Water and Waste Water Treatment
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Module No # 09
Lecture No # 43
Design of sand Filter and Surface Filtration

Hello everyone, welcome back to the latest lecture session. We are still looking at filtration and, in this session, we will wrap up filtration. Filtration- we are trying to remove suspended particles but of relatively smaller sizes, than those that will be removed during sedimentation. Let us look at what we have understood from the previous session?

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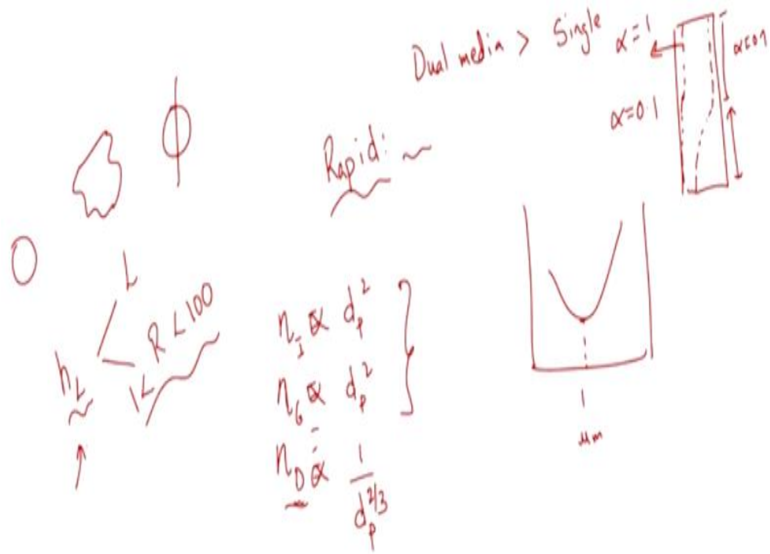

Fig 1

We know dual media filters, we looked at the relevant graph for this. Dual media filters in general do better than single media filters. We looked at the relevant profile if you remember and without chemical treatment this was the profile (refer Fig.1), this was the case when alpha was equal to 0.1 without chemical treatment or without coagulant addition upstream. And until this I think it was anthracite and here it was sand.

And with chemical treatment we saw that the efficiency was something like this; Dual media better than single. And in general, for rapid filtration, you want to add coagulant this was the case with alpha was equal to one or when we had chemical treatment upstream. And also from the relevant graphs we saw that the removal efficiency will be relatively less and the particle size is 1 micron.

Removal efficiency is lowest when particle size is around 1 micron and with respect to attachment efficiency, we looked at different aspects- One due to inertia, one due to gravity and one due to diffusion. And we looked at how it is depending upon the diameter of the particle and that these 2 factors are the principal mechanism for removal for bigger particles.

And with respect to diffusion, it is for the smaller particles. This is something we looked at. And we saw that head loss will increase over time of operation and for head loss depending upon whether it was laminar or for Forchheimer’s flow, Reynolds number being between 1 to 100, we have different equations. And also, within that we have equations for spherical particles and for non-spherical particles.

And for that to take in to account, we also have the shape factor. These where the aspects we looked at in the last session and we were about to look at the design aspect with respect to the head loss.

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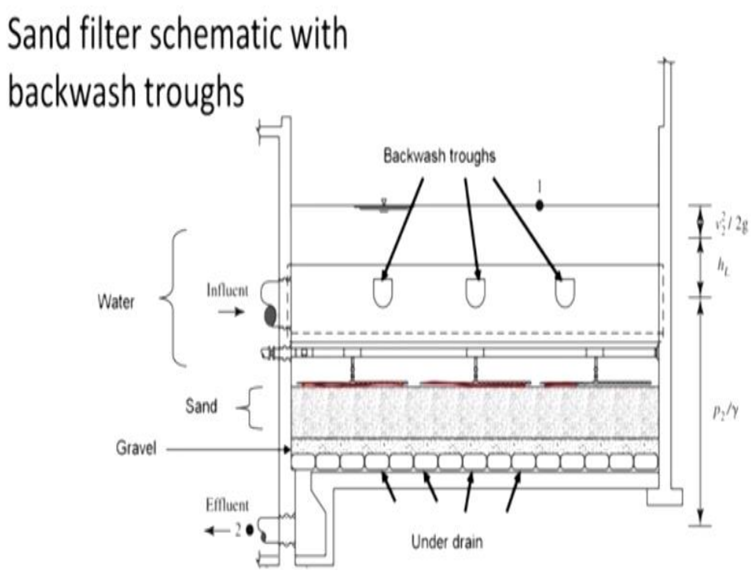

Fig 2

We looked at this aspect and we have the total head here (refer Fig.2), under drain and here we have the surface arms when you want additional level of mixing during backwash.

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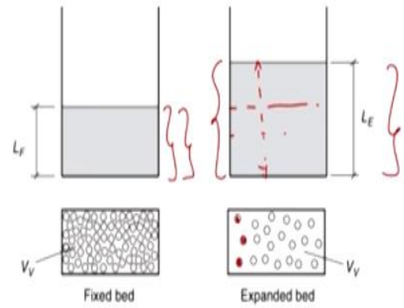

Fixed and expanded beds during backwashing of rapid filters. During filtration, the media grains are touching each other, but when media are fluidized during backwashing, the void volume increases, causing an overall expansion of the bed.

Fig 3

Fluidized bed and expanded bed, well this should not be a figure (refer Fig.3) that is should use because of considering what I am going to discuss later. But in general, you understand what is happening? Within this same volume, relatively lesser particles will be present why? Now the total volume has increased or the total height has increased but one aspect to keep in mind is that the volume of the solid

Or the media particles within this volume and within the total volume are still the same (refer Fig.3). The porosity of the bed is increasing here, porosity of the bed is relatively less here, as you can see porosity of this expanded bed is now higher. But the volumes of the solids itself, total volume of solids over the entire bed here and over the bed here still the same.

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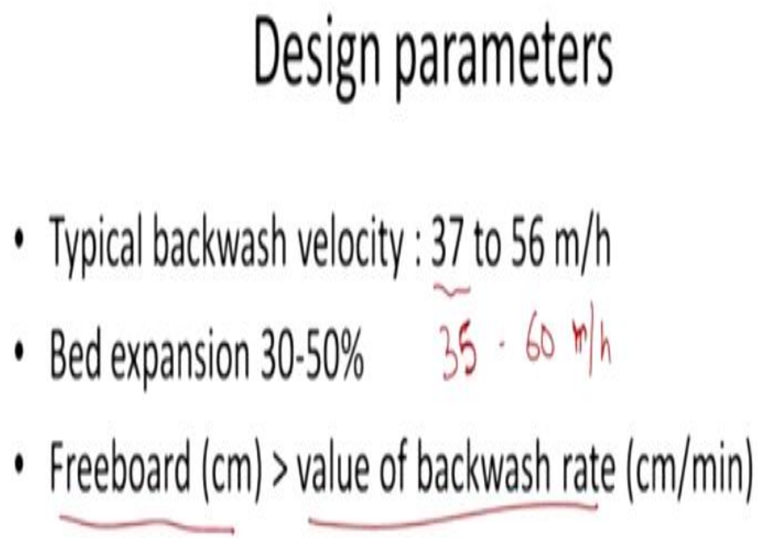

Fig 4

We will look at why that is relevant and we also looked at the backwash velocity. If the backwash velocity is higher than this settling velocity of the particle then this media, here I am talking about media, the media will be removed. I do not want this to happen that has to be taken into account. Backwash velocity must be high enough to give good expansion.

10 to 25 % depending on how dirty is the water coming in you can even have higher bed expansion or such. Design parameters; Typical velocities 35 to 60 meters per hour, you can get an understanding of what we are talking about. And if you remember we also looked at relatively lower filtration rates earlier. Bed expansion is 30% or so.

In general thumb rule, the value of the freeboard in centimeter should be greater than value of the backwash rate. that is something to keep in mind.

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Relationship between backwash velocity and bed expansion

- Volume of solids does not change when bed is expanded
  - $V_{solids} = V_{solids,\ expanded}$

Fig 5

Between backwash and bed expansion, there is going to be a relationship which we are going to use later. Let us look at what it is. This is what I was trying to say earlier (refer Fig.5). The total volume of the solids does not change. Now the total volume of the bed has increased but the volume of the solids within this total bed is still the same, that is something to keep in mind. Volume of solids before expansion is equal to volume of solids after expansion; Total volume.

