Water and Wastewater Engineering
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Lecture # 14
Filtration (Continued)

In the last class we were discussing about filtration. We have seen what is the requirement of filtration is after the other treatment operations like coagulation, flocculation, softening etc. Because during these processes what happens is the flocs are formed and we are going for settling but the settling will not be hundred percent efficient so whatever water that is coming out of these treatment units will be having minute flocs and that will be deteriorating the appearance of water or the aesthetic quality of the water as well as it will deteriorate the quality. So if you want to get aesthetically pleasing water then we have to go for this filtration.

We have discussed about the different types of filters commonly used in water treatment plants and we have seen that rapid sand filter and slow sand filter are being used at maximum in community water treatment plants and pressure filters are used in swimming pools and other industrial complexes where space is a limitation. We have also discussed the different mechanisms involved in the filtration. We also saw that, as the filtration progresses there will be head loss in the filter. So we will discuss about the head loss in detail today.

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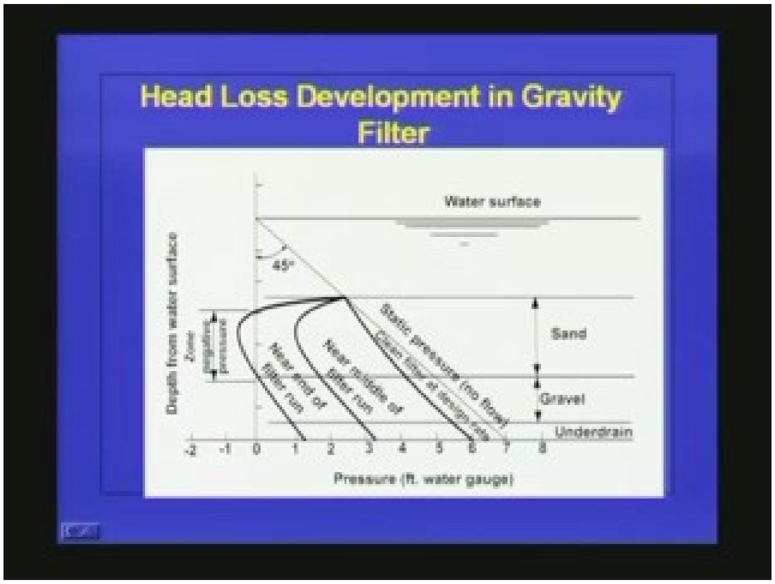

Head Loss Development in Gravity Filter

This picture shows how the head loss varies as the filtration progresses. So this straight line shows the static pressure that means the water column is just standing above the filter media at that time the pressure distribution will be like this. But once the clean filter media is there and water starts flowing through that one the head loss in the filter will be something like this. And with respect to time or during the filter run then on half way through the head loss will be something like this (Refer Slide Time: 3:04) the head loss decrease will be higher in the top portion then it is going almost like this. Thus, later on, the pressure drop will be so high that there is a negative pressure zone developing here. So if negative pressure zone dialogues in the filter what will happen is the efficiency of the filter will be coming down drastically.

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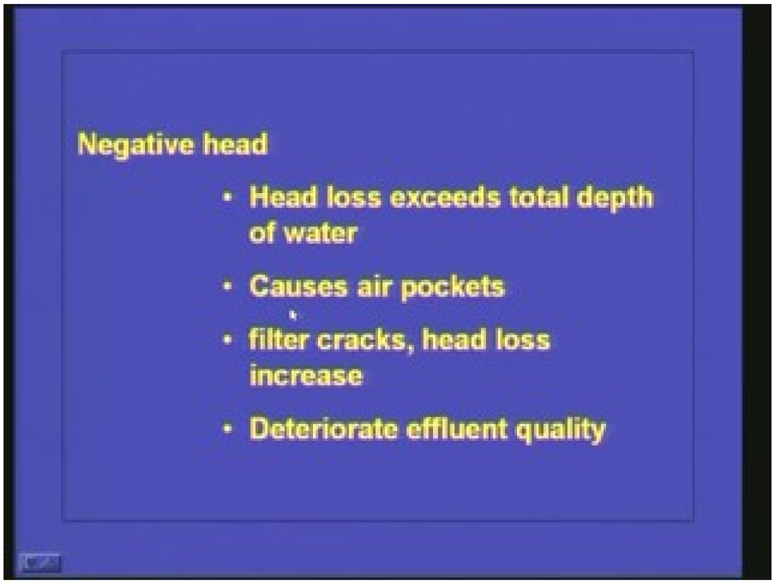

Negative head

- Head loss exceeds total depth of water
- Causes air pockets
- filter cracks, head loss increase
- Deteriorate effluent quality

The reasons for this negative head development are head loss that is when the head loss exceeds the total depth of water whatever is standing over the filter and if negative pressure develops then it causes air pockets inside the filter. So, if air pockets are there naturally there will be short circuit or the entire filter media will not be used completely so naturally the efficiency of the filter will be decreasing.

Moreover, there will be filter cracks because of the head loss. So when filter cracks are there the filtration will not be proper, just the water will be passing through the cracks just like short circuiting then there will not be any removal of particulate particles from the water so whatever influent we are giving the same quality of effluent will be coming out. So we have to clean the filter once the negative pressure is developed or it is always advisable to clean the filter before the head loss exceeds the permissible limit.

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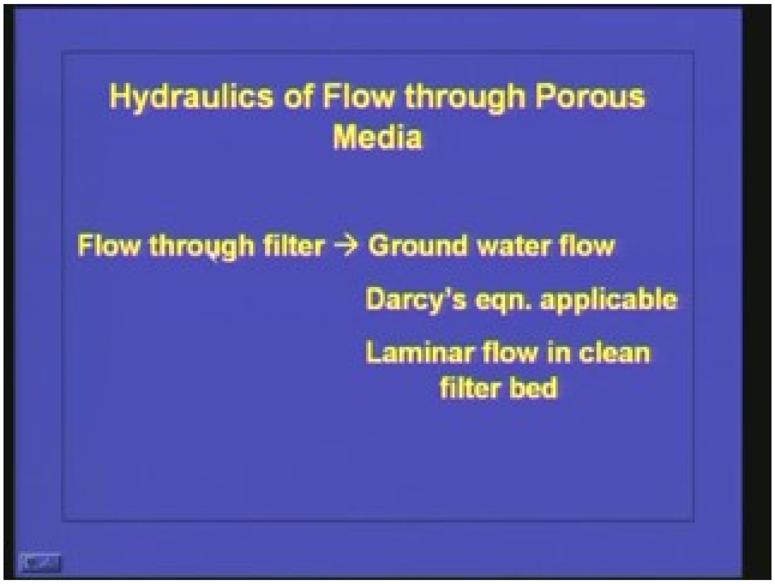

Hydraulics of Flow through Porous Media

Flow through filter → Ground water flow

Darcy's eqn. applicable

Laminar flow in clean filter bed

Now we will talk about the hydraulics of flow through porous media because the filter can be consider as a porous media like our ground water flow. What is happening there is, water is flowing through the porous of sand, soil, silt etc so the filter can also be considered as a porous media so the flow through porous media is being studied in detail. This can be applied in ground water flow. And in ground water flow most of the time we use Darcy's equation for finding out the head loss. And always we assume that the flow is laminar. So looking at filters, for clean bed filter also the flow through the filter media is in the laminar range. So we can use this Darcy's equation or modified Darcy's equation for finding out the head loss.

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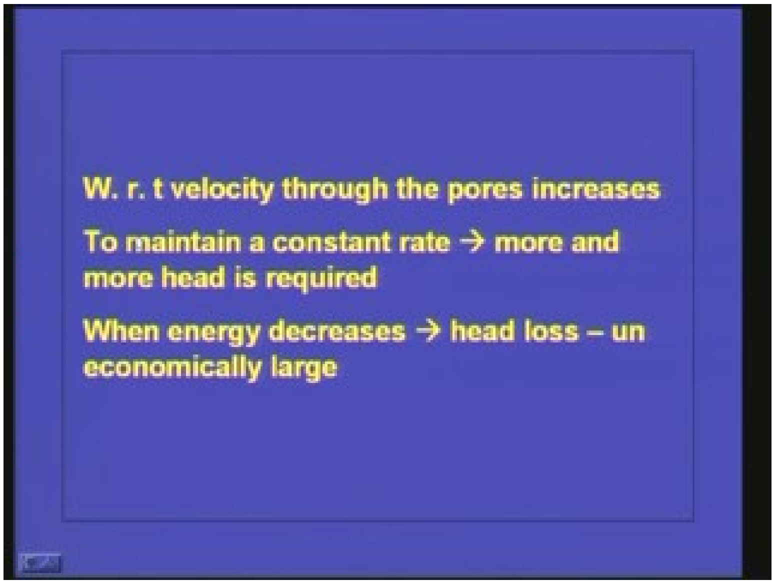

W. r. t velocity through the pores increases

To maintain a constant rate → more and more head is required

When energy decreases → head loss – un economically large

Therefore, when the filtration is progressing we have seen that filtration grains are there and the solids from the water or the particles or the colloidal matter or the flocs whatever is coming through the water when it passes through the filter what will happen it is getting deposited on the filter media so as the particle gets deposited on the filter media the pore size between the filter media decreases. So, as the pore size decreases what will happen is the pore velocity will be drastically increasing. So when the velocity increases it will be shearing of the particles whatever is already being attached to the filter media. Hence, once the particles are sheared of it will come along with the effluent of the filter so naturally the filter quality or filter effluent quality will be very very bad. Moreover, the filtration rate will be decreasing. So if you want to maintain a constant rate we have to apply more and more head.

When the energy decreases head loss goes on increasing and after a certain time the head loss will be so uneconomical. If you want to overcome the head loss it is always advisable to go for backwashing. What is that? That is cleaning method we use in depth filters because entire depth of the filter is being used for the cleaning purpose. So we can clean the filter bed by backwashing so that all the particles whatever are already attached to the filter media can be detached and the media will be getting cleaned again.

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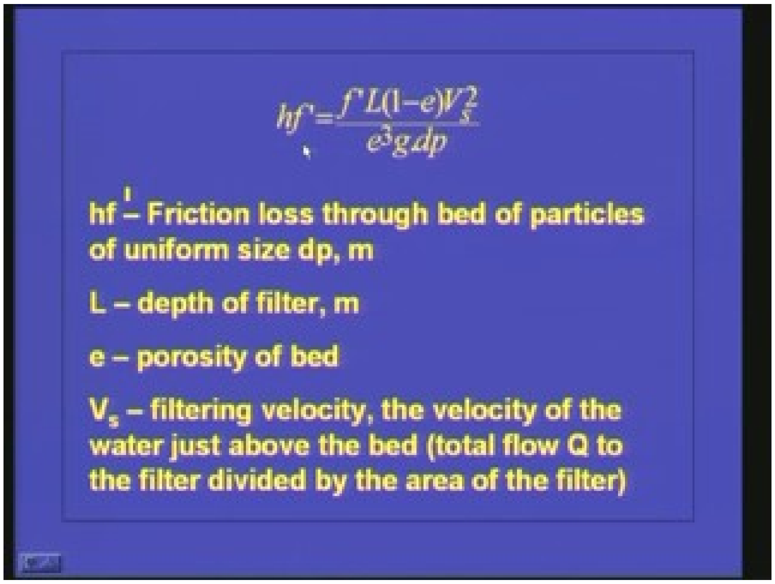

$$hf' = \frac{f' L(1-e)V_s^2}{e^3 g\, dp}$$

hf' – Friction loss through bed of particles of uniform size dp, m

L – depth of filter, m

e – porosity of bed

V_s – filtering velocity, the velocity of the water just above the bed (total flow Q to the filter divided by the area of the filter)

So if you want find out the head loss we can use this equation. This is the modified form of Darcy's Weisbach equation and this equation (Refer Slide Time: 7:40) is known as Carman kozeny equation. Here head loss' hf' through the filter is equal to f dash into L into 1 minus e into Vs square divided by e cube g into dp. So we can see that the head loss is directly proportional to the filtration velocity. Vs is nothing but the filtering velocity. The velocity of the water just above the bed which we can find out using this; total flow cube to the filter divided by the area of the filter so we will be getting the filtration velocity and it is inversely proportional to the diameter of the filter media grains.

