Water and Waste Water Treatment
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Module No # 09
Lecture No # 41
Filtration

Hello everyone, welcome back to the latest lecture session. In the last couple of sessions we were talking about removal of the suspended solids from drinking water. We were measuring that by turbidity and the principle was forming bigger particles by destabilizing them and then letting them form flocs the bigger particles. And then we use sedimentation to settle them down.

Even after this there will still be some particles that are still suspended or will take much more time to settle down in a sedimentation tank. What are we going to do next? We are going to look at filtration, so let us move on and look at filtration.

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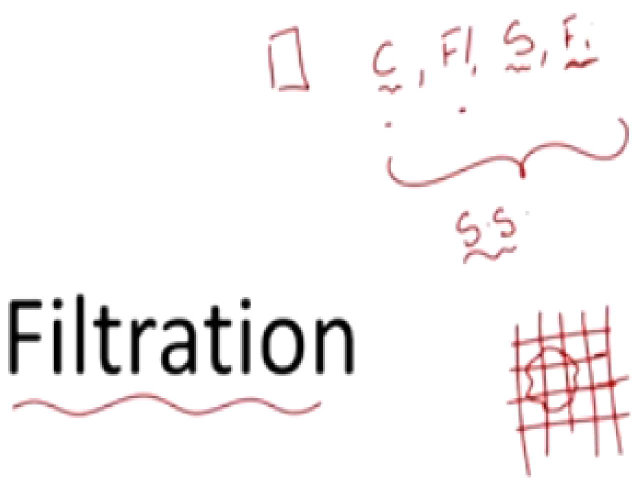

Fig.1

What have we looked up until now in water treatment? Let us just e just put it up. Preliminary treatment in terms of coarse screens or such and then we are going to look at coagulation and then flocculation; Destabilizing the particles forming flocs and then sedimentation. Filtration is next (refer Fig.1), I am going to filter the particles out, that is pretty straight forward.

And what is the primary purpose? We are always trying to remove the different size of suspended solids. Why cannot I remove the sedimentation and directly have filtration? It will choke your filter, maintenance can be high, head loss will be high, we will discuss this in this in today's session. Let us get this started. Filtration; Typically, when we think of filter we will think of this size and if my particle is bigger than this then it is going to be trapped.

This is like the plan view; I am trying to say that this is the pore size or such and this is my particle (refer Fig.1). But that is not the only way how filtration occurs here, let us look at it.

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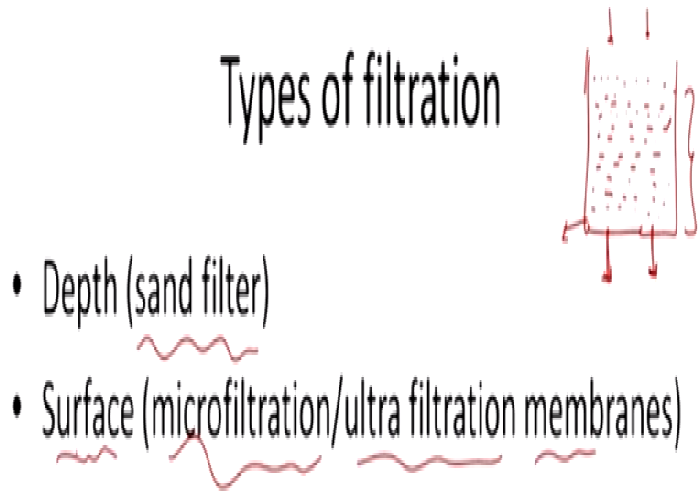

Fig.2

What are we trying to do? We are trying to remove suspended particles so that the turbidity is what we want. Turbidity was supposed to be less than 1 at least in Indian conditions. Depth or sand filter; We have a sand filter, so water comes in (refer Fig.2), you have sand of relatively different diameter depending upon whether it is slow sand or rapid sand filter.

We will go back to that so water comes in and particles are filtered out and then water leaves the system (refer Fig.2), typically depending upon where you have your water collection system here. Depth of the sand filter, that is what we have here; The filtration occurs over the depth and then surface where we use the micro filtration and ultra-filtration membranes.

I think when we looked at the graph that illustrated the different sizes of particles, we looked at the different kinds of filtration mechanisms that can achieve the removal of those particles. In that context, we looked at these micro-filtration/ ultra-filtration membranes, these are based on filtration at the surface. We will look at this.

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Particle removal size with respective to different filtration techniques

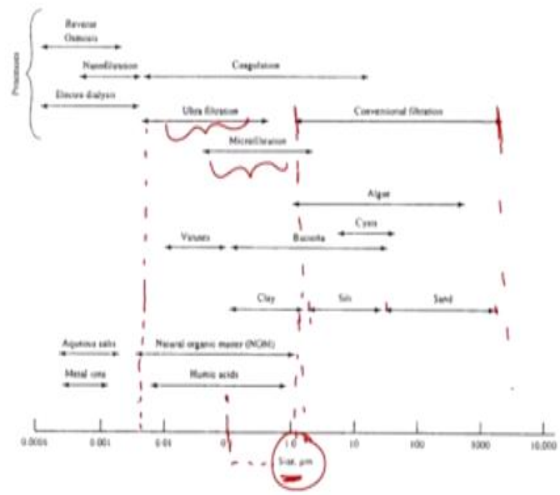

Fig.3

This is the graph (refer Fig.3) that I was looking at, so we have sand we have silt. We are looking at conventional filtration for now, I can capture some bacteria, silt and sand. And depending upon adsorption may be some of the other particles too will be removed. For example, NOM absorbed onto sand or at least some particles of clay can be removed.