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Relationship between backwash velocity and bed expansion

- If there is a constant expanded bed porosity (ε_e)
  - $(1-\varepsilon)aD = (1-\varepsilon_e)aD_e$
  - $D_e = (1-\varepsilon)D/(1-\varepsilon_e)$
- If the expanded bed is stratified with different porosity in each layer, a weighted average value can be substituted
  - $D_e = (1-\varepsilon)D\Sigma(f_i/(1-\varepsilon_{e,i}))$
  - f_i = mass fraction in ith layer
    - *D_e = depth of the expanded bed, m*
    - *ε = porosity of the bed* ε_e
    - *D =depth the unexpanded bed, m*
    - *f =mass fraction of filter media with expanded porosity*

Fig 6

Assuming that there is a constant expanded bed porosity, which is not always the case but for the purpose of understanding. This is

$$(1-\varepsilon)aD = (1-\varepsilon_e)aD_e$$

This is the depth before expansion and this is the depth of the expanded bed during backwash (refer Fig.6).

That is what it will be equal to. This will give me an idea about the volume of the relevant solid particles or the media. If I play around, I can get the depth of the expanded bed. If it is not only one layer but there are different layers with different porosities then the weighted average with respect to the porosities and the fractions will have to be taken into account. If it is not only one bed and there are stratified beds with respect to or if the expanded bed

Then the relevant weighted, this is the weight and this is the average, is that we have to take. let us move on f is the mass fraction the i_{th} layer at depth of the expanded bed, porosity of the bed and this is porosity of the expanded bed. Depth of the unexpanded bed, mass fraction of filter media with expanded porosity, different aspects that you can consider. But in general, for our understanding this is good enough. Surface area; Plan view or top view.

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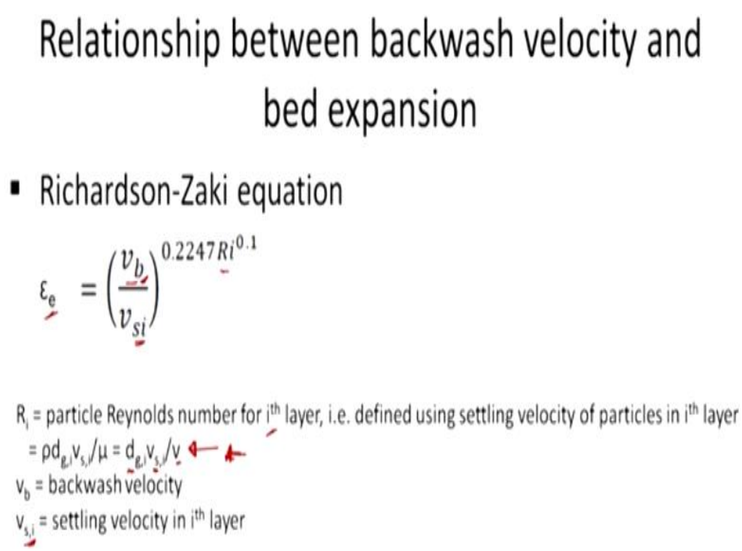

Fig 7

What is the equation that we will use too be able to look at the backwash velocity and try to relate it to our expanded bed porosities? It is the Richardson-Zaki equation and here it is dependent upon the particle Reynolds number for the i_{th} layer and it is also dependent upon the settling velocity of the relevant particles, that is what we have here, settling velocity of the particles here.

And this is backwash velocity and this is the settling velocity as we just have that there and typically people at least in India, my TA tells me that they have questions based on these particular aspects in some of the exams. And this is the kinematic viscosity and this is the diameter or the geometric mean base diameter of the relevant particle, that is something to keep in mind.

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Fig 8

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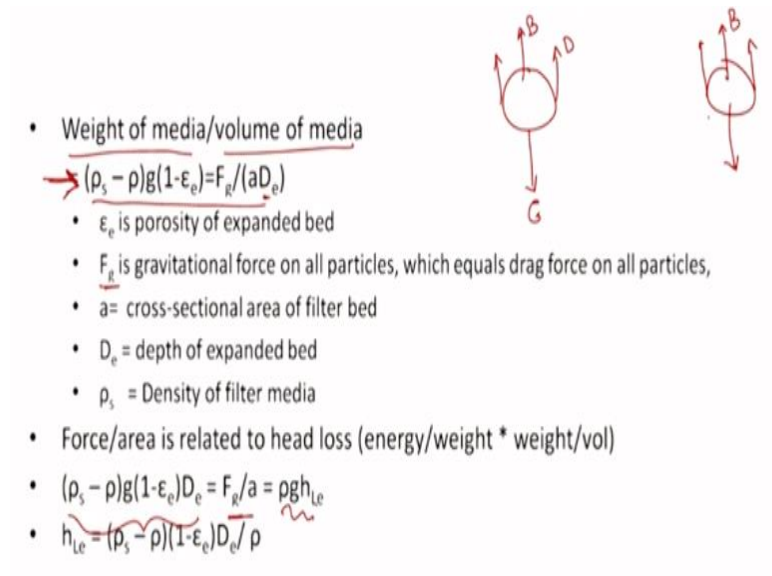

Fig 9

Head loss calculation; We have a numeric coming up, before that we are going to look at analyzing the system. I am going to look at weight of the media per volume of the media (refer Fig.9). And that is going to give me this particular equation. Where is this coming from? We know that earlier, when we were looking at sedimentation, we saw that there is gravity, there is buoyancy and then due to friction force, there is drag.

This was during sedimentation. This is gravity and drag and buoyancy. Even now it is going to be the same or gravity is always going to be there and buoyancy too. But here the particle is not moving down or at least the drag is due to the water moving past it. From that you can get the relevant equation, that is where you will get this equation from, that is why we have f_g is the gravitational force on all particles which is equal to the drag force on all particles, that is the assumption here.

Force per area is related to the head loss, so from this equation if I take the De out to the left hand side, depth of the expanded bed, so I will have this force per area and that can be related to the head loss here. And from that I am getting the equation for head loss. From that I am getting the equation for the head loss during that particular backwash.

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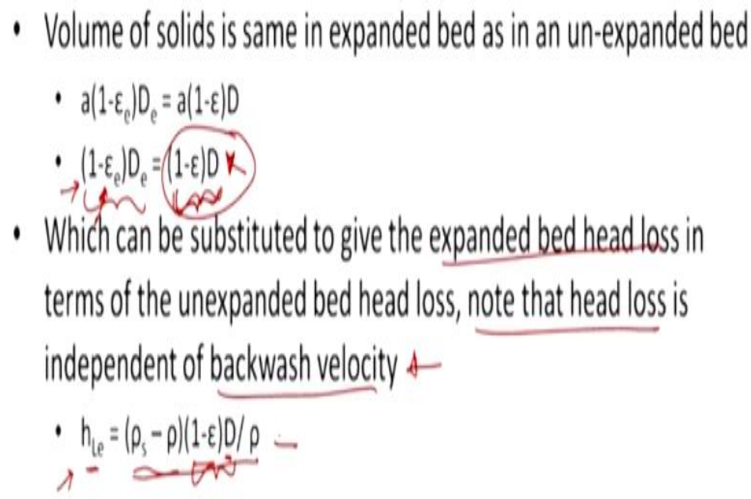

Fig 10

And here I have the porosity of the expanded bed but I know how to place that where the porosity of the bed in general, so we have this equation (refer Fig.10). And I know that this particular set can be replaced by this. This is during expanded bed when I am looking at backwash, this is the usual case when filtration is taking place. And this is relatively easier to measure when compared to this, so though we have some assumption.

As you can see more or less, I am concerned with this particular set of variables which I can measure easily. Now I can get the head loss here. Head loss during expansion. Expanded bed head loss in terms of the unexpanded bed head loss, note that the head loss is the independent of the back wash velocity. One other aspect seems to be that, as can be seen here, it is independent of the backwash velocity.

Density of the particles and the relevant water, porosity and the depth of the bed. These are the relevant aspects but not the backwash velocity.

