Water and Wastewater Engineering
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Lecture # 13
Filtration

Last class we were discussing about softening. We have also seen the different methods that can be employed to remove hardness. Those are chemical precipitation and ion exchange. Chemical precipitation we usually use lime and soda ash and we can either treat the entire water or we can treat partially and blend it. That is known as heat treatment. We have seen that when we go for ion exchange process especially if you want to remove the hardness completely we have to go for ion exchange process.

Today we will be discussing about another treatment process which is commonly used in all water treatment plants that is filtration what is the need of filtration?
Filtration is the polishing unit as we have seen in sedimentation process and coagulation flocculation process or softening process. these processes will not remove the solids whatever is present in the water completely because after coagulation and flocculation we are going for the settling the settling will not be hundred percent efficient so what will happen some flocs will be remaining in the liquid.

Similarly, in softening also the precipitation will not be completed fast or the settling will not be hundred percent efficient so some flocs will be remaining in the water. Therefore, if you want to remove all these flocs whatever is left over after coagulation flocculation or softening process we have to go for filtration. So filtration is basically a polishing treatment unit. But if the quality of water is good and the turbidity is low then we can use it as a salt treatment unit followed by chlorination as I have written here. Filtration is the polishing step to remove small flocs or precipitant particles not removed in the settling of coagulated or softened water.

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If the flocs are remaining there it will not be aesthetically appealing. So the major objective of filtration is to improve the aesthetic of the water. Beyond that one if turbidity is present, after the filtration we are going for chlorination or disinfection, if turbidity is present in the water disinfection will not be effective; the reason is, the pathogens or the microorganisms whatever is present in the water will be taking shelter under this turbid particles so the chlorination will not be effective and the treated water may cause many problems that means it will not be bacteriologically safe.

Therefore, in that point of view also we have to go for filtration to remove turbidity. So the drinking water standard according to Bureau of Indian Standard is the turbidity should not be more than 1 NTU. If you want to achieve that one it will not be possible by plain sedimentation or coagulation flocculation so filtration is an essential unit.

As I mentioned already sometimes we can go for direct filtration which is a primary turbidity removal unit. After this direct filtration we can go for chlorination. This direct filtration is employed only if the turbidity of the water is less than 20 NTU. And filtration can also remove pathogens but not a complete treatment unit for bacteriological safety. It can remove around 90 to 99 percentage of the pathogens but again that 1 percentage is left over so that can cause diseases. So it cannot be considered as a complete treatment for pathogen removal.

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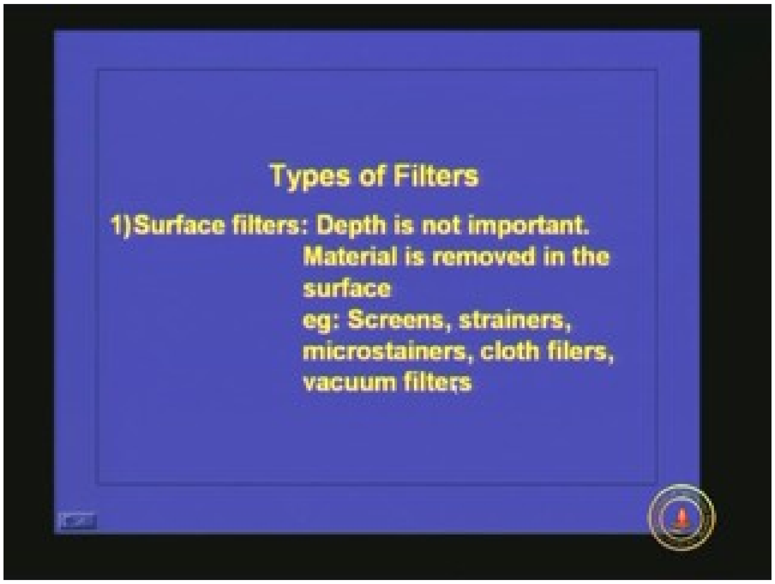

Now we will come to the different types of filters. types of filters can be classified based upon the direction of flow of water; whether it is down flow mode or up flow mode the filter is operating or based upon the filter media because if it is sand we can go for gravel, we can go for dual media, we can go for mixed media filters or sometimes we can go for activated carbon filters or the ………… [earth filters 5:23]. So, depending upon the filter media also we can classify the filters into different categories.

Another classification is based upon the driving force. What is the driving force which is responsible for the filtration? It can be gravity because the water will be staying over the filter bed at a constant head and because of the gravity it will be filtering through the filter that is one type of a filter and another one is, we are applying the water under high pressure so the pressure will be the driving force for the filtration. Another classification is method of flow control which tells how we are going to control the flow in the filter and the last one is filtration rate because certain filters are designed for having a constant rate and some filters operate at a declining rate or variable rate filtration. These are the major classification of filtration.

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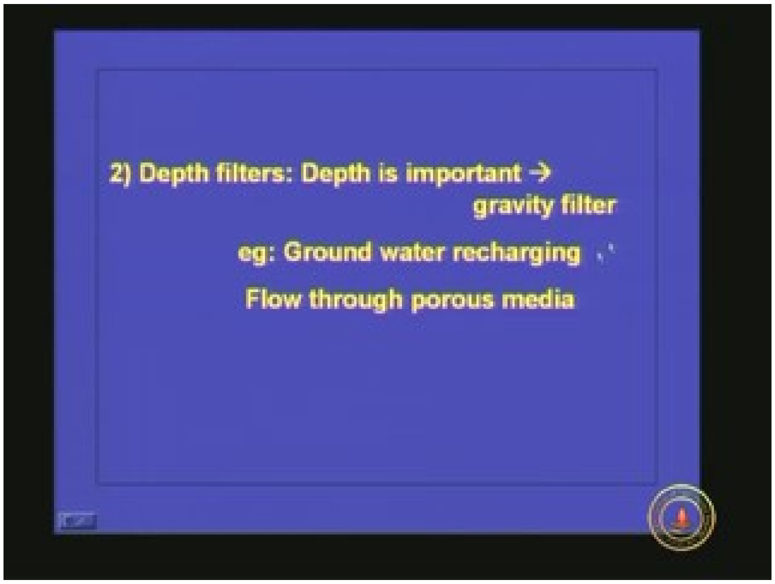

Once again I will tell, depending upon the direction of flow of water types of filter media driving force whatever we are applying, how we are controlling the rate of filtration and the last one is how the rate of flow varies.

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Coming to the practice the most common filter being used in most of the water treatment plants is the granular medium and diatomaceous earth. This is also commonly used in swimming pools and industrial applications and another type of filter is precoat filters. it consists of a porous septa and we add turbid particle or clay particle and that will be acting as the filter.

Already I have discussed how we can classify the filters. This gives another type of classification. We can classify the filters again into surface filters and depth filters. Surface filters are the ones where depth is not important. The name itself emphasizes that filtration is taking place in the surface so the mechanism of filtration is nothing but simple straining; the material is removed in the surface. The examples of surface filters are screens, strainers, microstainers, cloth filters and vacuum filters.

Depth filters: here entire depth of the filter is being used for the cleaning of water so depth is very very important here. And example of this depth filter is gravity filter and other examples are; ground water recharging and flow through porous media.

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Now we will discuss about the most commonly used filters in water treatment plants; those are slow sand filters and rapid sand filters.

Slow sand filter is the simplest filter without any mechanical equipment. This can be used in places where the water is relatively clean that means the turbidity is less than twenty NTU. The slow sand filters can take pre-treated water or raw water as such and this can be used where the lounge, labor and sand is available without much problem, they are not very costly so in such cases we can go for slow sand filter.

Here the pore size is very very small and the mechanism of removal is by straining. That means the sand will be acting as a sief and whatever particle that is coming it will be screened or strained through the sand. That is the mechanism of particle removal. Hence with respect to time at the surface of the filter there will be a biological growth known as dirty layer. This dirty layer dirty layer is responsible for removing any dissolved solids mainly organic matter present in the water.