But you understand the size, in general though, but depending upon the type of filtration, you will be able to achieve until 0.1. But usually just above one that is good enough cut off for conventional filtration. 1 micrometer is the typical cut off though you will have some removal of particles between 0.l and 1, in general you can think of 1 as cut off.

And 1 micrometer size particles are usually the hardest to remove by conventional filtration. We will come back to this aspect. And now as you see if I want to remove smaller particles I need to look at micro filtration or ultra-filtration and this is what we talked about. When we say surface filtration, it is based on the type of the mechanism.

You have a membrane and most of the filtration occurs on surface or pores which are not very deep. But with respect to the filtration using sand, the filtration occurs across the depth so that is why we say it as depth filtration, that is something to keep in mind.

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Fig.4

Filtration mechanism, typically as we mentioned one can think of it as of it is straining. My pore size is this big and my particle is this big and so the particle will not fit through the pore size and it will be filtered out (refer Fig.4), that is straining. That is but one mechanism of how particles are removed, we looked at the different mechanisms.

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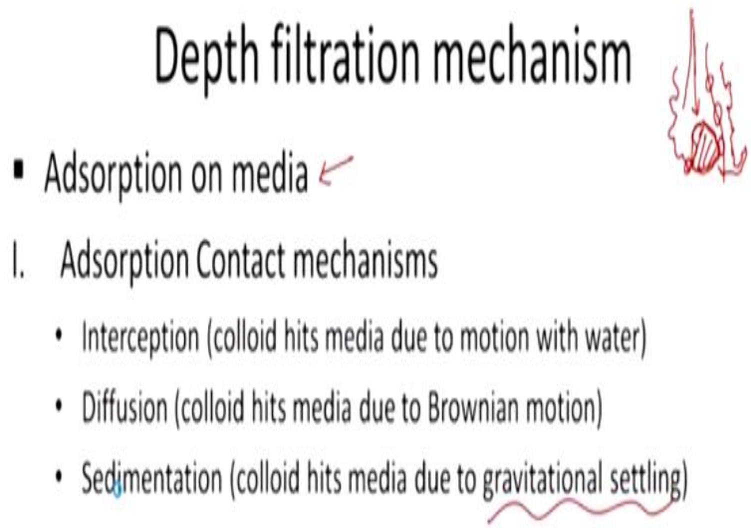

Fig.5

Depth filtration mechanism, as can be seen we are going to look at adsorption (refer Fig.5) onto the media and adsorption contact mechanisms; It can be by interception- colloids hits the media due to motion of water. My particle is out here and the water particle is flowing near the relevant media, this is my media (refer top right drawing on Fig.5) and then the colloid that is coming along with the relevant water will be intercepted- “Interception”.

And in diffusion you have the thermal energy, due to which the particles having their Brownian motion and they can end up absorbing onto the media. And this is how my particle can also be adsorbed on to the media. And sedimentation as in if the particle is going through it’s way,

but because of the weight of the colloid or the relevant particle, it is going to come down and it is going to undergo sedimentation due to gravitational settling. Sedimentation also can occur but this is within the filter. Interception, diffusion and sedimentation. we will look at these aspects but these are the primary aspects other than straining.

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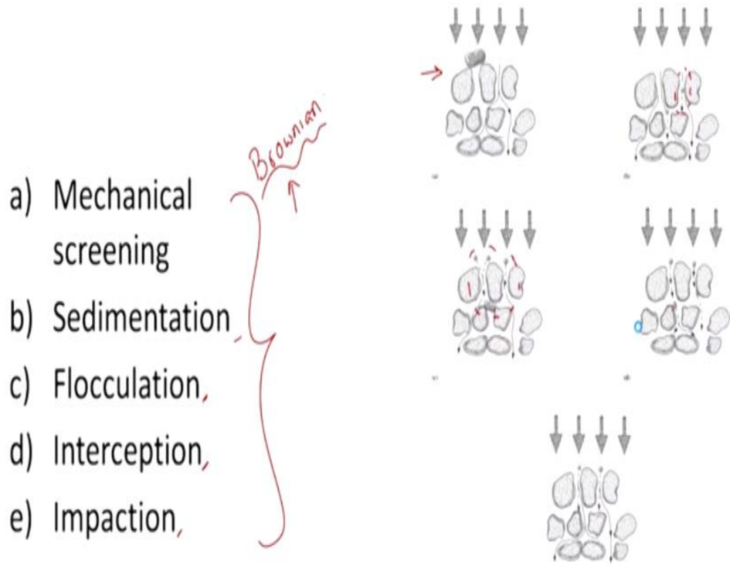

Fig.6

Here we have a decent figure from “Water and waste water engineering by Davis McKenzie” where you can see the relevant mechanisms being illustrated. We have mechanical screening (refer figure a) on Fig.6), they screen out as the particle size is bigger than the pore size. And then you have sedimentation (refer figure b) on Fig.6), instead of the particle taking this flow path,

the settling velocity in this case is such that it will come out here and settle on the relevant particles. You see this sedimentation occurring out here. And flocculation; If these particles have been destabilized by coagulation earlier, flocculation can take place even with in the relevant media. The flocculation is pretty representative here (refer figure c) on Fig.6) but there are different kinds, it is not the only way that flocculation can occur.