Another factor that is influencing is the length of the filter because if the length is high definitely the head loss will be high and here this f bar is the friction factor and these are the terms; hf is the friction loss through bed of particles of uniform size dp so we are assuming the particle size along the filter depth is uniform. This equation can be use only for uniform size filter media.

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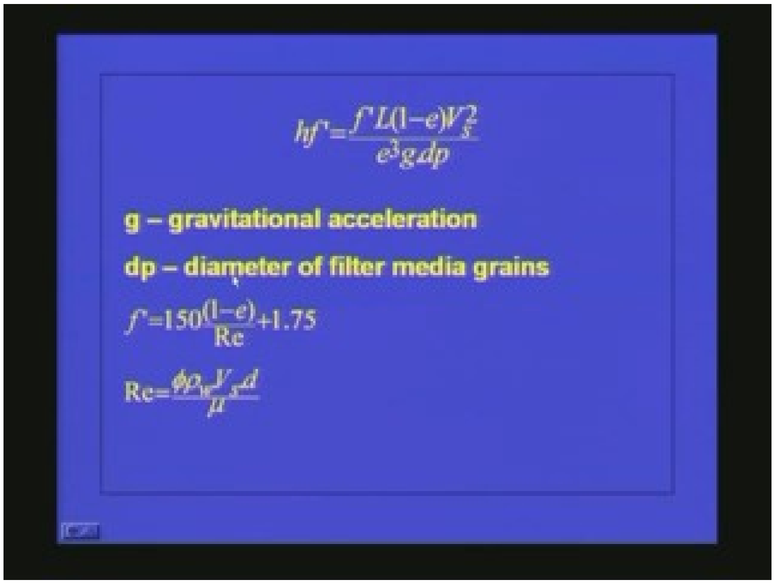

$$h_f' = \frac{f' L (1-e) V_s^2}{e^3 g \, d_p}$$

g – gravitational acceleration

dp – diameter of filter media grains

$$f' = 150 \frac{(1-e)}{Re} + 1.75$$

$$Re = \frac{\phi \rho_w V_s d}{\mu}$$

And e is the porosity of the bed; small g is the gravitational acceleration. I have already mentioned that f dash is the friction factor which we can find out using this formula; 150 into 1 minus e divided by Re plus 1.75 this is applicable if the flow is in laminar range. But we have seen that most of the time that the velocity water we are employing in filtration the flow will be coming under laminar condition. How can we find out whether the flow is under laminar condition or turbulent condition or transitional condition? It is depending upon the Reynolds number. Reynolds number we can find out using the formula pi rho Vs d by mu where pi is the safe factor; rho w is the density of water; Vs is the filtration velocity; d is the diameter of the particle and mu is the dynamic viscosity and the shape factor for the filter grains whatever we usually employee varies from 0.75 to 0.85.

Therefore, if you put the velocity here we can calculate the Reynolds number. if the Reynolds number is less than 1 we know that the flow is laminar. If the Reynolds number is in between one to two thousand then it is transitional then naturally we have to change this formula to find out the friction factor. So before going to use this formula first what we have to do is based upon the velocity we have to find out the Reynolds number and find out what regime the flow is, whether it is laminar regime, transitional regime or turbulent regime so according to that we have to find out the friction factor and use the correct equation.

But you know that the filter media in a filter especially in a gravity sand filter varies because we use different grades of sands, the final sand at the top because of backwashing because the density of the sand will be always the same so the finer sand will come at the top then coarser and the biggest one will be coming under bottom of the filter so the sand size will be varying. In such cases how can we find out the head loss? What we have to do is we have to find out the head loss of each segment with uniform size particle and sum it up then we will be getting the entire head loss.

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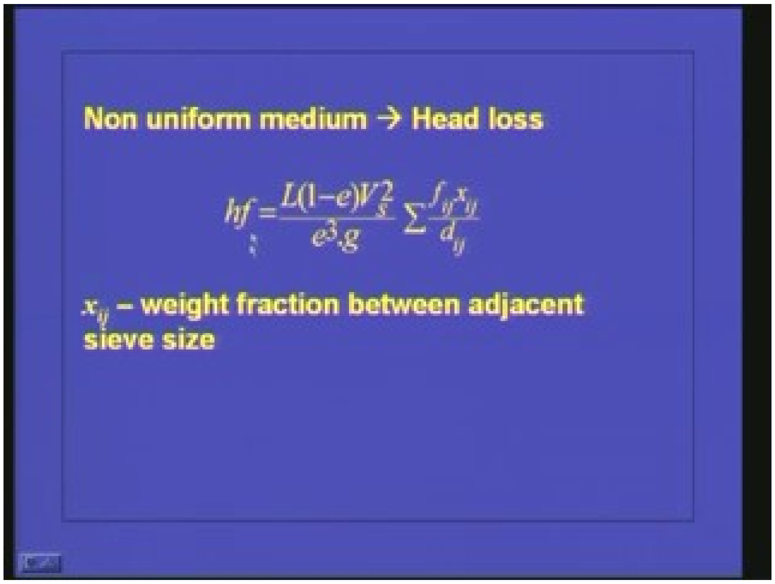

Non uniform medium → Head loss

$$hf = \frac{L(1-e)V_s^2}{e^3.g} \sum \frac{f_{ij} x_{ij}}{d_{ij}}$$

x_{ij} – weight fraction between adjacent sieve size

This formula can be used for non uniform medium; hf is equal to L into 1 minus e into Vs square by e cube into g and sigma fij xij by dij where xij is the weight fraction between adjacent sieve sizes. That means from the top portion to the middle to the bottom what is the weight fraction or the length fraction of that particular material. For example, you have a rapid sand filter of 75 centimeter depth so we are using the fine sands for 20 centimeter then the coarser one another 20 centimeter and the biggest one for 30 centimeter or so, so how can we find out? This xij is nothing but 20 divided by 60 that is the fractional length of that particular layer so we can find out the head loss using this formula if it is a non uniformed medium and in most of the case the sand medium is uniform.

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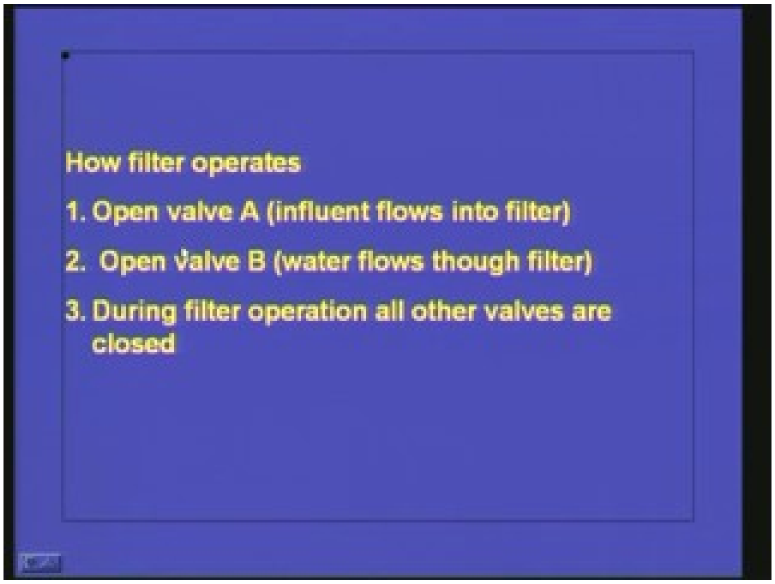

How filter operates

1. Open valve A (influent flows into filter)
2. Open valve B (water flows though filter)
3. During filter operation all other valves are closed

Now we will see how the filter operates. There are different operations involved in the filterant because most of the time the filtration will be taking place. But we have seen that after filtration progresses the head loss will be increasing so the flow rate or the filtration rate will be declining and the quality of the effluent will be deteriorating so at this stage we have to go for backwashing so we have to make the arrangement for all these things in the same unit. For that, in detail let us see how the filter will be operating. This picture shows a typical rapid sand filter.

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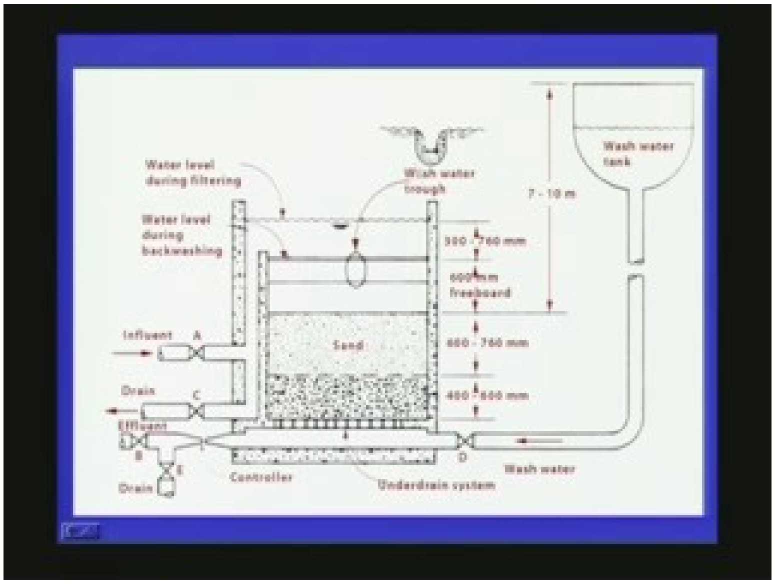

We can see that this is the wash water tank where the clean water will be stored for the backwashing of the filter and this is the water level during filtration so the water level will be up to here and here you will having a free board of around 0.5 meter and this is the wash water drum, the detail is this one. So this is the one which is collecting all the wash water and taking it to the drain (Refer Slide Time: 13:43) and during filtration this much water head will be available up to here. So that is the force available for the filtration. And we can see here this is the sand around 60 to 76 mm and this is the gravel 40 to 60 mm and this is the under drainage system which collects the filtered water and at the same time this under drainage system can allow whatever water required for cleaning of the filter to pass through these pores in the upward direction.

Here (Refer Slide Time: 14:29) this is the influent pipe and this is the drain pipe and here we can see another drain pipe and this is the effluent. So first, during the operation what we do, how the filter operates or during the filtration how the filter is operating is what we are going to see now. Open the value A and open the value B, which is the value A? This is the value A that means influent water is coming to the filter and it goes up like this and it will be staying here so the water will be passing through the filter and the clean water will be collected here and it will be coming like this and we can collect the clean water through this pipe, this is value B. therefore, during regular run of the filter only the values A and B will be open but all other values C, D, E everything will be closed, that is the normal filter run.

