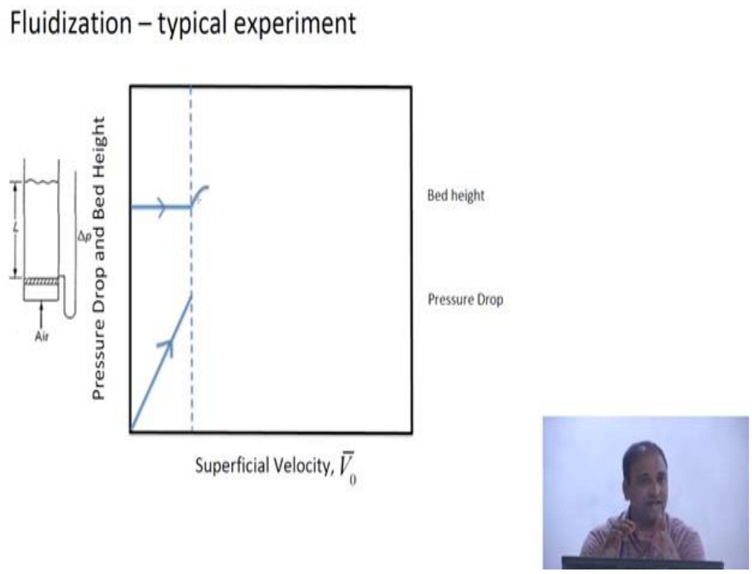
Fluid and Particle Mechanics
Prof. Basavaraj M. Gurappa
Department of Chemical Engineering
Indian Institute of Technology, Madras

Lecture – 46
Fluidized beds

So, yes I think an important concept that we learned about Fluidized bed was something called minimum fluidization velocity right, minimum fluidization velocity.

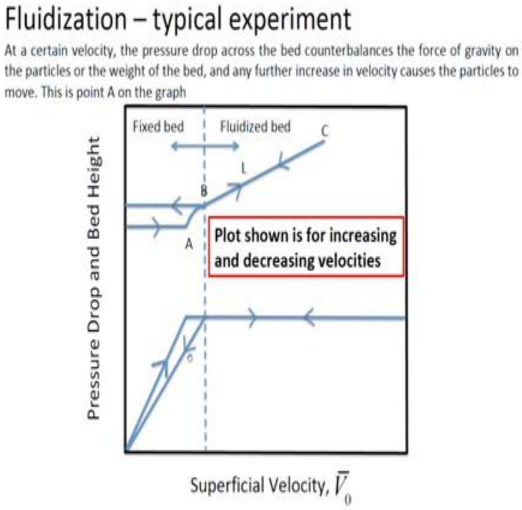
(Refer Slide Time: 00:26)



So, I was just trying to explain it based on a typical experiment that everyone performs ok, in which what you do is you basically monitor, how does the bed height change as a function of the superficial velocity. In a similar experiment I can also follow how does the pressure drop change as a function of superficial velocity, right. And, we said that you know in the initial region right, with the increase in the flow rate, there is a increase in the pressure drop, ok. Because, which there is a linear change in the or linear increase in the pressure drop.

However during that period your bed height remains constant because, you know the upward force that the fluid is basically imparting onto the bed of solids, is not enough to lift the particles that form the bed, right. And, we said you know there is a small change in the bed height, that is where you know all the particles kind of loosen up, there is a small change in the epsilon, ok.

(Refer Slide Time: 01:31)



However, your pressure drop still continues to remain constant and that is what we are done ok. We are done this for people typically do it for a cycle you know wherein you start with a packed bed, you go on increasing the flow rate and then you know and then you come back to the original state, right. And, actually Praveen had asked a question as to why should we you know why do we take you know the point B, right.

There is this particular line, that is what corresponds to the minimum fluidization velocity right and there is a question as to why that is the case, ok. It has to be that point and it should not be this point that is because of the fact that; so, when you make a packed bed, ok. So, when you make a packed bed, what do you think this these lines right, the initial line. What do you think it will depend on?

So, in the initial line is kind of varying in this way right, that is that is your initial increase, right. So, why does not it very; well, why is not the slope a little steeper or a little smaller? What does that depend on? It depends on the way you pack things in the packed bed, right. It depends on the porosity that you create by packing and it is known that I can actually create a packed bed of different porosity, starting with the same column particle combinations, ok; that means, if I take a vertical column, if I pour solids, ok. They pack in a particular way and they give rise to a bed of particular epsilon.

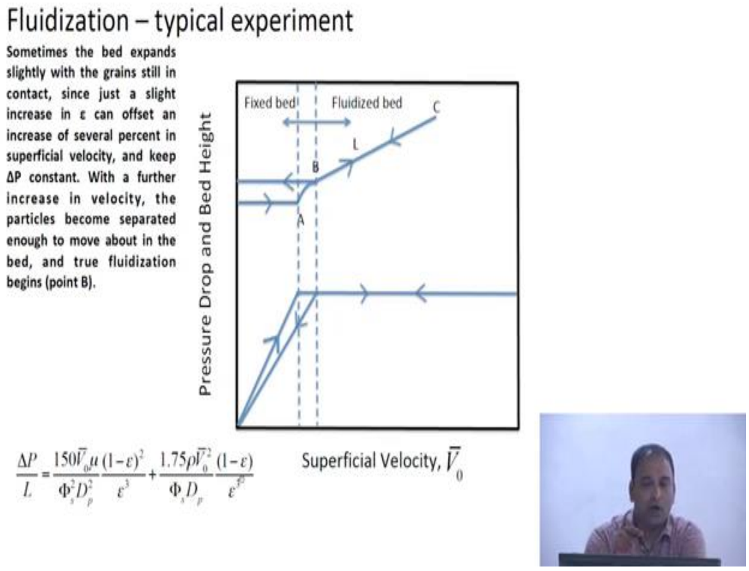
Now, if I do exactly the same process, but in the end if I shake it up ok, they pack a little differently, right. So, that initial line basically depends on you know the kind of operation that you are trying to do in order to create the pack bed, ok. However, when you do the reverse cycle; when you do the reverse cycle. What you do is, you take it to a fluidized state and then you slowly reduce the flow rate, ok.