But particles can floc together or aggregate because of differential velocities due to either the fluid or the relevant settling velocities and you can end up have flocculation here. And interception; Water is taking the particle nearer to the relevant media (refer figure d) on Fig.6), this is the media, and then you see that you have the interception of the relevant particle on the relevant media.

That is something that you see here. And impaction; Depending upon the velocity and the inertial forces sometimes, and this depends upon the weight of the particles too, They do not change direction with the flow of water but they impact on the media and that is how you are going to have removal of the relevant particle. Mechanical screening, sedimentation, flocculation, interception and impaction, we have covered this.

But as I mentioned earlier Brownian motion too, but that will depend upon the type of motion ideas, this is typically for smaller particles. But we will look at this in detail but this is usually accepted overview of how particles can be removed.

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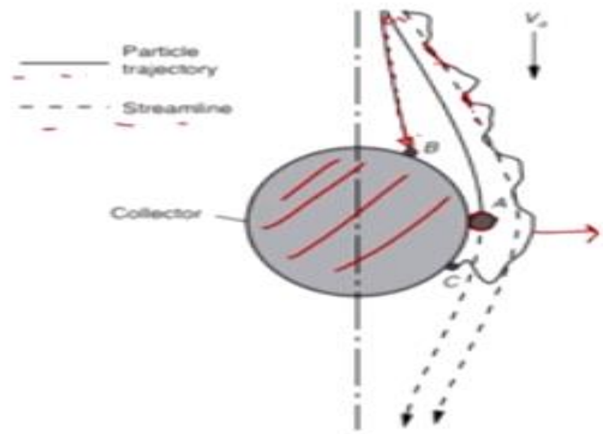

Fig.7

Here we have another mechanism (refer Fig.7) that clearly illustrates what I wanted to mention earlier. What do we have here? You have the particle trajectory and the stream line here. what do I have here? This is the one with respect to Brownian motion, as you can see typical smaller particles in the context of filtration, you are going to have Brownian motion diffusion.

In this random motion, the particles will come and be absorbed by the relevant media and what else? Interception in a way, the water is taking the particle near the relevant media and then it is intercepted. The other one is settling, because of the settling velocity of the particle it is going to take this path rather than path of water out here.

That is with respect to sedimentation, these are the aspects. If you look at it; Interception diffusion and sedimentation. These are the 3 aspects that we mention and depending on how you want to nitpick you have other aspects coming into the picture.

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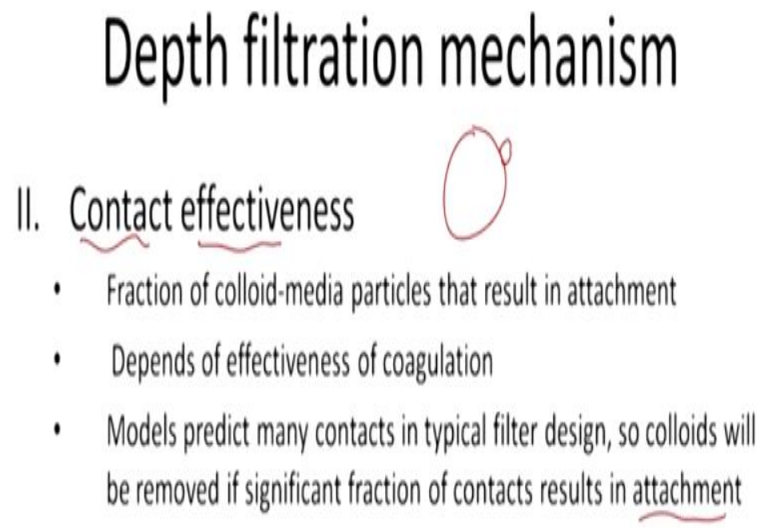

Fig.8

Let me move on, depth filtration mechanism; Now that the particle has been adsorbed that does not mean it is going to be removed, some of these collisions are not going to lead to removal. What am I concerned with? I am concerned with the effectiveness of the contact between the media and the relevant particle.

It is the fraction of colloid media particles interaction that will result in attachment depends on effectiveness of coagulation. If the particles are very stable, we looked at some of the aspects that will prevent particles from being adsorbed to each other, we are not going to that aspect here. Models seems to be predicting that different types of contacts occur in a typical filter design, we will look at the data later.

Colloids will be removed when the significant fraction of these interactions or contacts result in attachment. That is the different thing, it just means that not all interactions or contacts lead to attachment and removal.

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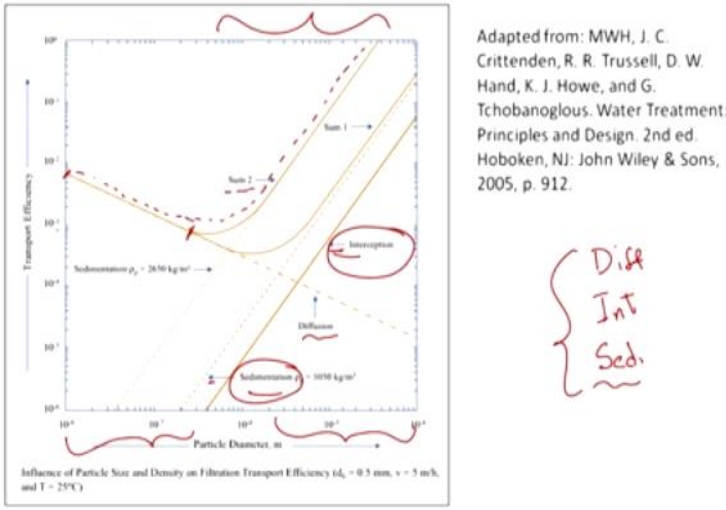

Fig.9

We talked about aspects such as removal by diffusion, removal by interception and removal by sedimentation. Let us see which kind of mechanism predominates at which particle size (refer Fig.8). Here looks like you have transport efficiency and here we have particle diameter. Influence of particle size and density on filtration transport efficiency. What do we have out here?

