denature sensitive biomolecules. So, it can be preferable for proteins actually. So, generally, it does not denature the biomolecules. So, we can have particles or solids adsorbents; it can have various sizes; it can be very very small particle going right up to very large particle as well actually.

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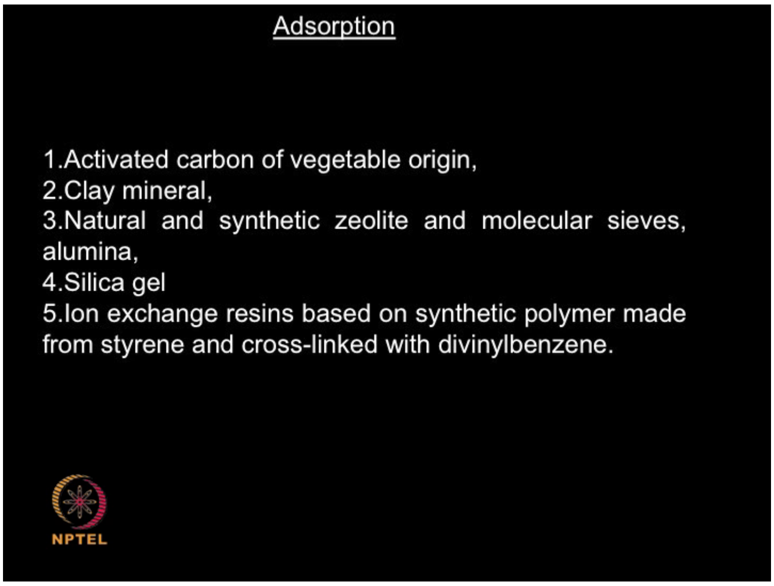

So, we can use activated carbon from vegetable origin. We can use clay minerals. We can use natural and synthetic zeolites; zeolites are nothing but different types of alumina. We can use molecular sieves. We can use normal alumina – gamma alumina, alpha alumina. We can use silica gel. We can use ion exchange resins; different types of ion exchange resins – cationic resins, anionic resins; they are all attached to polymers like styrene or cross-linked divinylbenzene polymer.

So, a large number of adsorbents can be thought off of varying particle size depending upon what you want to adsorb from the slurry. As I explained before in the previous slide, the quantity of adsorbent you would like to select as well as how long you want to do the adsorption process depends upon the thermodynamics of the process as well as the kinetics of the process; that means equilibrium concentration of the solute or the partition of the solute from the liquid to the solid as well as the mass transfer rate. So, these are the two terms, which come into deciding on adsorption process.

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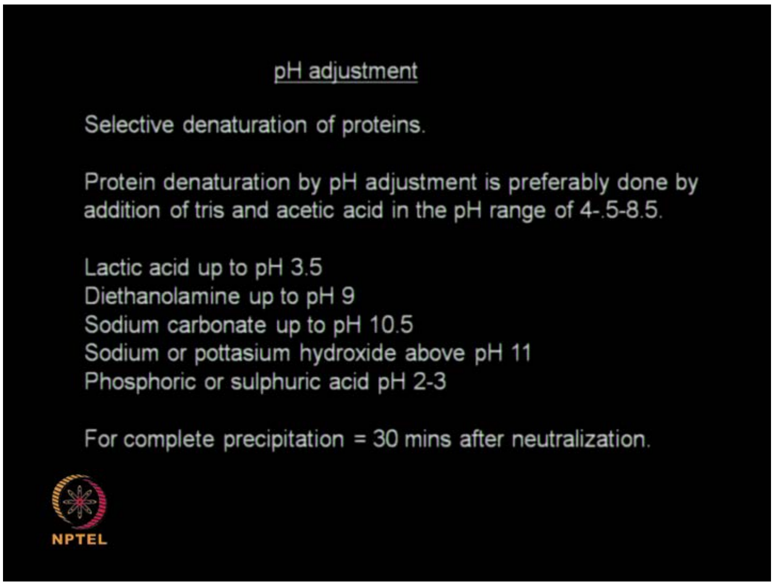

Another approach by which we could improve the filterability is pH adjustment. Sometimes when you change the pH, some solids will precipitate out; solids which looks like flocs will agglomerate and then start precipitating out. Once it precipitates out, filtration may be very fissile. Sometimes you like to denature proteins, so that once it gets denatured, it can precipitate out. So, by altering the pH of the medium, you can improve this type of process actually. So, we can add acetic acids in the pH range of 4.5 going right up to 8.5.

And, we can add lactic acid up to a pH of 3.5; we can use diethanolamine. Especially in the alkaline pH, we can add sodium carbonate up to pH of 10.5; sodium or potassium hydroxide going up to very large – pH 11. We can add phosphoric or sulphuric acid at pH 2 to 3. So, you see that, if I want to move into acidic range or if I want to move into alkali range, I can consider all these acids and alkalies. Depending upon the denaturization of the protein and precipitation of the protein, we can select the pH. So, once we denature a material, then we allow it to precipitate and settle down. We need to put in some time, so that it settles down completely to the bottom of the vessel. So, pH adjustment is also a technique. But, then you need to decide on how much of these acid or alkali you need to add; how much of a sodium carbonate I need to add; or, how much of phosphoric or sulphuric acid I need to add, so that the unwanted material precipitates out.