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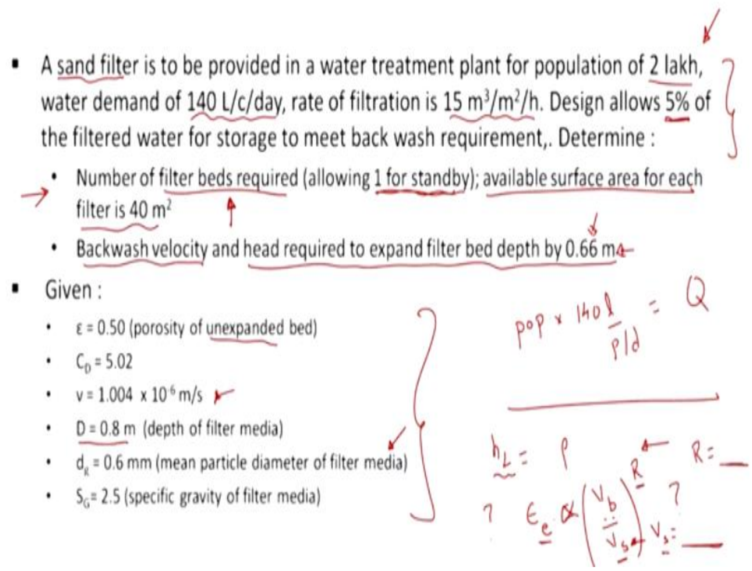

Fig 11

Let us look at a numerical here to better understand the relevant aspects and the applications. We have a sand filter and we are trying to cater to 2 lakhs population and they consume water at 140 liter per day per person. Rate of filtration is also given and looks like we need 5% of the filtered water for storage to meet the backwash requirement. Here I should have been clearer, 5% of the water consumed per day, we need it for backwash.

And we are going to have to calculate the number of filter beds and one for standby assuming that the once that you are going to design will need maintenance from time to time. And what is the information that we have? From the relevant aspects I can calculate the total surface area. They say that the surface area per bed per filter is 40 meters square. Accordingly we can calculate the number of filter beds, so that is relatively straight forward and what is the backwash velocity?

And what is the head required to expand filter bed depth by an additional 0.66 meters. I want to know the backwash velocity and also the head required in a sense the energy required to expand the filter bed depth by an additional of 0.66 meters. What is given? The porosity of the unexpanded, keep in mind that this is the unexpanded bed. And coefficient of drag, kinematic, depth; This is the depth of the unexpanded bed.

And we want to expand it by 0.66 meters during backwash, the diameter (geometric mean) and specific gravity. This is the information we have, before we dig further let us look at the approach we are going to take. First aspect is we have the population and we know we have the relevant consumption per day; 140 liters per person per day. From this I will be able to calculate the flow rate Q.

And depending upon the need for backwash volume and we talked about per day so we know we need to look at 5% additionally. And I also have the over flow rate filtration here, rate of filtration, from that it is relatively straight forward, simple calculations here and there and we will be able to come up with the area here for the filter beds. First let us get that done. Our backwash velocity and also

Head required for expanding the bed will be nothing will the head loss for that particular expanded filter bed depth. We have an equation where it is depended upon the relevant densities, this is relatively straight forward. But with respect to backwash velocity, how are we going to do that? For this I think we have formulas that give us the relationship between the porosity of the expanded bed to velocity of the backwash by the Stoke's or the inverse of it, raised to some function of some Reynolds number.

It is not exact to this but this is something like this if I am not wrong. And from this you can calculate the backwash velocity but what do we need for that? For that we need Reynolds number. For Reynolds number we have relevant info and I think we have the kinematic viscosity and we have the diameter. And I think we should be able to get that done. But for that too we also need to have the Stoke's velocity and this Stoke's velocity, we will have to calculate first.

With that we can get this Stoke's velocity which is needed here and also get the Reynolds number. But how do we get this porosity of the expanded bed, what is the approach there?

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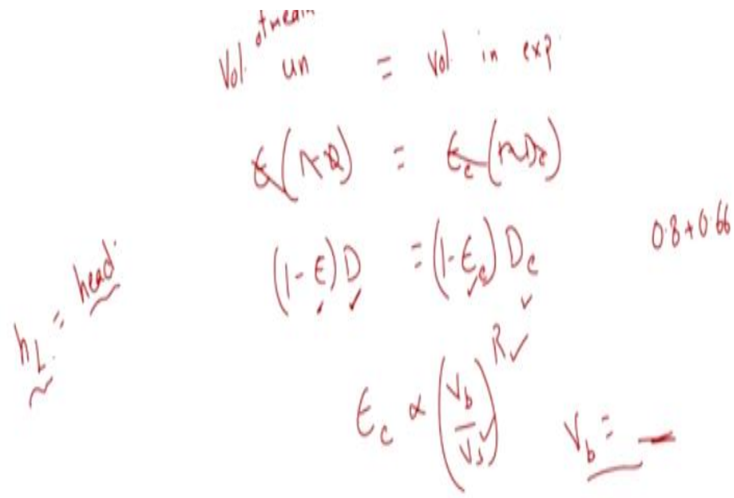

Fig 12

And I think for that the approach was that we looked at the volume of the media in the unexpanded bed. And that will be equal to the volume of the media in the expanded bed. From that we have the relationship and we have this casting out the surface area. I think we have something like this (refer Fig.12) and D is the depth.

I cancelled out the surface area here and we are just looking at the volume of the media or the support. Here I have the relevant depth of the unexpanded bed and I also have the depth of the expanded bed, that it is 0.8 + 0.66.

From this I can get the porosity of the expanded bed, so once I get this porosity of the expanded bed I can plug it into this equation. And I calculated Reynolds number, I calculated the Stoke's velocity of settling and then I will be able to get the backwash velocity. With that that I will be done, but in general here obvious assumptions are that we are assuming that the head loss will be equal to the heads that is exactly required but that will not be case.

In general, you will require slightly higher head or energy. We have looked at the approach. Let us go forth and finish this up.

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- Total water demand = $140 \times 10^{-3} \times 2{,}00{,}000 = 28000\ m^3/day$; $1167\ m^3/h$
- Backwash water requirement = 5% of total water filtered per day
- Total water to be filtered per day = $(1.05 \times 28000)\ m^3/day$; $29400\ m^3/day$

  $= 1225\ m^3/h$
- Rate of filtration (given) = $15\ m^3/m^2/h = Q/As$?
- Total filtration area required = $1225\ (m^3/h)\ /15\ (m^3/m^2/h) = 81.67\ m^2$ $40\ m^2$
- Available surface area of one filter bed (given) = $40\ m^2$ $2+1=3$
- Total filter beds required = $81.67\ (m^2)/40(m^2) \sim (2+1) = 3$

Fig 13

Total demand- We have the per capita and total population, so I get the flow rate required. Backwash requirement is 5% so we are increasing it by 5%, 1167, 1225 (refer Fig.13). In general, if there are any calculation error you can look at them. And rate of filtration is already given and I have this flow rate volume per time.

And here I have the rate of filtration so Q/ As will give me the rate of filtration and I need the surface area. Surface area required for total filtration or the total surface area required will be 81.67-meter squares. But the question motioned that it is per bed, we are limited to 40 meters square. It will require 2 beds and 1 additional should be equal to a total of 3 beds, one is for the redundancy.

In case something breaks down. We have 40 meters square. And from that approximately 3 beds required. Now let us move on to the other aspects.

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$h_L =$

$V_b =$

- S_G (specific gravity of filter media) = 2.5 ; ρ_s / ρ_w
- ρ_w = 997 kg/m^3 (density of water)
- ρ_s = 997 kg/m^3 x 2.5 = 2492.5 kg/m^3

- Head loss:
  - $h_{Le} = \{(\rho_s - \rho_w)(1\text{-}\varepsilon)D\} / \rho_w$
  - $h_{Le} = \{(2492.5\text{-}997)(1\text{-}0.50)(0.8)\}/997$
  - **h_{Le} = 0.6 m**

Fig 14

We were asked to calculate head loss and the back wash velocity, how to go about it? Specific gravity is given, density of water, specific gravity is the density with respect to reference. The reference is water, the density of water is given. The density of the relevant media or the solid particle can be calculated. Specific gravity gives us the references or the density with respect to reference which in this case is water. What is the head loss?

