Water and Waste Management
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Module No # 09
Lecture No # 42
Depth Filtration

Hello everyone, welcome back. In the last session we introduced ourselves to different mechanisms by which suspended matter can be removed by different types of filtration. One is depth and one is surface filtration by the membrane.

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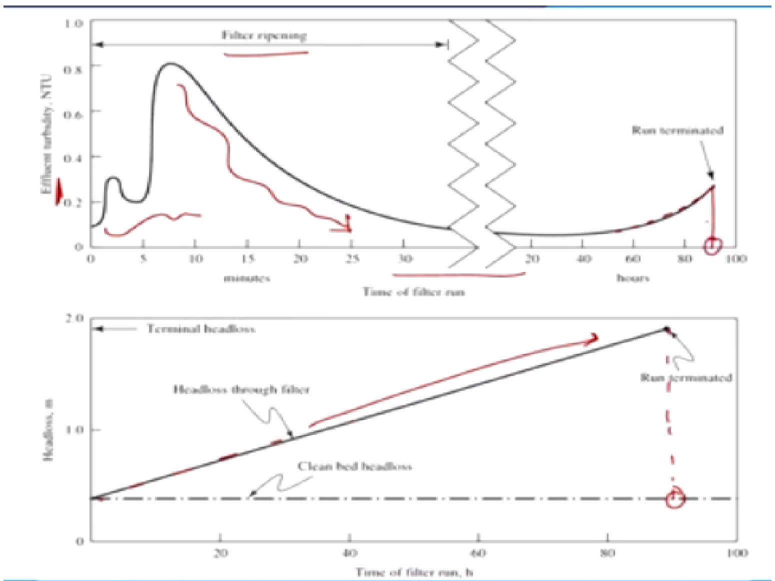

Fig 1

And then we started looking at the aspects relevant to depth filtration (refer Fig.1). Initially performance is not good but this is required. Because that well in effect will lead to increase in filter performance during this ripening. And after that for 1 or 4 days, you are going to have good removal efficiency with respect to turbidity or decrease in turbidity. And afterwards you are going to have increase in turbidity and then the run is terminated.

And in that context, we also saw that this head loss is going to keep increasing and that is also one factor to terminate it. Which factor to choose will depend upon which one comes earlier and also the operator’s frequency or ease of back washing due to the operator’s convenience. Let us move on here.

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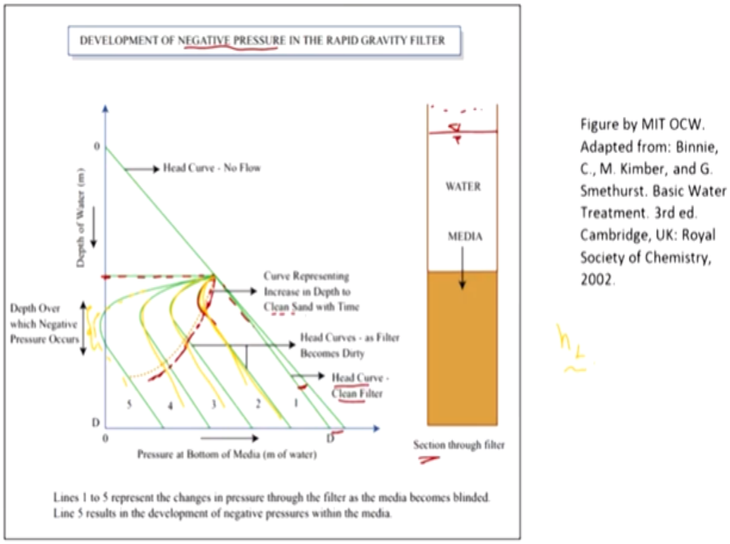

Fig 2

One aspect is that if, we do not look at the relevant performance and relevant backwash, we can even have negative pressure being developed during rapid filtration (refer Fig.2). Here we have this water potential at this level and here just water above the media. This is what we typically have and under this head water is filtered through this particular sand.

This is cross section and this is the media. We see this with increase in depth in water, increase in head and this is where the media starts. And here we see a curve and this curve gives us the depth to clean sand. As in initially clean sand is available right here but after operation of the filter over a certain period of time, what is going to happen? This particular initial toppler is not very clean. To reach this particular clean sand layer,

We are going to have to go deeper and deeper, that is what it means, curve representing increase in depth to clean sand with time. That is what is happening. What is going to happen during this operation? Head loss is going to increase, that is what you see. This is the head curve with clean filter, this is due to the clean filter head loss and not much depending on how you design.

But as you are running the plant, first head loss something like this and then it goes into the negative zone- negative pressure. That can lead to air bubbles and considerable detoriation in your plant operation efficiency. You will have to see to it that this does not occur or you backwash it before your head loss is so high.

That is one reason. Other reason is if head loss is too high, your pressure or your energy requirement later to pump it up will increase. That is something to keep in mind. Let us move on.

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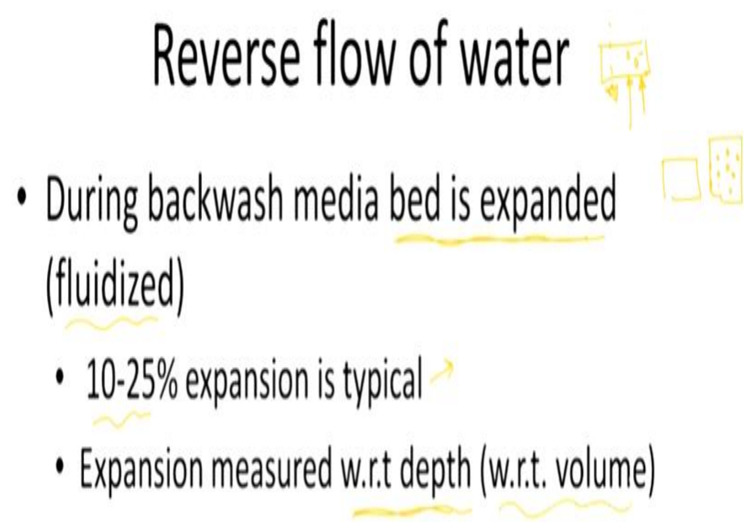

Fig 3

Reverse flow of water. We just established the needful backwashing, usually water flow is this through the media (refer Fig.3). But we need to backwash it from time to time to decrease the head loss and also prevent this negative pressure from being developed. Within the depth of the relevant filter. What do we do? We are going to have to backwash or fluidized the bed.

During this backwash, what is going to happen? The bed is going to be expanded. Earlier it was like this and now it is going to be like this (expanded), why? The particles which were compacted earlier, we are pushing them against gravity. They are not going to be as compacted. The bed is going to be fluidized or expanded. And in general, the total volume expansion of the bed is 10 to 25%, but one aspect to keep in mind is that the mass of relevant media is still the same or volume of the actual media is the same.

Volume of the total bed is increasing but the volume of the media is still the same, that something to keep in mind and we will use that later in this or the next session. Expansion is measured with respect to depth because the surface area is the same with respect to the depth or with respect to volume, in general with respect to depth.