Therefore, when the water with turbidity and this dissolved organic matter passes through this slow sand filter turbidity will be removed by the straining action because of this dirty layer or slim layer whatever is formed on the surface of the filter which consists of very very active microorganism. Hence these microorganisms will eat all the organic matter present in the water and since the process is very very small it will be able to remove to a great extent the microorganisms present in the water also. Therefore, any amount of water coming out of the filter will be completely cleaned. Mostly the removal in slow sand filters takes place in the top 2 inches so the bottom portion of the slow sand filter will be relatively clean. That is why the slow sand filter is known as a surface filter.

Usually the sand size used in slow sand filters are very fine compared to rapid sand filter. The sand size varies from 0.25 mm to 0.35 mm and the uniformity coefficient varies from 3 to 4 and usually a bed depth of 1 meter is provided in the slow sand filter and as the name itself tells the flow rate is very very slow in slow sand filter. So if you want to have a large quantity of water to be treated the area required is very very high so it is a land intensive process. But for small community where the water is of reasonably good quality it is the best treatment option because with a single unit we can achieve the complete treatment then after the filtration we can go for chlorination and we will be getting water of portable quality.

Therefore, if you want to see what are the operational conditions of a slow sand filter usually the filter box of the total height of the filter varies from 2.723 meters with a free board of around 0.2 meters and usually the sand height will be 1 meter and there will be a gravel layer under the sand which will be around 0.3 meter and the under drainage system will be taking another 0.2 meter and the height of the water column standing above the filter will be around 1 meter.

We will see once again; total height is around 2.7 to 3 meter so free board is around 0.2 meter and water column is 1 meter, sand depth is 1 meter and gravel depth is 0.3 meter and under drainage system is around 0.2 meters so altogether it comes to 2.7. That is why I said that height varies from 2.7 to 3 meters.

Why we are providing this 1 meter height of sand is because, we have seen that the mechanism of particle removal in slow sand filter which is merely straining and microbial action and most of the cleaning is taking place in the top 2 inch portion so what will happen is with respect to time the top portion of the sand will be getting clogged because of the turbid particle and the microbial growth so at that time the rate of filtration will be coming down drastically.

Now, how can we clean the filter? Since it is a surface filter we have to clean only the surface. That means we have to remove the dirty layer from the top. That means around ten centimeter depth of the filter sand we have to remove. So what will happen? You have already 1 meter depth of sand so you are removing around 10 meter depth of the sand from the top so remaining 90 centimeter will be there, so the filter will be running perfectly alright.

At any case the filter sand should not go beyond 0.4 to 0.5 meter. So, once you fill the filter it can be operated without sand replacement for two to three years because we may have to remove sand only once or twice in a year depending upon the quality of raw water coming to the filter because every time we are removing only 10 centimeter of sand. It is very very easy because once the height reaches 0.4 meter we have to remove entire sand and replace it with new sand and we will be getting clean water through the under drainage system which we can collect in a tank and provide a (doubt 14:25) and measure the quantity of water if you are interested.

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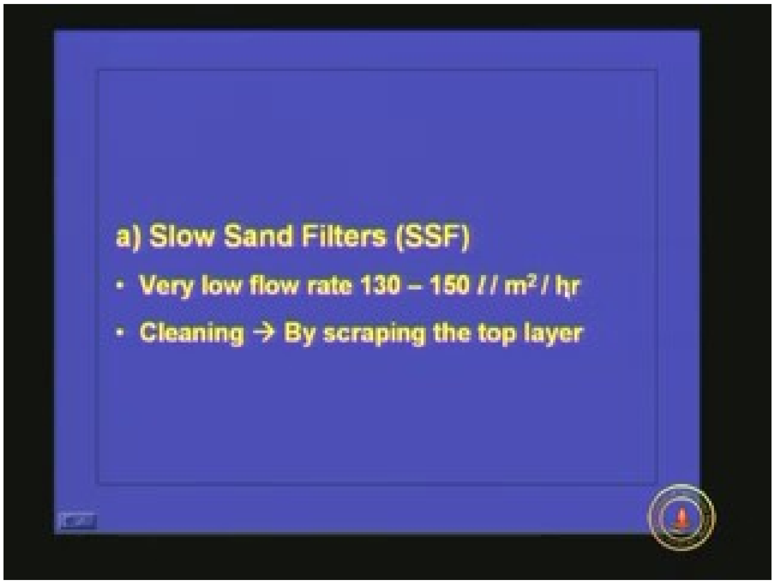

The flow rate of slow sand filter is very very low; it is only 130 150 liter per meter square per hour. Or if you want to have linear meters it varies from 0.1 to 0.2 meter per hour so it is very low. so whenever we talk about different treatment units most of the time what we do is we provide a standby unit because whenever the cleaning is required the other units have to be there in operational condition but in case of slow sand filter it is not the same case because if you have two filters both the filters can run continuously with flow rate of 0.1 meter per hour which is the recommended value. But during cleaning you can close one filter and the other filter can be overloaded up to 0.2 meter per hour. Thus we need not go for another filter which is just a standby one. The one already existing can take overloading but we have to have proper inlet arrangements so that the sand surface of the slow sand filter will not be getting affected because the dirty layer or the microbial slim layer will be there over the sand bed and if it gets disturbed the quality of filtrate will be affected.

I have already discussed that cleaning is by scraping the top layer and rate of filtration is very low that is why the names slow sand filter exists. One more thing, when we go for slow sand filter the sand whatever we are getting as the builders sand or something like that we can directly use that sand and there is no need of grading or preparing that sand for slow sand filter. The sand as such we can dump it into the filter otherwise if you want to grade it the cost of that sand filter will be very very high. Even if you use the available sand as it is it is not going to hamper the efficiency of the system much.

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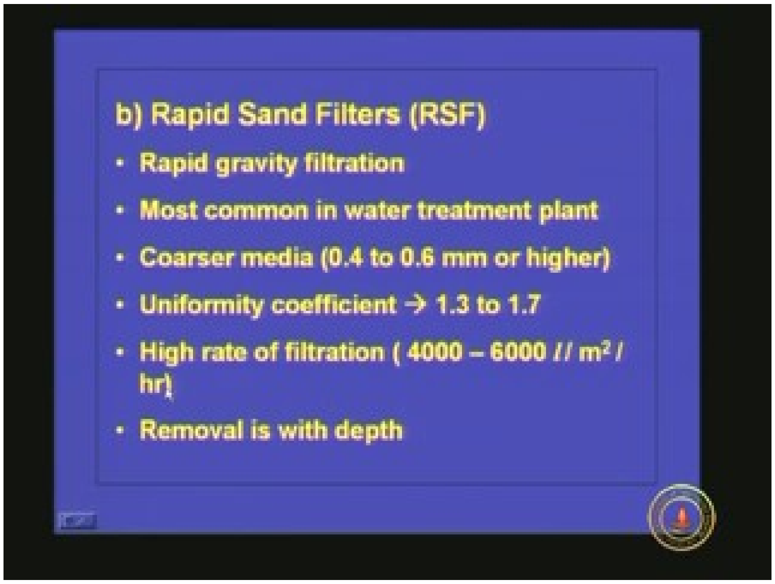

Now we will see rapid sand filters. Of course here the flow rate is very very high compared to the slow sand filter. The filtration is by gravity so it is known as rapid gravity filtration and this is most commonly used filter in water treatment plant and here the media is coarser compared to slow sand filter. Here we can see that the effective size varies from 0.4 to 0.75 mm and 0.6 mm is the usual range but it can go up to 0.75 mm and uniformity coefficient is 1.3 to 1.7. And the filtration is very very high. The rate of filtration is 4000 to 6000 liters per meter square per hour. Or if you want to have the velocity in velocity terms the flow rate is in the range of 4.8 to 6 meter per hour. Even we can go up to 10 meter per hour.

The most important difference between rapid sand filter and slow sand filter is in the rapid sand filter the removal is with depth it is not only the straining which is responsible for the removal of suspend colloidal particle in rapid sand filters. Since the entire filter media is used for the removal of particulate or turbidity cleaning cannot be done by stopping the top layer, we have to clean the entire filter media so usually we adopt backwashing for the cleaning of rapid sand filter. The most commonly used filter media is sand. Sometimes people use coal, anthracite, coconut shell and ballistic stone etc.