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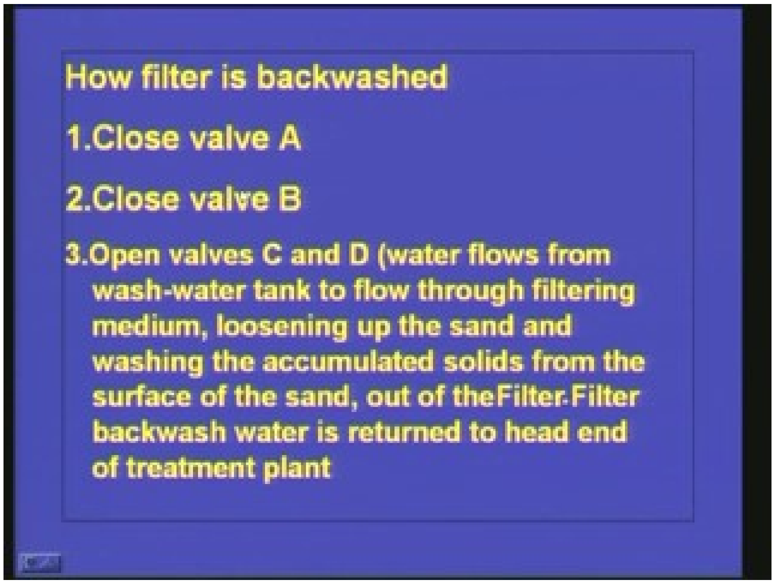

How filter is backwashed

1.Close valve A

2.Close valve B

3.Open valves C and D (water flows from wash-water tank to flow through filtering medium, loosening up the sand and washing the accumulated solids from the surface of the sand, out of theFilter.Filter backwash water is returned to head end of treatment plant

So when we want to do the backwashing what we have to do is close value A and close value B so these are the two values use for the regular filter run so we have to close them then open values C and D, water flows from the wash water tank to flow through filtering medium loosening up the sand and washing the accumulated solids from the surface of the sand out of the filter. The filter backwash water is returned to head end of the treatment plant.

I will explain again; first what we have to do is we have to close this (Refer Slide Time: 16:11) value A and value B and open the value D and value C. So what will happen the water comes from here, it goes up to the under drainage so from here the water will be moving in the upward direction. So here you can see the head available is 7 to 10 meter and at high head what will happen is the water will be flowing at a high velocity so because of the high velocity all these fine particles will be getting lifted up so enough velocity will be there all the particles will be lifted up. Therefore, in that process what will happen is high velocity is there and all the sand particles are fluidized so whatever the depth is or the dust particles collected to the filter media will be getting detached.

So the entire detached particles whatever is present will be rising up and the water level will be up to here. Here we can see the wash water drops so the water will be collected here and it will be coming here and going to the drain so this is what we usually do for backwashing. And for backwashing the filtration rate will be 40 to 60 meters per hour. We know that the regular filtration rate is 4.5 to 6 meter per hour but backwashing rate is around ten times more than the regular filtration rate. And usually the backwashing is done for 10 minutes so by that time all the particulate matter whatever is attached to the filter medium will be getting removed.

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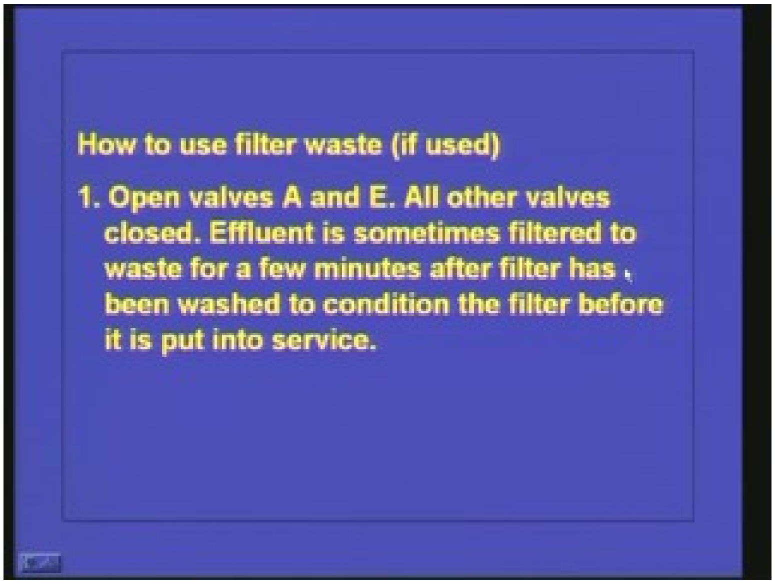

How to use filter waste (if used)

1. Open valves A and E. All other valves closed. Effluent is sometimes filtered to waste for a few minutes after filter has been washed to condition the filter before it is put into service.

Then after that one we find out how to use the filter waste. So what we have to do is open value A and E and all other values closed, the effluent is sometimes filtered to waste for a few minutes after filter has been washed. So here what we have to do is during the backwashing all the filter medium is getting disturbed or everything is fluidized and everything will be settled down when the filtration or backwash is stopped.

But what happens is some particulate matter or some particle or colloidal particle will be still there which is already loosened and it is not completely removed. So if you start the filter again what will happen is at the initial stage the effluent quality or the filtrate quality will be will not be so good so what we have to do is we have to go for the regular filtration but waste the water for few minutes. For that one what we have to do is open the value A and the regular filtration will be starting so instead of collecting the effluent through this B we have to drain the effluent through E which will restrict the effluent from entering the disinfection unit or the distribution system so something will be wasted here till the effluent quality reaches the required limit. This is how the filter is being operated.

We have seen that a very high rate of water flow is use for backwashing. That means around 40 to 60 meter per hour and that flow rate will be continued for ten to fifteen minutes that is, so much of water will be used for backwashing. So instead of wasting water what we usually do is we send the entire backwashed water coming out from the filter to the head end of the water treatment plant. That means this water will be collected and sent to the primary sedimentation tank where the debris will be getting removed then again it will be coming to the coagulation flocculation system. Hence we are not wasting that water even though it is dirty; we can clean it up because already destabilized particles are present there so the removal will be much easier.

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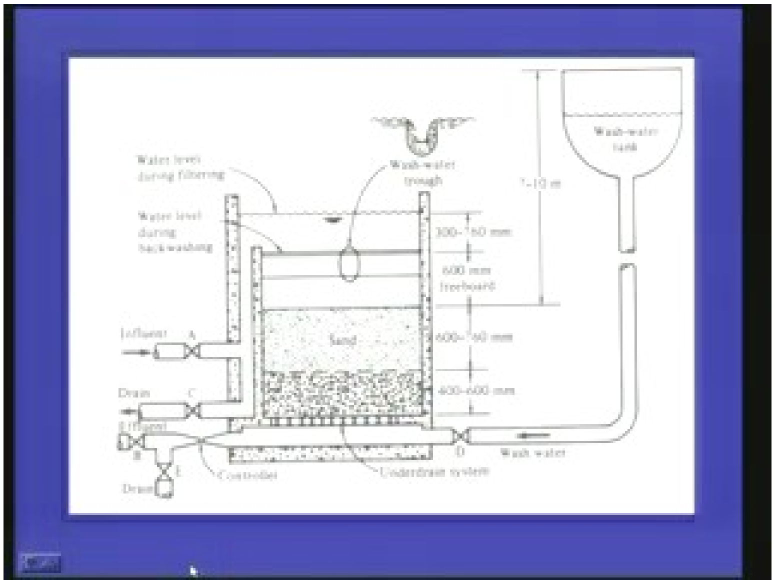

Now we will see how the filter operates. We have seen that during the filter operation the flow will be getting reduced if we are applying the same pressure. So the filter can be operated under different conditions. If we want to have a constant flow rate then we have to keep on increasing the energy applied because as the head loss increases we have to supply more energy to overcome the head loss. That is known as constant rate filtration. That means irrespective of the head loss we want to get the same rate of filtration or same quantity of filtrate from the filter. That is known as constant rate filtration.

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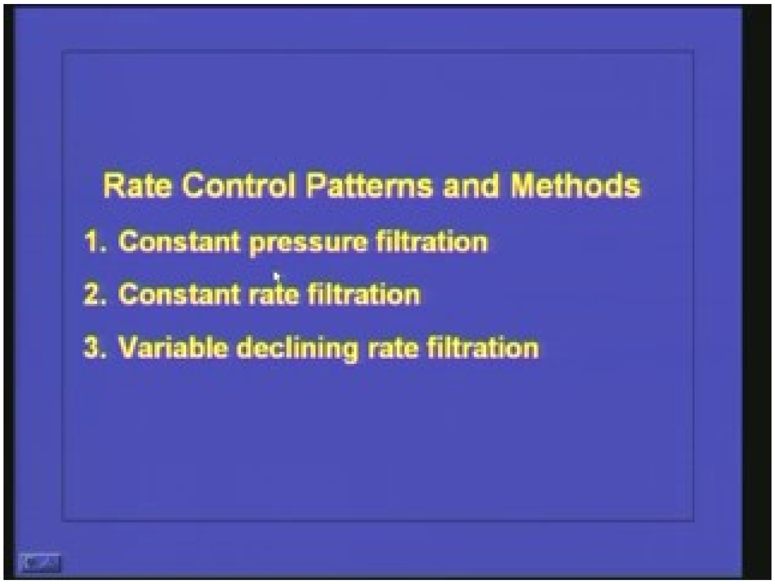

Rate Control Patterns and Methods

1. Constant pressure filtration
2. Constant rate filtration
3. Variable declining rate filtration

Another one is constant pressure filtration. That means always we will be giving the same pressure. That means the water level above the filter will be always same so at that particular head the filter will be running so initially the rate of filtration will be high and as the filter pores get clogged or as the head loss increases the filtration rate will be decreasing.

And another one is variable or declining rate filtration. Here the rate will be declining as the head loss increases. I will show you a picture explaining all those things.

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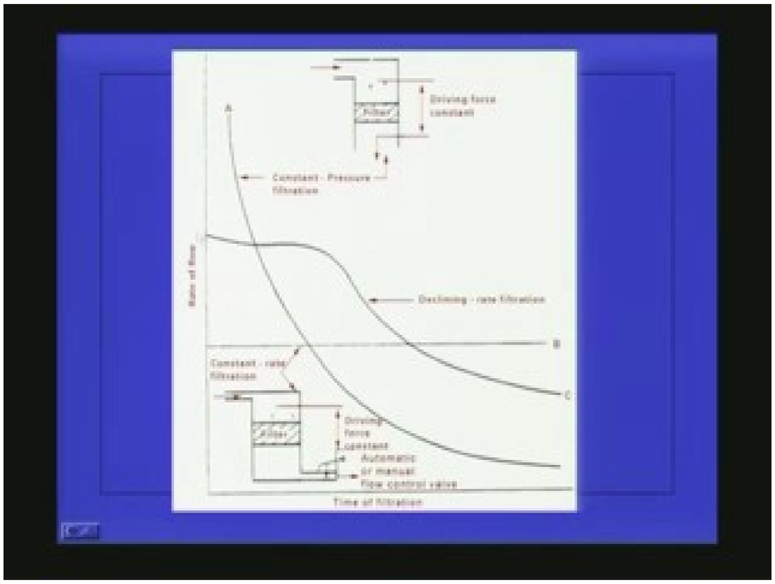

This is the rate of filtration and this is the time of filtration. So if you plot the rate of filtration versus time of filtration and if we get a straight line like this B then it is constant rate filtration. Irrespective of the time we are getting a constant rate. And second one is constant pressure filtration. We are allowing the same head above the filter and initially we will be having a very high head so as the head loss increases the filtration rate will be decreasing and afterwards it will become asymptotic.