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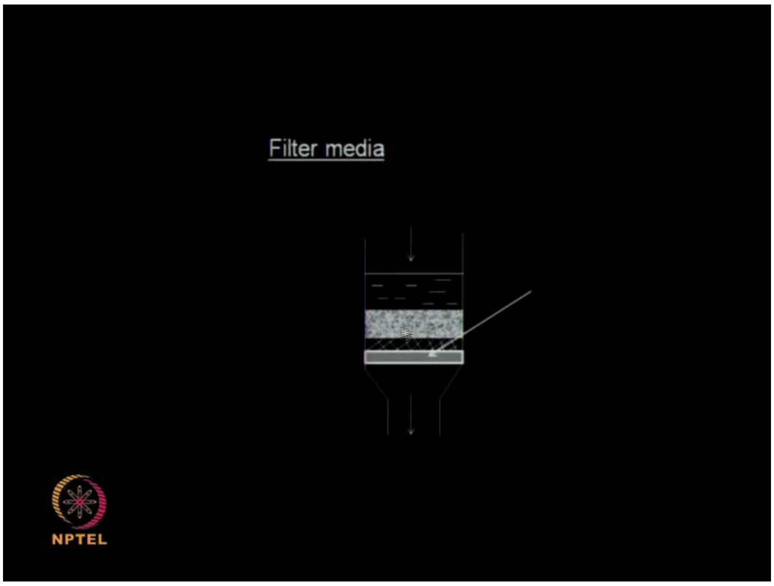

Now, let us look at the filter media. Filter media is also part of the filtration setup. So, if you look at this particular filtration assembly, you assume this as the cake or the solids, which settles down; and, this as the liquid, which is getting in the slurry; and, the liquid – the clear liquid comes down here. This is called the filter medium. This sort of supports the bed of solids and it has certain particle size. So, depending upon the particle size of this filter medium, we will be able to filter different types of slurry.

So, this can be made of different materials – polymeric materials, membrane materials, and ceramic materials, stainless steel, cloth and so on depending upon the process, which you are studying. And, each material has its cost of associated with it as well as advantages and disadvantages are associated with it. So, commonly used filter medium – filter paper – we use it in our lab. So, then after the filtration, we throw the paper out; we sometimes burn the paper out to collect the solids and way the solids and find out how much solids is present.

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Woven material, cloth – different types of cloth: nylon cloth, polyester cloth, cotton cloth, cheese cloth, woven polymer, fiber, woven glass fibers, non-woven fiber pads; that means you can have thick pads like in car or in air conditioners for example; we have pads, which capture very fine particles and holds it. Sintered and perforated glass; sintered and perforated metals – if the solids are going to be abrasive, it is better to use a metal type of filter medium. Ceramics – if you are talking about high temperature filtration, ceramics will be able to which stand these high temperatures.

Membranes – synthetic membranes; different types of membranes: hydrophilic membranes, hydrophobic membrane. So, all these materials are being used currently. And, some of them are very inert; they can withstand very high temperature; they can take in abrasive materials; they are long lasting. Some of them are short lasting. So, you need to replace these filter media. So, the cost of the filtration; working capital I would say – depends on how many times in a year or a month you replace this filter medium.

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Porosities of filter media

	% free area
Wedge wire screen	**5-40**
Woven wire : Twill weave square	 15-20 25-50
Perforated metal sheet	30-40
Porous plastic (moulded powder)	45
Sintered metal powders	25-55
Crude kieselguhr	50-60
membranes	80
paper	60-95
Sintered metal fibers	70-85
Plastic, ceramic foam	93

So, look at the porosities of these filter medium. It varies from almost 5 rating going up to 85 percent free area available actually. So, we are talking about wire screen, woven wire, and perforated metal sheets, porous plastics, sintered metal; and, kieselguhr, membranes, paper, metal fibers, ceramics, foams, plastics. So, large number of synthetic or natural materials are used for this filtration process actually.

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Classification of filter media, based upon rigidity

media type	Subdivisions	Smallest particle retained (μm)
Solid fabrication	Flat, wedge-wire screen Wire-wound tubes Stacked discs	100 10 5
Metal sheet	Perforated Sintered woven wire Unbonded mesh	20 1 5
Rigid porous media	Ceramics Sintered metal powders or fiber Carbon Sintered plastic powder or fibre	1 1 1 <1

So, they can be grouped into solid fabrication, metal sheets, rigid porous media. This is based upon the rigidity of this filter media. They also act as a support for the bed that is getting accumulated over a period of time during the filtration process. So, they should have sufficient mechanical strength. And, the smallest particles they can capture also varies; you can see that, very very small particle – less than the micron going right up to hundreds of micron. Ceramics, sintered metals powders, carbons and so on. We can have wires, mesh material; and then, we can also have discs. So, we have solids materials, metal sheets or rigid porous material.