When you do that ok, the kind of packing factor or the porosity that you achieve is fairly you know, kind of no matter what kind of salt that you work with. If I take spherical particles, it turns out that you know this the porosity that you get when you decrease the flow rate. It is typically around the same value and that is the reason why you know people choose the second cycle ok, where you decrease the flow rate, ok.

And, that B where you start seeing the flat line which corresponds to the packed height, right. That is the point where you should be choosing for the minimum fluidization velocity and it is not this point because, the superficial velocity corresponding to this point depends on the way you pack stuff ok.

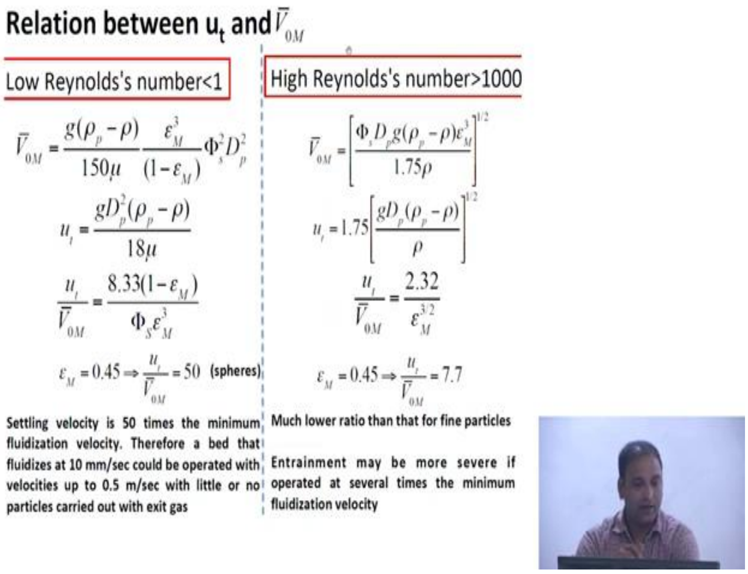
But, however the return cycle, ok typically always gives you a bed of a porosity which is very similar for whether I use smaller particles, larger particles as long as I work with the same particle shape, ok. You will always end up with epsilon M that is the porosity at the minimum fluidization which is very close to we discussed in the last class right, it typical value of a 0.36 ok, that is the, ok.

(Refer Slide Time: 05:07)



And, what we had also done was; yeah, we said that you know when, you do; you basically do a force balance right, you do a force balance wherein you equate the upward force, that the fluid is imparting to the bed, ok. When that equals to the weight of the bed ok, that is when you know the packed bed starts fluidizing, right.

(Refer Slide Time: 05:33)



And by equating the pressure force to the weight of the bed, we obtain expression for what is called as a minimum fluidization velocity. And, for different conditions right when, the Reynolds number is less than 1 and the when the Reynolds number is greater than 1, ok. And, then from that we also calculated what is a typical ratio ok, what is the typical ratio of the terminal velocity.

In the particulars you know flow regime again ok, divided by the minimum fluidization velocity, it turns out that is of the order of 50 for spherical particle for the laminar flow conditions, ok. However, if you take the higher Reynolds number case, that is the turbulent flow conditions, it is number basically gives rise to 7.7, right. This is a typical values that is obtained by assuming a particular value of epsilon M, that is the porosity at minimum fluidization, ok.

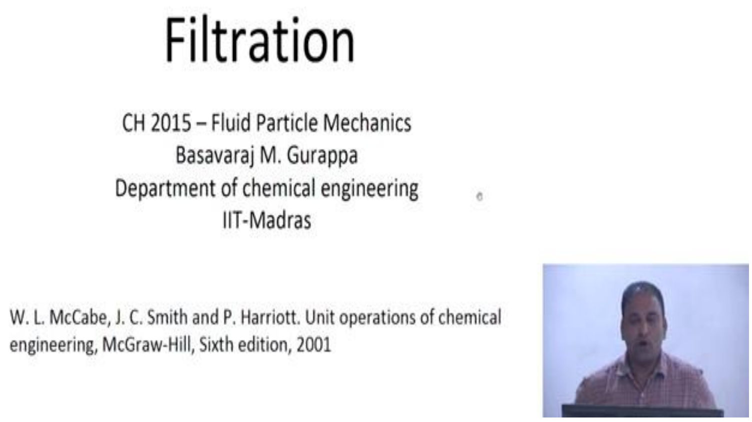
At the take home from this particular you know analysis was that, you get up a larger you know range of flow rates over which I can operate the bed, you know under in the fluidized condition. So, that the entrainment does not happen right; that means, you know. So, we said that for you to have the particles continue to remain in the column, I would have to maintain some velocity, right. Of the fluid velocity, if the fluid velocity is much larger or higher than the terminal velocity. What will happen is, it will take out all the particles also along with the fluid, right.