The third one is declining rate filtration. Here initially for sometime it will be remaining almost a constant and afterwards it will be decreasing. So depending upon our requirement we can select any one of this one. But if you go for constant rate filtration the energy requirement will be very very high because initially you will be getting a very high flow rate and afterwards if you want to carry out or continue with that same flow rate then the energy to be applied is very very high.

Now we will talk about Mixed Media filters. Till now we were talking about sand filters. Sand filter means we are using different grades of sand. But the disadvantage of this system is that in sand filter whatever be the particle distribution whatever way we want to put it after backwashing everything with be settling with the settling velocity. Definitely the coarser sand particle will be having a higher settling velocity compared to the finer particles. So what will happen is the coarser particle will be coming in the bottom of the filter then the finer will be at the top.

So, if you see the pore size between these particles what will happen is the top layer will be having small pores compared to the bottom layer. But as we know the water coming to the filter is already having destabilized particles or the flocs whichever is from during coagulation, flocculation or softening process. So those flocs will be relatively larger in size. So what will happen is these fine pores whatever is present on the top of the filter when this flocs comes will be just strained through that layer and the pores will be getting chocked or clogged. Now what will happen is, the finer ones will not be able to pass through that one so maximum head loss will be felt in the top layer of the filter and the bottom layer of the filter may not be used completely.

So if you want to use the filter effectively the best pore distribution is like this; the biggest pores should come in the top then the pore size should decrease gradually. So how can we achieve that one? This can be achieved only by using different media. This different media selection is depending upon the specific gravity of that particular material. Because if you select a lighter particle in the top layer what will happen is…, we can use a coarser particle size and denser medium in the bottom. So, that is the principle of this mixed media filters.

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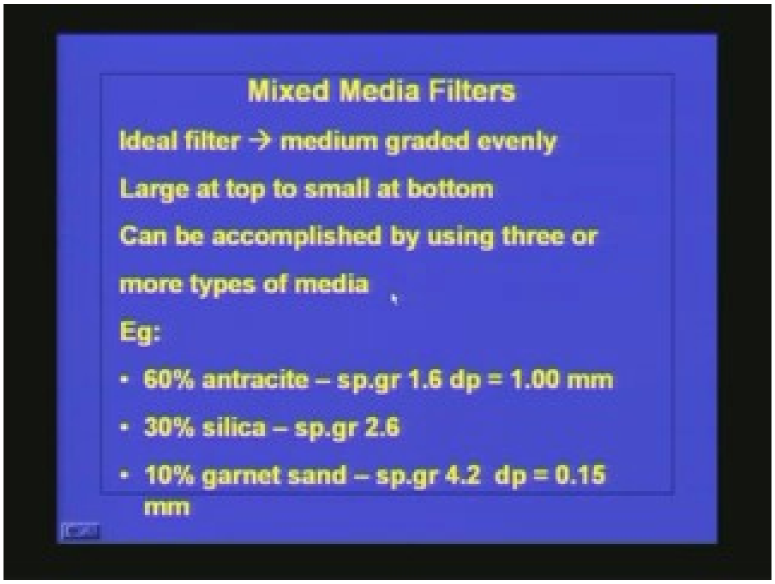

Mixed Media Filters

Ideal filter → medium graded evenly

Large at top to small at bottom

Can be accomplished by using three or more types of media

Eg:

- 60% antracite – sp.gr 1.6 dp = 1.00 mm
- 30% silica – sp.gr 2.6
- 10% garnet sand – sp.gr 4.2 dp = 0.15 mm

We have seen dual media filter; the mixed media filter is also working in the same principle. So the ideal filter is medium graded evenly, large at top to small at bottom can be accomplished by using three or more types of media. In mixed media filters we use three types of materials; one is antracite, another one is silica and another one is garnet sand. For antracite the specific gravity is around 1.6 and for sand silica or sand the specific gravity is around 2.6 and for garnet the specific gravity is around 4.2 to 4.6. So, since the specific gravity is different we can have different grain sizes so when we use different grain sizes naturally the pore distribution will be different.

So if you want to find out if you know the specific gravity of the particle if you want to have a pore size distribution or grain size

For example, here we can see that if the specific gravity is 1.6 and we are using antracite we can go up to 1 mm particle size as the effective size and silica the particle size will be around 0.4 to 0.5 mm and for garnet sand it will be 0.15 mm so we will be getting a gradual distribution of pores like this. This is the dual sand filter, coal is in the top and sand is in the bottom so we can see that in the coal itself there is a size distribution; the finer coal particle will be on the top and as it comes towards the bottom the particle size will increase, then comes the sand bed because sand is having a specific gravity of around 2.6 so here also finer particles are in the top then gradually the size is increasing and the bottom is having the largest particle.

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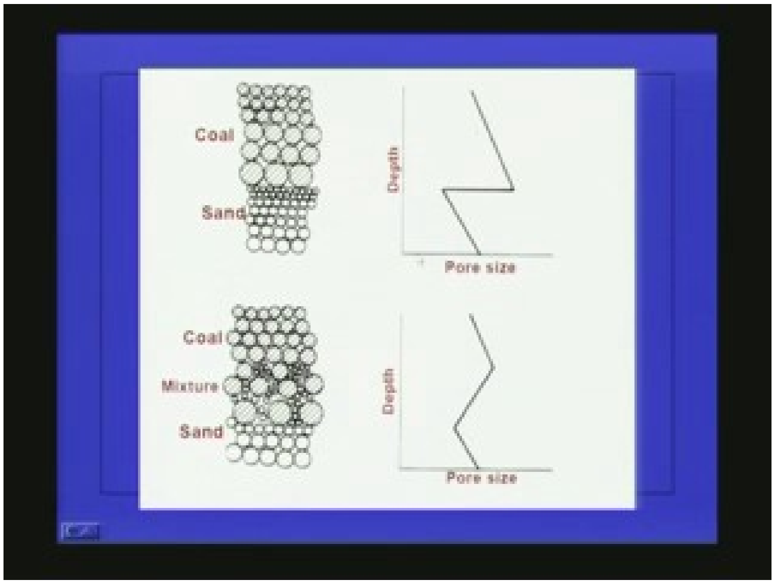

Hence, if you see the pore size distribution it is something like that. Initially we have smaller pores and it will be increasing as we go around this line. Afterwards there will be a sudden change in the pore size and the pore distribution will be something like this (Refer Slide Time: 27:28). Definitely this filter will be much better than the sand filter. For sand filter the pore size distribution will be in this direction; it is in the opposite direction and the pore size distribution will be something like this. That means the pore size at the top will be extremely small and it will be increasing like this. After backwash what happens is some mixing of the medium will be taking place that is some sand particles will be getting into the coal particle so after backwash the pore size distribution is something like this; this steep variation (Refer Slide Time: 28:10) is getting reduced to the variation like this. So the pore size distribution is like this.

But the ideal case is something like this. We have to have a pore size of maximum at the top and minimum at the bottom. How can we achieve that one? If you have three materials and if you want to find out what is the grain size we can use this formula to find out the different grain sizes. If you know the three materials or their specific gravities whatever we are going to use

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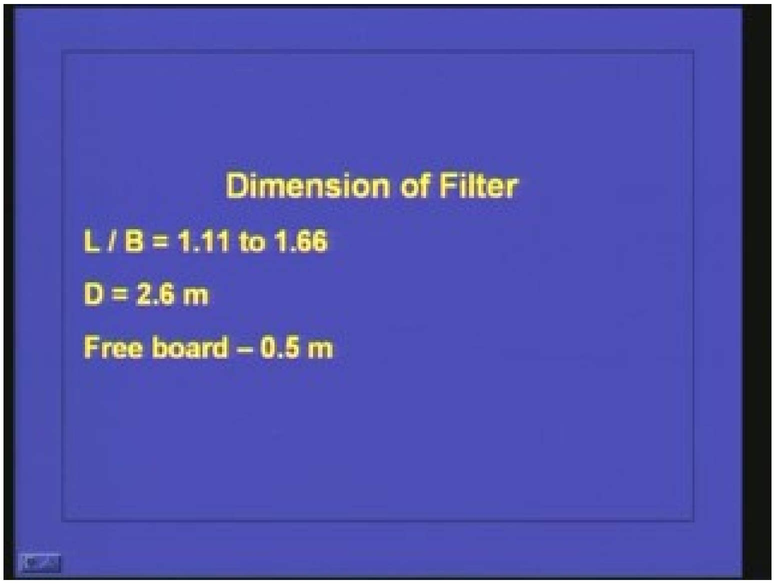

Dimension of Filter

L / B = 1.11 to 1.66

D = 2.6 m

Free board – 0.5 m

The formula is like this; d_1 by d_2 equal to ro2 minus rhol by rho1 minus rhol raised to 3 by 2. So we will solve a small example. Say we have sand with 0.5 mm as effective size and we know that the sand specific gravity is 2.65 and we are going to use antracite as well as garnet. The specific gravity of anthracite we will take as 1.5 and garnet specific gravity we will take it as 4.2.

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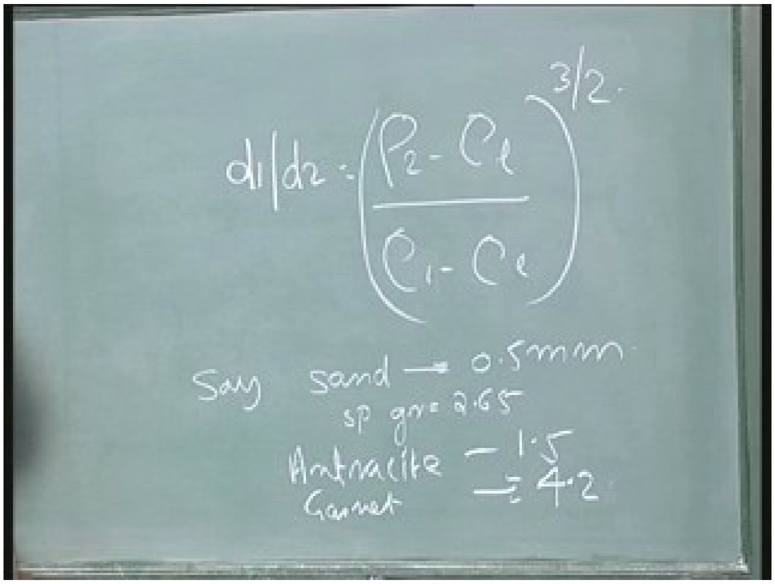

$$d_1/d_2 = \left(\frac{\rho_2 - \rho_l}{\rho_1 - \rho_l}\right)^{3/2}$$

Say sand → 0.5 mm

sp gr = 2.65

Antracite = 1.5

Garnet = 4.2

So if sand is having a size of 0.5 mm so what is the size of antracite we have to use and what is the size of garnet we have to use. We can use this formula; so it is something like this; d_1 for antracite it is 0.5 into 2.6 minus specific gravity or density of water, so specific gravity of water we take it as one divided by 1.5 minus 1 raised to three by two so we will be getting the diameter as 1.5 mm. That means if you use antracite with a specific gravity of 1.5 and sand with specific gravity of 2.6 and a diameter of 0.5 the antracite diameter requirement or the size of the particle requirement is 1.1 mm. Similarly, we can find out what is the garnet diameter requirement. So here everything else will be remaining the same, we have to change the specific gravity of 4.2 mm so the result will be 0.3 mm.