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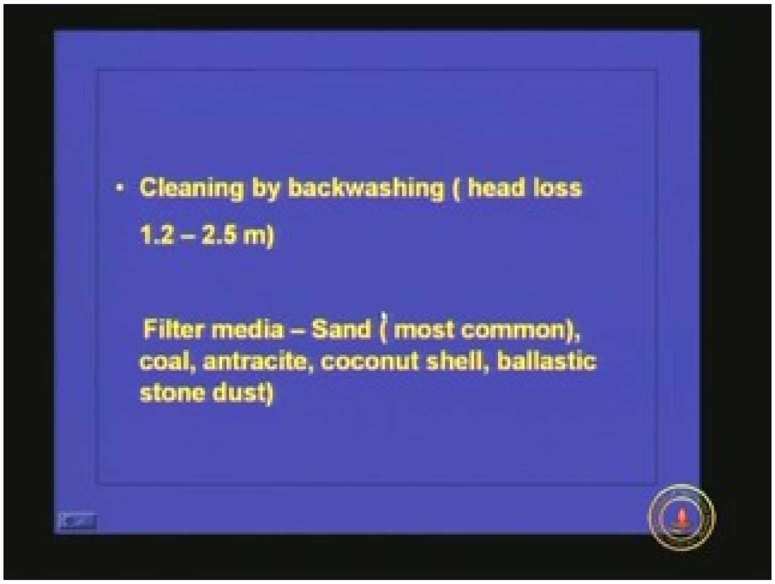

Anyway we will come back to this rapid sand filter in detail afterwards. Before that we will see what is this dual media or multimedia filter. As we have discussed the rapid sand filter most of the time we use sand as the filter media but if you use sand and we are going for backwashing what will happen is in backwashing everything will be lifted up or the entire filter will be in a fluidized state.

Once we remove the backwash or we reduce the backwash velocity the particles will be settling down so the coarse particulate matter will be coming to the bottom and in the medium and in the middle and the finest one will settle on the top. So if you see the pore size distribution throughout the depth of the filter how it will be is the pores size will be least in the top most portion and it will be gradually increasing and the pore size will be maximum in the bottom.

But if you look into the mechanism of filtration this is not the advisable pore size distribution. If you can have the maximum pore size at the top and the minimum in the bottom the filters can be used much more effectively. That is the purpose of this dual media filter. Here what we are doing is we are making the combination of two media with different density.

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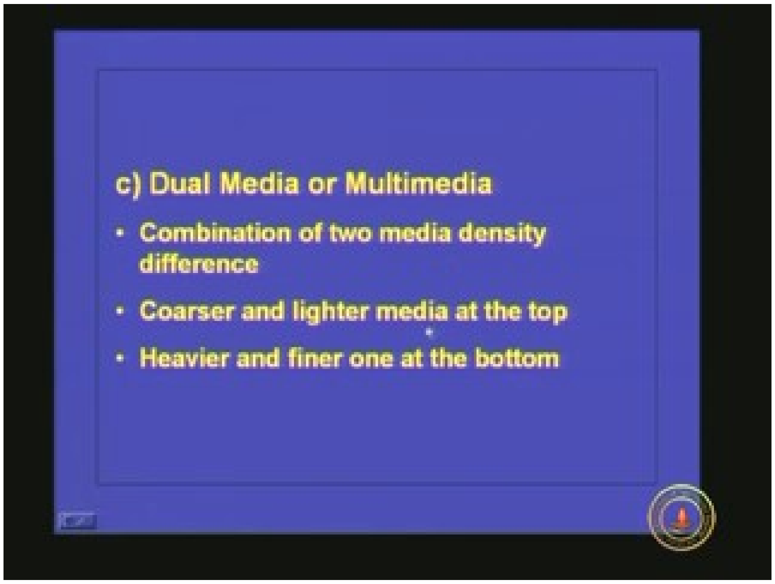

Now what will happen is the coarser media with low density in the backwash will be staying in the top and the finer media with high density will be in the bottom of the filter so we will be getting a pore size distribution in somewhat the other way. That means high pore size will be there in the top and lower pore size will be in the bottom and this will increase the efficiency of the filtration. So if you go for dual sand filter we can increase the filtration rate considerably compared to rapid sand filter.

Anyway we will come back to this pore size distribution after discussing in detail about rapid sand filtration.

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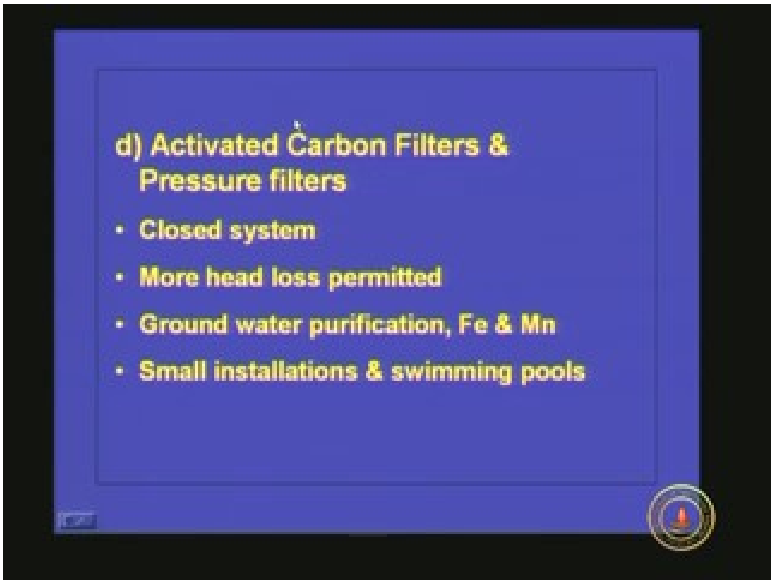

Another one is activated carbon filters and pressure filters. Activated carbon filters are pressure filters usually used in industries so they will be removing turbidity as well as the dissolved solids present in the water because activated carbon as we all know is a very good adsorbent so filtration as well as adsorption will be taking place simultaneously. So depending upon the quality of raw water we can desire which type of filter we have to use and it can remove even dissolved gases.

Most of the time these filters are operated in closed system and more head loss is permitted because the filter is running under high pressure so it can take more head loss. Usually it is used for ground water purification where Fe and Mn have to be removed and this is used only in small installations like swimming pools or some industrial complexes etc. But in usual practice wherever community water treatment plants are there we usually won't go for pressure filters because these pressure filters are having various disadvantages.

The reason is it is operating under high pressure so the control of flow is very very difficult and another thing is since the contact time is very less the filtration is taking place under high pressure so if you use it as a chlorination unit also the chlorine will not be getting enough contact time so the disinfection will not be proper.

Another thing is it is in a closed cylindrical shape so examination of the interior of the filter is very very difficult so we won't be able to make out how effective the filtration is taking place. This is more serious in case of backwashing. We won't be able to make sure whether the filter bed is expanding according to the requirement. Because unless the filter bud is expanded properly the turbid particles whatever is attached to the filter media will not be coming out so we have to have a certain percentage of expansion. But since it is invisible inside the pressure filter most of the time it will be very very difficult to find out what is the effectiveness of backwashing and because of its geometry the back water or dirty water coming out of backwashing is not distributed properly on the surface of the filter so the collection of water after backwashing also gets very very difficult.

Another disadvantage is it is working under high pressure. So you see the outlet is under high pressure and if you suddenly release the pressure in the inlet the entire filter bed will be getting disturbed and you will be getting a very bad quality of effluent in the outlet. These are the disadvantages of pressure filter, because of these disadvantages pressure filter is used only in very very limited places especially in swimming pools and industrial operations.

One advantage of this pressure filter is it can have a very very high filtration rate, because the filtration is taking place and the pressure the filtration rate is very very high so wherever space is a constraint we can go for pressure filtration and the last one is cake or precoat filtration.