Here is the sum (refer Fig.8), this is the total if you want to look at sum 2 and as you can see when the particle size is relatively lesser what predominates? Diffusion predominates. And that is what you see in this zone particle size is lesser, then diffusion predominance. And at the relatively higher particle sizes what do you see? You see that you have sedimentation and then interception.

Sum of only these two and sum of all the particles, as you can see initially for very small particles this is the sum with respect to removal efficiency and then later removal efficiency increases and later part of the removal efficiency is due to interception and sedimentation. For bigger particle sizes, diffusion relatively plays a lesser role. You can see that it is a logarithmic scale here, that is something to keep in mind.

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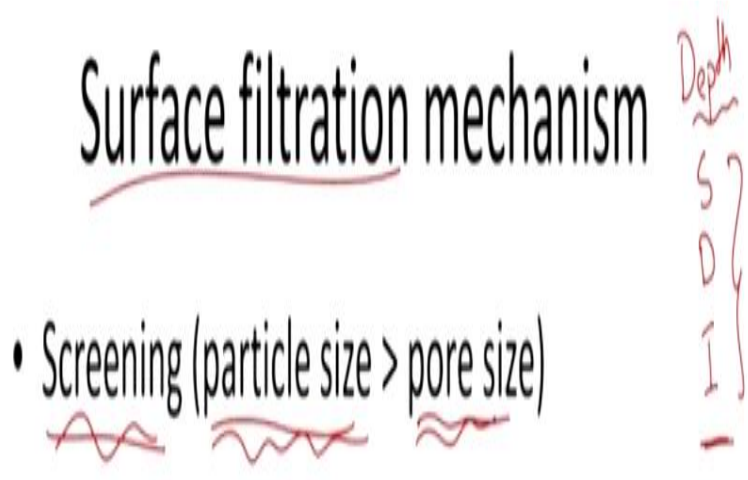

Fig.10

Surface filtration mechanisms; Screening, this is what I mentioned earlier or straining (used a different word), when the particle size is greater than the pore size. Here though I should have pointed this out; We were talking about depth filtration until now. In the context of depth filtration, we looked at sedimentation, we looked at diffusion and we looked at interception.

In general, the principle based mechanisms and if you are looking at other aspects, we also looked at the other 5 mechanisms which included flocculation and so forth. Here this was with respect to depth filtration but with respect to surface filtration when we have the ultra-filtration or micro-filtration mechanisms or membranes. What is the primary mode? It is screening.

For screening to occur what needs to happen? The particle size has to be bigger than the pore size, that is the primary aspect.

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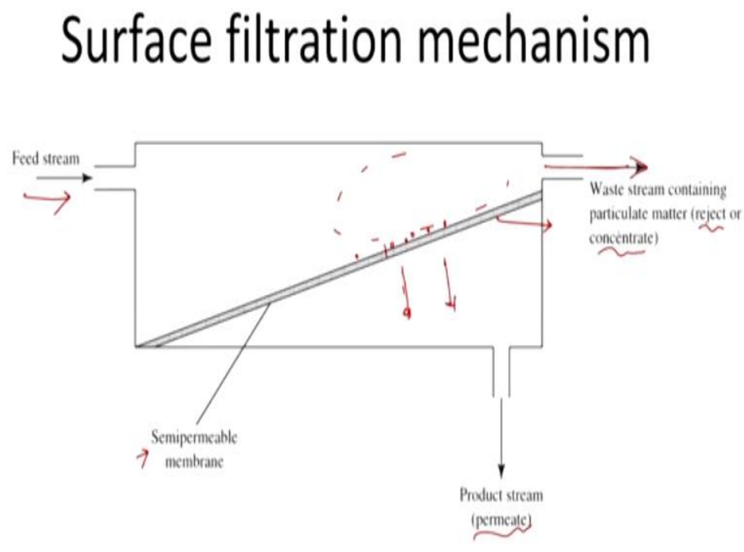

Fig.11

That is what you see, this is the relatively turbid water coming in (refer Fig.11) and here you have the relatively impermeable or semi-permeable membrane, either the ultra or micro filtration membrane. The particles will be removed out here and the water that filters through is called the permeate and this is the reject or concentrate.

Why concentrate? Particles are being removed here and relatively less particles are going through here. And then what is going to happen? The concentration of the particles out here in the water is going to increase, that is why we are calling it reject or concentrate. Waste stream containing particulate matter and this is the treated water that we are looking at.