And, we said that is something was a entrainment right when, some of the particles from the in the bed or carried along with the fluid, that is called an entrainment and you do not want entrainment to occur, ok. Of course, there are cases where entrainment may be required right, you know if you really want to you know say that you know I have particles of different sizes, I would like to take out the larger ones or smaller ones, right.

You know I can also exploit entrainment in some cases, but; however, if you have cases where I do not want the particles to come along with the fluid, ok. Then, you know this is; so, basically what I can do is I can actually work with a flow rate range ok, all the way from whatever value that you are using up to about 50 times. The minimum fluidization velocity without entrainment occurring in the case of low Reynolds number case or the laminar flow conditions.

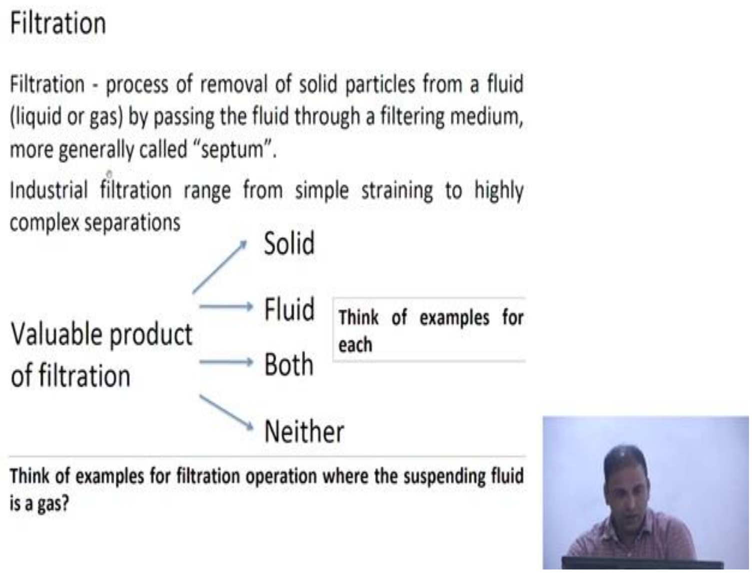
However, if you look at the high Reynolds number case, that range of flow rate that I can operate is limited right. So, that is why we have stop with the fluidization, right. So, any questions that you have about these concepts, if you have any questions we can discuss otherwise, we want we will move on to the next problem, ok.

(Refer Slide Time: 08:26)



Next I want to talk a little bit about some variation of you know flow through packed beds but, something called as a filtration.

(Refer Slide Time: 08:41)



So, I mean the simple definition is that you know the filtration is the process of removal of solids from a fluid and this fluid could be either a liquid or a gas, ok. And, for you to separate up the solids, you know you would have to pass this through a filter medium, right. This should be some you know or this filter medium is also what is called as a septum ok; that means, you have a some medium that has a capability of retaining solids, ok.

What you do is you have a fluid that contains particles and you would have to pass it through this medium and, ultimately the particles get deposited on the medium and the clear fluid comes out right. That is what is done in a in in filtration and the valuable product of filtration ok. It could be just the solid particle that you want to recover or it could be the fluid, it could be both or it could be neither ok. It depends on you know what kind of operation that you are trying to deal with.

Can think of an example where a both the fluid and the solids after the filtration are not useful. Can you think of an operation, where I am carrying out filtration using a fluid which contains particles, where after the filtration I get the solids and the liquid but, none of these products are useful?

Student: (Refer Time: 10:18).

Yeah.

We start is water treatment I would not I would call it, I would kind of classifies under cases where the fluid is useful but, the solids are not right. Because, you know if you have a wastewater treatment right, you have solids you know typically the solids are the ones that you want to you know remove out and throw it out, right. And, I would like to use the fluid that comes out right, the fresh water of the clean water for some use, right.

So, that will essentially come into this case right, where the valuable product is a fluid but, the solid is not right. Of course you may have cases where, like say industry has a waste and if this is a waste sludge, ok. Where neither the liquid nor the solid is useful to them, they want to dump it into some you know, some you know they want to use kind of do some of the, how should I say this, some of the after treatment methods, ok.

But, if that after treatment method requires, removal of both the liquid waste and the solid waste and you know they may have a separate process for each of them to you know kind of dispose right. So, when you are doing that neither the solid nor the fluid is useful right, you know in the in the end, I they just want to dispose it off.

But however, they just they do not want to dispose it as a fluid particle combination but, they want to separate it out because, there are certain after treatment methods, which are specifically suited for solids; some after treatment method which is specifically suited for the liquid, right. Can you think of an example where the solids are the useful product?

What is that?

Salt water; but, I do not think you can take salt water and then filter it right you know. The salt is too small you know in size to be retained on an on, right. So, typically there are a lot of people who work with this nano technology right, the nano particle synthesis, synthesis of particles and stuff like that, right. Where what people do is they make particles and then they want to take out these particles for some application, right.

And, typically when they make these particles, it is of course; there are several different techniques available for making it. But, one of the simple technique that people use is a kind of a chemical synthesis route in which you have the formation of particles in the solution, ok. Now, if I want to take out particles from the solution, what is done is typically you can use a centrifugal filtration or you know or some kind of a process where you retain the solids, ok.