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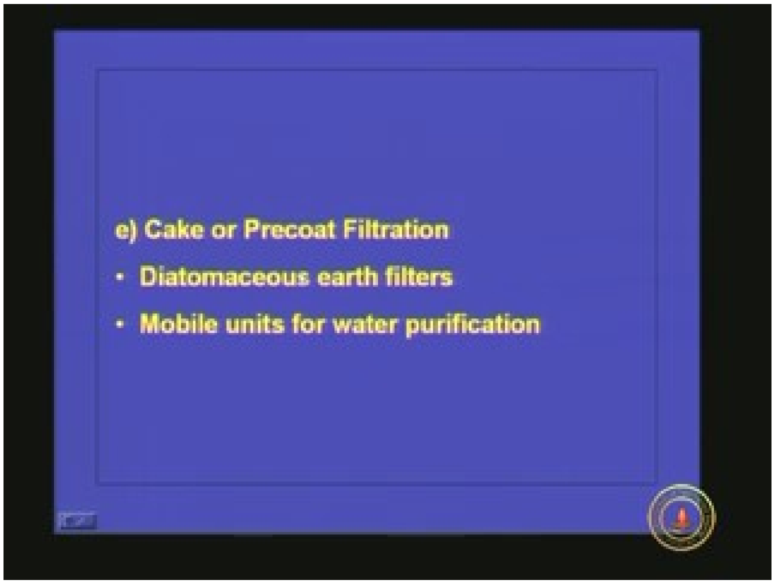

Usually diatomaceous earth filters are used and they are mobile units for water purification. Whenever we have to have a water treatment unit which is mobile at that time we can go for precoat filters as it is very very easy to move from one place to another place.

Now we will comeback to the rapid sand filter which is the most commonly used filter in water treatment plant. We have seen in slow sand filters the removal of suspended particles or turbid particle is taking place because of straining so only the top layer of the slow sand filter is being used. But in rapid sand filter it is a depth filtration so entire depth of the filter is being used for cleaning purpose. So, if straining is not the only mechanism then all the other mechanisms are involved in the cleaning process when we use a rapid sand filter. The mechanisms can be classified into two categories; one is the transport step and another one is the attachment system so the removal is taking place because of the combination of these two processes the transport and the attachment. Transport means from the bulk liquid the particle is moving towards the filter media and in attachment step once the particle comes in the vicinity of the filter media it is getting attached to the filter media and getting removed known as the attachment step.

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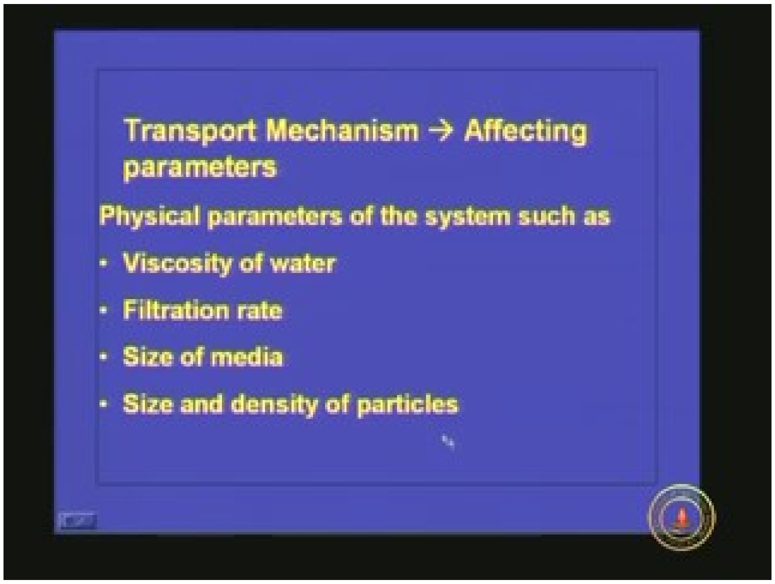

We will see what are the physical parameters that affect the transport mechanism. Those are the viscosity of water, filtration rate, size of the media and size and density of the particle. Here we can see it is independent of the chemical properties of the particle present or the turbidity present. So either it is the flocs by coagulation flocculation or flocs formed after softening or it is just turbidity after adding coagulance or without coagulance it is independent. So the efficiency will be depending upon the viscosity of the water or in other words by temperature of the water.

Filtration rate: if you have high filtration rate naturally the efficiency will be less and size of the media and size and density of the particle. Now we will see what are the different transport mechanisms.

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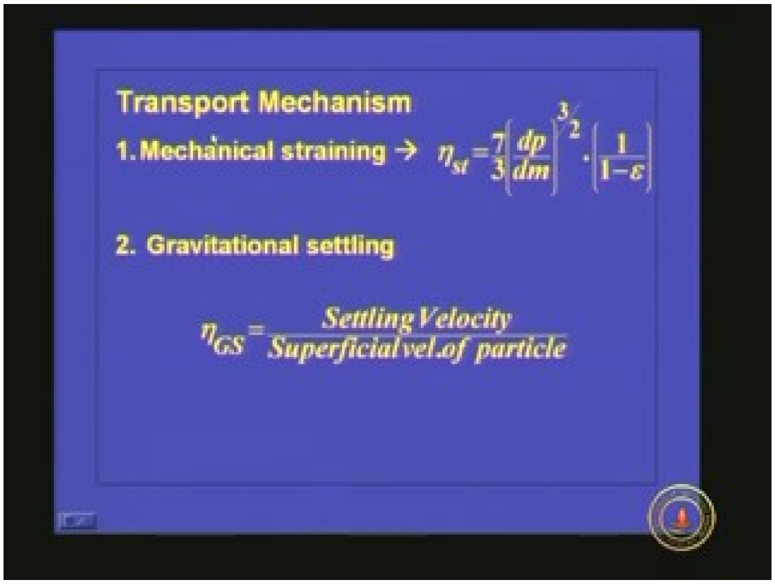

First one is mechanical straining. Here also mechanical straining will be taking place. So for example we are having the filter media so if three filter media is there and if they are sitting closely to each other then what will happen is there will be a pore in between that one. Hence, if the turbid particle size is bigger than that pore that can be removed by straining action and with respect to time what will happen is this pore size in between these particles………. I will just draw in the black board (Refer Slide Time: 28:05**)** these are the filter media the particles are here so here you can see there is a space where the particle can go through this space but if your turbid particle is larger than this pore size whatever is there in between this filter media then it will be getting removed and with respect to time more and more particles will be settling here so the pore size will be getting decreased with respect to time so more and more finer particles will be remove by the straining action.

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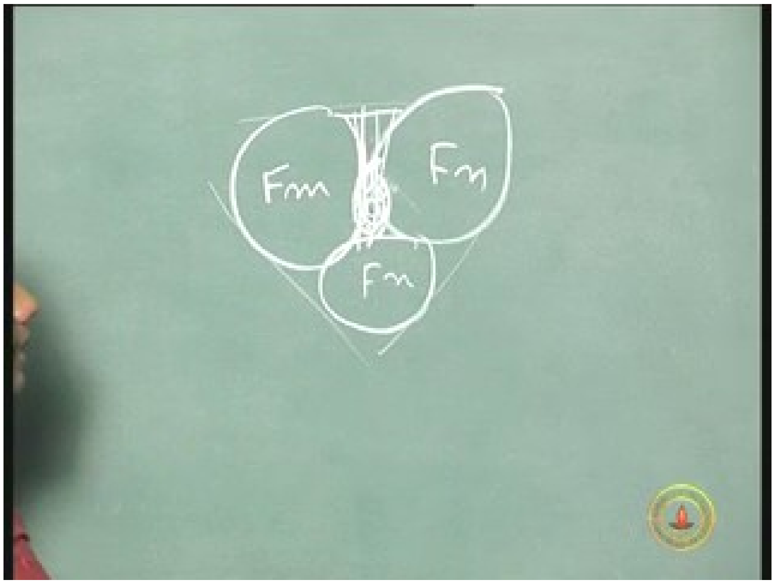

This is the mechanical straining. Whenever the particles are there, in between the pores will be there so depending upon the pore size the particle can be removed. Therefore, if you want to find out the efficiency because of this mechanical straining we can use this formula (Refer Slide Time: 29:02); 7 by 3 into dp by dm whole raised to 3 by 2 into 1 by 1 minus epsilon where dp is the diameter of the turbid particle and dm is the diameter of the filter media and epsilon is the porosity of the filter media.