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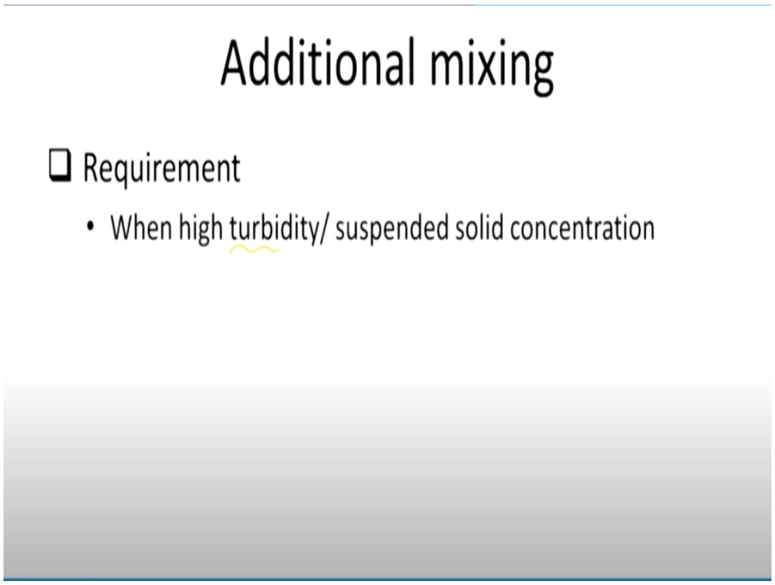

Fig 4

When is more mixing or more level of backwashing required? When there is remarkably high turbidity or suspended solid concentration in the influent meaning a lot of suspended matter has been absorbed onto my relevant filter media, one thing and when else? For example If I have coagulation before the relevant filtration or I just did not have sedimentation. I have already had coagulation or coagulant being added or polymers being added.

Then I will have to wash them off to it, that is when we need it. When polymers are added that is something you have to look at and when else we will have to look at this?

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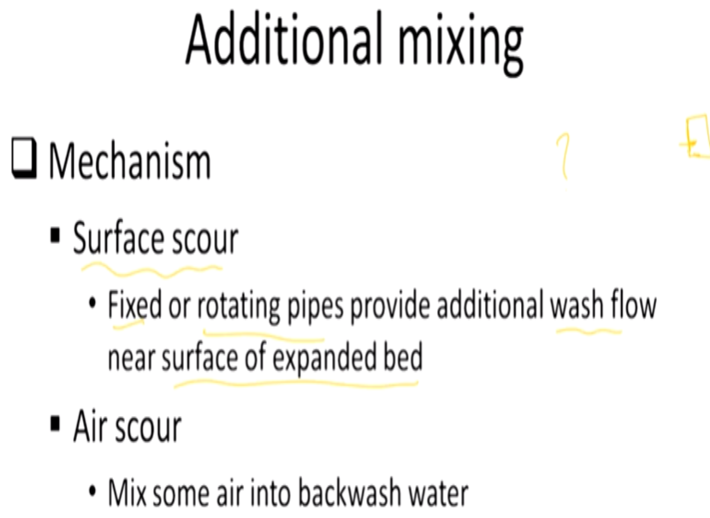

Fig 5

What is the mechanism? Mechanism is surface scour as in surface cleaning to it can be done. You will have surface scour pipes, that is one way to go about it. You have fixed a rotating pipe which will provide additional wash near the surface of the expended bed. That is one way to go about it and sometimes you will even pump air in along with this water. That will give that additional level of mixing that is required.

Where is this backwash water going to come from? You will typically store some water to be used or store some treated water to be used for backwash that also will have to be taken to account when you are going to design for a particular filter. The amount of backwash required and how frequently is that required.

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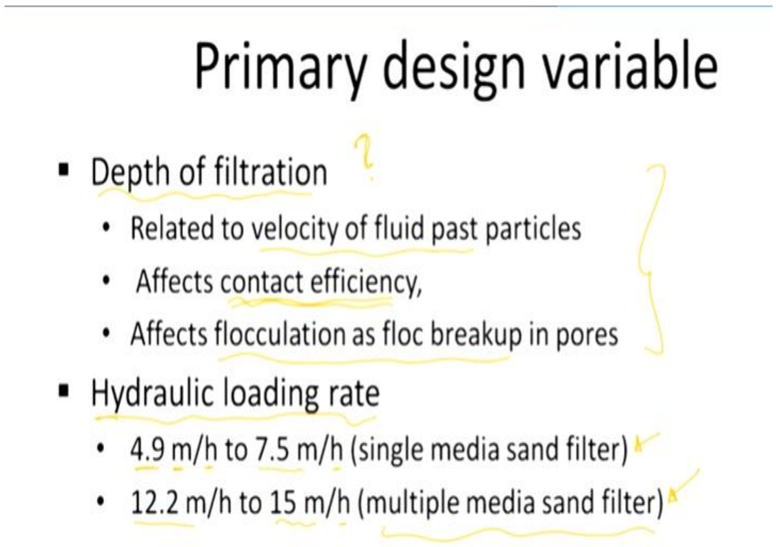

Fig 6

Design criteria. First aspect is depth. What should the depth of the relevant filtration be and what is that depend upon? Velocity of fluid past the particles, what is the velocity of fluid past particles or the filtration rate in a way. And why is that important? Because we looked at contacts- how many contacts and how many contacts are leading to removal?

It will affect the contact efficiency and it will also affect flocculation. Flocs breaks up as the relevant speed is too high, that is something to keep in mind. Depth filtration will have to be taken into account. Well, here is one aspect- Hydraulic loading rate. At what rate is the water being loaded, so it is volume per area per time.

That is why it comes out to be one-dimension meters per time (refer Fig.6), this is 4.9 or 5 meters per hour to 7.5 meters per hour if it is single media sand filter. If it is dual or multiple media sand filter, it is relatively high- 12.2 meter per hour to 15 meters per hour. Multiple media sand filter, that is when typically, the efficiency increases. We will look at the design later.

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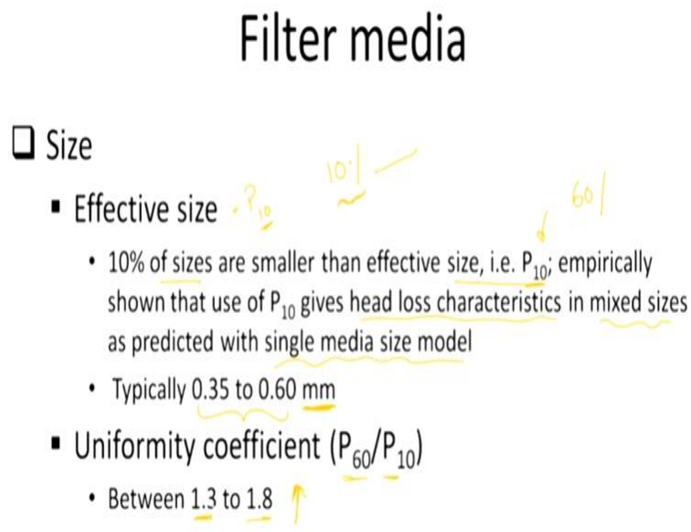

Fig 7

What are the other considerations? The kind of media and how many layers as in is its single media, 3 kinds of media or a multiple media or such. when these things come into play. When I choose media, I need to look at the size of the relevant media and when I talk about size I am talking about effective size as in effective size typically the well-established norm is that

We look at 10% of the particles by weight passing through a particular size and that size is referred to as the effective size. 10% of the size is by weight or smaller than the effective size which I am referred to as P_{10}, different nomenclatures. Empirically why is that important? It gives the head loss characteristics in mix-in sizes as predicted with single media size model.