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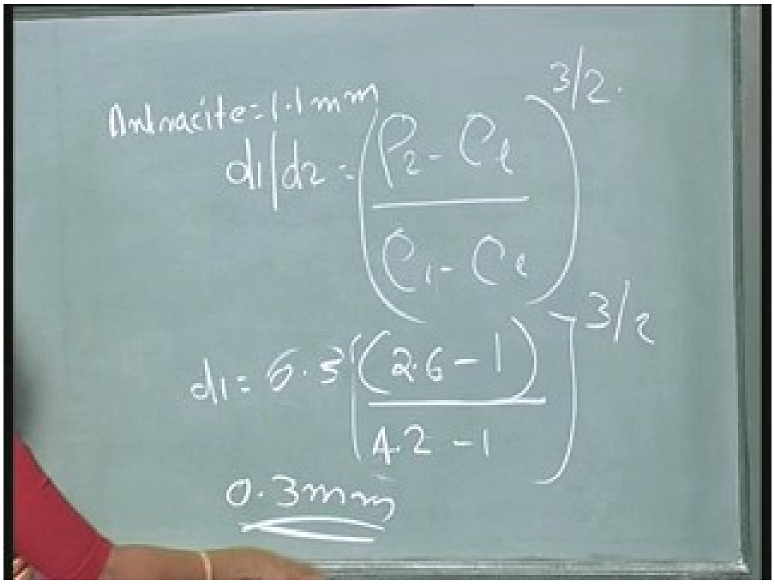

Antracite = 1.1 mm

$$d_1/d_2 = \left(\frac{\rho_2-\rho_\ell}{\rho_1-\rho_\ell}\right)^{3/2}$$

$$d_1 = 0.5\left[\frac{(2.6-1)}{4.2-1}\right]^{3/2}$$

0.3 mm

So we can see that the size distribution of antracite as 1.1 mm; sand equal to 0.5 mm and garnet as 0.3 mm. This will be the size distribution. So if you want to plot the pore size versus depth, remember that antracite will be at the top because it is having the least specific gravity then comes the sand then comes the garnet. So the size distribution will be something like this (Refer Slide Time: 31:44); that means the largest or the biggest pores will be in the top then it will be decreasing like this. So if the filter is something like this it will be having the maximum efficiency. What will happen is the bigger particles will be getting attach in the top and finer and finer particles will be coming to the bottom and here everything will be getting collected. That means entire depth of the filter media will be used.

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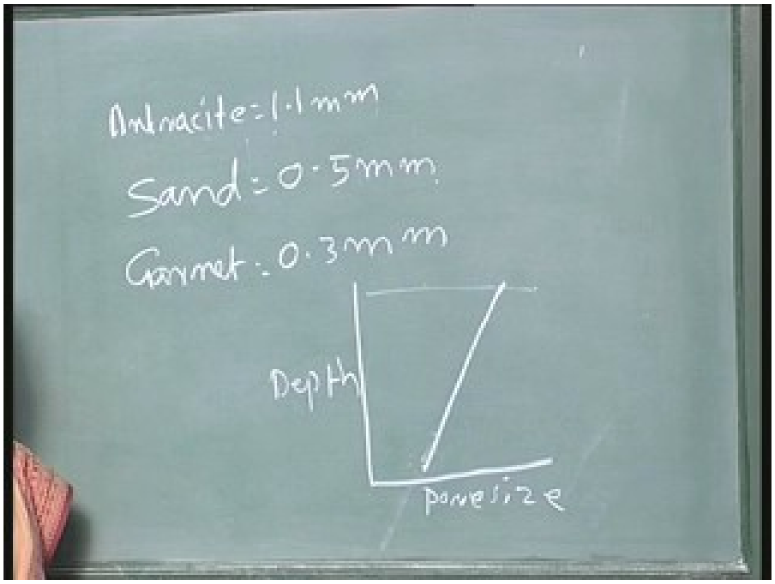

Now we will talk about the dimensions of the filter. This is the dimension of a standard rapid sand filter. L by B ratio varies from 1.11 to 1.66 and depth of the filter is around 2.6 meter and we usually provide a free board of 0.5 meter. Now how to select the filter sand, whether we can dump the builders tank just like that in a gravity sand filter, no, we have to have proper sand and properly graded sand. In slow sand filters we can use the sand as such.

What is the property requirement of the filter sand?
It should be hard and resistant. If the sand is corrosive and if it breaks fast it is not advisable to go for such type of sand. And effective size of the sand should be in the range of 0.45 to 0.70 mm. You know what is this effective size; effective size is the size of particles, means only ten percentage of the particle is less than that one, that means it is the P_{10} value of the size distribution curve and uniformity coefficient should be in the range of 1.3 to 1.7. The uniformity coefficient is nothing but P_{60} by P_{10} value should be in the range of 1.3 to 1.7 and there should not be much ignition loss. Ignition loss should be less than 0.7%.

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Filter Sand

- Hard and Resistant
- Effective size – 0.45 to 0.70
- Uniformity coefficient 1.3 – 1.7
- Ignition loss < 0.7 %
- Soluble fraction is HCl < 5 %w
- Silica content > 90%
- Sp. Gr – 2.5 – 2.65
- Wearing loss < 3%

Ignition loss means whatever is the organic material present in the sand it should be very very less, it should be less than 0.7%. That means when we ignite it all the organic matter or all the volatile compounds will be going out as carbon dioxide and moisture so that should be very very minimal. And soluble fraction of the sand in HCL should be less than 5% and silica content should be more than 90%.

If the sand is having more silica content it will be very very hard so sand should be having a silica content above ninety percentage and specific gravity should be in the range of 2.5 to 2.65 and wearing loss should be very very less. That means it should be less than 3% because in back washing what will happen all the grains will be fluidizing and so much of wear will be taking place. If the sand is not very hard then the sand will be getting lost in this process so that type of sand is not recommended for rapid sand filters.

The depth of sand varies from 0.6 to 0.75 centimeter and standing water depth varies from 1 to 2 meter and free board we have already seen it is 0.5 meter. Now we will see; if you have a heap of sand how we can prepare the filter sand. It can be done by sieve analysis by calculating the percentage of different size of sand present in the heap.

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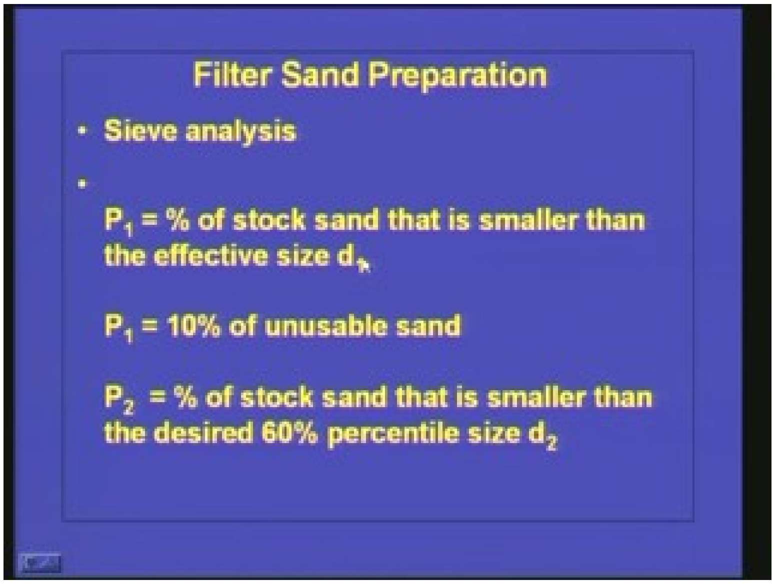

Filter Sand Preparation

- Sieve analysis
-

P_1 = % of stock sand that is smaller than the effective size d_1

P_1 = 10% of unusable sand

P_2 = % of stock sand that is smaller than the desired 60% percentile size d_2

Therefore, we assume that P_1 is the percentage of stock sand that is smaller than the effective size d_1. That means d_1 we know; d_1 is specified, it should not be less than 0.45 to 0.75. P_1 is nothing but 10 percentage P_{10} that should not be less than 0.45 to 0.7. So we know this d_1 value. And if 10 percentage of the sand is less than the effective side so from that one ten percentage can be used so P_1 is 10% of unusable sand. That means you have the distribution and from that one we find out what is the P_{10} value which is available from the effective size so we can find out what is the P_1 percentage, from that P_1 percentage 10% of the sand can be used for the filter because 10% of the sand is less than the effective size that's why we are using ten percentage of that sand and P_2 is the percentage of stock sand that is smaller than the desired 60 percentage size d_2.

Thus, what is happening is this sixty percentile we can find out from the size distribution curve so P_2 is the percentage of stock sand that is smaller than the desired sixty percentile size d_2 and d_2 value is also known because we know that the uniformity coefficient it should be in the range of 1.32 to 1.5 and uniformity coefficient is nothing but P_{60} by P_{10} so from that one we can find out what d_2 is. P_3 is the percentage of suitable stock sand. That is nothing but 2 into P_2 minus P_1 that means P_2 is the 60 percentile and P_1 is the 10 percentile so P_2 minus p_1 is 50%.

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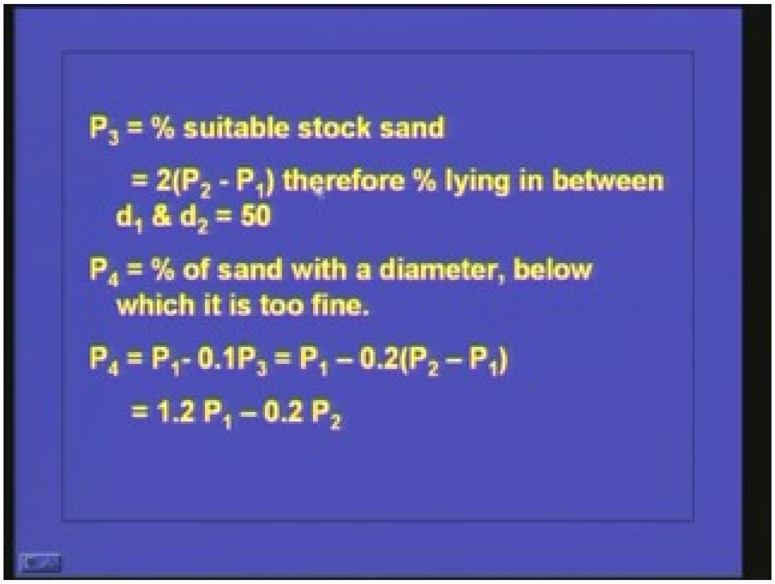

P_3 = % suitable stock sand

= $2(P_2 - P_1)$ therefore % lying in between d_1 & d_2 = 50

P_4 = % of sand with a diameter, below which it is too fine.