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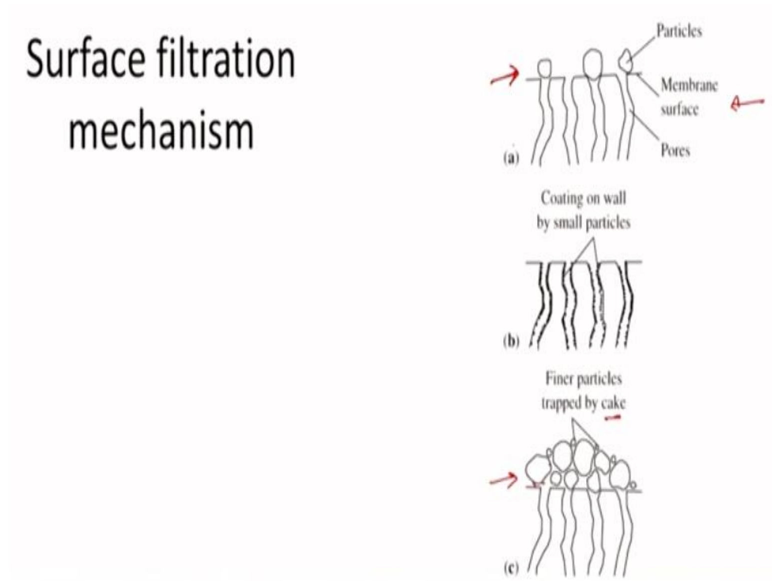

Fig.12

Let us look at in a closer detail. Surface filtration mechanism; Straining or screening, this is the usual way and sometimes you can also have coating on wall by small particles. And another aspect is that after time progresses this straining leads to a case where these finer particles are trapped by the layer here which we are referring to as cake. But in general, as you can see the main aspect is screening, that is something to keep in mind.

As you see the thickness of the membrane is not going to be very high. It is going to be pretty low and that is why we are talking about removal at the surfaces.

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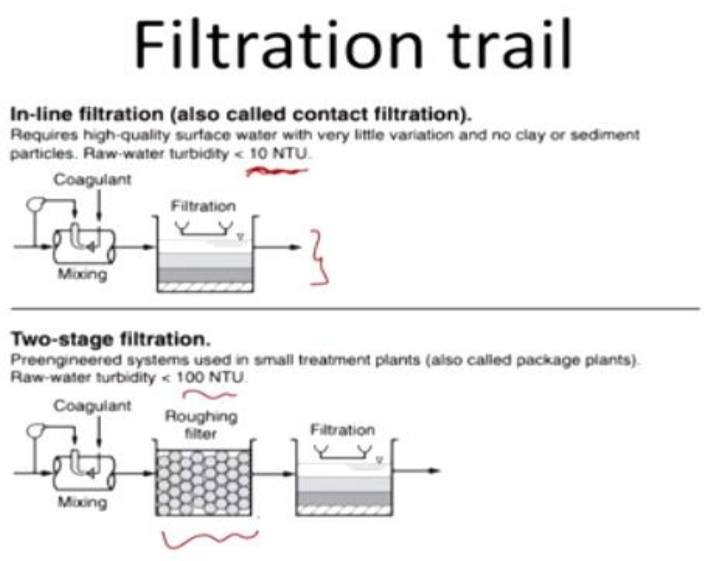

Fig.13

With respect to when or how you will have the unit process of the filtration fit in into the bigger scheme of water treatment plant. We will see what are the ways (refer Fig.13). here is the usual way when the turbidity is high and it will vary. We know that we are going to add a coagulant so that we destabilize it and then we are going to create mixing conditions with respect the G

so that your particles flocculate and then you are letting them to settle down and then I am going to send the water through. Here we have the multiple media filter and the filter water is what we are using, this is the conventional one. But when the water source is that the raw water turbidity is not very high.

It is not very high though and here the case we are looking at is lakes or reservoir where the water is not moving but it is relatively static. And there is the assumption that the turbidity of the water coming is relatively low, we are going to do away with the sedimentation step and after flocculation directly going to have filtration. But one aspect to keep in mind is that, even here if you remove sedimentation what is going to happen?

You have the much bigger particles which will be deposited here or will chock up your relevant filter very quickly. What happens over time? The particles that you are filtering out will be adsorbed there, after sometime you have to clean it what should we refer to as back wash. But if the load of the particles coming in is very high and also even the bigger particles which can be removed have not been removed earlier with the sedimentation step what is going to happen?

You will have to clean this filter pretty often because of the higher head loss. You will have to have some pressure and that pressure or the head difference between what is coming in and what is going out, the head loss will be remarkably high. That is one reason why you will usually have sedimentation prior to filtration, especially if the turbidity is relatively high. And depending on the extent of turbidity or extent of suspended solids,

you are even going to do away with flocculation and just coagulation and then you are going to have filtration, that is something in mind.

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Fig.14

Let us move on to granular media filtration; We are going to talk about the media here.

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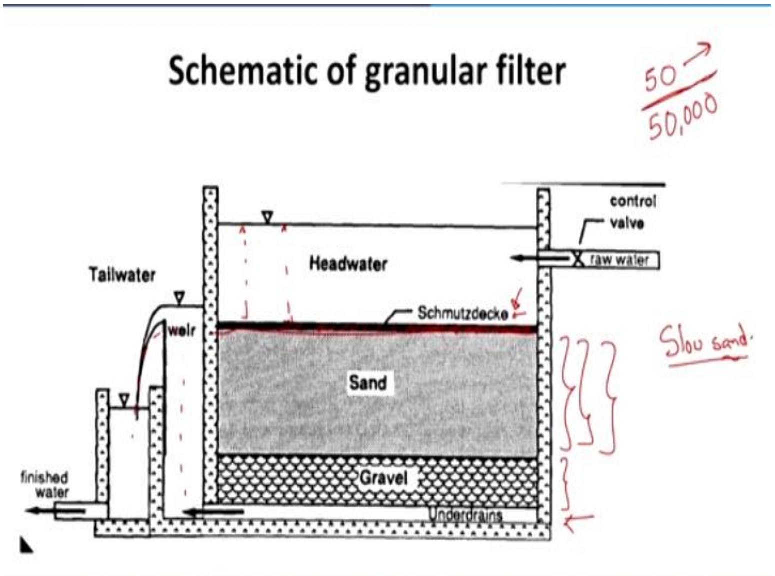

Fig.15

In granular media, we have the sand typically sand and then underlying layer of gravel, you cannot have only sand and you have the standing water (refer Fig.15). You can see the water coming in and the head of water over the filter, this is what you see. And then you see that the water will filter through it and come out here.