We already looked at this equation, at least in this course as I mentioned earlier too you do not need to mug up such equations. Mass balance, you have to understand that and apply that. We have all the relevant variables. And we can just plug them in- Density of the particle, porosity of the unexpanded bed, depth of the unexpanded bed and density of the water. We plug that in, so head loss is going to be 0.6 meters.

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- Settling velocity (Stokes law); $v_s = \sqrt{\dfrac{4(S_G - 1)gd_g}{3C_D}}$
- v_s = 0.048 m/s
- Re (particle Reynold number)= $d_R v_s / v$

$= (0.6 \times 10^{-3}) \times (0.048) / 1.004 \times 10^{-6}$

$= 28.68$

$R_e \quad V_s$

R

$\epsilon_e \propto \left(\dfrac{V_b}{V_s}\right)$

Fig 15

What else do we have? Stoke’s velocity, we have the relevant equation and this is specific gravity, diameter, co-efficient of drag and from that, looks like you can calculate the relevant settling velocity. And Reynolds number, so we have the diameter, kinematic viscosity or the viscosity and the Stoke’s velocity. And from that you are able to calculate the Reynolds number.

Its Forchheimer flow as expected so we calculated the Reynold’s number we calculated the Stoke’s velocity. And now we have to calculate the porosity of the expanded bed before we can put that into this equation or similar equation (refer Fig.15) to be able to calculate the backwash velocity. Let us see how we can calculate the porosity of the expanded bed.

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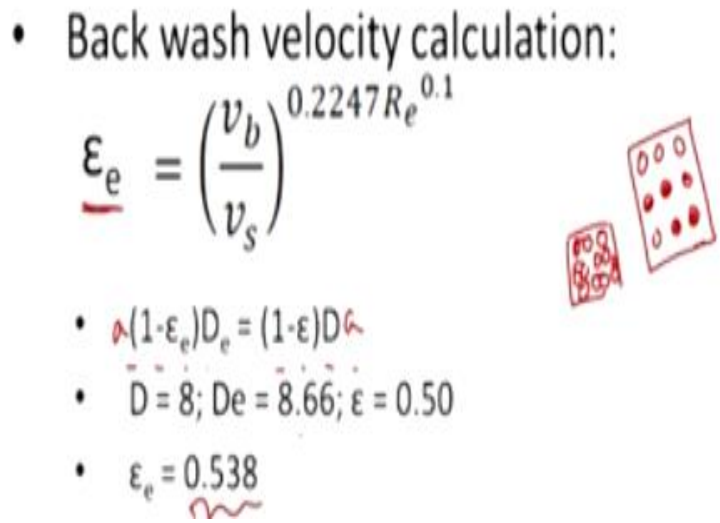

Fig 16

That we will go by looking at the media so, this is the equation (refer Fig.16) that we have and for that I need this porosity of the expanded bed. But because I know that this is the case, volume of the media of expanded and unexpanded is going to be the same. The total bed, earlier it was closely packed and now during backwash it expanded, the total volume expanded. But the volume of the media itself, the media which I am highlighting here is still the same.

That is why it is $(1 - \varepsilon)$, so area cancel out and you see that I can calculate the porosity of the expanded bed given the other variables. And porosity of the expanded bed is supposed to be 0.53.

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- $v_b = (\varepsilon_e)^{0.2247Re^{0.1}} \times v_s$
  - $v_b = 0.39\ m/s$

Fig 17

I plug this into the relevant equation and we get the back wash velocity to be 0.39 meters per second.

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Surface filtration

Fig 18

And with that we are done with the major aspect, so until now we have looked at filtration. Let us just quickly sum it up as in with respect to our drinking water treatment plant, what have we done? We looked at screens, that is fine and then we looked at coagulation and flocculation, why? We wanted to destabilize the particles and that we achieved by coagulation, adding a coagulant.

And then we have flocculation bringing flocs together or aggregating the particles and thus forming flocs, which are heavier. And then we had sedimentation and then you will still have some suspended matter and that you are going to remove by filtration. And this filtration, you have to backwash from time to time to clean the relevant bed or media, that is something we have done.

But there is a different kind of filtration which we are going to refer to as surface filtration, this we referred to as depth filtration. What is the surface filtration about and how is that we are going to achieve it?

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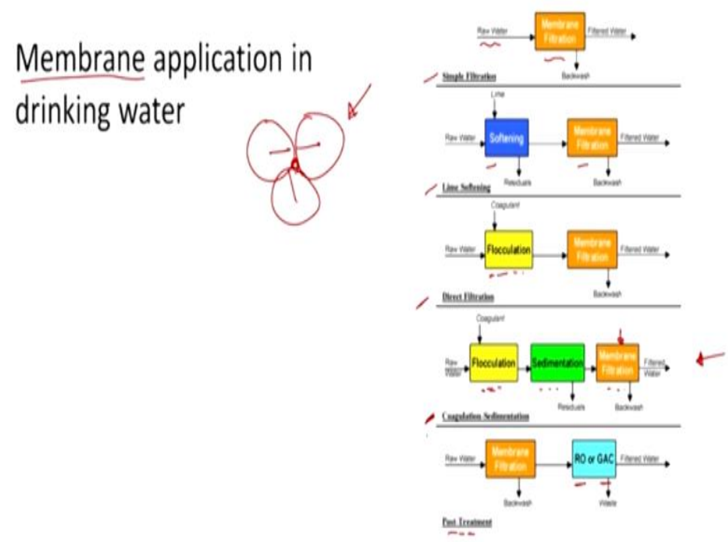

Fig 19

Here we are going to use membranes, earlier we had media. The media we expected is to be spherical, that is the assumption, so this is the space through which it will go through and there is a way to calculate this, based on this diameter what is this opening going to be. We looked at the relevant applications with respect to depth filtration.

Here we are talking about membrane, so here we have either organic, inorganic materials that act as the relevant membrane or that make up the membrane, we look at that. Depending upon the raw water quality, you can directly have membrane filtration. But sometimes you have look at softening before membrane filtration depending on the relevant quality of the water.

You are trying to increase the size so if you can remove it. You are going to have less load on your membrane filtration, life will be higher. If required you will add a coagulant and then allow for flocculation, bigger particles and then membrane filtration. If the load is too high and you have considerably big particles, you are going to first have coagulation, flocculation and sedimentation and then membrane filtration, in India certainly this is what we need.

But typically, I do not think in India we have a lot of membrane filtration based full scale water treatment plants. One more thing is raw water, here it is post treatment membrane filtration before it goes to RO or granular activated carbon. Simple filtration, lime softening, direct filtration and coagulation sedimentation. Nothing to mug up but just to understand.

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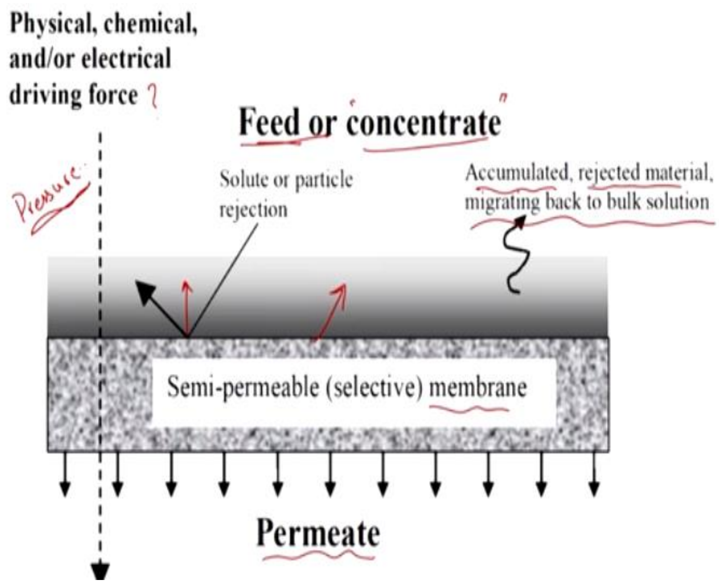

Fig 20

But when we are talking about membrane, what is it that is going to drive this particular system or the water and what happens here? For example, in depth filtration we had media of sand and we had water at considerable head, that head is driving the relevant water through. And you have head loss both due to the clean bed and also due to the ripening bed. And we looked at this aspect. Here you are going to put in driving force, what is the driving force?