$P_4 = P_1 - 0.1P_3 = P_1 - 0.2(P_2 - P_1)$

$= 1.2\,P_1 - 0.2\,P_2$

So 2 into P_2 minus P_1 gives you hundred percent. This (Refer Slide Time: 37:27) 2 into P_2 minus P_1 is therefore the percentage lying in between d_1 and d_2 that means it gives 50 percentage and P_4 is the percentage of sand with the diameter below which it is too fine. That means P_1 we know is 10 percentile sand and from that one for 10% of the sand which is smaller than P_1 that d_1 diameter can be used but remaining 90% we have to waste so we can find out P_4 the percentage of sand with the diameter below which it is too fine. So P_4 is nothing but P_1 where P_1 is the 10 percentile diameter p1 minus 0.1 P_3 and P_3 is the total sand. Therefore, out of the total sand 10 percentage of the sand can be used with a size lower than d_1 corresponding to the P_1. So P_4 which is not being used is equal to P_1 minus 0.2 into P_2 minus P_1 because P_3 is nothing but 2 into P_2 minus P_1 so we will be getting 1.2 P_1 minus 0.2 P_2.

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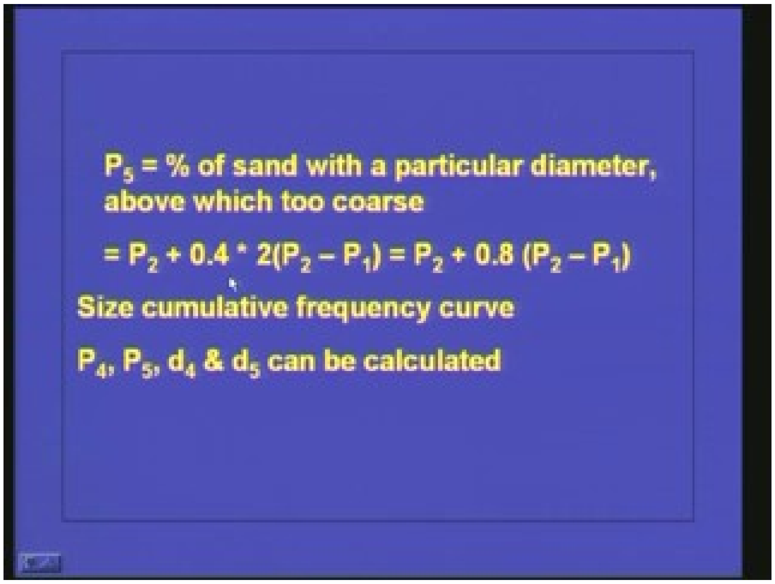

P_5 = % of sand with a particular diameter, above which too coarse

$= P_2 + 0.4 * 2(P_2 - P_1) = P_2 + 0.8 (P_2 - P_1)$

Size cumulative frequency curve

P_4, P_5, d_4 & d_5 can be calculated

Similarly, P_5 is the percentage of sand with a particular diameter above which it is too coarse. That means we cannot use too fine as well as too coarse sand. P_5 is the sand particle size which is too coarse which cannot be used in the filter so that can be found out, this P_2 is the sixty percentile plus 0.4 into 2 into P_2 minus P_1 because P_2 minus P_1 you know it is 50% so 0.4 of this one will give you the hundred percent. That means P_2 plus 0.8 into P_2 minus P_1. So from the size cumulative frequency curve we can find out the diameter corresponding to this P_4 P_5 that means d_4 and d_5 and the percentile. So we will be getting the size distribution along with the percentage of sand. From that one we can make up the sand required for the filter.

Now we will see how the under drainage system of the filter is because that is also very very important. Because whatever water is filtered through the filter it has to be collected in the under drainage system, the same time whatever water is required for backwashing the filter that also should pass through this under drainage system.

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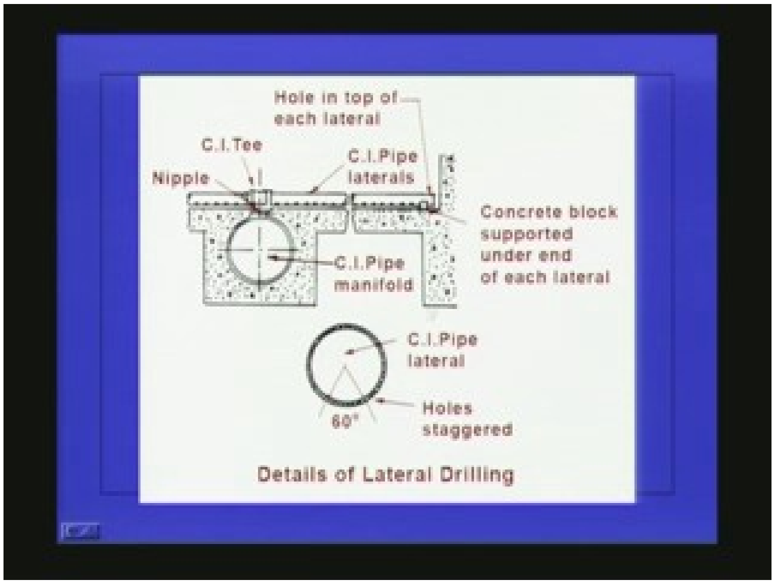

Details of Lateral Drilling

So under drainage system consists of many laterals, we can see how the laterals are placed. These are the laterals (Refer Slide Time: 40:14) and we can see the holes here. Here the gravel bed will be there and these laterals are supported on concrete block and whatever is the water collected from the laterals are coming to the man-fall which is q big pipe and through the man-fall it is coming out of the filter. So we can see how the holes are put in the laterals. The holes will be put in a standard fashion so one hole will be here and another one will be here and so on.

Now we will see how to find out the velocity required for backwashing and how to do the backwashing because backwashing the entire bed has to get expanded or fluidized. Therefore, for this process we have to find out what velocity we have to provide or what amount of head loss taking place in backwashing. How can we find this out?

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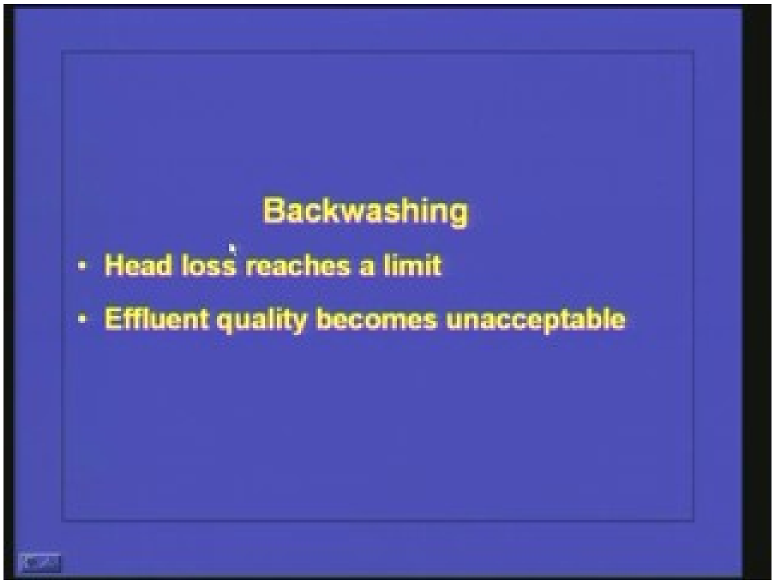

Backwashing

- Head loss reaches a limit
- Effluent quality becomes unacceptable

So here what we have assumed is that the head loss taking place during backwash is equal to the **buoyant** weight of the sand particles. So we have to make the bed fluidized.

Now, how can we find out the head loss in a fluidized bed?
Head loss in a fluidized bed; head into density into acceleration due to gravity which is equal to Le this is nothing but the fluidized bed depth Le into ro_s minus ro_l where ro_s is the density of the sand particle minus this is the density of the liquid (Refer Slide Time: 41:50) into g into 1 minus epsilon e, this is the porosity of the expanded bed so this gives you the buoyant weight of the expanded bed so head loss will be equal to the buoyant weight of the expanded bed.

Here the drag and gravity forces are in equilibrium so we can find out what is epsilon e of the sand or if you know what Le is then we can find out the porosity of the sand or if you know how much expansion is required we can find out even the head loss.

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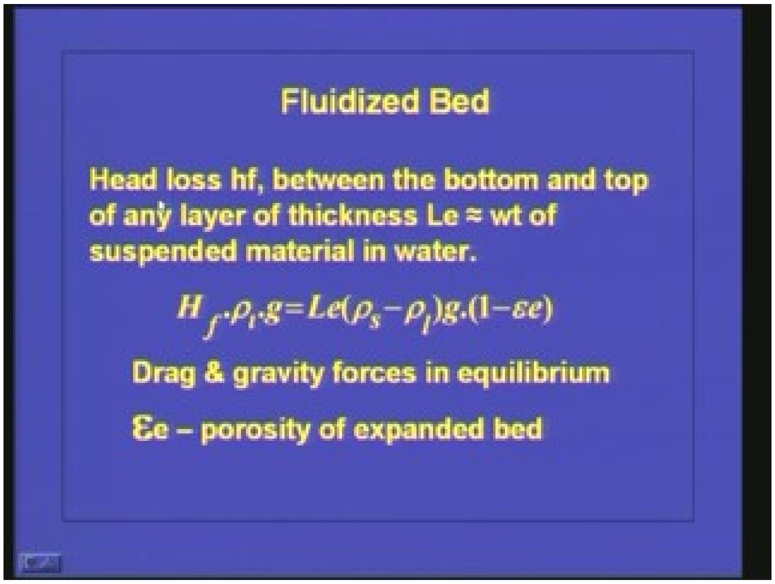

Fluidized Bed

Head loss hf, between the bottom and top of any layer of thickness Le ≈ wt of suspended material in water.

$$H_f \cdot \rho_l \cdot g = Le(\rho_s - \rho_l)g \cdot (1-\varepsilon e)$$

Drag & gravity forces in equilibrium

εe – porosity of expanded bed

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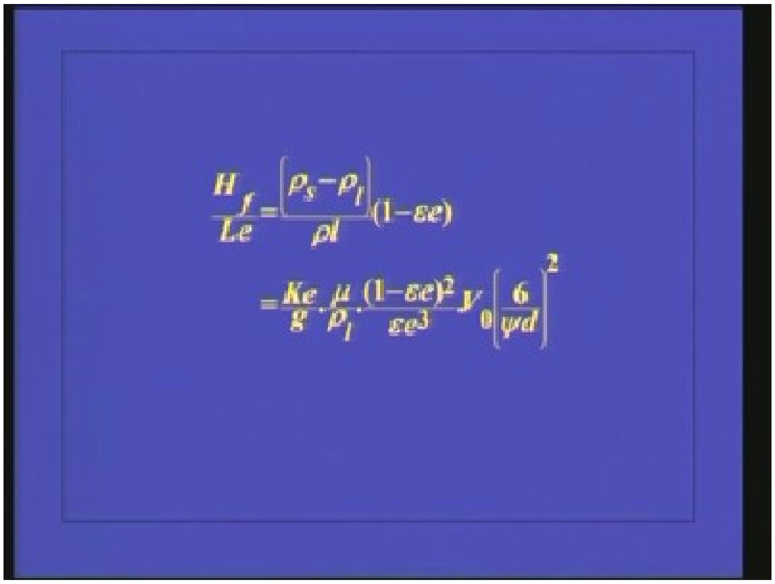

$$\frac{H_f}{Le} = \frac{(\rho_s - \rho_l)}{\rho l}(1-\varepsilon e)$$

$$= \frac{Ke}{g} \cdot \frac{\mu}{\rho_l} \cdot \frac{(1-\varepsilon e)^2}{\varepsilon e^3} y_0 \left(\frac{6}{\psi d}\right)^2$$

Or we can assume that the buoyant force of the unexpanded bed and the expanded are the same because with the mass conservation principle we can drive on how the head loss is taking place. I will just derive that formula because head loss in the fluidized bed and head loss in the regular bed will be equal that means L into 1 minus epsilon that means the porosity of the regular bed into ro_m minus ro_l divided by……. and this one (Refer Slide Time: 43:21) we can write as ro_w because water is the fluid into ro_w into g which will be equal to L into fb which is the length of the fluidized bed into 1 minus $epsilon_{fb}$ this is the porosity of the fluidized bed into ro_m minus ro_w by ro_w into g.