It gives me an idea about head loss characteristics. That is why we typically look at P_{10} and then we also look at uniformity coefficient, how uniform is your relevant media and that is going to be depend upon P_{60}. P_{60} measure in the same way as P_{10} but instead of 10 %, we look at 60%. P_{60}/ P_{10} here is 1.3 to 1.8. If uniformity coefficient number is too high that means that the particles are not too uniform.

I think that is the understanding here as in there is great variation here and typically effective size 0.35 to 0.6 mm, keep that it in mind it is mm size and uniformity coefficient around 1 and a half that something to keep in mind.

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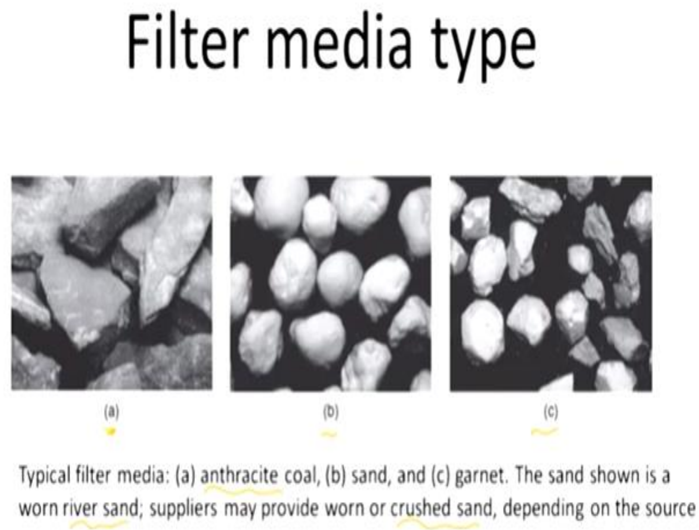

Fig 8

This is the figure where we zoomed in. You have anthracite coal here, sand and garnet that is sometimes used and why is this well rounded, they say that because it is from river sand because water has flown around it. You are going to have rounded shapes, vendors can also provide crushed sand depending on the source. That is something keep in mind because that will affect your percentage or kind of removal.

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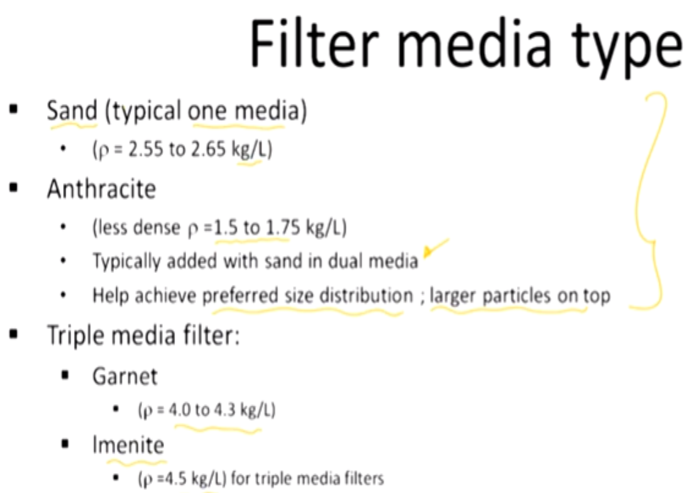

Fig 9

Filter media type. Sand- this is the most widely used sand filter, well first its inert and it is typically used when you are only using one media and density 2.5 kilograms per liter. If it is dual media, you are going to use anthracite above sand relatively less dense typically added with sand as I mentioned in the dual media filter and why is this it will achieve the size distribution? With larger particles on top.

Larger particles on top and small ones on the bottom if not you are going to have issues with respect with head loss and also removal efficiency and particles sinking in. If it is triple media filter, then you can also have different minerals- Garnet and Imenite, but here you see the density is relatively higher. In general, dual media filters with anthracite above sand is the typical or usual way to go about it.

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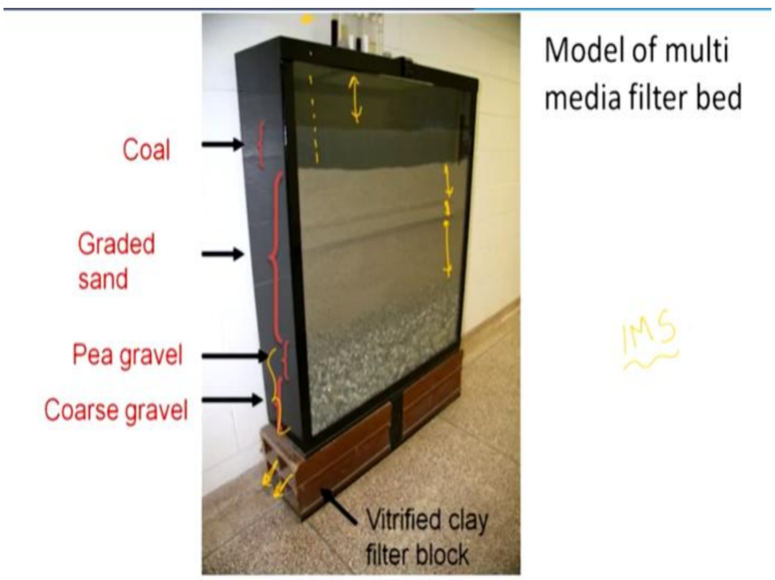

Fig 10

And we have a picture here (refer Fig.10). We have coal, we have graded sand, you can see its visual, you can see the graded sand different kinds of sand and then pea gravel and the coarse gravel that form the bed here. And then this filtered water is collected in this vitrified clay filter block. This is something we looked at in the previous session. We have perforated pipes. We have vitrified filter blocks which were widely used or maybe still used and many places.

And now people are moving on to IMS (Integrated media systems). Typically, you have the water head out here and the water under that head will be flowing through this while these particles or while the filter does its job.

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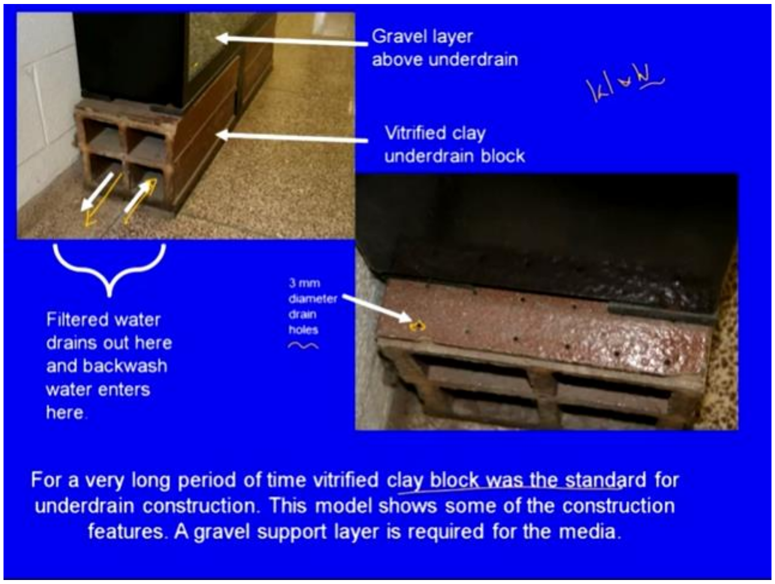

Fig 11

Here we have another picture (refer Fig.11), these are from the student presentations of Mekenzy Davis, water and waste water. These you can access to, there are many more such worthwhile pictures which give an idea about practical aspects and the aspects of construction or how to construct relevant media or unit processes. You can always access them. gravel layer above the under drain.