It can be physical, chemical or electrical but here we are going to have pressure. The pressure is the driving force here, so what do we have here? Just some terms to keep in mind; Feed water which is raw water that comes through or that comes in contact with this semi-permeable membrane. And you have the particles typically based on the size being rejected, you have going to have rejection. And the water that comes through which we are going to use for our own purposes is permeate.

Feed and permeate and this particular particle is rejected, so the concentration in this particular reject or such will be relatively high. It can then be called concentrate or as you can see it is accumulated and the rejected material is migrating back into the solution that is why we call it as concentrate. Feed, permeate and concentrate, these are the things to keep in mind and what is driving the system? It is the pressure.

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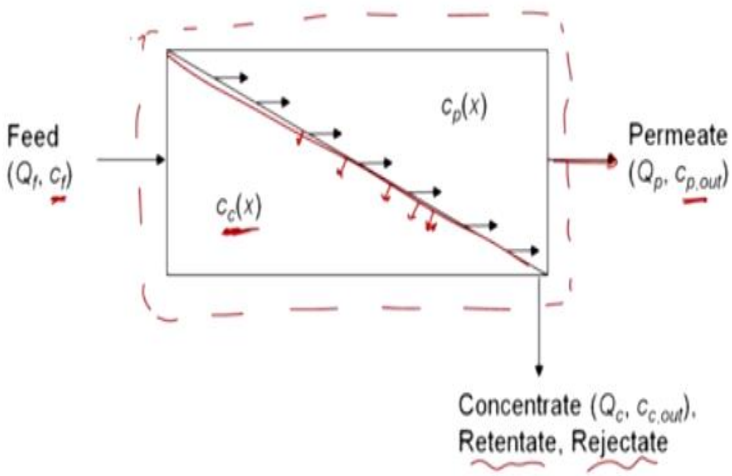

Fig 21

Let us move forth, so here I have the feed and here is my membrane here (refer Fig.21) the concentration is too high something that I would not want. And after passing through the membrane, I have the permeate and Cp,out the concentration is lesser than this concentration of the feed. And because some of the suspended particles are being rejected here,

The concentration of the particles will increase and that will come into the concentrate or it is called retentate or rejectate. If somebody ask for a mass balance, I will not look at internal aspects I will apply the mass balance all around this to be able to conduct the relevant analysis. That is something to keep in mind.

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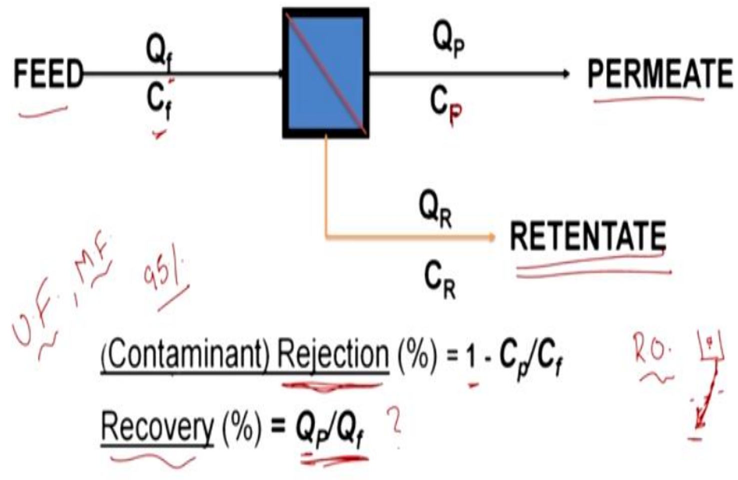

Fig 22

That is the representation if I am looking at mass balance, this is what I can look at. Feed, permeate and retentate, rejectate or concentrate. Here we have some terms, percentage rejection. 1 - C_p / C_f, contaminant rejection, what is the rejection percentage. And what is the recovery? Q permeate by Q feed, why is this important? For example, in homes you would have seen your RO systems.

RO is not relevant here, but it is slightly similar anyway it is also a kind of membrane but based on reverse osmosis. You would have seen that from your RO based system, you would have drain pipe to your relevant sink, while here you fill up your water so what is this? This is that reject or retentate which is high in concentration. For RO, this amount or the flow rate of the rejected as a percentage of the feed is very high.

Or the recovery for RO is less but in the case of the filtration, when we talk about filtration we are talking about micro-filtration and ultra-filtration. Recovery is reasonable around 95% or 90% that is something to keep in mind. But you are going to have rejection and then we are going to talk about the recovery with respect to water, rejection with respect to the contaminate, these are some terms to keep in mind.

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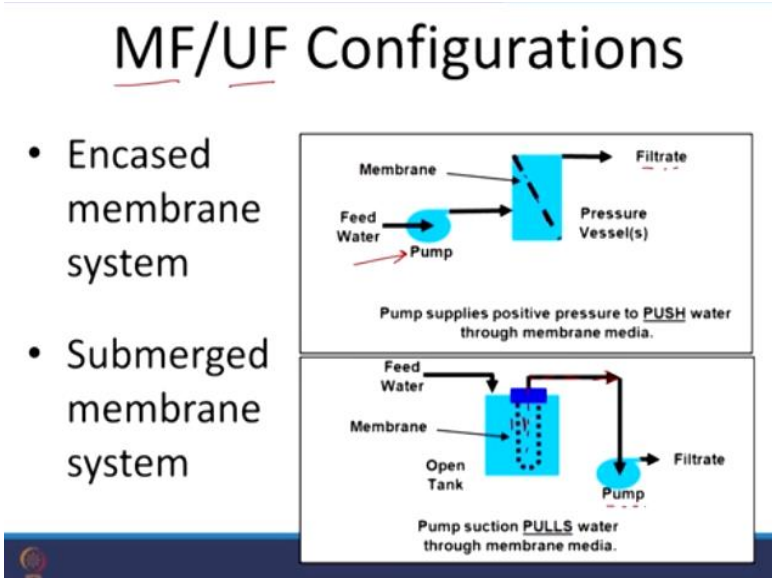

Fig 23

What are some configurations of this micro-filtration and ultra-filtration? I need pressure to pump the water through or to push the water through this particular membrane. I can have water pump and pressure is created in this way and here it is at the atmospheric pressure in general or I can have feed water here and membrane relevant tank and with vacuum or suction, I am going to pump this out here.

Pump suction pulls the water through the media that is why you are again going to have a difference in pressure between here and here, Trans-membrane pressure. That is something to keep in mind, just some generic configurations.

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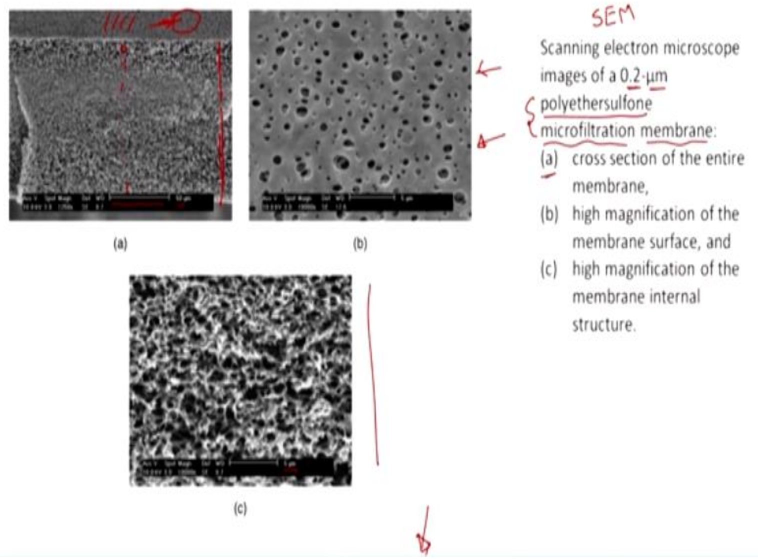

Fig 24

From Crittenden et al, we have some great figures of different membranes (refer Fig.24), so let us look at what we have. First this is based on some scanning electron microscope images of 0.2 micron, keep that in mind. And look at the kind of membrane we have. It is polyethersulfone micro filtration membrane. That is something to keep in mind and first one is cross section of the membrane, if I cut the membrane how does it look like.