Now these two terms are the same for both the filters that means L into 1 minus epsilon will be equal to L_{fb} into 1 minus epsilon b so we can write like this; L into….. that means the matter the solid particles whatever is present in the filter before expansion and after expansion will be the same that is what it shows; L_{fb} into 1 minus epsilon is equal to L_{fb} into 1 minus epsilon b mass conversion. Or if you want to find out the length of the fluidized bed it is equal to L into 1 minus epsilon by 1 minus epsilon$_{fb}$. By practice we have seen that to get a proper backwashing this epsilon$_{fb}$ should be in the range of 0.6 to 0.73. This is the range.

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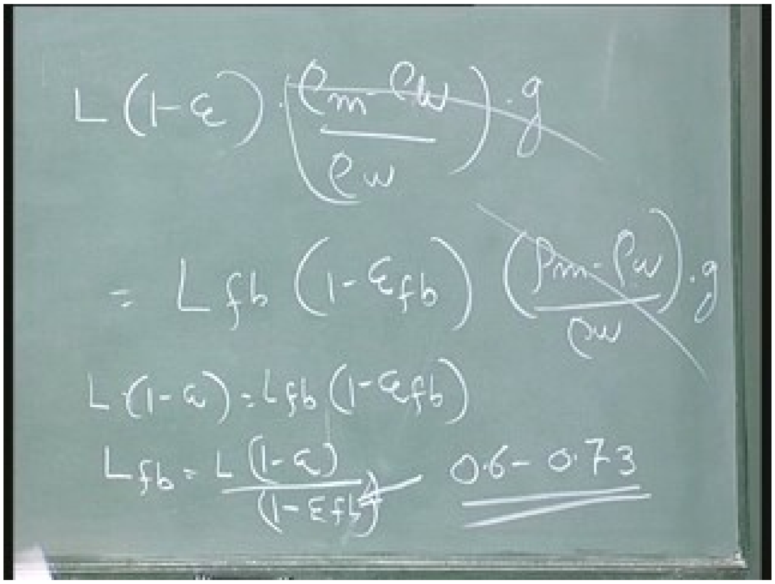

$$L(1-\varepsilon)\cdot\cancel{\left(\frac{\rho_m-\rho_w}{\rho_w}\right)\cdot g}$$

$$= L_{fb}(1-\varepsilon_{fb})\cancel{\left(\frac{\rho_m-\rho_w}{\rho_w}\right)\cdot g}$$

$$L(1-\varepsilon) = L_{fb}(1-\varepsilon_{fb})$$

$$L_{fb} = \frac{L(1-\varepsilon)}{(1-\varepsilon_{fb})} \qquad \underline{\underline{0.6-0.73}}$$

This is the range Amritrajan has found out that the expanded bed to porosity should be in the range of 0.6 to 0.73 to get a proper backwash. Now we will see how to find out the backwash velocity. This epsilon$_{fb}$ means that the fluidized bed porosity is a function of the backwash velocity and the settling velocity because if you have a particle like this and one backwash velocity of water is like this (Refer Slide Time: 45:34) also called VB and another velocity acting on the particle is the one settling velocity Vt. Vt we have discussed earlier so the resultant velocity is the one with which the particle will be moving. So this epsilon$_{fb}$ is a function of the backwash velocity as well as the settling velocity so we can write like this; VB by Vt raised to 0.22 here VB is the backwash velocity Vt is the settling velocity so Lfb is nothing but L into 1 minus epsilon divided by Vt raised to 0.22 and for non-uniform size particle bed we can find out Lfb equal to L into 1 minus epsilon into sigma Xij divided by 1 minus VB by Vtij raised to 0.22 because with respect to the particle size this settling velocity will be varying. Thus, from this one we can find out either the backwash velocity if you fix up the fluidized bed length.

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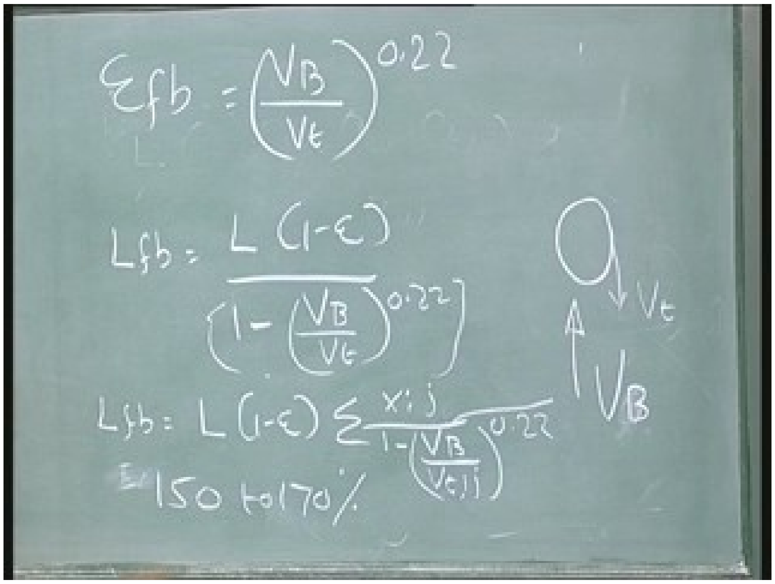

$$\varepsilon_{fb} = \left(\frac{V_B}{V_t}\right)^{0.22}$$

$$L_{fb} = \frac{L(1-\varepsilon)}{\left[1-\left(\frac{V_B}{V_t}\right)^{0.22}\right]}$$

$$L_{fb} = L(1-\varepsilon)\sum \frac{x_{ij}}{1-\left(\frac{V_B}{V_{t,i}}\right)^{0.22}}$$

E 150 to 170%

So usually an expansion of 150 to 170 percentage is recommended for proper backwashing that means it is getting expanded by 1.5 to 1.7 times so this is the principle of backwashing.

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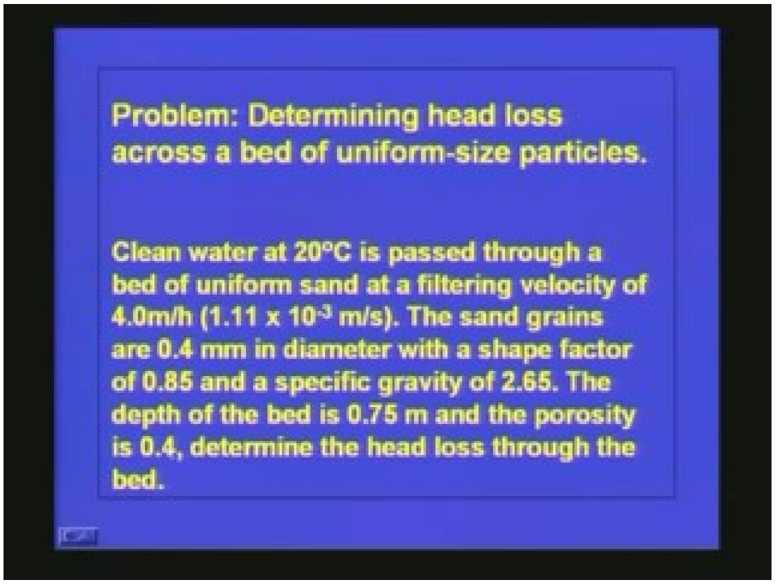

Problem: Determining head loss across a bed of uniform-size particles.

Clean water at 20°C is passed through a bed of uniform sand at a filtering velocity of 4.0m/h (1.11×10^{-3} m/s). The sand grains are 0.4 mm in diameter with a shape factor of 0.85 and a specific gravity of 2.65. The depth of the bed is 0.75 m and the porosity is 0.4, determine the head loss through the bed.

We will see the problem determining the head loss across a bed of uniform size particles. The problem is like this:

Clean water at 20 degree centigrade is pass through a bed of uniform sand at a filtering velocity of 4 meter per hour which is equal to 1.11 into 10 raised to – 3 meter per second.

The sand grains are 0.4 mm in diameter with a shape factor of 0.85 and a specific gravity of 2.65. The depth of the bed is 0.75 meters and the porosity is 0.4. Determine the head loss through the bed.

We will see how to find out the head loss through a homogeneous filter media. What we have to do for the solution?
First we have to find out the Reynolds number because we have to find out whether it is in laminar flow regime or in turbulent flow regime or in transitional flow regime. So first we have to find out the Reynolds number.

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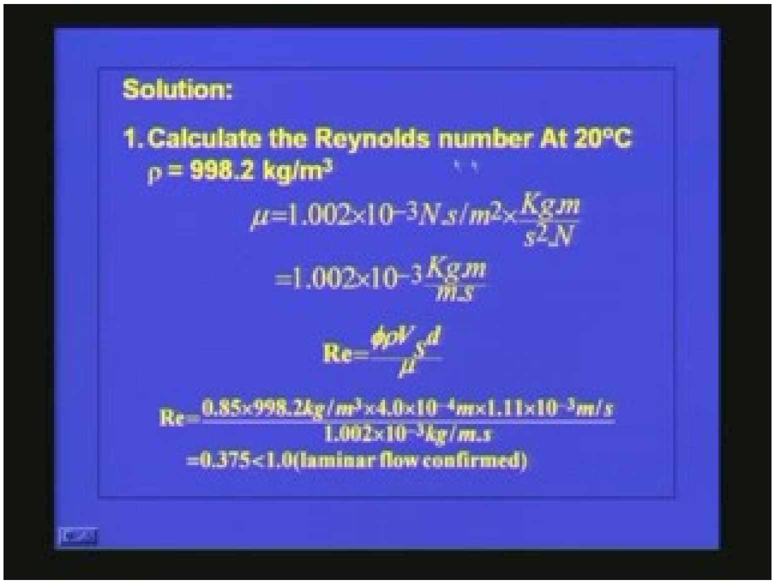

Solution:

1. Calculate the Reynolds number At 20°C

ρ = 998.2 kg/m^3

$$\mu = 1.002 \times 10^{-3} N.s/m^2 \times \frac{Kg.m}{s^2.N}$$

$$= 1.002 \times 10^{-3} \frac{Kg.m}{m.s}$$

$$Re = \frac{\phi \rho V_s d}{\mu}$$

$$Re = \frac{0.85 \times 998.2 kg/m^3 \times 4.0 \times 10^{-4} m \times 1.11 \times 10^{-3} m/s}{1.002 \times 10^{-3} kg/m.s}$$

$$= 0.375 < 1.0 \text{(laminar flow confirmed)}$$

Already the specific gravity or ro is given as 998.2 kilograms per meter cube, the density of water at 20 degree centigrade is given and mu is also given, mu is 1.002 into ten raised to minus three kilogram meter per meter second. The Reynolds number we can find out using this formula; pie into ro into Vs d by mu we have seen this formula earlier so Reynolds number is nothing but this and here pie value is 0.85 and density is 998.2 into and this is the diameter of the particle 4 into 10 raised to minus 4meters and this is the velocity 1.11 into 10 raised to minus 3 divided by mu where mu is 1.002 into 10 raised to minus 3 kilogram per meter second. Thus, by substituting this one we will be getting a Reynolds number as 0.375 and we know that if the Reynolds number is less than 1 the flow is in the laminar regime or it is a laminar flow. Therefore, based upon this one we can find out the friction factor.