You have the filtered media and you have the under drains here, this this kind of system is typically called a slow sand filter. Schmutzdecke, what I am referring to? What happens is over time this particular layer will be formed at the top of the sand layer. Here what is happening?

You have water with high organic content either natural or due to human origins (organic content), whenever there is organic matter, you know that the microbes want to grow. You will have this mixture of microbes, organic content and this cake being called which you are going to refer as Schmutzdecke. You will even have degradation of some of the organics and you will have removal by straining.

In this kind of slow sand filter, mostly the removal is by straining at the top layer and not by removal across the depth of the sand layer. But keep in mind that is probably one of the reasons why you it will be a slow sand filter where the rate of filtration is going to be relatively low. And also, that is why rarely do people use slow sand filters. But you will have removal across the depth but usually it is more on the top by straining.

And how is it people clean it? People clean it by either replacing or scraping of this layer from time to time, that is something to keep in mind. But very rarely used; The MIT courseware says 50 out of 50,000 filtration units in the U.S are slow sand filters, that is something to keep in mind. But what is the principle here? you have media and then you are going to have layer developing over the top due to the screening action and this layer will also have microbes developing there.

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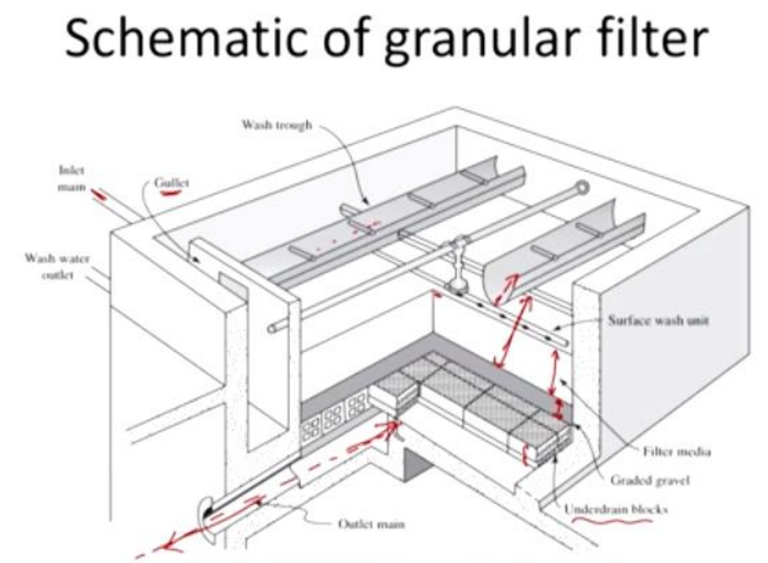

Fig.16

You can even have slow sand filters like this (refer Fig.16). But we are moving into the zone of rapid sand filters. This is the picture (refer Fig.16) that will give us an idea about what we are looking at. Water is coming in and you see the gullet and you have next the filter media.

And then the graded gravel and after this the treated water has to be collected and that is done through these under drain blocks. That is what you see out here and that water flows out through this main and these are the main aspects we have covered. But over time, head loss across the filter is going to increase.

You have particles taking up the pores spaces, the pores size decreases so over time a lot of head is required to take the water through and if it pressured filtration, much more pressure is required. Think of this what have to flow through this filter, you can think of energy being lost or more energy is being required so head is being lost.

What do we do? People see to it that they backwash it, they pump water in the reverse direction backwash. And then you are going to see to it that this particular filter is suspended and then you are going to pump water out until these adsorbed particles are going to be removed and your filter media is relatively clean, that is what you see. And once you do that you have these washed rows.

This is where the waste water will be collected because earlier this is the filter but after you pump water in the reverse direction the bed is going to expand. And then this high turbidity water because you are washing your filter is going to be collected in this washed rose.

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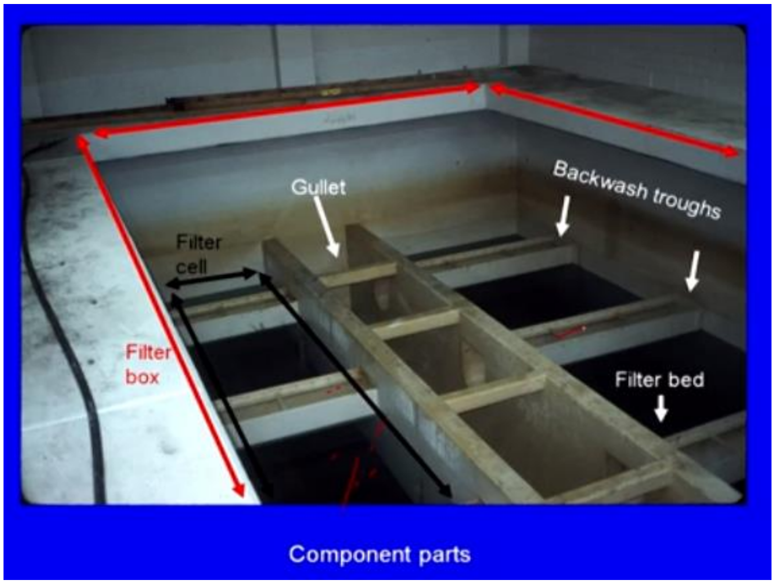