Next one is gravitational settling. Here what is happening is there are many filter media or grains are there so in between this filter media there will be small pockets so each of these pockets will be acting as a sedimentation tank so what will happen is the particle whatever is coming from the bulk liquid will be moving and in that pocket it will be settling because of the gravitational effect so that is the second mechanism of transport that means gravitational settling. Thus, whatever space is available between the filter media is acting as a settling basin so the efficiency by gravitational settling can be found out using this formula; settling velocity divided by superficial velocity of particle.

Third one is interception. You know that whenever there is n number of filter media in a filter the filter media is stationary there and the bulk liquid is moving from the top or from the bottom therefore, when the water comes and passes through the filter media it will be going away like this because of this boundary layer effect. therefore what will happen is, if the streamline is something like this and a particle is here (Refer Slide Time: 30:55) the distance between the filter media and this streamline is less than the diameter of this particle then this particle will be hitting on the filter media. Now once it dashes the filter media we are assuming that it is getting removed and the same thing is happening here also. And here you see that these are the streamline.

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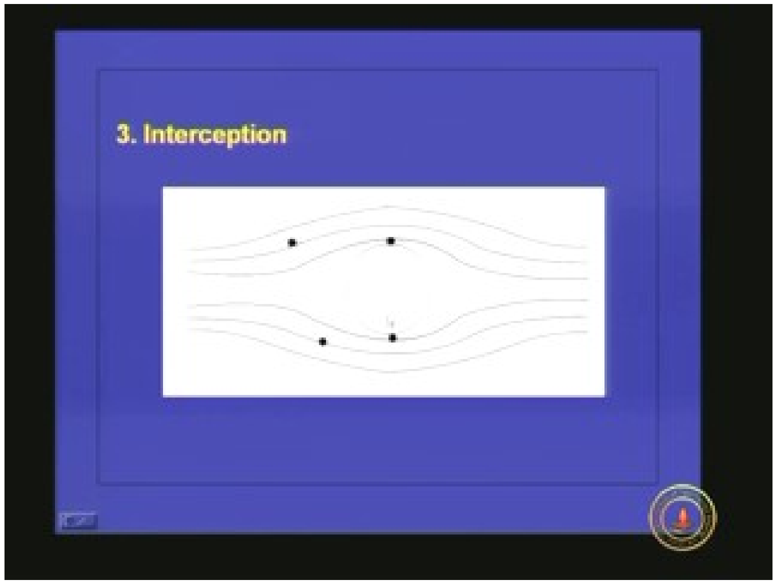

The distance between the filter media and the streamline is less than the diameter of the particle to me removed which is known as interception. So lot of particle can be removed by this mechanism. This is the third transport step. The fourth one is inertial impaction. We know that the turbid particles are having high density compare to the water.

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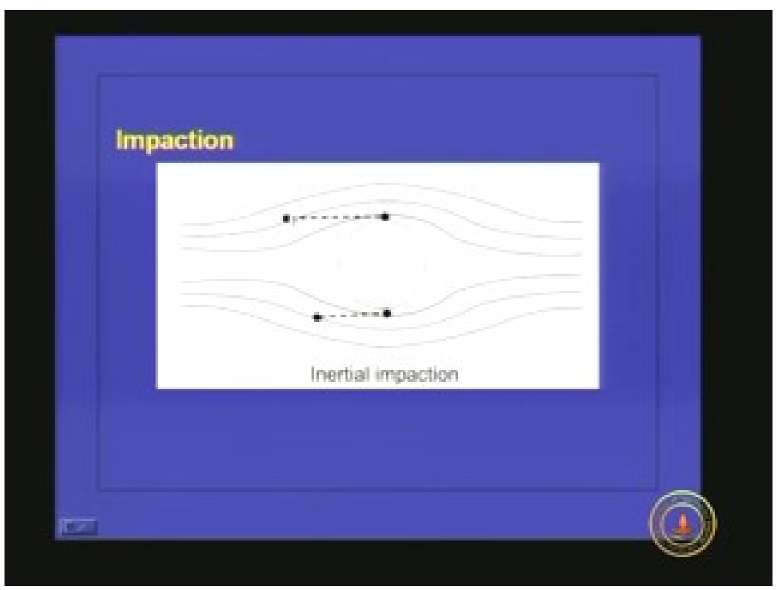

Here the filter media is there and water is flowing and because of the filter media the water is deviating its floc path so what will happen is since it is having high density it will be having inertia so it may not be following the streamline of water so it will be taking another path like this. Therefore, because of the inertia it maybe taking a straight path and due to this, what will happen is, this particle can come and hit on the filter media. Here also the same thing is happening; the water is moving in this direction, here also the water is moving in this direction (Refer Slide Time: 32:31) and because of the inertia of the particle it is not deviating its direction of motion, it is moving in a straight line and it is coming and hitting the filter media. Once it has touched the filter media because of the attachment step process then it is getting removed from the system.

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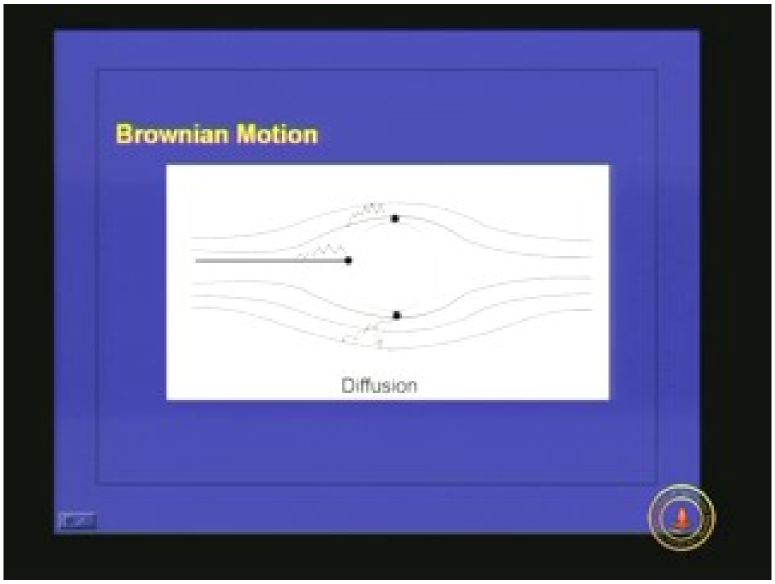

Another one is Brownian Motion. In Brownian Motion you know that sometimes colloidal particles are so small so their surface area, means their surface phenomena is much predominant compared to their mass. So what will happen, the Brownian Motion or random movement of these particles will be taking place. This is the case for very very small particles colloidal particles. the streamline is like this or the water is moving like this (Refer Slide time: 33:23) so the particle is there which is following the streamline and because of the random motion or the Brownian movement this will be moving in zig zag direction and during such a movement sometimes it may come and hit the filter media. Once it hits the filter media it will be getting removed from the system. Here also we can see that this particle was actually in this frame line so because of the random motion of the Brownian diffusion it is coming and it is hitting this filter media and as a result it is getting removed.

This one is another example (Refer Slide Time: 34:03). This is direct intersection. Some streamlines are directly coming and hitting the filter media. The water is flowing in this direction and that is having some turbid particle so, if it is not deviating or it is big enough and if the random motion is not so predominant then what will happen is it will be following the same path and will come and hit the filter media so it can also get removed. These are the different transport phenomena.

Once again we will see the different transport phenomena. One is the mechanical straining. We know how it is happening. In between the filter media there will be pores so if the pore size is lower than the particle diameter naturally it will be getting removed and with respect to time the pore size will be getting smaller and smaller so more and more finer particles will be getting removed.

Second one is gravitational settling. Here what is happening is the space in between the filter media is acting as a settling tank so the particles will be settling so that is another transport step. the third one is inertial impaction because the particle are denser than water so it will be having inertia to follow the same path in which it was moving and the water will be taking a different path because of the filter media so because of inertia it will be coming and hitting the filter media.