You see that there are pores, lot of pores so for suspended particle of size greater than or even equal to this particle pores size, it is going to be pretty difficult to go through here. You see the relevant pores or the relevant structure and magnification of the membrane surface at the top of this surface. This is the surface and we are looking at it here, this particular part and this is the cross section.

Please note that this indicates the thickness- 50 microns, so you can understand the thickness that we are talking about. Let us move forth, so here you can see the pore size and the particles are going to come here. Particles meaning suspended particles in the water and you have pores of different sizes but you understand how it is looking in the cross section. They are going to be removed by filtration. Here the primary mechanism is straining or screening.

With respect to depth filtration, we looked at various aspects; Sedimentation, flocculation. But here it is usually only screening or straining, so we looked at the cross section here in greater detail and the surface. You are talking about exclusion based on the relevant size here.

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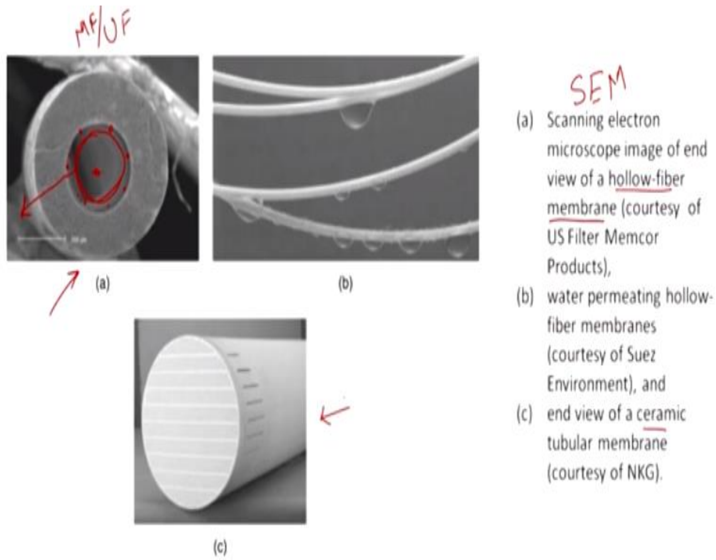

Fig 25

Let us move on and here we are looking at this particular membrane here, earlier we cut this and looked at it. These are SEM images, hollow membrane here but let us look at that. SEM image of hollow fiber membrane usually used for micro-filtration and ultra-filtration. And water permeating hollow membrane, as in what happens is you have different kinds, water will go through here, go through the screen through this particular hollow portion here.

And then the particle is going to be filtered out here and the water will permeate through. That is one way for it to go out through. The permeate will be here, the particles are going to be removed or filtered at this particular surface. That is one way and different one; Ceramic tubular membrane, different kinds of membrane but I just wanted to show that.

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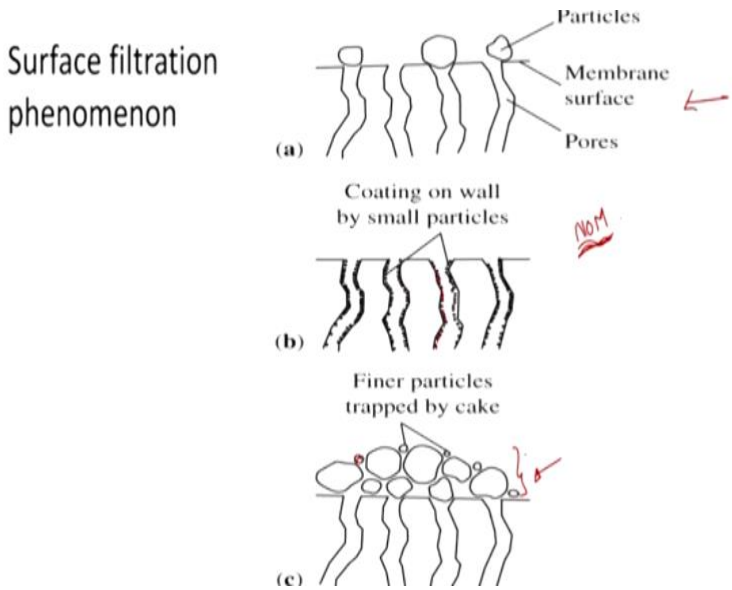

Fig 26

What is the phenomenon? As mentioned, this is the most usual one, you saw the pores sizes, particle bigger than the pores size will be strained out but you also have particles that are relatively smaller than the pores sizes. And depending on the type of particle or type of material, for example if it is NOM, natural organic matter, that will be adsorbed on the surface of this particle.

And this will be an issue because it will cause fouling of the membrane. Natural organic matter will lead to fouling of the membrane leading to greater and greater pressures being required for the same flow that has to be achieved. And sometimes you will also have finer particle being trapped by cake but you will keep back washing the membranes usually. That is one aspect but this is one possible mechanism.

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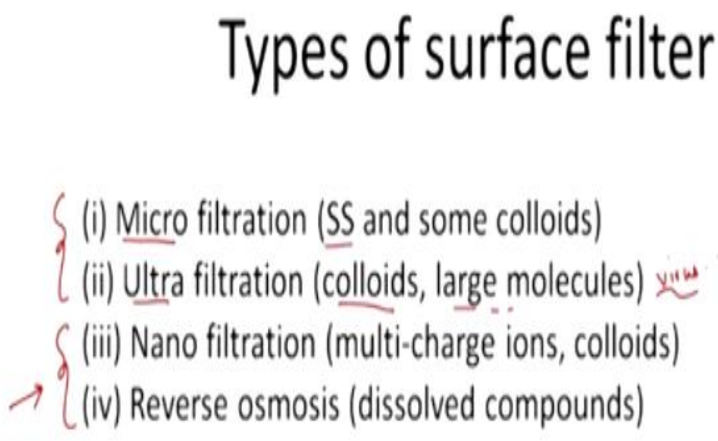

Fig 27

Types of surface filtration, when we talk about surface filters, we have 2 categories here; Micro and ultra-filtration and nano and reverse osmosis. These we do not refer to has filtration even though we have nano-filtration there, when we talk about filtration, we are talking about micro and ultra-filtration. Micro-filtration, typically suspended solids and ultrafiltration typically colloids and even some molecules.

But most of the bacteria and even some viruses, some not all, can be removed by ultrafiltration, we will look at this in greater detail.

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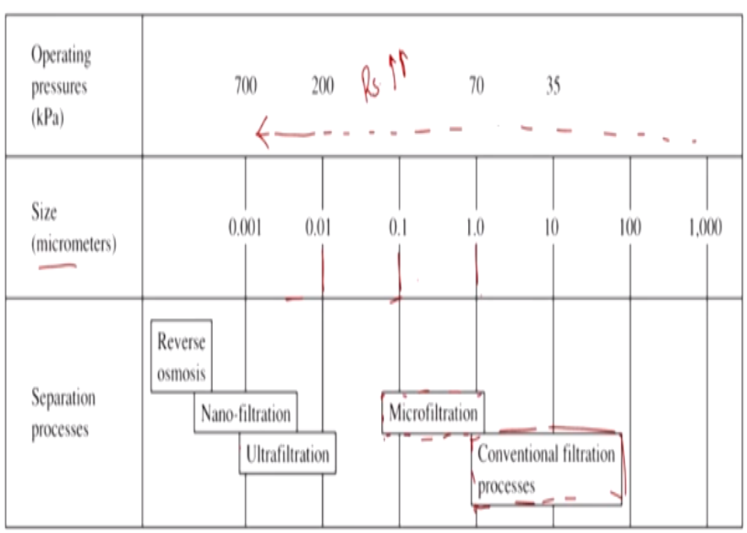

Fig 28

If the pore size is less, size is less, I will have to apply grater pressure for the water to go through that means the cost will also go up, that is one thing to keep in mind. Conventional filtration, well you see not much, but with respect to micro filtration, keep in mind that it is 1 order of magnitude lesser here. Micro filtration here and ultrafiltration and nano filtration considerable overlap.