That is something we looked at and from the section, verified clay under drain block. filtered water as you mentioned comes out and backwash enters here. You have these holes; 3 mm diameter drain holes from which the water comes from above into these vitrified clay blocks. As mentioned, clay blocks are standard for under drain construction.

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Typical properties of filter media

Property	Anthracite coal	GAC	Garnet	Ilmenite	Sand
Effective size, mm	0.45–0.55[a] 0.8–1.2[b]	0.8–1.0	0.2–0.4	0.2–0.4	0.3–0.6
Uniformity coefficient	≤ 1.65[a] ≤ 1.85[b]	1.3–2.4	1.3–1.7	1.3–1.7	1.3–1.8
Hardness, Moh	2–3	very low	6.5–7.5	5–6	7
Porosity	0.50–0.60	0.50	0.45–58	N/A	0.40–0.47
Specific gravity	1.5–1.75	1.3–1.7	3.6–4.2	4.2–5.0	2.55–2.65
Sphericity	0.46–0.60	0.75	0.60	N/A	0.7–0.8

[a]When used alone.
[b]When used as a cap on a dual media filter.

Fig 12

And different types of properties of filter media. We should have discussed this earlier too. We did discuss density earlier but let us look at the effective side usually of anthracite coal widely used (refer Fig.12). Granular activated carbon is used depending upon your relevant objective and here you have the relevant size. This is what we have already looked at earlier. Uniformity coefficient, you see this level of uniformity coefficient depending on the relevant kind of particles.

Porosity is also within the relatively close range. Why sphericity? This is what we talked about when we looked at sand which is well rounded or relatively crushed and irregular because most of the models looked at or assumed that the media is rounded. And thus, the mechanisms and the models depend upon the kind of or the shape of relevant media. But if it is crushed sand, you can look at empherical equations or look at the experimental data too.

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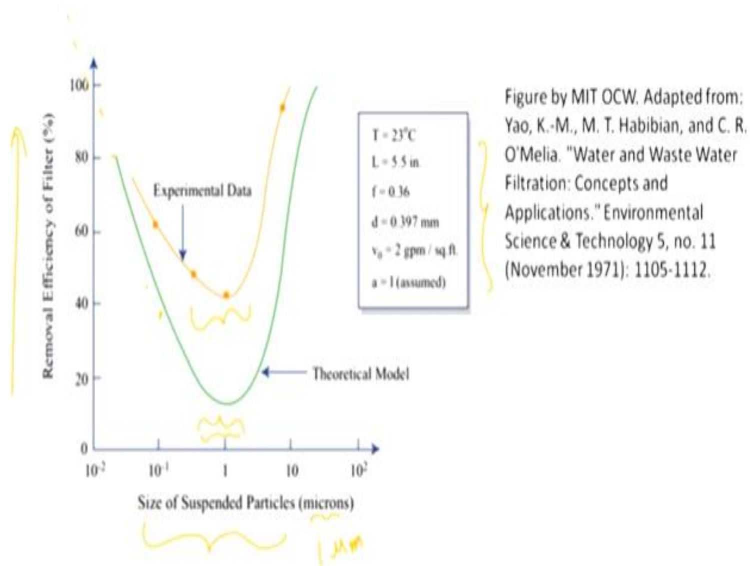

Fig 13

Why this experimental data versus theoretical data graph (refer Fig.13)? We want to look at the efficiency of removal with respect to this size of the relevant particles. Here on the y-axis, we have removal efficiency of the filter and here we have suspended particles and we see that as I mentioned earlier too, the particle range around one micron are relatively difficult to remove by filtration at least with respect to size as in such that we look at it.

And relevant information is mentioned here. Experimental data and the theoretical model, what do they both predict? They both predict that efficiency is lowest for the sizes around 1 micron. Here you can see increase but it does not going to be keep increasing, there is going to be limit also.

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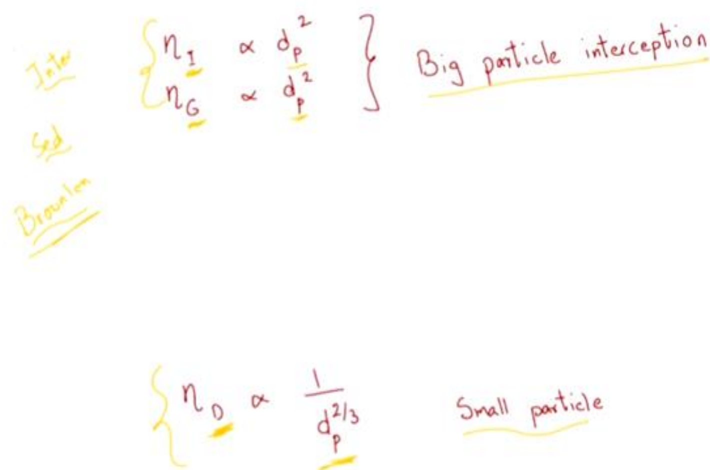

Fig 14

And why is that? If you look at it removal efficiency due to inertia, due to gravity or sedimentation and due to diffusion or Brownian motion. We looked at different part aspects, we looked at interception and we looked at sedimentation and we looked at Brownian motion, aspects related to these kinds of removal. As you can see removal efficiency due to inertia or due to gravity.

It depends upon the square of the diameter of the particles (refer Fig.14). Big particles interception typically occurs by these two ways, with respect to smaller particles it is with respect to diffusion or due to Brownian motion. That is what you see and thus you see that as diameter of the particles decreases, the efficiency due to removal by diffusion or due to Brownian motion increases. That is what you see out here.

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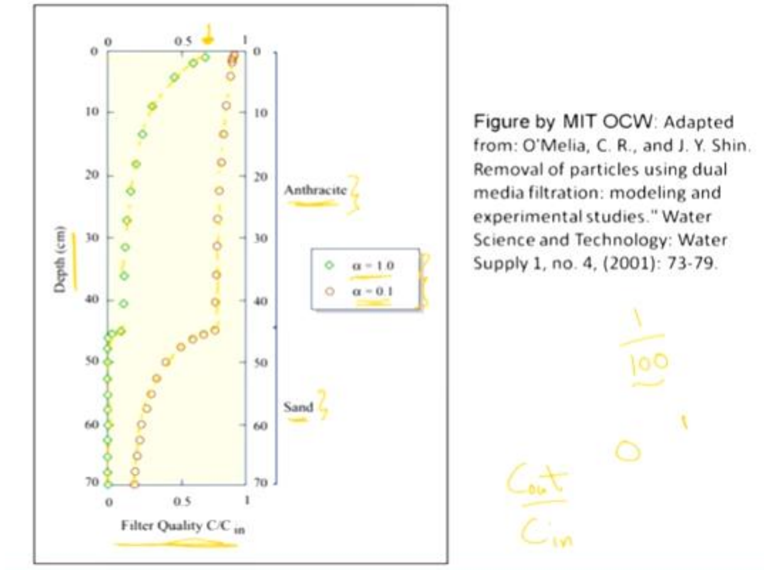

Fig 15

Let us move on. Here we have another figure (refer Fig.15) that gives us an idea about dual media filter, so sand and then anthracite above it. And alpha gives you an idea about the level of chemical treatment or chemical activity if I can say so. What do we see here? Here we have on the left side y-axis the depth and here we have the filter quality. This is C_{out} / C_{in}.