Another one is direct interception. That means the streamline or the direction of path is directly coming and hitting the filter media. The last one is because of Brownian Motion. Because of the random motion the particle can come and hit the filter media. There is another transport phenomenon that is orthogenetic flocculation. Then we were discussing about coagulation and flocculation. We have seen that there are many mechanical and non mechanical flocculates especially where ortho flocculation is concerned. So, the filter media itself is acting as a flocculator so with respect to time what will happen is if it is a destabilized particle and if it moves through the filter bed there will be a velocity gradient so there is a chance that many particles will be coming in contact with each other because of the relative velocity and bigger flocs can be formed which can also help in removal.

Till now we were discussing how the particle is coming in contact with the filter media so that is the transport step. From the bulk it is coming and sitting on the filter media. So if it just comes and touches there it is not being removed from the system. So, if there is no force which can hold the turbid particles to the filter media then what will happen is, it will be again detached from the filter media and will be coming out through the bulk liquid. So there should be some attachment steps.

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We will see what is the attachment step mechanisms. Those are electrical double layer interaction, the second one is Van der Waal's forces and the third one is mutual adsorption or bridging. We are very very familiar about these mechanisms. We have seen in detail these mechanisms when we were discussing about coagulation and flocculation. In coagulation we saw how the particles are destabilized and are bringing together the mechanisms like ionic layer compression, adsorption and charged neutralization and this one. The Van der Waal's forces are also coming into picture, the ionic layer compression then mutual adsorption or bridging.

In the other way we can tell that in coagulation and flocculation the mechanism is the same, one is a static unit and other one is a dynamic system, that is the only difference. If you consider this electrical double layer interaction how it is taking place in the filter. The filter media is there and your particulate matter is coming, now where the double layer is formed? In the filter medium most of the time we are using sand so naturally that also will be having some ions attached to it and the liquid will be moving through that filter media so what will happen is the ionic layer will be just shearing off or the electrical double layer is just shearing off where a streaming potential develops across the filter.

Now, because of this streaming potential the filter particles will be having a potential difference in the top and the bottom. That means the filter media in the top maybe having high negative charge compared to the bottom one. The bottom one will be having high positive charge compared to the top one. Similarly the particulate matter whatever is present in the system will be having the charge the other way. So because of that one there are chances of particles getting attached.

Another one is, because many turbid particles are moving along with the bulk liquid there are chances of this colloidal particles themselves interacting with each other. As we have seen in coagulation when the colloidal particles come close to each other, when the Van der Waal's force is more predominant than the repulsive force because of the ionic layer the particles will be getting attached so that is what is happening in Van der Waal's forces. Then sometimes what will happen is because of the functional groups present in the filter media there will be mutual adsorption and bridging.

We have seen that the filtration mechanism basically can be classified into two groups; transport mechanism and attachment mechanism and attachment mechanism is almost similar to that of coagulation. So, in filtration also if you add coagulants and destabilize the particle the removal will be much much easier compared to the colloidal particle which is not destabilized. This is true when we talk about rapid sand filter which is the depth filter where the mechanism is entirely different from that of slow sand filter.

But when we talk about slow sand filter the removal can happen whether the particle is destabilized or it is as such. In rapid sand filter it is always advisable to go for coagulation or add little coagulant dose before going for the filtration because the turbid particles will be getting destabilized and the removal will be much much easier. This is important when we go for direct filtration because this filtration, though we told that it is a polishing unit sometimes it can be used only as a treatment system when the turbidity is very low and the water quality is relatively good.

So, if the turbidity is less than 20 NTU we can add little coagulant dose to the water to be treated then allow it to pass through the rapid sand filter. Therefore, by adding the coagulant dose the particles are getting destabilized because of the chemical reactions whatever we have seen earlier. And once the destabilized particle comes to the filter it will be getting removed because of all these mechanisms so it is always better to add little coagulant dose when we go for direct filtration to improve the efficiency because the mechanisms are like this.

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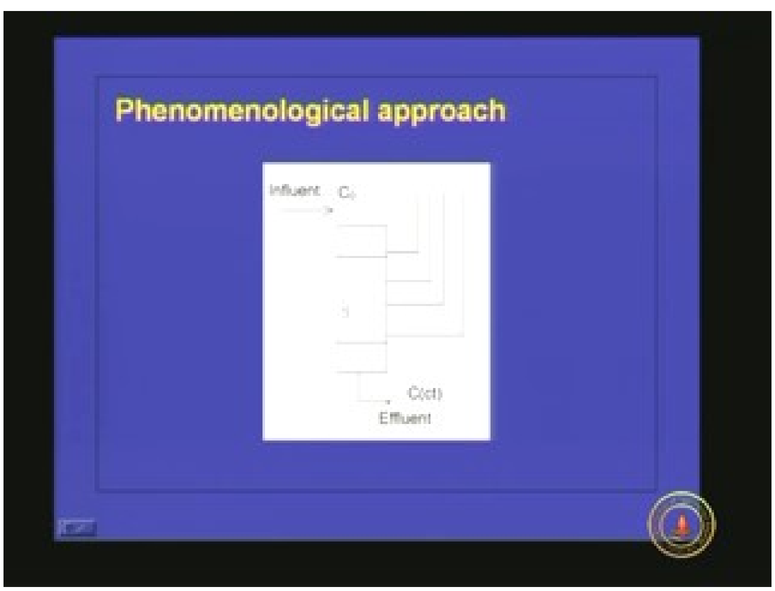

Now we will see how we can find out the efficiency of the filter or if you know the turbidity of the inlet water and when we are using a particular length of filter we are getting the effluent quality of something so if you want to improve the efficiency how much is the filter depth we need or what is the performance of the filter; whether we can predict the performance of the filter properly.

This is the filter (Refer Slide Time: 42:40) and we can have different manometers to measure the head loss at different points. Now, water is coming like this. Most of the time especially in the community water treatment plant we use downward filtration so influent is coming and here there will be a constant water head available and this is the filter media and filter media depth varies from 0.6 to 0.75 meters and you will be having a gravel bed and under drainage system to collect the treated water and whenever it is required to backwash the filter we can backwash using this under drainage system and this is the effluent. Thus, initial turbidity is C_0 and this is the turbidity C at any t.

Thus, if you plot the C by C_0 versus depth, at different depths if you plot the C by C_0 it is like this. Initially we can see that with respect to depth the C by C_0 is reducing considerably that means if you take after 10 centimeter depth of the filter the turbidity reduction is not so much but it is increasing gradually and at the bottom of the filter almost everything is getting removed but with respect to time the turbidity removal efficiency is getting reduced and reduced.

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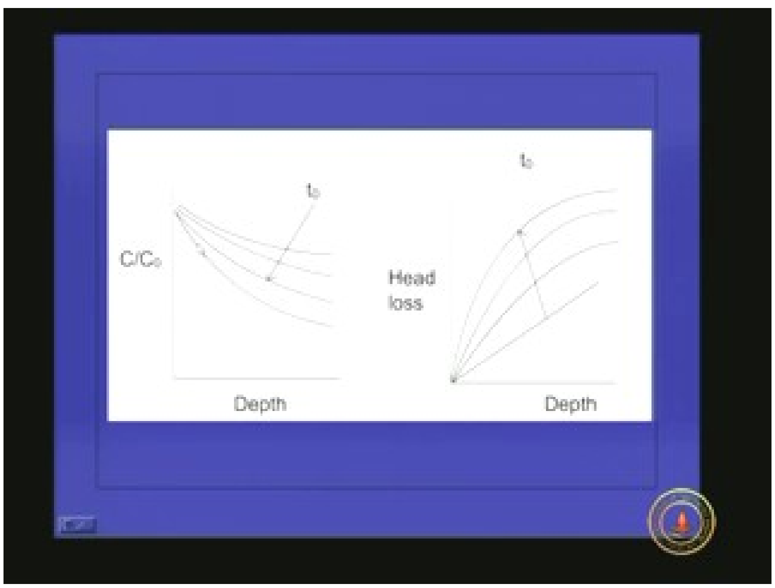

Here we can see the reduction is not much. This is different curves at different times. This is initially, that means the filter has just started operating and as time progress the filter and operation efficiency is coming down so this is with respect to turbidity. And if you plot the same with respect to head loss, this is the head loss and with respect to depth (Refer Slide Time: 44:30) so this is when t is equal to 0 the head loss will be very very less. We will be getting that hydrostatic pressure line then after filtration increases the head loss will be increasing, increasing and increasing as we can see here. Here we can see the slope itself is changing.