And, the solids are the useful product and then you know the liquid is you know, it could be waste you know of course, you may also have cases where you know, if I if there are some reagents in the liquids, I mean you know. I may be wanting to reuse it as well. But however, if this if the particles are that your generator are useful, you know it that is the case you know where the solids are the useful product and you know the liquid is not so much right. Can think of an example where both are valuable products.

Student: Crude oil.

Crude oil, what about a crude oil? I do not think people use filtration in crude oil yeah, maybe during their, you know extraction properly, but not ok. So, you could have a case where is imagine a case, where I have a particulate dispersion and say that these particles are kind of acting as a site for some reaction ok. And, say that you know there is a reaction going from a to b, and it happens on the surface of the particle that are dispersed in the fluid, right.

Now of course, the reaction products, if they are formed in solution, I would have I can take out the solution and I can use it for you know I can the separate out the product right, ok. So, therefore, the fluid or the or the liquid is useful. And, you can also what you can do is after the reaction has happened, you know I can recycle the particles right. I can you know take it out, you know I can you know use it back in next subsequent, you know operations, ok.

So, essentially what I am trying to say is that whenever you are working with filtration right, you can have you know any combination, ok. You can have a case where only the solid is useful or the fluid is useful, could have a case either neither of them are useful or case where both of them are useful, ok. It depends on the kind of filtration process that you are going to work with or the kind of the fluid particle system that your you are dealing with, ok. I have a question here ok; think of an example for filtration operation where, the suspending fluid is a gas.

Yeah.

Yeah that is true, right. So, one of the example is in you know. So, he is talking about an example where you have a polluted air and I would like to remove you know for example, when people use this mask, right. You would have seen, you know these days, you know traffic junction or somewhere. A lot of people use this masks right and the purpose of those masks is essentially to filter out all the solid particles and then you know let the clean air right. So, you can inhale the clean air right.

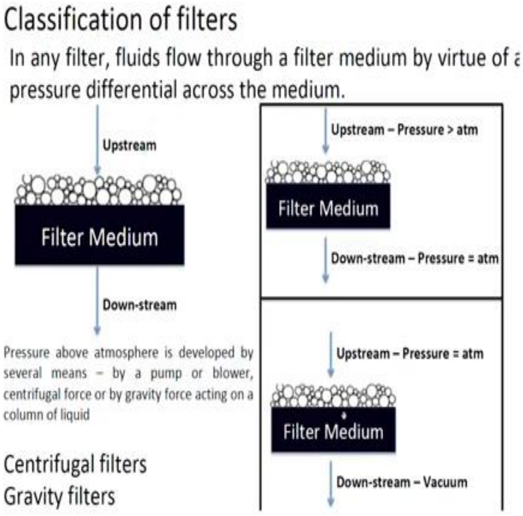
So, of course, the vehicular emissions; so, there is a like say a diesel engine or a or a petrol engine you know combustion occurs, ok. And, typically whatever you know comes out of the engine will have some you know gases for example, or some particulate matter. And, before the gas is you know the exhaust is kind of let into the atmosphere, there will be some filters; you know where you basically remove some particulate matter, ok.

That is a case where you may have there is an example where the filtration operation is carried out to remove the suspended, you know the suspending medium is a fluid and what you removing is a particle. Can you think of an example where the suspending particles are liquid and the fluid medium is gas? Can you think of an example where I would like to recover, the liquid particles you know or the liquid droplets present in a, you know a fluid stream and the fluid is a gas.

Again industrial exhaust right for example, you will have cases where you know the flue gases that come out of the industry right, will can have some mist right, some liquid droplets and you would like to recover them, ok. So, essentially filtration is a very important operation right, you know in industry and again you know all of you are exposed to filtration when you in daily life as well, right. When you when people make coffee or tea right, what you are essentially removing is, when you strain it right.

You have a filter medium that is your filter medium and then what you pour on to the filter medium is your coffee plus some coffee particles and milk and everything, right. And, what comes out of is a clear liquid right or the coffee which is the useful product in that case and you basically dispose your solid, ok.

(Refer Slide Time: 18:10)



So, that is a some brief about you know filtration. I just want to spend a little bit of time talking about classification of filters. And, whenever it somebody carries of the filtration operation, typically the fluid flow through the filter medium occurs because of the pressure difference that you maintain, ok. You know we know that you know for any fluid flow to occur, you would have a, you need a pressure difference right.

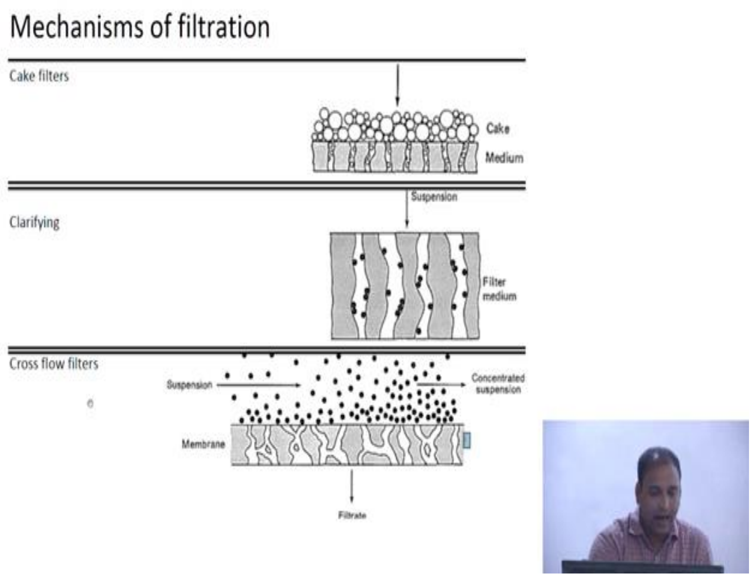
Similarly, in the filtration as well because, you would like to have the fluid flow happening across the filter medium, I would have to maintain a pressure difference across the filter medium, right. And, so therefore, you can talk about what is called the upstream and a downstream right. And, that is your filter medium and of course, you know the solids get deposited on the filter medium, right. So, depending upon you know.