C_{out} should be as low as possible that is what you want, almost 0 or 1 so 1 by 100, pretty low. What is the first aspect? Let us look at 1, so with respect to the case where we have some chemical role to play or chemistry has a role to play, so chemically treated. What do we have? We see that even at relatively low depths, you do have some removal but not lot of removal. The removal efficiency is relatively poor. But with depths as you can see the efficiency increases.

Much more and by the time it reaches the sand, there is a quantum increase and you can see that the filter quality is remarkable good. Yes, so you can choose your size accordingly. With respect to relatively less chemical treatment, what do you see? Anthracite not doing very well, but from the sand the removal efficiency increases. Here you can see the role of the chemical treatment, the role of the dual media filter media. This is something to keep in mind

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Fig 16

Filter media depth typically 60-75 meters, minimum is around 60 centimeters typically.

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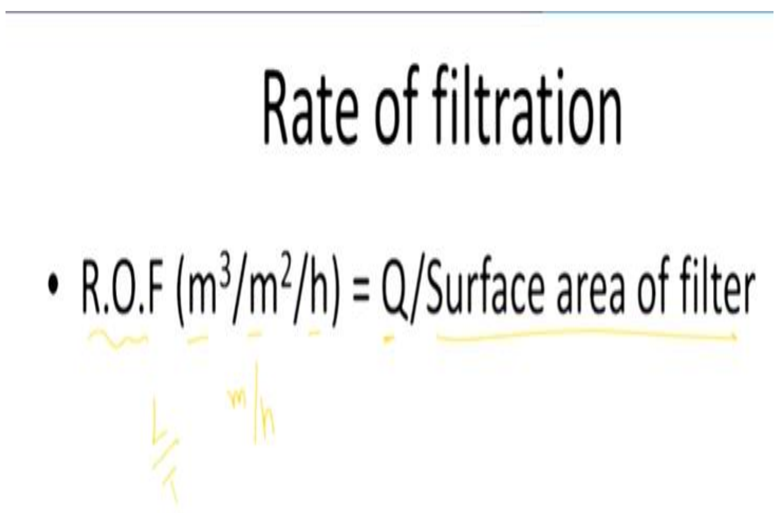

Fig 17

And rate of filtration, this is something we came across earlier; Q by the surface area of filter. I think I already mentioned this, units are meter cube per meter square per hour. Effectively they come out to be meter per hour or dimensions per time.

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Fig 18

Head loss at the clean filter. Just because there is media, that is going to lead to some head loss. And afterwards when the filter has been put into operation, we know that, If I can use layman's terms, it is going to choke. Or you are going to have the particles being deposited on the relevant media and between the pores and you are going to have increase in head loss. To look at that, let us understand some of the variables that we are going to look at.

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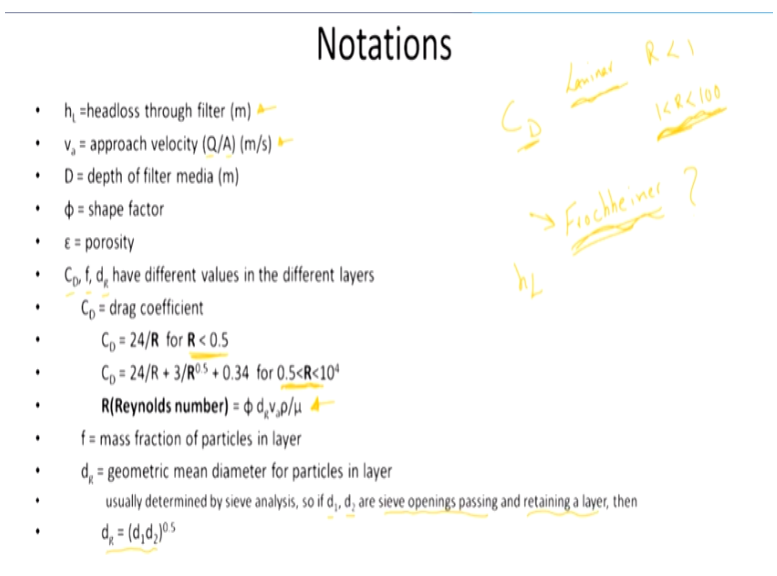

Fig 19

Head loss through the filter, approach velocity- this is easy to calculate Q by the surface area which we just also looked at, depth of filter media, shape factor giving as different shapes different levels of removal, I think we have also discussed this earlier, porosity of the media, coefficient of drag f and d_g, this is the relevant geometric mean. Coefficient of drag depends upon the Reynolds number.

We looked at it, Reynolds number typically we are here concerned with laminar flow. When R is less than 1 and then transition flow between may be 1 to 100 and then we have turban flow later. But in general in our filtration relevant flows, we are going to have may be laminar or most probably during this transition flow when Reynolds number is between R and 100, this is called Forchheimer flow, if I am not wrong.

Why is this relevant? Because based on the relevant flow the coefficient of drag will change and based on that your head loss will also be changing. In general, we are dealing with flows mostly Forchheimer flows, we will look at this. Head loss, if it is laminar flow will be different. Head loss if the Reynolds number is this zone will be different, that is something to keep in mind.

When the Reynolds number is relatively less and Reynolds number in the transition or particularly in the turbulent zone, turbulent flow conditions but rarely we will get that. You can calculate Reynolds number and, in this course, I will give the relevant equation in sheet at least for this course.

But depending upon which exams you want to pass in such, they might lead you to mug up relevant stuffs. f is the mass fraction of particles in the layer, as I mentioned d with the subscript g is the geometric mean diameter of the particles in the layer. When we say by sieve analysis, d1 and d2 are the sieve size openings and then they retain a layer.

Then

$$d_g = \sqrt{d_1 . d_2}$$

This is something that you have looked at, you have different size, the relevant particles or filter media is passed through sieve of different size depending upon the need you will look at different sieve sizes and you will look at the size of sieves and the fraction that is retained and then you will be able to get your geometric mean diameter.

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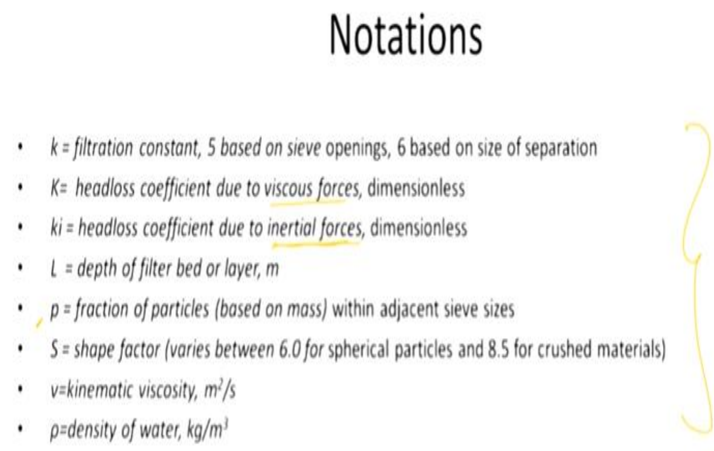

Fig 20

What else do we have? k is equal to the filtration constant, K is head loss coefficient due to viscous forces. K_i is head loss coefficient due to inertial forces, this is something to keep in mind due to viscous and due to inertial forces. One is predominant during laminar and one is predominant during the Forchheimer's flow, the Reynolds number is between 1 to 100 that something to keep in mind.