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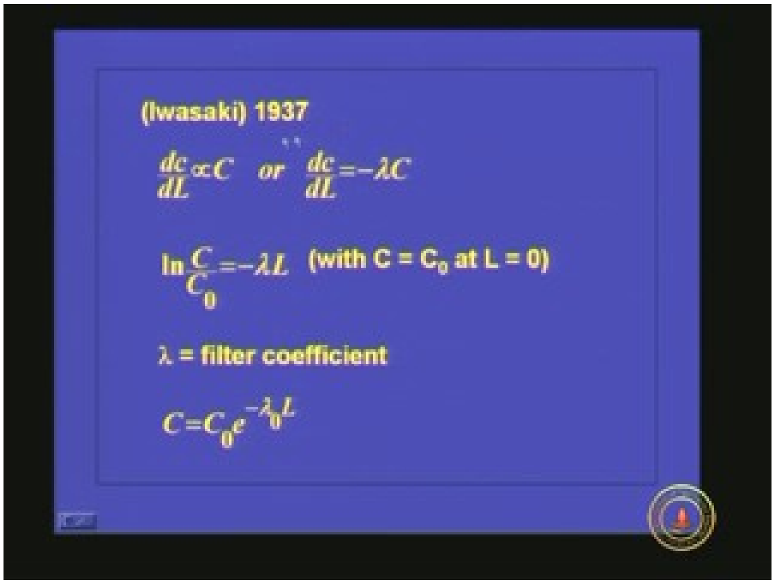

Iwasaki in 1937 developed this equation on how the filtration efficiency depends upon the length of the filter. He has shown that the rate of change of concentration of the turbid particle with respect to length is propositional to the initial concentration of the turbid particle. Or we can write like this: dc by dL equal to minus gamma into C where gamma is a constant this is known as filter coefficient. Or if we integrate this one we will get ln C by C_0 is equal to minus lamda L where when L equal to C; L equal to 0; C is equal to C_0 and here lamda is the filter coefficient.

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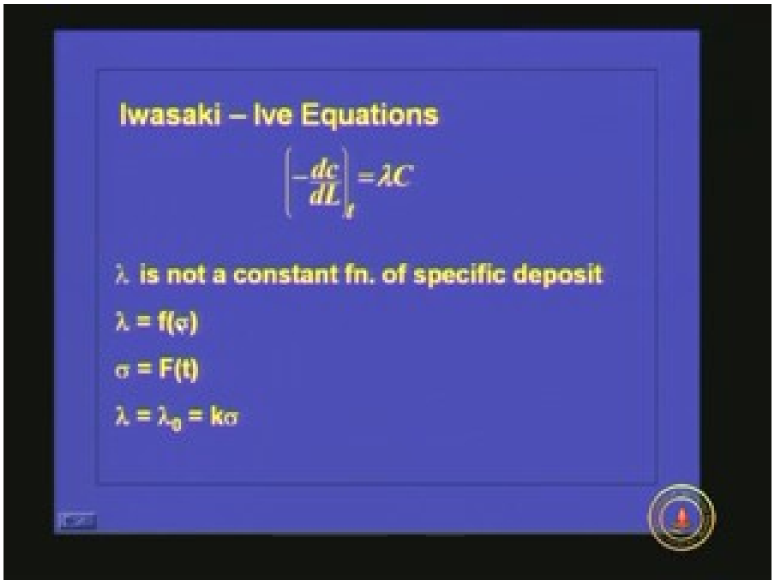

Or we can write like this; C is equal to C_0 into e raised to minus lamda L. So, if you know what is the initial turbidity of the water and if you know what is the length and the filter coefficient we can find out the turbidity that is coming out after the filtration. So this filter coefficient we can find out by conducting the laboratory experiments.

What we have to do is, you know the different lengths, we have to find out the C value with respect to length, we can find out C by C_0 with respect to depth where depth is nothing but the length of the filter media as we have seen earlier. So we will be getting the curve like this (Refer Slide Time: 46:33) so from this one we can find the value of lamda. And once the value of lamda is found out we can predict the performance of the filter.

Again Iwasaki showed that this lamda is not a constant because Iwasaki was assuming that this lamda was a constant but I have found out that this lamda is not a constant and it changes with respect time or it is a function of time or specific deposit.

We were discussing about straining. In between the filter metrics there are pores so with respect to time the pore size will be decreasing with respect to the specific deposit so the pores will become smaller and smaller so the filtration efficiency will be increasing to a certain extent. If the pores become still smaller the pore velocity or the velocity with which the water is flowing through the pore will be increasing drastically because your q is a constant so what will happen is with high velocity whatever particle is already attached to the filter media it will be shearing off and coming along with the liquid.

Therefore, to a certain extent the filtration efficiency or this specific deposit is increasing with respect to time and after that the filtration efficiency will be decreasing with respect to the effluent quality. That is what is written here; lamda is a function of sigma where sigma is the specific deposit that means what is the amount of turbid particle deposited per unit mass or unit volume of the filter media that is the specific deposit and that is also a function of time so we can write lamda is equal to lamda$_0$ which is equal to a constant into the specific deposit at that time.

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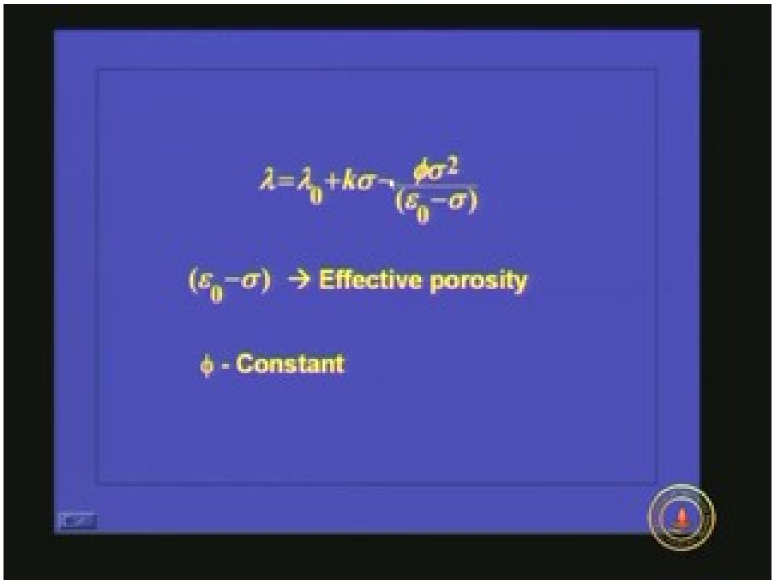

But again we have seen that lamda is increasing with respect to time to a certain extent and after that it will decrease so the equation can be modified like this; lamda is equal to lamda$_0$ where lamda not is the filter coefficient of the clean filter plus k into sigma minus pi into sigma square minus epsilon$_0$ minus sigma because epsilon$_0$ is the porosity and sigma is the specific deposit so epsilon$_0$ minus sigma is the effective porosity because the pore is getting reduced and reduced and pi is a constant. This is very very important if you want to see that in filter operation. If you plot this lamda that means filter coefficient and sigma, so up to certain value what will happen is the efficiency of the filter is getting increased, we can see that efficiency is increased or C by C$_0$ value is decreasing so up to this point this is known as maturation of filter and after that the quality is deteriorating. The reason for this is because of sigma, sigma is the specific deposit.