So, there are cases where what you do is, you maintain in the upstream, you maintain a pressure, which is greater than the atmospheric pressure and your downstream is maintained at the atmospheric pressure. So, this is an example of a what is called as a pressure filtration, ok. This is an example of what is called as a pressure filtration, where the upstream is maintained at a pressure above the atmospheric pressure and your downstream is the atmospheric pressure.

Or you can have a case, where your upstream is maintained at atmospheric pressure; however, and the downstream you put you apply a vacuum, ok. In both cases you are essentially creating a you are applying a pressure difference and the flow of liquid through the filter medium occurs because of this pressure differential ok. And of course, there are different ways of maintaining the, you know applying a pressure for example ok. There are cases where I can use a pump or a blower or a centrifuge force, ok. Or I can also have a case where you know where I have a filter medium and I have a long column of liquid above it right.

So, there are different ways by which I can apply your pressure, you know greater than that atmospheric pressure ok. So, it depends on you know. So, therefore, in terms of the present pressure differential across the filter medium, you can classify the filters into two categories ok. One is the pressure filters other one is what is called is a vacuum filters, ok.

(Refer Slide Time: 20:45)



And, yeah; so, you can also classify filters based on what is called a filtration mechanism, ok. In what is called as a cake filters; a cake filters are typically used when you are trying to filter out, a large amount of solids from a slurry ok. I have slurry, which contains a large concentration of particles in a fluid ok. And, what you do is there is a filter medium and then that is your you know upstream, that is your downstream ok. And of course, all the particles are kind of deposited on the filter medium, ok.

Now, when it comes to clarifying filters; so, clarifying filters are typically used when you are required to remove a very small amount of solids, ok. Typically the input to such filters is almost the clear liquid with very few fine particles, ok and, if your objective is to remove even those small little, you know amount of solids are present.

So, you basically pass it through a clarifying filter and one distinction that you see between the image in the top on the bottom is that, you know most of the solids are kind of deposited over the filter medium in the cake filters right, that is what the schematic shows, ok.

However, if you look at the clarifying filter, there are lot of solids, that are deposited within the pores, right. That is the pores that are ok that is the pores of the filter medium. You see that the size of the particles are even smaller than the pores in the filter medium right. And, typically the removal actually occurs because of the addition of these you know small particles to the surface of the filter medium.

And, the only distinction between these two; the cake filters and the clarifying filters is that, one is typically used for cases where you want to remove a large concentration of solids, the second one is used for cases where the concentration of solids in the slurry is very small and the other difference is that the pore size ok. The size of the pores in the case of cake filters is smaller mostly smaller than the size of the particles. However, in the case of the clarifying filters; the size of the pores is larger than the particle size that you have.

And, typically the particles adhere to the surface of the medium because, of some you know some specific interaction between the particles in the medium that you use ok. In what is called as a cross flow filters, what you do is you have a cross stream of suspension, ok. That is being flown over a filter medium that is your the filter medium right, that is a filter medium, ok and, there is a suspension which comes from the left in this case.

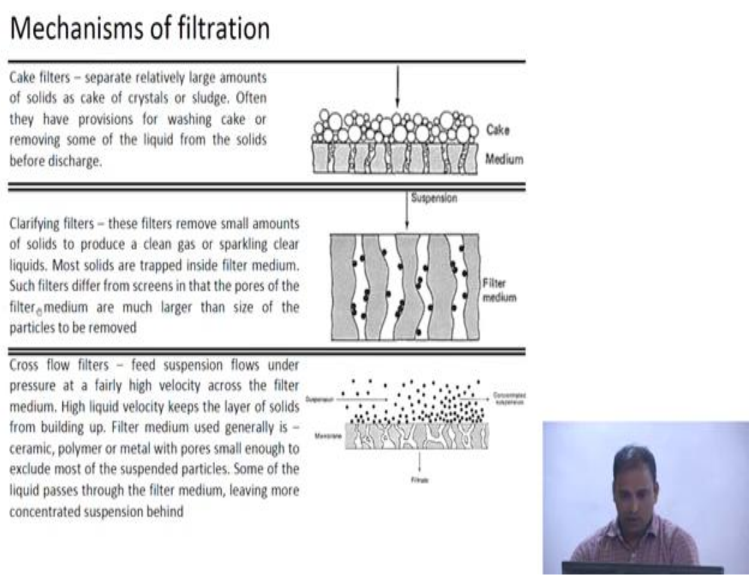
And, typically what you do is you maintain a specific velocity with which the suspension is basically sent and the velocity should be sufficiently larger. So, that the particles do not sediment right because, you know you would like to keep them floating over the, you know the filter medium. And, what happens you know some of the thus the liquid basically comes through the pores that are present in the filter medium and what you end up to the right is a concentrated dispersion, ok.