Only thing is greater pressures but we are looking at smaller and smaller sizes, we are talking about different separation processes.

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	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Pressure (psi)	1-15	10-100	75-150	125-1000
Flux (m^3/m^2-d)	0.40-1.6	0.40-0.80	0.20-0.80	0.30-0.50
Water recovery	94-98%	70-80%	80-85%	40-50% seawater 70 - 85% brackish
Pore size (nm)	80 – 2000	5 – 200 0.9 – 20 (Davis)	1 – 10	0.1 - 1
Typical configuration	hollow fiber	hollow fiber	spiral wound	spiral wound R.O.

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Fig 29

Here are some aspects we need to keep in mind, I will primarily look at micro and ultrafiltration here. Pressure is increasing, why is that? Pore size is decreasing as we go from left to right. In general, the typical configuration is the hollow fiber, the picture for which we looked at earlier, spiral wound is usually used for nano filtration and reverse osmosis. Reverse osmosis, we will talk about this later, so that is something to keep in mind.

Water recovery as we mentioned earlier, for micro filtration pretty good, for ultrafiltration reasonable and even for nano filtration but for reverse osmosis, you see that it is relatively less. That is something to keep in mind. Flux, volume of water going through per meter square of your surface area of the membrane per day. Here it is relatively less and getting lesser and one aspect is we will consider this or look at this later.

If the flux is so less, then how am I going to achieve this level of volume of water treatment within a reasonable plant area, we will come back to that. That might mean that I may need a huge plant area.

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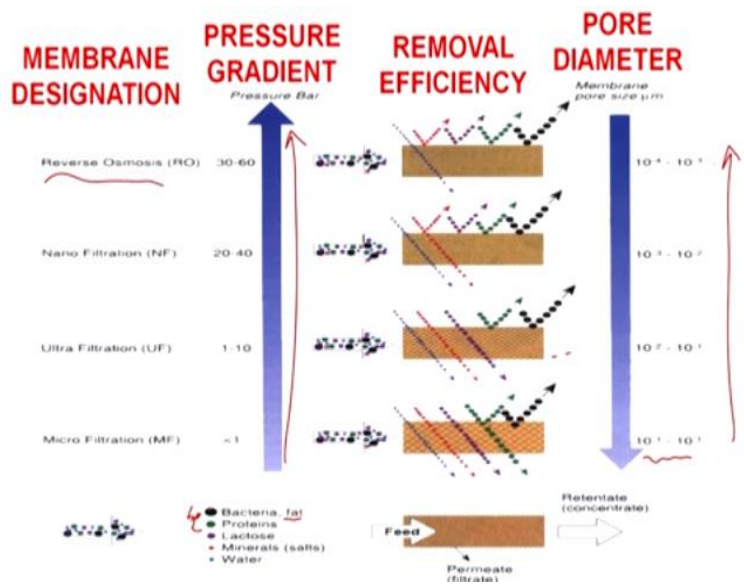

Fig 30

Well, that is not the case, we will look at it later. What are the different kinds of particles that can be removed, we will look at that. But one aspect is as the membrane pore size decreases or let us say, pore size here is highest. As the membrane pore size decreases, the pressure required will increase considerably and then the money too. The cost for reverse osmosis is due to 2 factors; one is the pressure and also because of changing the RO membrane from time to time.

Micro-filtration typically will remove bacteria and bigger particles certainly suspended particles, most of the suspended particles in this range. And ultrafiltration will remove, they are saying proteins. But in general, even some viruses not all will be removed and any bacteria that is left will be removed by ultrafiltration certainly. These are the 2 aspects we are going to be concerned about.

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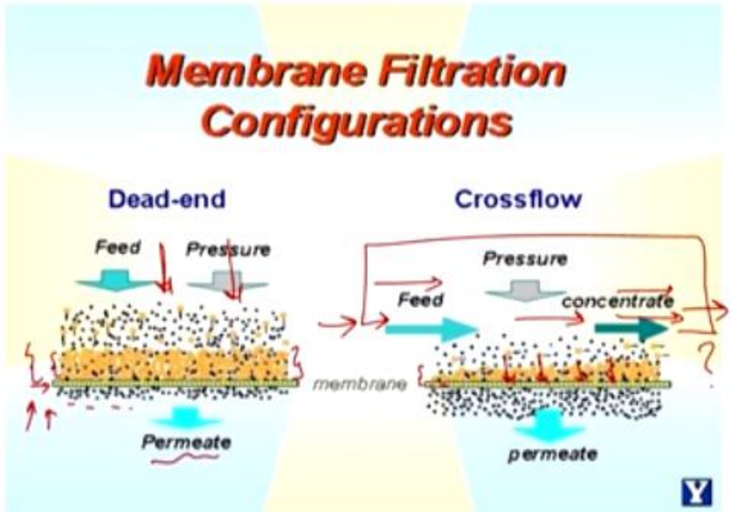

Fig 31

Let us go forth, so membrane configuration. There are 2 kinds of flows (refer Fig.31); One is the water is coming in like this I am also applying the pressure in this way and the permeate is going through here. Only some goes through and lots of particles are trapped here and this is the membrane. The other one is the cross flow, so flow is going through like this and the superficial velocity that is coming towards this.

Flow is going through here but pressure is up being applied in the different direction here. This velocity will be around 10 times lesser than this velocity and you are going to have permeate coming through, why is this (Crossflow) relatively better? Because you do not want to have scaling or cake being developed on the membrane. With this kind of cross flow, you will see that this cake formation is relatively minimized, you can think of it as built-in washing.

But here you are going to have dead end flow, so this cake formation will be greater, so back washing is required often but for the kind of hollow fiber ones that we use, typically at least I have seen or came to know that people look at dead end. Crossflow typically used in RO at least you would have seen this in your homes. That is one thing one aspect to keep in mind and the reason is another aspect to consider is that for this (Crossflow) the removal rate or such is such that you will have to recirculate this water quite a lot.

And it can be as high as 25 or 30% and that for a bigger plant, will be huge volume of water, this recirculation with the water that is coming in. That is something to keep in mind.

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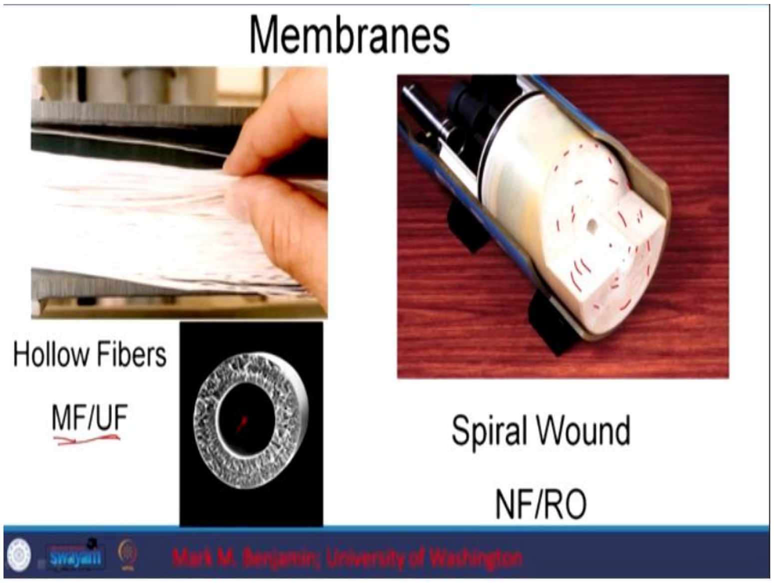

Fig 32

For membrane filters we looked at this; Micro and ultra-filtration, this is hollow fibers this is the usual one and we looked at this; Water is going through into the plane and spiral wound so water is going to flow like this (refer Fig.32), we looked at this and then is going to be collected here. For typically RO, that is what we are going to have.

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Fig 33

Let us move on, so here we have the hollow.