Fig.17

I think we have a better picture here (refer Fig.17) this is what you have actual one. You have the filter box mentioned out here. This is the gullet and this is the filter cell. I think you can see the filter cell out here in the filter bed. And then backwash troughs, when it is pumped up this will expand. You can see that it is expanded or the bed is expanding now. Earlier water is coming in this direction, bed is in this thickness during backwash I am pumping it up so bad is going to expand.

And then that water during backwash will go through this backwashed troughs, so that is something that you can see, we will come back to more pictures later.

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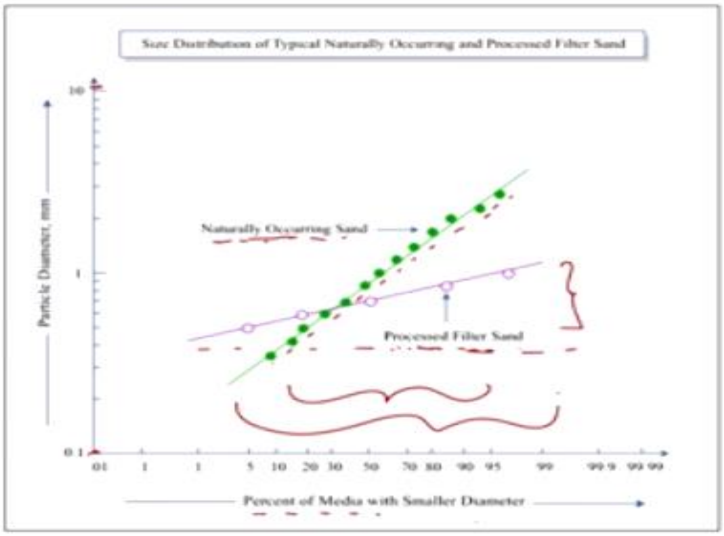

Fig.18

We were talking about sand or the media and in general in slow sand filter, you can use naturally occurring sand. And in the rapid sand filters or such where the rate of filtration is going to be relatively higher you will typically use process filter sand. And what is the aspect that you can notice? You can see the naturally occurring sand (refer Fig.18), keep in mind this y-axis where you have the particle diameter is at logarithmic scale.

And you see that the particle diameter includes variable considerable range of particle diameters for naturally occurring sand. But processed and filtered sand you see that it is relatively more uniform, that is something that you can see and that is something to keep in mind. And also, here it is percentage of media with smaller diameter (x-axis), here it is relatively less (for naturally occurring sand).

And here the range is relatively more with respect to process sand filter. That is something to keep in mind.

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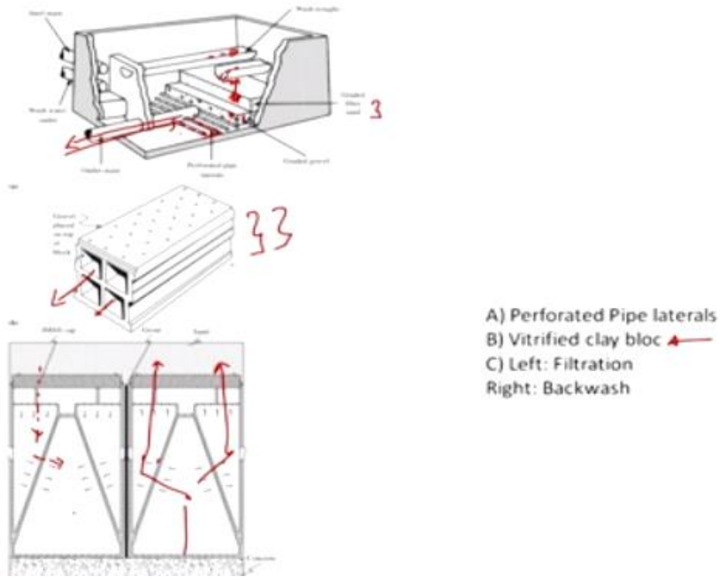

Fig.19

Different pictures out here this is something that we already looked at (refer Fig.19); Washed rouse inlet, main. And you see this graded gravel, filter sand and then perforated pipes because the water will then pass through these perforated pipes and go through the outlet during backwash in the reverse direction and this is going to lead to an expansion in your filter bed.

And then that water will be removed through these washed drops. And here at the bottom what do we see? Here we have perforated pipes, you can also have had vitrified clay blocs, gravel placed on top of block, this is what they will look like. And here you see the vitrified blocs through which you water is going to be collected here. And here you have something called an IMS cap, integrated media system.

Here you see during filtration, the water will flow this way (refer Fig.19) and then this way and then this collected water, this is the side view, this is the suction, it will be collected here. During the backwash though, I am going to pump the water into this and then it is going to clean this and move up through here, that is what happens. Different kinds of water collection mechanisms here; Perforated pipe, vitrified clay bloc and then the IMS cap.