So, therefore, cross flow filters are typically used when you want to convert slurry from a dilute slurry into a concentrated slurry, ok. So, of course, you can do it by other methods, you know I can take a dispersion which contains a smaller concentration of particles, I can evaporate the liquid right. And, I can make it into a concentrated solution of course,; however, that is much more time consuming, right.

If I even if I take like say a 10 micro liter fluid, it takes about you know a several minutes to dry, right. Therefore, if you want to go from I dilute slurry to a constant slurry, it may take much larger time if you want to use something like drying process. However, if you use this cross flow filters, it is a you know it is a much quicker operation and I can actually go from a dilute slurry into a concentrated slurry, you know a reasonably quick time, ok.

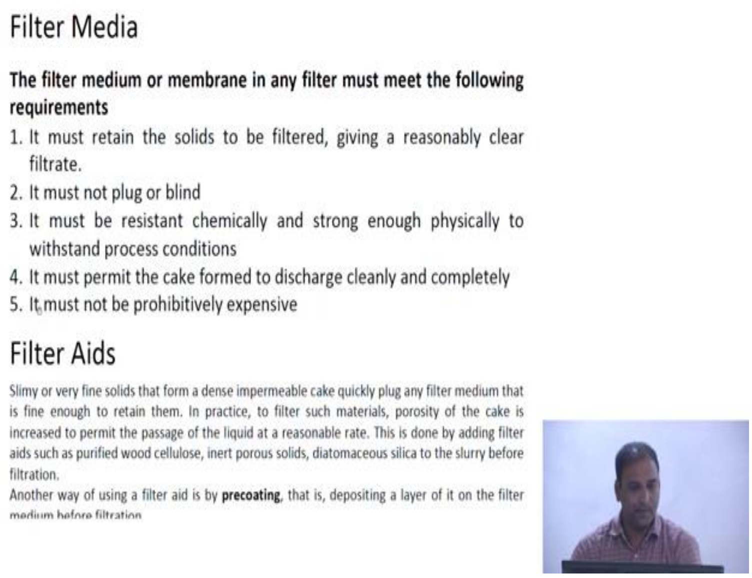
So, therefore, based on the filtration mechanism, you can classify the filters into cake filters, clarifying filters and cross flow filters, ok; any questions that you have, ok.

(Refer Slide Time: 25:22)



So, yeah there is some right up so, you can go through it later.

(Refer Slide Time: 25:25)



Now, so I just want to introduce couple of so the filter media right. So, I said people use septum you know or the filter medium for separation of particles right. And, of course, you know the filter medium or the membrane that you are using for filtration and that should have several requirements right. So, therefore, one of the requirement is that you know, it must retain the solids to be filter giving a reasonably clear filter aid, right.

So, therefore, so the septum that you are using you should not let the solid particles also along with the fluid right. The object is to you know filter out the solids; therefore, the filter aid that you get ok. The filter aid is the fluid that comes in the downstream, right. You have the upstream, the slurry comes in and whatever comes in the downstream is called a filter aid right ok.

Therefore, this one of the requirement of the filter medium is that it should retain most of the solids and it should give a reasonably clear filter aid, it must not plug or blind ok. What it basically means is that, I have a filter medium with time, ok. With time what could happen is you know depending upon the operation that you are trying to deal with, these solid particles may get embedded in the filter medium, right.

Of course, that depends on several factors that depends on the type of the particle that you are working with, it depends on the pressure difference and things like that ok. And, the moment you have solid particles that kind of you know are incorporate into the filter medium, that is what is called as the plugging or a blinding ok, of the medium and of course, that should not happen ok. And of course, it should be chemically resistant ok; it should be strong physically as well to withstand whatever operation condition that we were dealing, right.

You may be doing up; you may be doing filtration at high temperature with you know higher pressure differential, ok. So, you should be able to withstand, you know all these operating conditions. In the other requirement is you know, it should permit the cake formed to be discharged cleanly and completely, ok. So, what you do is, once the filtration is done you are the solids are deposited onto the on the filter medium right. There should be some easy way of discharging the you know the solids and of course, it should not be expensive, ok.

So, that is the some of the requirements of filter medium. The other definition that I want to touch upon is what is was a filter aids and as the name itself says, this is something that helps in the filtration process, right. So, this is what typically happens is they know if your, if the solid particle that are there in the slurry that you are trying to filter ok. If the particles are too small and if the particles are what a called slimy or sticky then, what will happen is doing the course of filtration.

So, what will happen is that the cake that is formed on the filter medium, it becomes very dense, ok. When it becomes very dense, the porosity is much lower. If the porosity is lower is difficult for the filter aid to come out, ok. Therefore, ultimately what will happen is the liquid may not even come out ok. So, what do you do, I want to avoid that, ok. What people do is, they add some additives, ok.