L is depth of filter bed, p is fraction of particles based on mass within adjacent sieve sizes. S is the shape factor which, this is the different set of notation used by the different set of books but I wanted to give both the notations, we have also seen this earlier. Kinematic viscosity, density of water.

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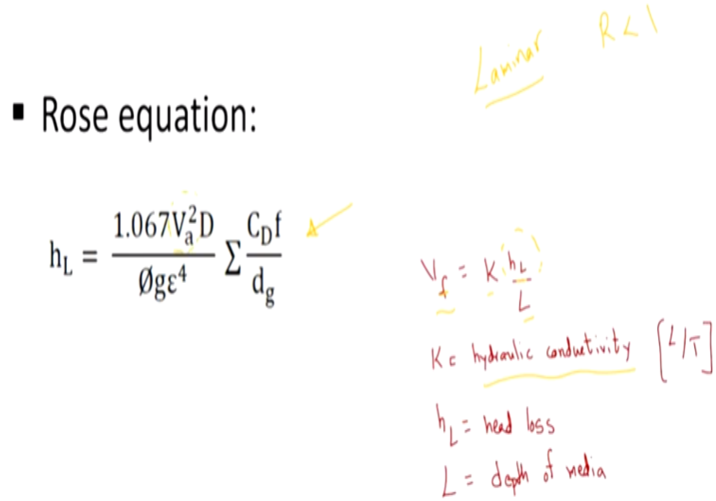

Fig 21

Rose equation; And this is when you have laminar flow conditions, Reynolds number is less than 1. And for that laminar flow conditions, we have this

$$V_f = k\left(\frac{h_L}{L}\right)$$

h_L is your head loss and k is your hydraulic conductivity, dimension per time. And from this you can calculate your head loss and more or less from that we have the Rose equation out here for the Laminar conditions typically. See that, it is V^2 here that is something for you to keep in mind.

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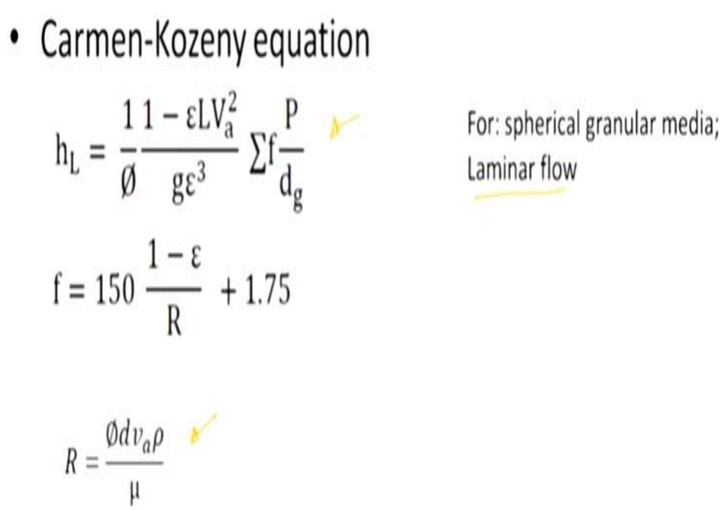

Fig 22

And then we have Carmen Kozeny equation, this is for spherical granular media and Laminar flow. That is something to keep in mind. You do not need to mug this up for this particular class. Reynolds number calculation based on the relevant variables that are relevant to filtration are given here.

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- Fair-Hatch equation

$$h_L = k_v \frac{(1-\varepsilon)^2 L v_a}{\varepsilon^3} \left(\frac{6}{\phi}\right)^2 \sum \frac{p}{d_g^2}$$

Takes account of non spherical filter grains also

Fig 23

Fair hatch equation takes you to account of non spherical filter grains. Laminar flow, but we have non spherical, so here spherical and non-spherical.

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Ergun equation :

$$h_L = k_v \frac{(1-\varepsilon)^2 \mu L v_a}{\varepsilon \rho g d^2} + k_i \frac{1-\varepsilon}{\varepsilon^3} \frac{L v_a^2}{g d}$$

For head loss through granular media at higher filtration velocity

Fig 24

This is the case of you have this Ergun equation where you have 2 independent terms that will give you an idea about when to choose this equation. This is the one we have a Forchheimer's flow and Reynolds number is between 1 and 100. And for this head loss, will be depending upon two aspects, one is $k_1 \times V^2$ and the other one is $k_2 \times V$, so that is what you see here.

When you see something like this that means this is for the case when you have relatively faster velocities at play and thus it is not Laminar conditions but may be transition flow. If not transition, just about reaching transition, Forchheimer's flow. That is why you have two terms. One with V_a, and one with V_a^2. As we can be seen this is for head loss through granular media at high filtration velocity or with respect to Forchheimer's flow that we talked about earlier. This is the Ergun equation.

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- Calculate the clean-bed head loss through a deep-bed anthracite filter with 1.8m of effective size = *0.95 mm media at a filtration rate of 15 m/h and a* temperature of 15°C.

Given:

- kv = 228
- ki = 4.4
- ε = 0.50
- ρ_w = 998 kg/m^3
- μ = 1.*14* × *10*$^{-3}$ *kg/m.s*

Fig 25

We are asked to calculate the clean bed head loss, this is the clean bed head loss through a deep bed anthracite filter with 1.8 meters of effective size is equal to 0.95 mm media at a filtration rate of 15 meters per hour and a temperature of 15 degree centigrade. Effective size and deep bed of 1.8 meters, this is given. How go about it? We have the relevant Constants which are given, if not we have to look at the relevant table.

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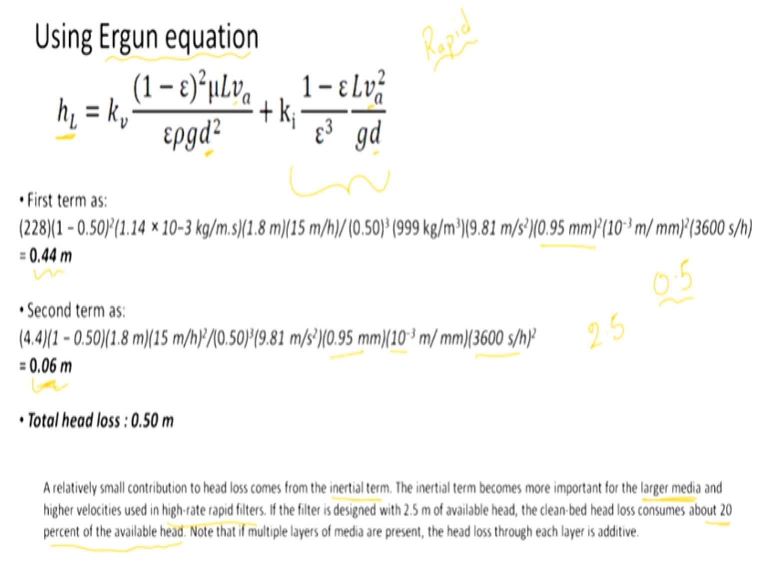

Fig 26

Here we are using the Ergun equation, expecting it to be the use for rapid sand filter. The expectation is that have been useful for rapid sand filter if it is typically deep bed. You are going to look at relatively greater depths, the reason is because you are going to use them for rapid sand filtration. That is why we are looking at rapid sand filtration and using this particular Ergun equation, what do we have?