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Cartridge	Yarn wound Bonded granule or fibre Pleated sheet	5 1 <1
Plastic sheet	Perforated Sintered woven filament	10 5
Membrane	Ceramic Metalic polymeric	<0.1 <0.1 <0.1
Woven media	Stable fibre yarn (ploymeric filament)	5
Non-woven media	Dry- laid Wet-laid (paper) Wet-laid(sheets)	10 2 0.5
Loose media	Fibres powders	1 <0.1

Going further, cartridges – we have different types of cartridges. We can have ceramic material; we can have solid metal. Then, we can have plastic sheets. We can have membranes. Again membranes – we can have polymeric membranes, metals, ceramics. When we talk about membranes, the particle size that can be filtered becomes very very small. We go down to very small – 0.1 micron or even less than 0.1 micron material can be. Then, if you look at woven media like fiber yarns, polymeric fiber yarns; they can capture only about 5 micron sized particles.

Then non-woven material like papers or sheets. Then, loose media like fibers and powders. So, large number of different morphology, different structures, different types of preparative methods can be thought of depending upon the type of application you are looking at, depending up on the thermal conditions, depending up on the pH conditions, depending upon the percentage of solids that needs to be retained, depending upon the properties of the solids, one can select.

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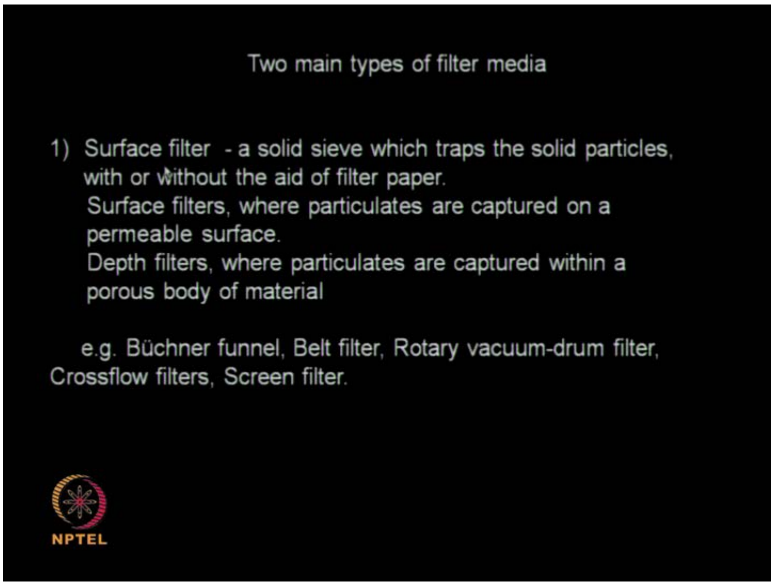

So, two types of filter media we can think off. One is called the surface media. This is the normal filtration. Whereas, solids sieve – it traps the solid particles. They are used in a surface filter. Then, you have depth filters, where the particulates are captured within a porous body. So, the depth filter will have several layers of material, which captures the solids which you need to filter.

So, surface filters can be Buchner funnel, which we use it in our lab; Belt filters, rotary vacuum-drum filter. We looked at it in detail sometime back. Then, cross-flow filters, screen filters and so on. The other approach is the depth filter. So, you have a bed – granular material bed of varying particle sizes, granules, pebbles, sands, which try to capture the solids present in a fluid. Especially this type of depth filter is used in water treatment facility. They are also called as sand filters.

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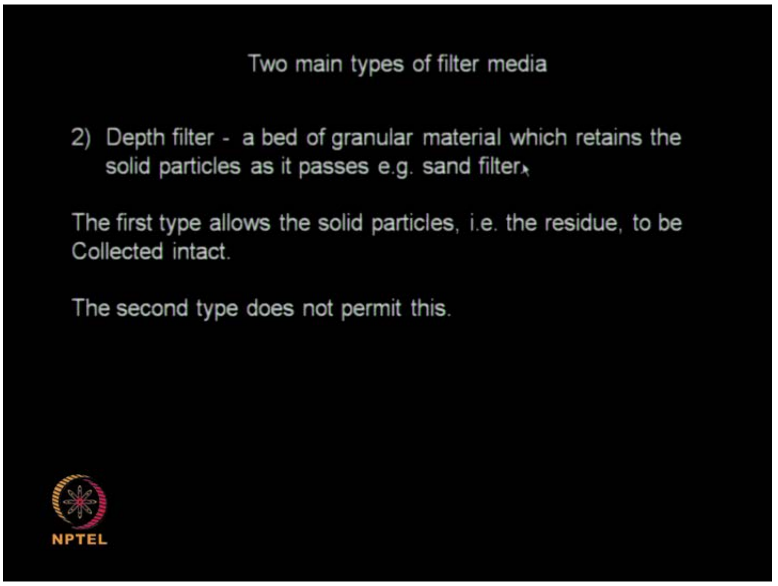

This first type allows the solid particles, that is, residue to be collected intact. The second – this type of depth filter does not allow you to collect the solids back. Whereas, the surface filter allows you to collect the solids intact. Whereas, the depth filter does not allow you to collect the solids intact. So, here we are more interested in the liquids, the amount of solids that is present is not also very very large. So, in that situation, depth filter is ideal. Whereas, if you are interested in the solids or if the amount of solids present in the slurry is very large, surface filter or belt filter is the best approach.