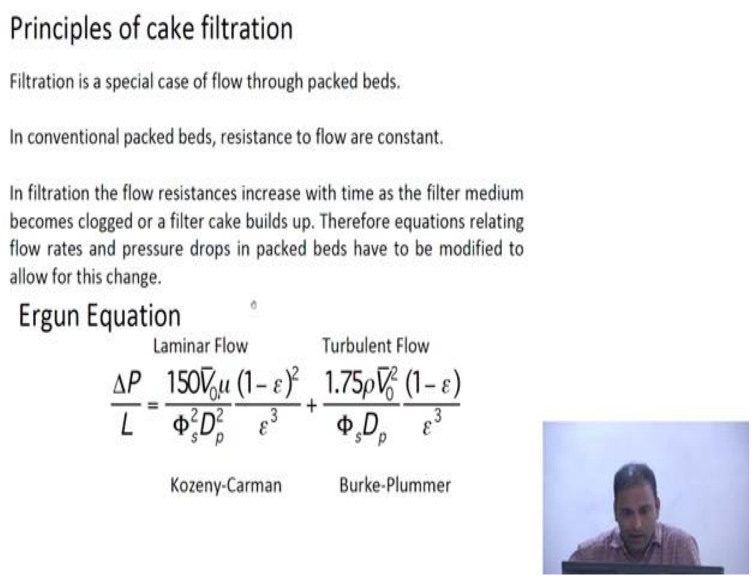
So, these additives are there inert ok, they do not you know do any other job right ok, they do not chemically interact with the liquid neither the solid right. There are inert particles and the moment you add them what will happen is, they will try to maintain a typical porosity throughout the filtration process, ok. It will prevent the formation of this dense impermeable quick cakes, ok.

Therefore, the filtration can continue for a longer period of time, people typically use you know some cellulose particles, you know you can buy, you know cellulose particles in the market. So, you can I can put it is inert, it does not really affect either the fluid or the particle, right. And, then some silica so, basically what you do is. Before you do filtration, you add these additives into the slurry and carry out filtration, ok.

Therefore, the cake that is formed has both the solids as well as these additives and it will help you to maintain a typical porosity that is required for the filtration to occur. So, the, that is by adding; the so, when you add things additionally into the slurry ok. That is one way of doing it, the other way of doing it what is called as a pre coating. What you do is? So, you have a filter medium, I apply some layer ok, some material on the top of the surface right of the filter medium.

And, it will kind of prevent, it will prevent deposition of fine particles on the surface ok. So, either I can use the filter aids or I can use pre coat ok. These are two different ways of ensuring that you know the filtration occurs smoothly during the course of the operation that it correctly, ok. Any questions, any questions so far ok.

(Refer Slide Time: 31:11)

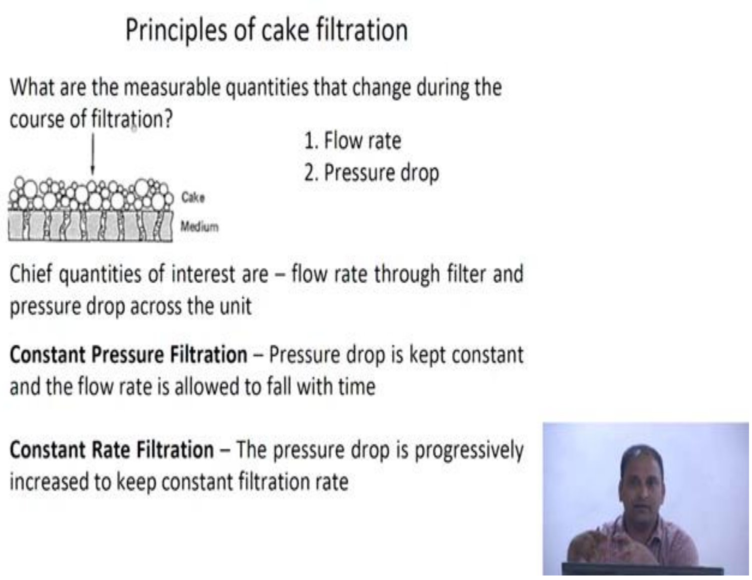


So, that then will just move on to the. So, the next few minutes I am going to talk a little bit about; so, the objective of the remaining class, you know is to look at principle of cake filtration. So, basically we would like to work you know, you would like to develop a working equation for filtration ok, that is the whole purpose, right. So, in essence, I can think of you know filtration as a special case of flow through packed bed, right.

Can I say that, filtration is just a special case of flow through packed bed. But, the only thing is in the conventional packed beds, the resistance to flow remains constant right. But however, in the case of filtration, the resistance to flow, it changes during the course of your operation, right. That is the only difference ok. So, therefore, what is what we are going to do is basically; they are going to start with the working equation for flow through packed bed and you are going to modify it to suit filtration process ok, that is what we are going to do, ok.

So, in filtration the flow resistance increases with time as the filter medium becomes clogged or the filter cake builds up ok, on the filter medium right. So therefore, so what we are going to do is, we are going to start with the Ergun's equation, which is which we developed for pressure drop across the packed bed for the flow of a fluid through a packed bed, right. And, then you are going to modify that to suit the filtration process, ok.

(Refer Slide Time: 32:49)



Now, before we do that I just have a question, right. So, whenever you are doing filtration process, what do you think are the easily measurable quantities that change during the course of filtration? So, I have I am carrying out a filtration operation right and I would like to measure some parameters during this process, ok. Can you think of; first thing is can we think of some quantities that we can measure during this process ok, the second question is quantity that can be easily measured, ok. What is your answer? What is that?

We can measure this all though this have connected right. So, if I have some what I can do is, I have a clean filter medium to begin with, ok and, there is a deposition of solids during the process and I can actually measure it, right. That is of course, I can do that any other parameter.

What is that?