First term just simply plugging in the relevant aspects, you can look up these variables and if there is an error, you can always change the calculations but it is just based on plugging in the values mentioned earlier. But you see why we are looking at these. First term is 0.44, second term comes out to be 0.06, 0.44 and 0.06. why is this that we are looking at this particular data?

As you can see, relatively small contribution to the head loss comes from the inertial term. Inertia term is relatively small. First term diameter square and second term diameter velocity, as we can see the inertia relevant term is relatively less. But it becomes important for larger media and higher velocities used in high rapid sand filters.

High-rate rapid filters and as we can see Crittenden et al. tells us that if a filter media is designed for 2.5 meters of available head and out of that 0.5, that is lot of head loss. The clean bedded head loss itself consumes around 10% or 20% of the available head, that is something to keep in mind.

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Backwash

Fig 27

Backwash I think I have pictures at this case.

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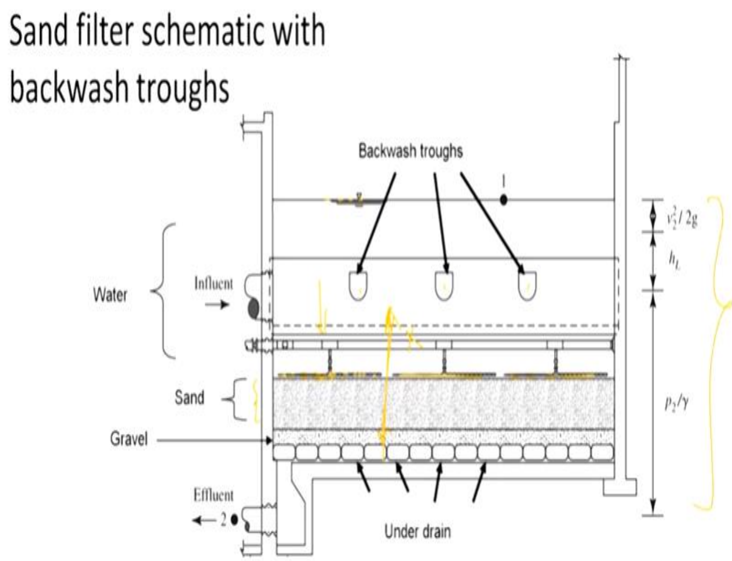

Fig 28

Sand filters schematic with different backwash troughs, so what do I have here? We have the section and we have the under drain and we are going to pump the water up, during that the we are going to have a fluidize bed. The bed is not going to be like this. This is going to be an expansion of the bed and then this backwash water is going to go through this or been going to be collected through these backwashed troughs.

During operation though, the water flow is in this direction and not in this direction. And during that you need a standing head of water and also you can see these arm which are required for cleaning the surface, this is what we mentioned where we talked about additional mixing or additional level of removal. Additional level of mixing when we have polymers, these are for surface cleaning and here you can see the surface and different total head here.

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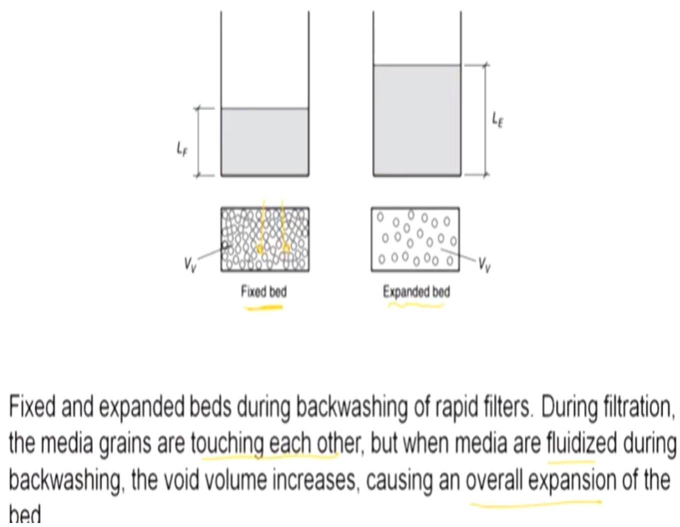

Fig 29

In general, what do we have? We have a fixed bed, relatively well packed but during backwash it is going to be relatively expanded here. Fixed and expanded beds during backwash during filtration they are touching each other. But when they are fluidized, that is why we call that fluidized. Fluidized during backwashing, the void volume increases causing an overall expansion of the bed.

But as you can see if I look at it the volume of the media is still the same that is the principle we are gong to use later. Volume of the media is still the same but the volume of bed is going to increase .

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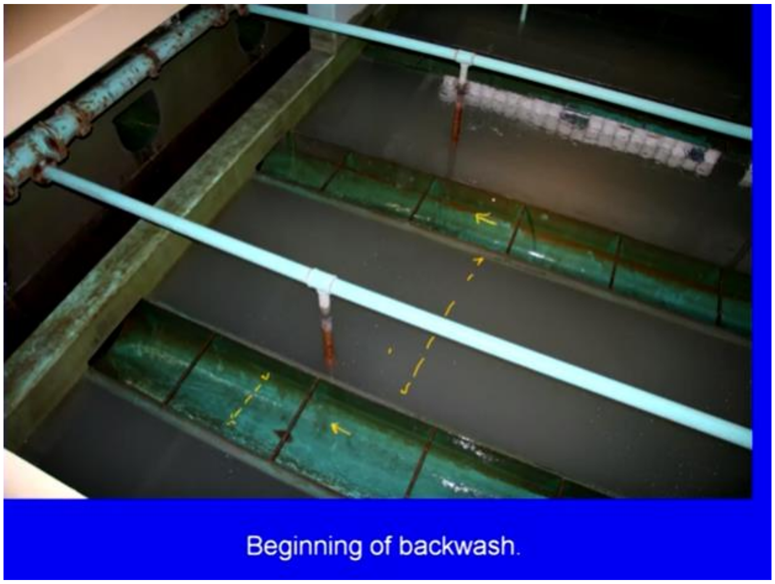

Fig 30

Let us move on, so what do we see here? Here they are going to begin backwashing here. These are backwash troughs; They are just about to start backwashing and this is where you have the relevant filtration occurring but they just started pumping water in the reverse direction. Water is going to come out from here and going to this backwash and will be collected in this backwash troughs.