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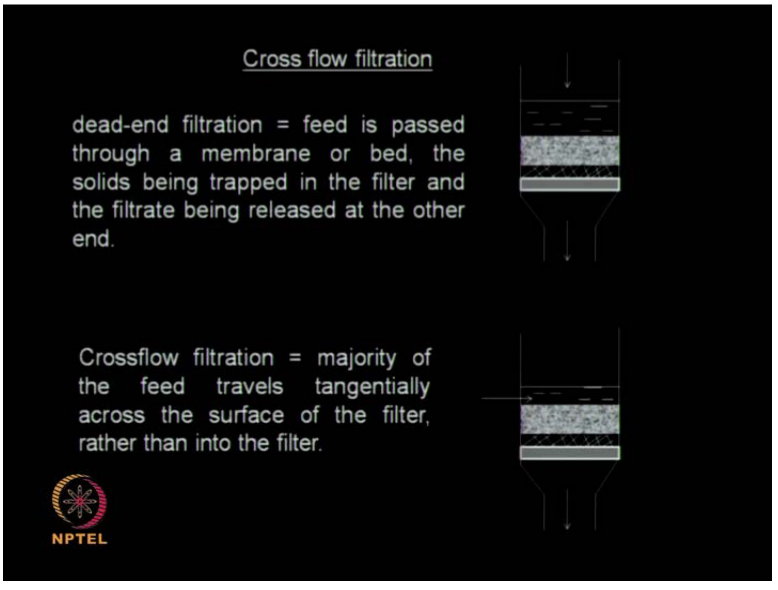

There is one way of doing filtration apart from the normal way, which you all know. This is called the dead-end filtration; that means you add the slurry; you have the filter medium here; you have the cake getting slowly deposited; you have the slurry; and, the liquid starts flowing through this various resistances depending upon the pressure you apply. This is the normal approach. There is another approach, which is called cross-flow filtration; that means the slurry comes in a cross fashion and the liquid is… The majority of the slurry comes in this cross fashion. So, that feed travels tangentially across the surface of the filter setup.

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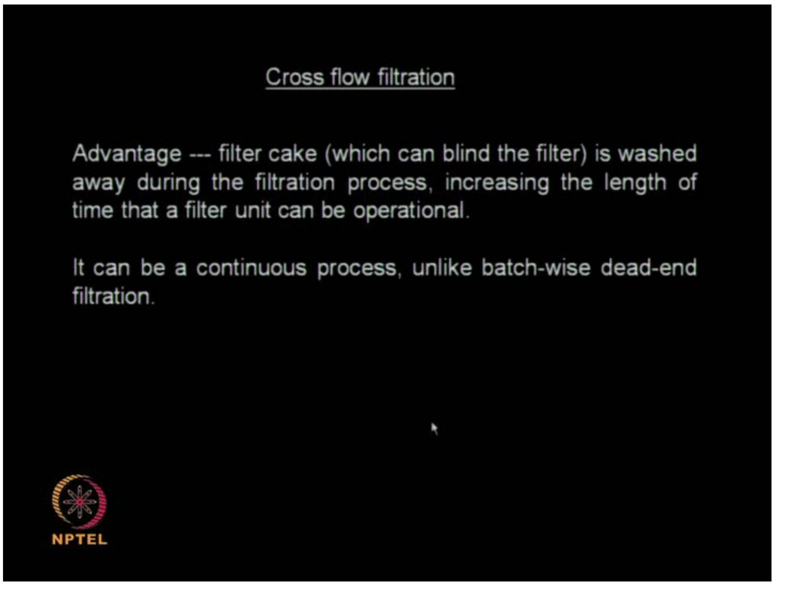

So, what are the advantages of this? As you can see, in the normal approach, the bed is sitting on top of the filter medium. So, it slowly blocks the holes and the filtration process stops. Whereas, in the cross flow, because the liquid is flowing like this, it sort of washes the solids that is settling on top of the filter medium. So, it prevents the clogging of the solids. So, it really prevents the solid clogging.

So, in a normal dead-end filtration, after sometime you need to remove the solids; that means it is a batch process; whereas, in a cross-flow filtration, we can do it in a continuous process actually. So, that way I can prolong the filtration time. So, that is the main advantages with the cross-flow filtration. But, there is one disadvantage in the cross-flow filtration; that is, when the liquid is… or the slurry is moving across or tangential to the filter medium, it sort of rubs the filter medium. So, if you have a polymeric membrane as the filter medium, the polymer gets slowly roded because of the liquid slurry flow, which is tangential. So, that is the main disadvantage of this cross-flow filtration; otherwise, it has got quite lot of advantages when compared to the normal dead-end approach actually.