Porosity, porosity how do we measure porous and during the filtration process. So, even the measuring the solid at a deposit on the surface, it is a little tough to do of course, you can put in some sensor and then see no. But, the quantity that you can easily measure are the flow rate and the pressure drop, right. I have a filter medium ok, upstream and the downstream, I can collect the rate at which the filter aid is coming out, right.

I can actually monitor that as a function of time, right. That is one quantity that I can measure and the other quantity that I can measure is the pressure drop that I have either that I have applied or if there is any change during the process. I can also measure, what is the pressure drop that is across the right ok.

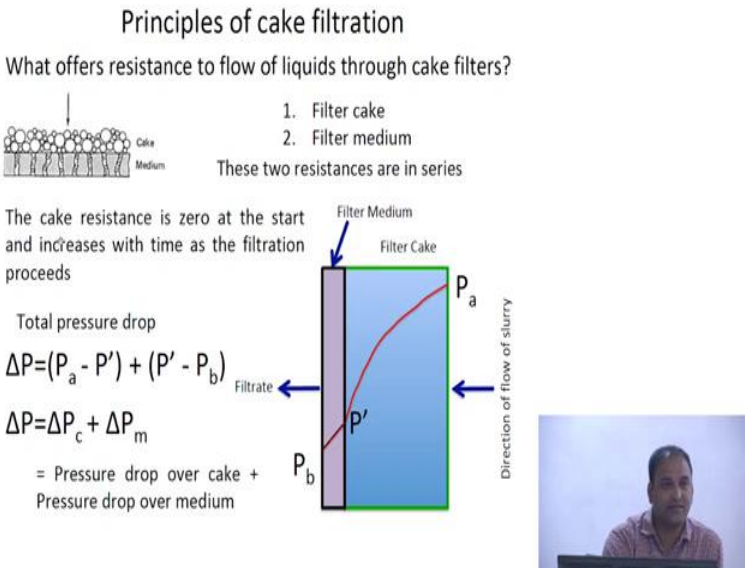
So, therefore; so, depend people talk about two different types of filtration processes ok, when because of the fact you know, the quantity that I can measure are the flow rate of the filter aid. And, the pressure drop I can talk about what is called as a constant pressure filtration ok. And, what is called a constant rate filtration.

In the constant rate filtration what is typically done is; I am measuring, I am actually collecting the filter aid right. Of course, if I look at a conventional filtration operation, the flow rate should actually decrease right with time, right. Does that will also; that is what had actually also happens in the in the coffee straining as well right. I have a, I have a made a coffee and I am just trying to filter it. Of course, you know after you know us after you pour out small amount of coffee, ok. Later on, it becomes difficult for the liquid to come out right, that is because a of the cake formation.

And, what you do is if you want to maintain the constant flow rate of filtration, what you do is? You start playing with the pressure drop. Therefore, what you do in the a constant rate filtration is because, your objective is to maintain, the constant rate of filtration. You go on increasing the pressure drop during the process of during the process. So, that the filter aid continues to come at the constant rate, but at the expense of progressively increasing the pressure drop across the filter medium ok, that is what is called as a constant rate filtration.

In the case of constant pressure filtration what you do is? You maintain a you fix the pressure drop right. I have an upstream pressure, under downstream pressure, I fixed that ok. I maintain that constant during the course of filtration and I let the pressure let the flow rate fall, ok. Typically when people work with this cake filtration ok, which involves passing of a slurry over a filter medium and collecting of the filter aid at the downstream. People typically work with either the constant pressure filtration mode or a constant rate filtration mode and we are going to develop working equations for both of them, right.

(Refer Slide Time: 37:16)



So, the other thing that is also important is that. So, in the case of so, that is a schematic that you have right. So, this is your ok, that is your you know the cake filtration, you know a schematic, upstream the medium, there is a cake formation and that is downstream, right. Now, if you look at this, if you want to think about the pressure drop right.

Now, there is two contribution to the pressure drop right. One pressure drop that comes because of the cake that is formed on the filter medium, the other pressure drop comes because of the medium itself, right. Because, medium is also a porous medium right, the medium that you are using for filtration. It is of course, again another porous medium ok, there is the when the liquid flows through the porous medium. There is a of course, a pressure drop that corresponds to the flow through the medium itself, that is this part and, delta Pc that corresponds to the pressure drop across the cake.

Therefore, the total pressure drop for the filtration process is the pressure drop across the cake plus the pressure drop across the medium, right. And of course, that you know the pressure drop across the medium is 0 to begin with, ok. And, it may remain constant throughout the process, if the medium is mechanically robust, there is no blinding right when ok. If the medium is not modified in any way during the course of filtration, your delta P m is going to continue to remain constant throughout the filtration process. But, however, if there is a blinding or if there is a higher pressure difference across the medium, you know even delta P m could also change, ok.

However, delta P c would always be there and it could increase during the course of filtration depending upon, how much of filter cake is deposited on the filter medium right. So, we will think a little bit about some of these things and then try and develop a working equation for them in the next class, ok.

So, I will stop here and if you have any questions I will be I will be happy to answer, otherwise you can stop here, any questions that you have. Simple concept right, I mean filtration is a fairly simple concept. So, we will try and you know work with the working equations in the next class and then yeah. So, we will have class on Tuesday and Wednesday and then a tutorial on the last day, which is Friday ok. So, if you do not want a tutorial, we can also end it by Wednesday; otherwise, we will have a last class on Thursday; Thursday, Friday sorry yeah ok.

Thanks.