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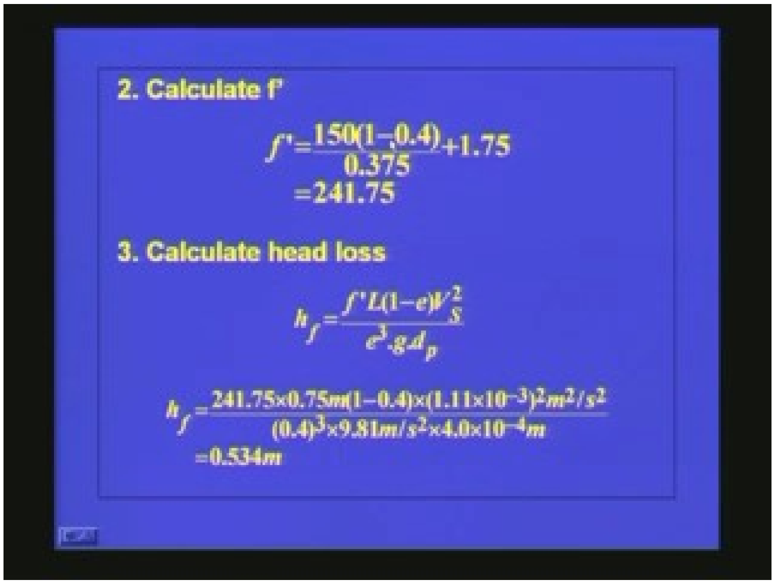

2. Calculate f'

$$f' = \frac{150(1-0.4)}{0.375} + 1.75$$
$$= 241.75$$

3. Calculate head loss

$$h_f = \frac{f' L (1-e) V_S^2}{e^3 . g . d_p}$$

$$h_f = \frac{241.75 \times 0.75m (1-0.4) \times (1.11 \times 10^{-3})^2 m^2/s^2}{(0.4)^3 \times 9.81 m/s^2 \times 4.0 \times 10^{-4} m}$$
$$= 0.534m$$

The next step is calculation of f dash and f dash can be find out using this formula; 150 into 1 minus e divided by Re plus 1.75 and we have an array value of 0.375 and then e value of 0.4 so we will be getting the f dash value as 241.75. Once this f dash value is available we can calculate the head loss using this formula; hf is equal to f dash L into 1 minus e Vs square divided by e cube g into dp so all the terms are known to us and f dash is 241.75 and length of the medium is 0.75 meter and 1 minus ctm is 1 minus 0.4 into Vs square 1.11 into 10 raised to minus 3 whole square divided by e cube into g into dp. So we will be getting the head loss as 0.534 meters.

Now I will show you some pictures which explain how the filtration is taking place. We were discussing about the mechanism of filtration in the previous class. There are different mechanisms like near straining; this is mechanical straining, then gravitational settling, inertial impaction, direct interception, Brownian notion electrokinetic process etc.

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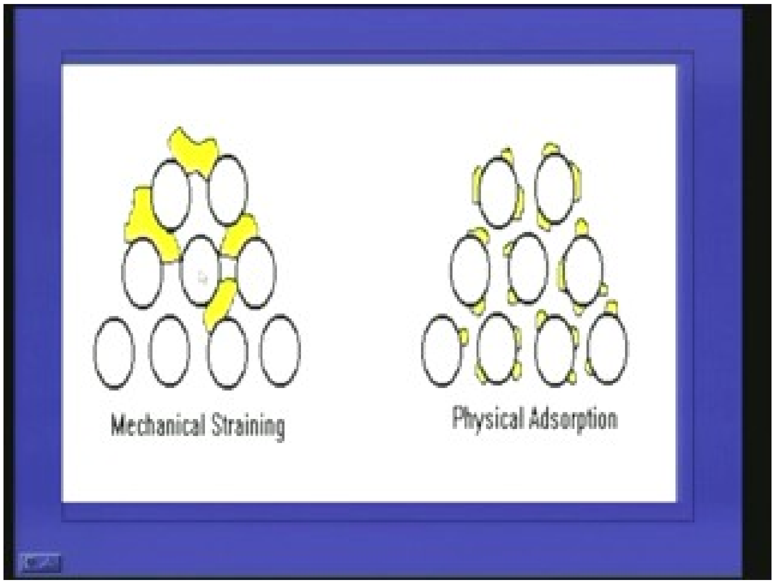

This is an example of mechanical straining. We can see here; this is a filter grain, this is another filter grain (Refer Slide Time: 51:30) the pore size available in between these two is this much and if a particle or floc of higher size comes here it is not able to pass through the filter grain so it will just stay there which is nothing but straining just like a surface filter. Here also the same thing is happening. This is how the mechanical straining is taking place even in a gravity filter.

This is the example of physical adsorption because sand grains are having some charge and these particles may have some charge or may not have some charge so when they come closer when the vicinity or the distance between them is such that the Van der Waal's force is predominant compared to the repulsive force when it will be coming and getting attached to the filter media. This is an example of physical adsorption. Here we can see in all the grains which is getting attached.

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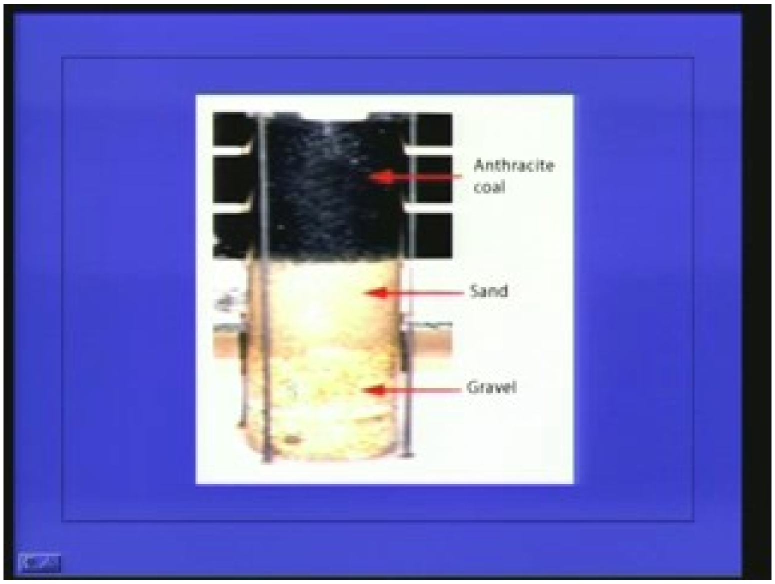

This is the photograph of a mixed media filter whatever we were discussing earlier. If you use different materials as filter media we can use different grains sizes and we will be getting a pore distribution in such a way that it will be increasing the rate of filtration and efficiency of filtration by utilizing the pore properly. Here we can see; this is the anthracite coal and here is the sand (Refer Slide Time: 53:08) this is the gravel so the pore size distribution will be the larger one on the top and the smaller one in the bottom.

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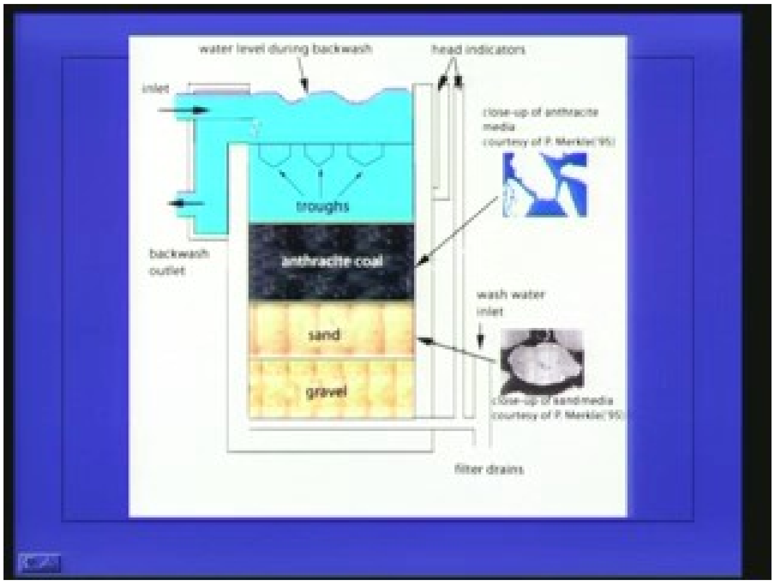

This is the picture of a filter, this is the inlet water and this (Refer Slide Time: 53:27) is the water level during backwash and we can see the anthracite coals, sand and gravel and this is the backwash outlet. And if you want to see the grains of anthracite we can see that those are not spherical grains. This is the picture of the sand particle.

(Refer Slide Time 54:07 min)

This is a picture of the wastewater trough whatever is placed in the top of the filter. When backwash is taking place this will be collecting entire dirty water and will be putting them back to the treatment system. Here we can see how the dirty water is getting collected in the trough and it is going for further treatment.

Now we will conclude whatever we have seen in filtration. Filtration is a polishing treatment unit. It improves the aesthetic of the water and if turbidity is present in the water it will be affecting the bacteriological quality of water also. The reason is this infection may not be effective if turbid particles are present. That is why the Bureau of Indian Standard has put the standard or the limit of turbidity present in drinking water as 1 NTU it should not exceed 1 NTU because as small turbid particles are there then the bacteria or the microorganism will take shelter on this colloidal particles or the particulate matter whatever is present in the water.

We discussed the different types of filters. The most commonly used filters are slow sand filters and rapid sand filter. Slow sand filter: the mechanism of filtration is mechanical straining and there is a biological layers formation on the surface of the slow sand filter so that will be removing all the dissolved organic matter from the water. So the cleaning mechanism or cleaning of slow sand filter is done by scraping the top layer because the filtration will be taking place only in the top layer so it will be getting dirty so if you remove that one the remaining portion will be working as such.

Rapid sand filter is most commonly used in water treatment plant because the rate of filtration is very high compared to slow sand filter, almost 40 to 50 times. So here entire depth of the filter is being used for cleaning purpose. Once the head loss is reached the permissible limit we have to clean the filter which is done by backwashing. We can find out the head loss through the filter by using the flow through porous media or Carmen Kozeny equation and we can even find out the backwash velocity.

Backwashing is achieved by fluidizing the bed and if you can provide enough backwash velocity then the medium will be getting fluidized around 150 to 170 percentage of the existing bed so because of this the particles will be shearing with each other and whatever is the dust particle or the dirty particle collected on the filter bed will be coming out.

We have seen how we can select the sand or how we can separate the sand required for a filter from a heap of sand and we have also seen what are the dimensions of different units in a filter. After filtration in the water will be very very clean, the only treatment left over is disinfection. That we will discuss in the next class.