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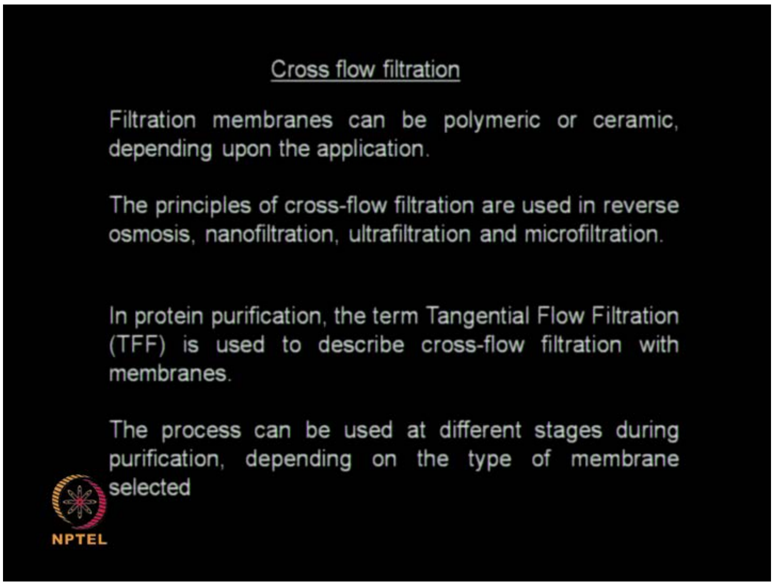

So, the membranes can be polymeric or ceramic in a cross-flow filtration. So, this is generally used in reverse osmosis or nanofiltration, ultrafiltration, microfiltration, and so on. We will talk about all these membrane-based processes later during the course of the work. It is also used in protein purification, this type of approach actually. So, we can use it at different stages of the membrane process and we can use cross-flow filtration for different types of membranes also.

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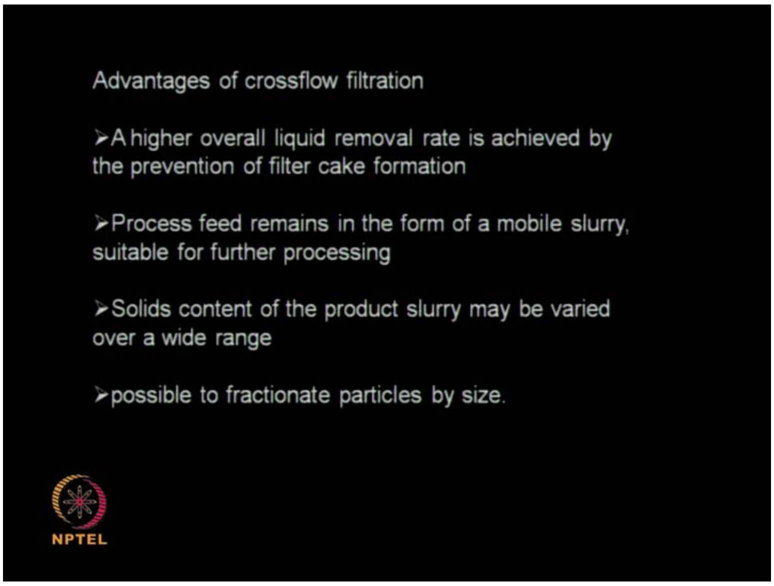

So, advantages as I said, removal rate is very good. And, it prevents the cake formation. And, the feed remains as a mobile slurry and like a normal filtration, where you have the solids and the slurry sitting on the solids. We can look at different percentages of solid present in the slurry. And, it can also do fractionation of the particles by size; that means I can get solids of different sizes separated using this type of approach.

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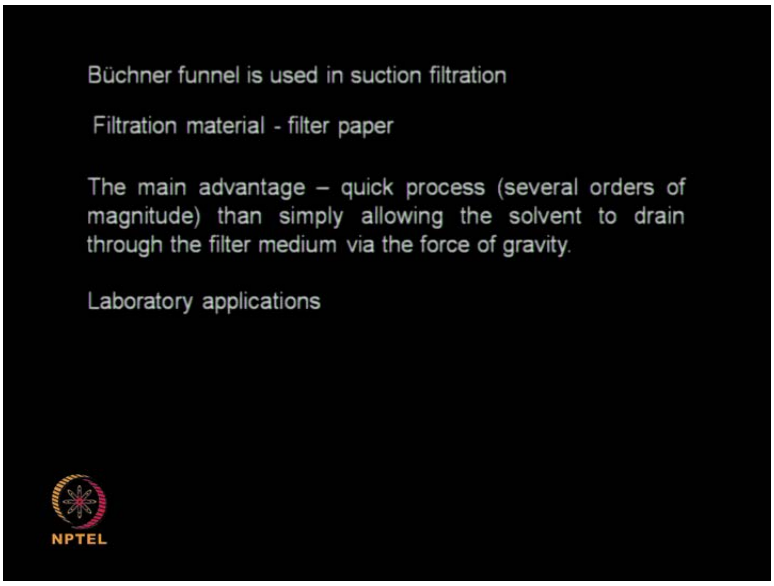

If you look at Buchner funnel, which we used in our lab, we can do the filtration process by the suction. So, here you have the filtration medium is generally a filter paper. So, this approach is very good. It is a quick process; it is simple. So, the solvent gets drained at the bottom; and, it happens because of the force of gravity. Generally, it is used in laboratory applications.