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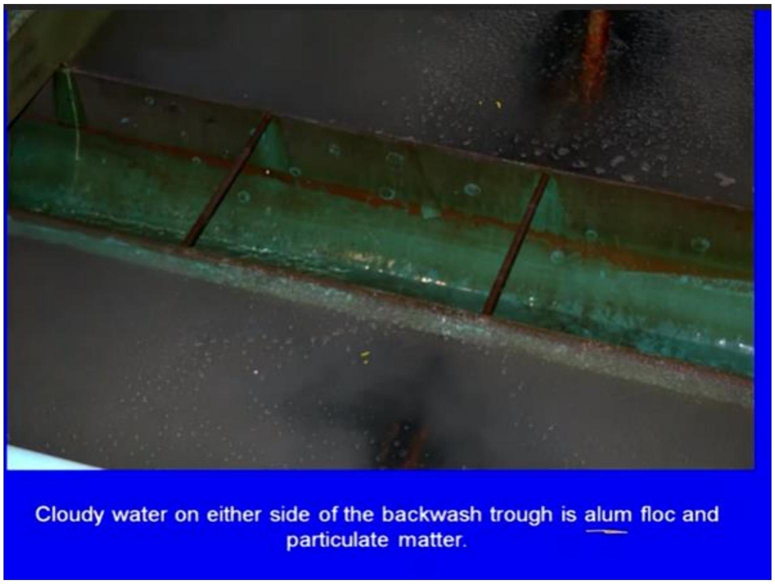

Fig 31

Cloudy water on either side of the backwash trough, why is this? This is alum floc and particulate matter. Looks like before this, they had relevant coagulant being added which was the alum. When they were backwashing it, you can see that this cloudy material is alum floc and some particulate matter on the surface.

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Fig 32

And from the backwash trough, it is being collected in the gullet.

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Fig 33

And now after backwashing is continued more of the particles that are absorbed are going to now be dissolved. And they are going to come out. Backwash continues and water become cloudy and colored with soil particles, that is what you see here and then that is going to be collected in your particular backwash troughs.

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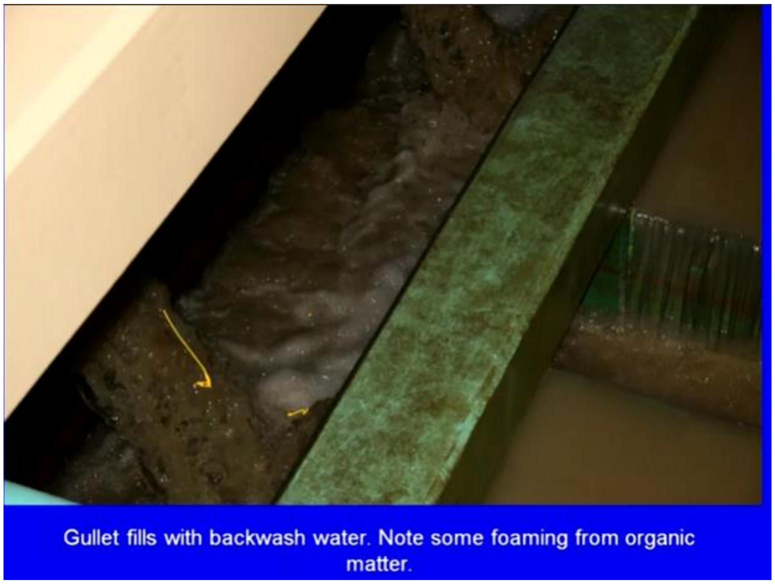

Fig 34

We also see foaming from organic matter, we see that and the backwash water now you see here it is relatively clouded or pretty poor in quality.

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Fig 35

And how long will I do that? Well, it depends upon the level of treatment but one thumb rule is- If you are doing that manually, you can look at how clean the water is but rarely is that done.

You can see that it is still cloudy but after some operation, you see that it is relatively clearer. Now is the case and after sometime water is starting to become relatively clearer. And again after more continuous backwashing, the backwash water is starting to become relatively clearer meaning the filter is relatively cleaner now.

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Fig 36

And backwash continuous to show foaming that means there is still organic matter that is taking longer to dissolve.

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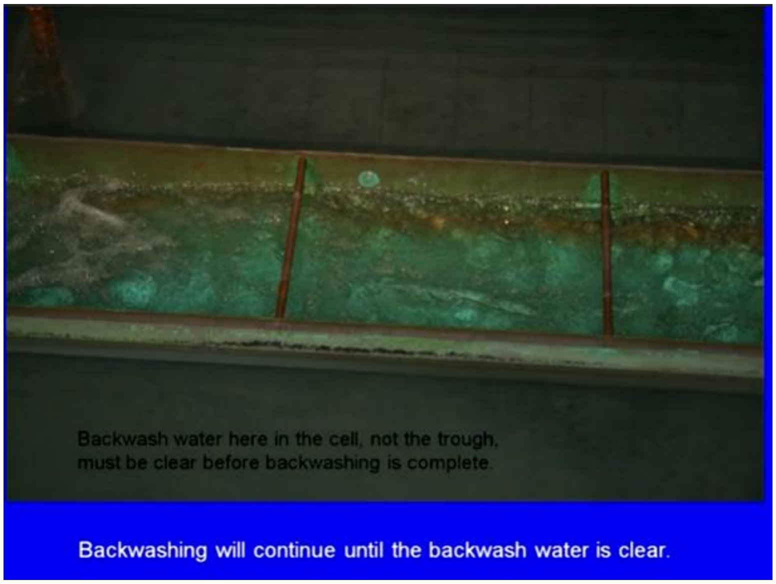

Fig 37

Backwash now continuous to be clear and looks like in this case the backwashing rate was too high and that is why it is leading to a backup in the backwash trough, you can compare that with the figure here and then this backup. This is something you want to avoid. Backwashing will continue until the backwash water is clear, you can have automated ones or you can see even manual backwashing with manual judgment is also relatively decent enough.

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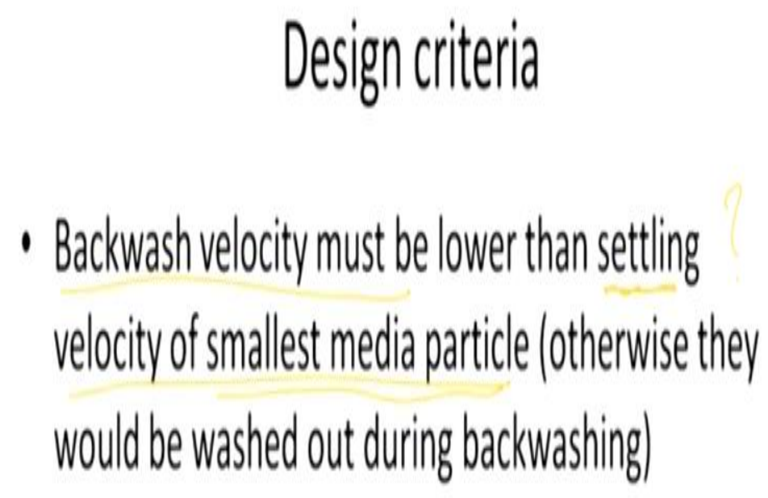

Fig 38

Design criteria with respect to backwash, what is it that I need to be concerned about? First aspect is that the backwash velocity must be lower than the settling velocity of the smallest media particle. Why is that? If not, I am backwashing it and when I am backwashing it the particles are not compact or settled anymore that are fluidized but still gravity is going to pull them down.

If I increase the backwash velocity to a certain value or beyond threshold then what is going to happen? This particular particle which is trying to settle down, the media which I want to retain, I do not want to lose this filter bed media, is also going to be removed with my backwash. This backwash velocity should always be lower than the settling velocity of the smallest media particles.

That is something to keep in mind and we will look at the aspects relevant to head loss and also solve the relevant example in the next session, with that I will end today session.