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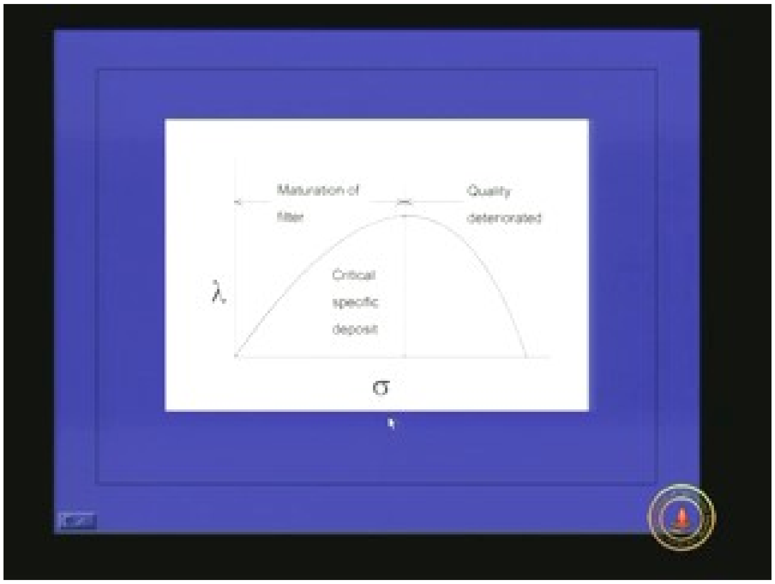

What is the amount of particle depositor?

If sigma is increased after a certain limit then the pore velocity will be very very high so that pore velocity causes shearing of the particle whatever is already sitting on the filter media. Therefore, with respect to time more and more particle will come out along with the effluent so the quality will be deteriorating drastically so we have to stop the filter operation at this stage.

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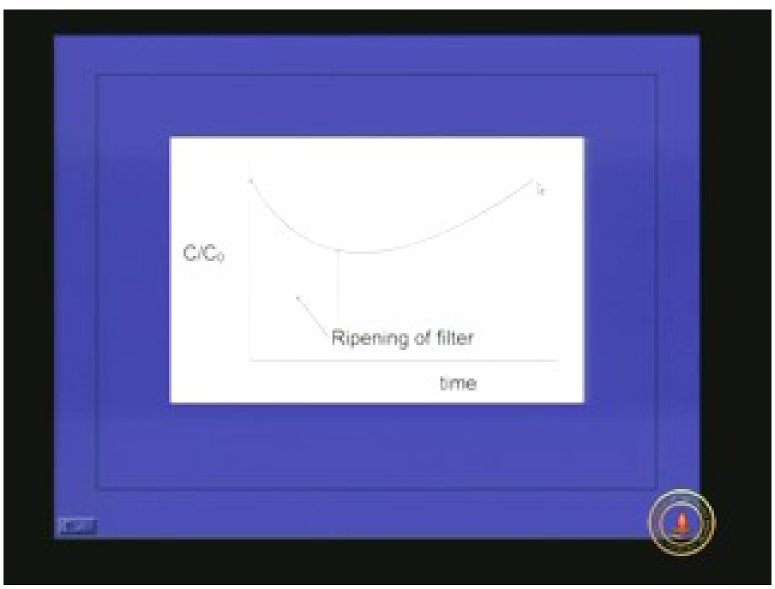

This is the same thing represented in terms of C by C_0 and time. So we can see that, as soon as we start operating a fresh filter the C by C_0 value will be relatively higher then with respect to time it will be decreasing, decreasing and you will be getting a lowest value here (Refer Slide Time: 50:39) so this is the one we call as ripening of the filter. At this time the filter will be operating at its optimum condition that means the pore size will be in such a way that it will be removing the particles to the maximum and velocity is also reasonable. Again the filter is being operated and more and more particles will be definitely coming and sitting on the particle so C by C_0 will be increasing. So, after a specified limit, where the standard is 1 NDU if this value is close to that one we have to stop the filter operation and backwash the filter and start it again.

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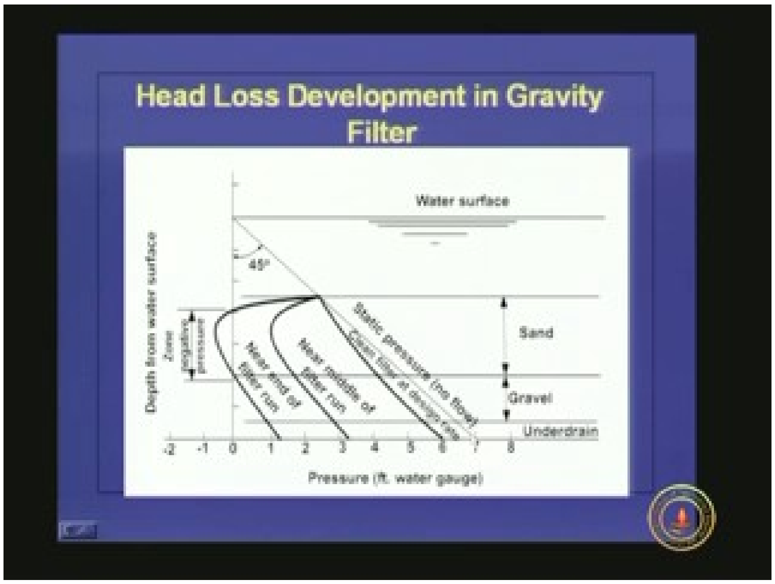

Now we will see why the head loss is taking place in the filter. If you see the head loss development in a gravity filter, this is the static pressure head. You see how the pressure is distributed in a water column in a container, you see a 45 degree line and it is static pressure and no flow is taking place, this is the clean filter, the filter is there so this pressure drop is because of the filter bed itself because the flow has to or the water has to pass through the filter medium so the clean filter will be generating some head loss which is this one (Refer Slide Time: 52:12) and after filtration increases or as filtration progresses the head loss will be increasing.

We can see that the rate of increase is more on the top and especially the rapid sand filter the fine particles will be in the top so the turbid particles will be coming and sitting in the top and the pore size will be getting reduced considerably here so we can see that the head loss will be very high and it is going like this. This is the head loss profile (Refer Slide Time: 52:54) when the filter is almost in the middle way through after the cleaning and before going to the next cleaning so this is the middle way.

And if you continue the filtration sometimes negative head can generate. So, if the head loss in the filter is more than the head available here this negative head can occur in the filter and this negative head occurring is very very bad in the filter because the filtration efficiency will be drastically reducing so we should avoid negative pressure development in the filter. Hence, in tomorrow's class let us discuss how to find out the filter head loss and how to calculate it and also discuss how we can clean the filter. Today we will see what are the things we have learnt till now.

We have seen that filtration is a polishing operation so the coagulation flocculation unit or the softening unit. After the treatment what will happen is the flocs may not be removed completely from the system so some flocs will be coming out along with the effluent in the carry flocculator or the softening system
so that is not aesthetically appealing so we have to remove those turbid particles.

Moreover, if the water is having turbid particle the chlorination will not be effective
because as I have already mentioned the bacteria or the microorganism will be going and getting attach to the turbid particle and it will be acting as a protective layer or protection for the microorganisms so it will be escaping from the disinfection process and based upon the operation or the material or the rate of filtration we can classify the filters into different categories.

But the most important classification is surface filters and depth filters based upon the mechanism of filter. Slow sand filter and rapid sand filter are the most commonly used filters in water treatment and pressure sand filters are being used in swimming pools and places where the space is a constraint. In slow sand filter the mechanism of filtration is straining, only the top layer is taking part in the removal of suspended particle or turbid particles and even dissolved organic matter because in the slow sand filter a dirty layer of active microorganism will be formed which will be taking part in the cleaning of all the other contamination. So the top two inches will be removing almost all the contaminants and as the water moves through the remaining depth of around 0.6 to 0.8 meter everything will be getting removed.

Rapid sand filter is a depth filter; the mechanism of practical removal is entirely different from that of slow sand filter. So the mechanism can be classified into two categories; one is transport mechanism and another one is attachment mechanism. Transport mechanism can be straining, gravitational settling, inertial impaction, direct intersection, Brownian Motion or orthogenetic flocculation and so on. The attachment steps can be double layer interaction Van der Waal's forces, adsorption and inter particle bridging or we can tell that mechanism wise rapid sand filtration and coagulation are almost same, one is the static system and another one is the dynamic system so it is always advisable to have coagulant in rapid sand filter.