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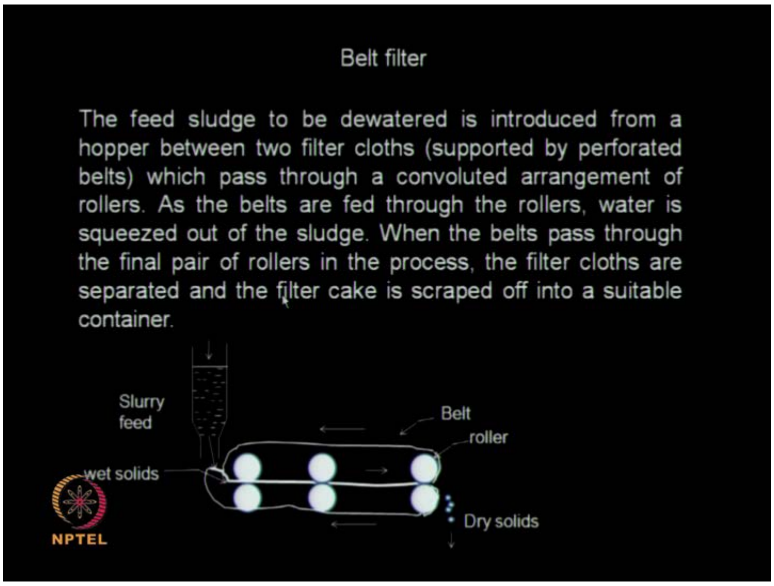

Belt filtration is another approach by which solids can be separated out in a continuous fashion from a liquid. And, here we are more interested in the solids, not on the liquids. This is very good for paste type of material, where you are wanting to remove just the water or solvent present in the paste. So, this is called dewatering. So, what you have is here you have a belt – two belts generally made up of filter cloth or porous cloth; and, these belts travel between these rollers – rotating rollers. So, the feed slurry comes in. And, these belts move in this direction. And, when they go through these rollers, their wet feed gets compressed.

So, the liquid gets sort of squeezed out; and, at the end of it, you have dry solids falling out. So, again the belt moves back; and, here again you are feeding the wet solids. So, as it moves, the two rollers compress the solids. So, the water gets squeezed out and here you get dry solids. So, this is the advantage of it. And, it is useful for dewatering of wet paste and soft paste and compressible paste. So, here we can either have a scraping unit; or, if the solids are not getting compressed, it can fall out on this side. So, belt filter is used as a continuous process, because here continuously, slurry can be fed in; and then, continuously, you can get the dry solids. And then, the dry solids can be fed into a continuous oven or a hot air dryer; and, it can be dried still further. So, it is used in fertilizer industry.

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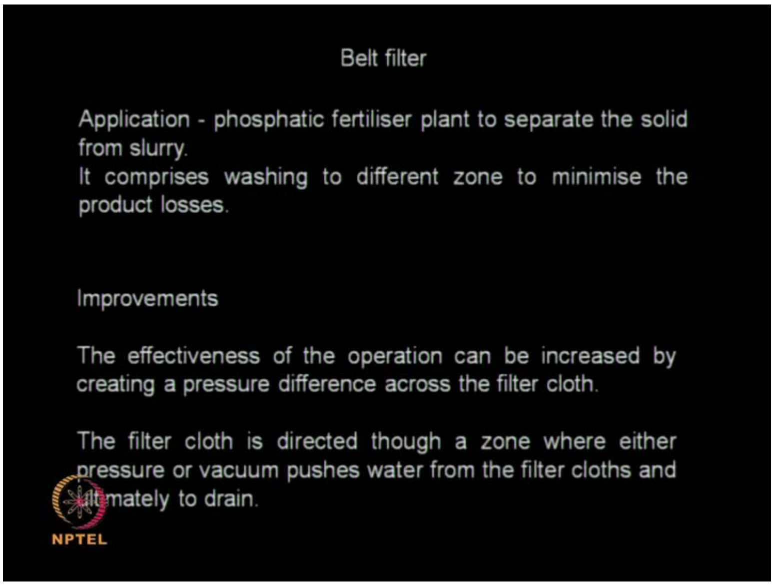

So, the effectiveness of the operation can be increased by creating pressure difference across the filter cloth; that means you can bring in the filter rotating drums closer; or, the rotating drums can be kept further. So, the closeness of the rotating drums determine the pressure that is applied to the wet paste.