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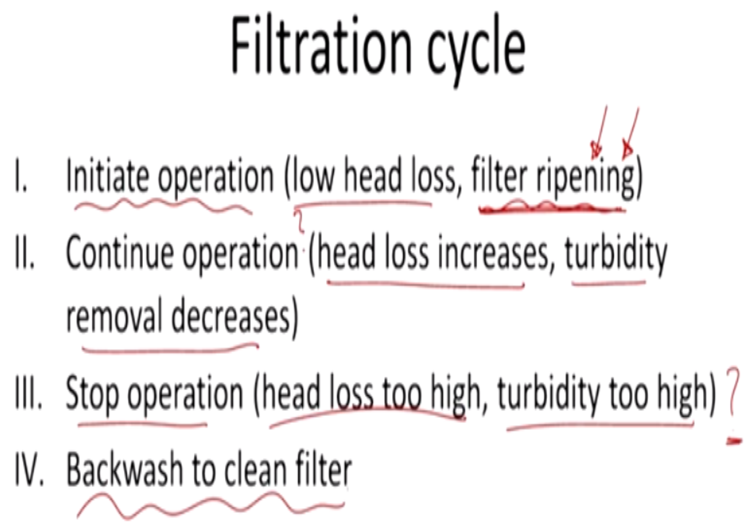

Fig.20

Filtration cycle; How is it that going to occur let us just look at that. First, I have to initiate operation. Because the filter is clean there is relatively less out there that will block my particles or rather water, there will be relatively low head loss. And during this time filter will start to ripen, why do we say ripen? We have a figure later in general; Fruit, raw and ripe fruit.

Ripe fruit is what you would prefer we will also see why filter ripening is what you want. I think looking at the figure will understand this. During this time, the performance efficiency of the filter will increase, why is that? You have the particles coming in with the water, they are going to take up the pore spaces and then you can have either flocculation or pore cells getting smaller.

That will lead to in effect relatively better filtration, so filter ripening. After filtering ripening, you will continue operation, but for how long will you continue this operation? The head loss will increase over time and the pores will be relatively smaller and this will lead to increased head loss over time.

And also, second thing is over time the performance efficiency of your filter will also decrease so the turbidity in your outlet will also keep increasing. You look at 2 factors when determining until now long is it you want to run the filter. You will look at time it takes for your unacceptably level high level of head loss to be achieved or time it takes for unacceptably high level of effluent turbidity to be reached.

That is what we look at; Head loss increases during the period and turbidity removal decreases, when am I going to stop operation? When the head loss is unacceptably high or turbidity is too high. We will choose this smaller of the two and then after this I cannot throw the filter out or media out what am I going to do? I am going to backwash to a clean filter.

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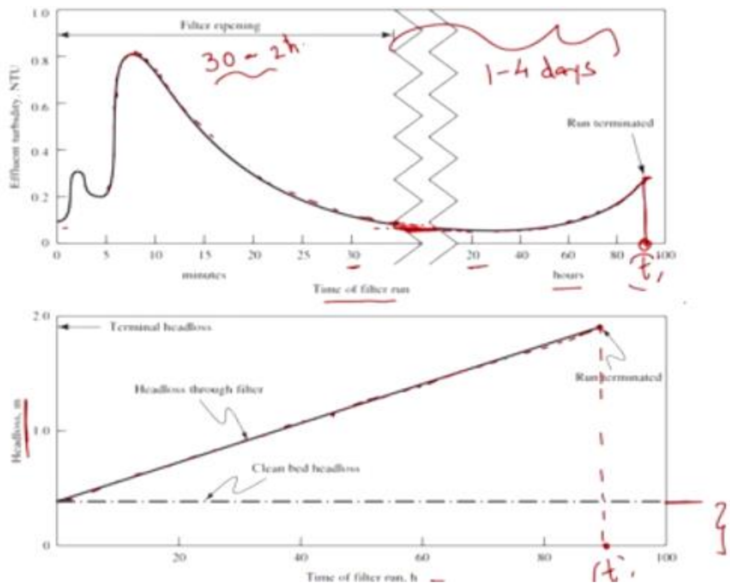

Fig.21

Hopefully I have this, what do we have here? We have 2 graphs (refer Fig.21) effluent turbidity on the y-axis and on x-axis, time in hours of filter run out here. In general, filter ripening takes 30 minutes to maybe 2 hours typically. And here what do you see? Effluent turbidity is initially high because of the pore sizes and relevant variation. But during the filter ripening you can see that the filter efficiency increases considerably, this is within the first 30 minutes or 2 hours.

The pores spaces are being taken up and you have more efficient filtration, after this 2 hour over time it runs pretty well. Here you see that efficiency pretty good, the effluent turbidity is relatively low. What happens after certain time though? Now your relevant turbidity starts increasing.

And then you are going to stop it. Time for this particular aspect can be noted and in general this period between ripening to run termination can be between 1 to 4 days. Simultaneously what will happen as your filter is being choked. Here time of filter run on the x-axis and on the y-axis head loss. What is happening? Head loss is increasing and increasing. With clean bed this is the head loss, with clean bed to you will always have head loss but not much depending on the uniformity coefficient.

Head loss through the filter is going to keep on increasing and at a particular time it is unacceptably high. I am going to stop it, so this is one particular time. I will look at which time is smaller and then choose that time to back wash it. It depends upon, if it is too hard you will also peel off and will also set up a regular back washing cycles but that has to look at the conditions on the site.

With that I will end today’s session and in the next session we will look at the relevant aspect of head loss, how do I design the relevant aspects. As usual thanking you for your patience, I end this session.