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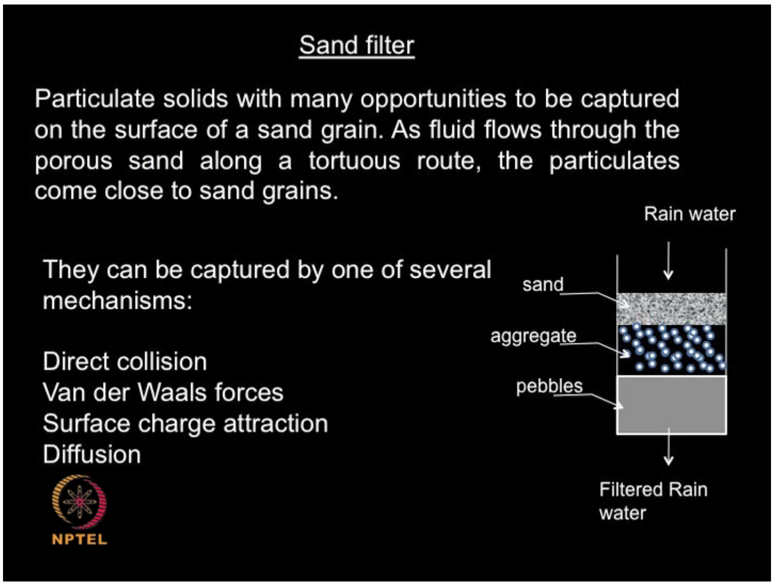

I thought about depth filter; and, this is a typical depth filter. Sand filter is a typical depth filter, which is used for purifying running water; it is used in water treatment facilities; it is used in rain water harvesting and so on. So, in the depth filter, what you have is you have layers of particles of sand here, big aggregates here, pebbles here. So, as the rain water flows through, the solids are captured at different places and the filtered rain water flows through.
So, you see this is useful only if you are not interested in collecting the solids; whereas, you are more interested in the liquid – number 1. Number 2 – when the amount of solids present is minimal, because if the amount of solids present is very large, then it will block… Over a period of time, it will block the entire filtration assembly, because here you are not going to collect the solids; they will be captured at different places; some solids depending upon the particle size maybe trapped in the sand. Some may be trapped in the pebble; some may be strapped in the aggregate. So, these filters are useful generally for rain water harvesting or water purification facilities.

So, how do they get captured? The direct collision between these particles or wasteful material with the sand or pebbles present; there could be van der Waals forces; there could be surface charge-based attraction; there could be diffusion and so on. So, different types of interactions take place as the fluid moves through this depth filter and the solids in the fluid gets captured or removed.

They are very useful and simple, very cheap. And, once you set up this type of filtration assembly, it can last for many many years. As long as the percentage of solids present in the slurry is minimal, these depth filters are extremely advantageous. And, the operating cost is practically zero; you do not need to spend any money on chemicals or any money on utilities and services. And, mostly they operate under gravity. So, you are feeding the liquid or water from the top. And, because of the gravity, it flows down and then it flows downstream into various locations or places or various points in the plant. So, that is the main advantage of these depth filters.

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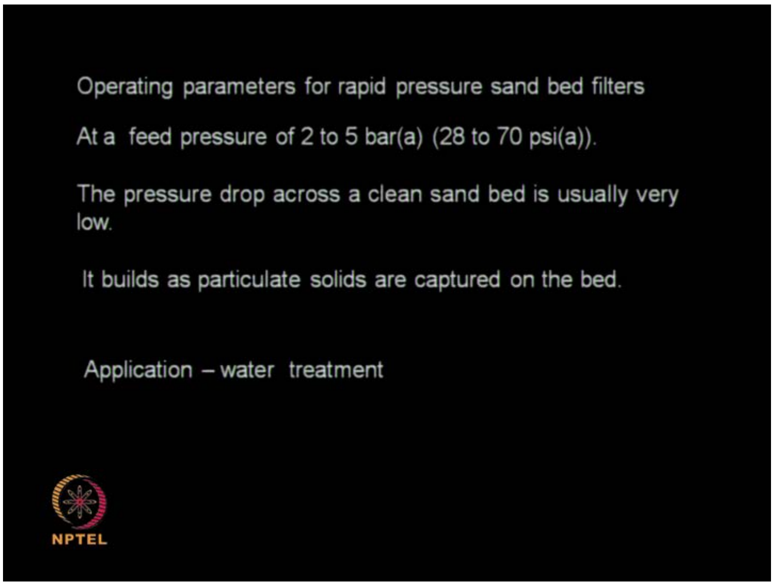

So, the operating parameters for rapid pressure; so, it can be operated at low pressures – 2 to 5 bar. Maybe generally, if the entire sand bed is very clean, the pressure drop also will be minimal actually. But, over a period of time, if you are accumulating wasteful material; if there is going to be biological growth taking place; then, slowly you may find that, the pressure drop across these increases. So, those periods of time, maybe you need to wash these type of sand filters. So, as I said, they are extremely useful for water treatment type of application.

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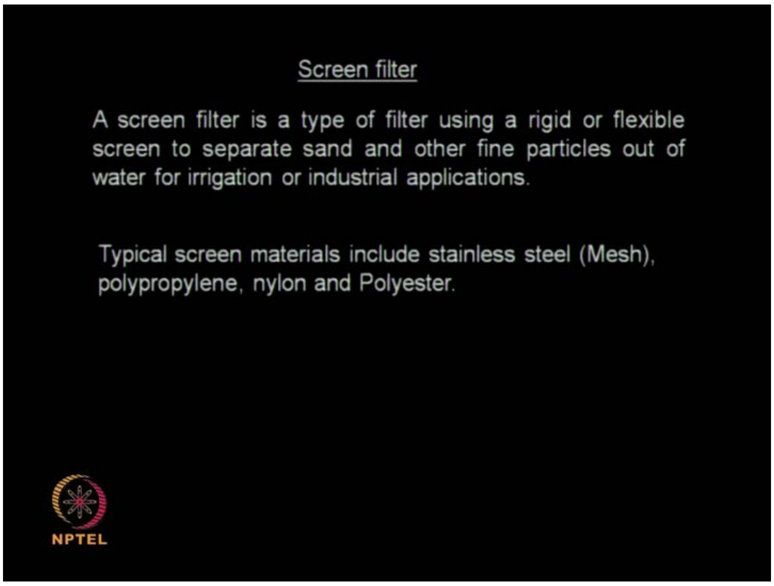

Then, you have screen filters. These are screen filters you might have seen for filtering or separating large particles – large rigid particles of various sizes. So, we can use a large screen, rigid screen, metal screens; even polymeric like nylon-based screens to separate sand or other fine particles. So, these are again used in industrial applications. So, the type of material you may use is stainless steel or iron mesh, polypropylene mesh, nylon mesh, polyester mesh. So, they are very rigid; they are very rugged. They can last for a very long time.

So, you can have mesh of different sizes; that means different holes. So, you will also be able to separate the particles into different categories depending upon the particle size. So, these filters are very ubiquitous if you are interested in collecting particles of various sizes. So, we have been covering a wide range of subjects relating to solid-liquid separations over the past four lectures.

And, I also mentioned that, this is almost the first – mostly, this is the first step after the fermentation or a biotransformation. And, here you are removing the solids from a fermentation broth. In some cases, you may be interested in the solids; in some cases, you are interested in the liquid. If the material or product is intracellular, you will be interested in the solid or the biomass. If you are interested in the metabolites – extra cellular metabolites, you are not interested in the biomass or the cell debris. So, you are interested in the liquid.

If you have a material, which is very suspended and it does not form precipitate, you may have to perform certain pretreatment operations; the pretreatment operation – wide ranging operations like increasing temperature or adjusting pH or adding certain flocculating or coagulating agent or using a filter aid or an adsorbing material. So, all these different approaches can be adopted to improve the filtration process. Once you have improved the process, you go into filtration.

It can be like a depth filtration or it can be a surface filtration. So, in a surface filtration, the bed starts accumulating – the bed of solids on top of a filter medium. The filter medium can be of any material starting from metals to ceramics to polymeric material. The bed as it forms, it can be compacting bed or it can be compressible bed, which will slow down the filtration process. So, you add a filter aid to that, so that the filtration is very fissile.

Then, we developed an equation using Darcy’s law, which will determine the time required to filter a certain amount of slurry. So, the time we found out depends upon the permeability of the bed or certain properties of the bed material. It depends upon the pressure you are applying; it depends upon the viscosity; it depends upon the amount of solids present in the fluid.

Sometimes you may have to resort to centrifugation because in centrifugation, you can resort to very high pressures. Then, we looked at different types of centrifugation. We looked at something called tubular bowl centrifuge; we looked at something called the disc centrifuge. In the tubular bowl, there is a bowl; and, in disc, you have many discs. So, what happens; during centrifugation operation, because of the centrifugal forces, solids are directed to the walls.

And, the main equation can be very simplified into the throughput through a centrifuge, is directly proportional to the terminal settling velocity of the solids multiplied by certain parameters, which determines the centrifuge properties as well as the operating conditions of the centrifuge. So, the centrifuge properties on operating condition of the centrifuge – we can get it from the vender. The terminal settling velocity of the solid depends upon the physical properties of the solid as well as the fluid, which you are using; which you can determine from the lab.

So, we can use this type of equation for scaling up when we move from very small scale right up to a very large scale. Then, we looked at something called the centrifugal filter; that is, the walls of the centrifuge are porous. So, the solids start accumulating at the wall. So, you form instead of a flat bed of solids, you will form something called a cylindrical bed of solids. And, the liquid comes out from the circumference. Then, we looked at the equations related to the centrifugal filter and compared it with the normal flat bed filter.

Then finally, we looked at the scaling up operation. Scaling up – when I move from a flat bed filter to a centrifuge or when I move from a small centrifuge to a large centrifuge, because ultimately, whatever data I collect in my lab, I make use of it to perform a scalar; which will help me to design a centrifuge or a filter, which can process a large amount of slurry. So, I went into that particular set of calculation. And, also we looked at a large set of problems, which tried to address these various aspects of filtration. So, the main equation that comes into filtration as you can see is the Stokes' law, which determines the settling time or the terminal settling velocity; and, the Darcy's law, which tells you the relationship between the quantity of liquid or slurry that needs to be filtered as a function of several parameters like pressure drop, physicochemical properties of the liquid as well as the ease of filtration.