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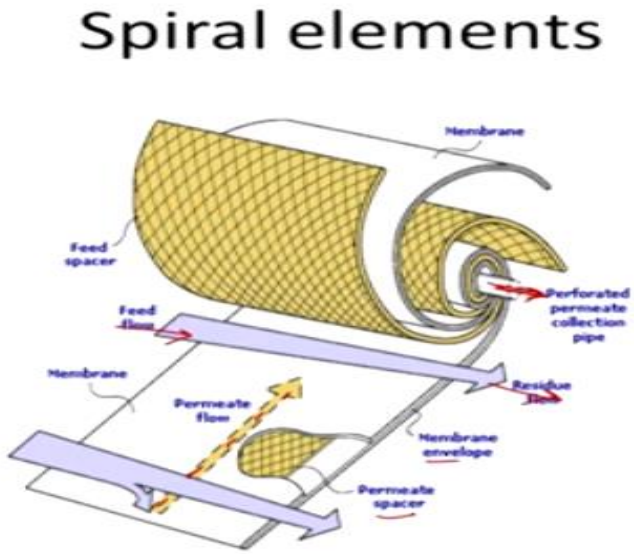

Fig 34

And spiral element, we will talk about this in the RO relevant section but here you can see the relevant flow. Feed flow is coming in, residue is coming out like this and the permeate is going to go through this spiral process and you are going to have the permeate being collected in this perforated central pipes. And you can see the membrane out here and the permeate spacer, membrane and the permeate spacer. We will talk about this in the relevant section for RO.

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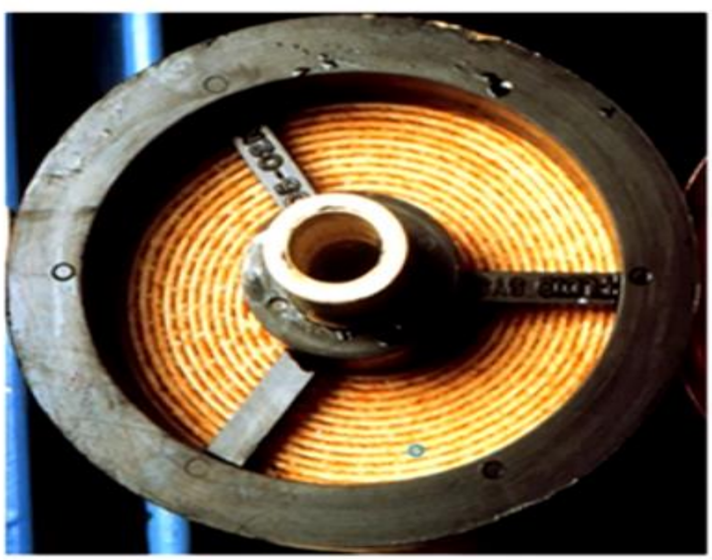

Fig 35

Here you see the relevant figure for spiral but this is for a bigger system.

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Filtration cycle

(a) Backwash to dislodge particles

(b) Sometimes clean with detergents, other agents at lesser frequency

Fig 36

Filtration cycle, you will have to have backwash to dislodge the particles from time to time similar to your depth filtration and sometimes you will add chemical agents depending upon the type of scaling or such that is occurring on your membrane.

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Criteria	Membrane Filtration	Rapid Granular Filtration
Filtration rate (permeate flux)	0.03–0.17 m/h[a] (0.01–0.07 gpm/ft^2)	5–15 m/h[a] (2–6 gpm/ft^2)
Operating pressure	0.2–1 bar (7–34 ft)	0.18–0.3 bar (6–10 ft)
Filtration cycle duration	30–90 min	1–4 d
Backwash cycle duration	1–3 min	10–15 min
Ripening period	None	15–120 min
Recovery	>95 %	>95 %
Filtration mechanism	Straining	Depth filtration

$\frac{m^3/h}{m^2}$

Fig 37

One aspect is we should consider the filtration rate as I mentioned between membrane filtration and rapid granular filtration. Here you see that it is 5-to-15-meter cube per hour per meter square of the relevant bed. But here you see that it is pretty low, 10 times or 100 times lower. How is it that I am able to achieve the level of treatment required while also being able to cater to the needs of this high volume of water?

I cannot have a huge plant, the reason is that you can pack it well enough, the surface area of your particular pad hollow membrane is going to be relatively high. Per unit volume there will be more surface area so that is the relevant aspect here, that is how you are able to achieve feasibility. And pressure you see relatively higher and comparable but relatively lower for rapid granular filtration.

And filtration cycle, we know that it is 1 to 4 days here, you see the order it is relatively less. And ripening period is none here, we know it takes around 2 hours for that ripening to occur so that you have the peak efficiency of filtration. As I mentioned, straining is the major aspects and here it is depth filtration.

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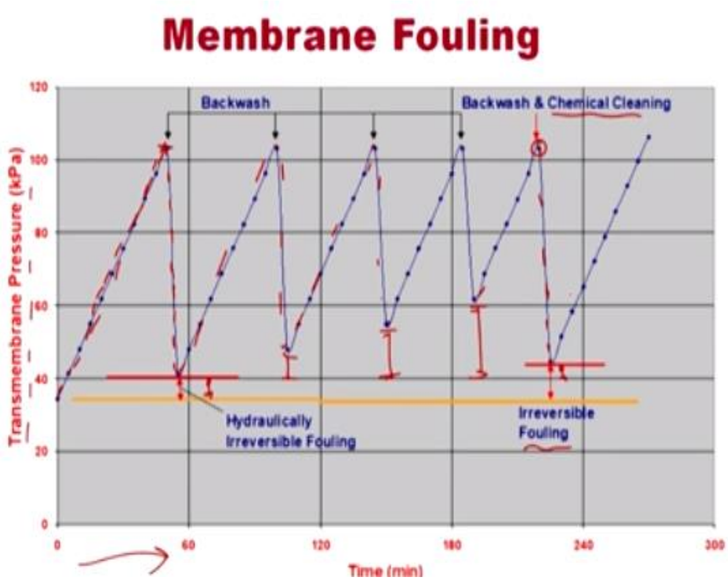

Fig 38

Let us move on, so membrane fouling will occur from time to time, so here is the hydraulically irreversible fouling initially. When fouling reaches this particular aspect or high enough, your trans-membrane pressure, pressure required to pump that particular flux through will be higher that is what it is happening with time. The pressure required to pump that particular water through is increasing. At that point you are going to stop and backwash.

And then the pressure required is going to come down and you are going to have these cycles but slowly but surely you see that your starting point, you are losing that. Even though you backwash, you are never able to come back to this particular or more or less near that particular initial case. And then you are going to sometimes have the backwash with chemical cleaning and you will come back to relatively better scenario but still you will have some fouling and this is irreversible fouling now.

And over few months or such, this membrane is going to be irreversibly fouled. And you will have to apply way too much pressure to get your water through, that is something to keep in mind.

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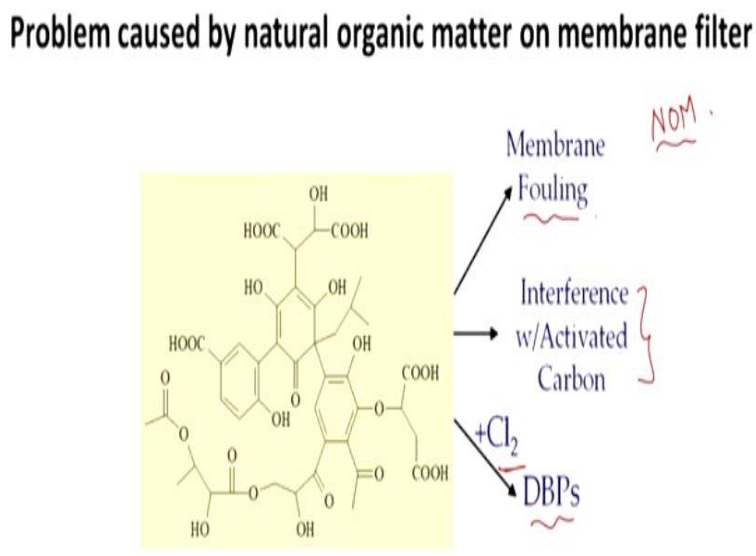

Fig 39

And one other aspect is we talked about the issues with respect to natural organic matter, it will interfere with activated carbon, with chlorine it will form disinfection by products. Here also it is going to cause an issue as in membrane fouling. It is going to foul the membrane pretty quickly, that is something to keep in mind.

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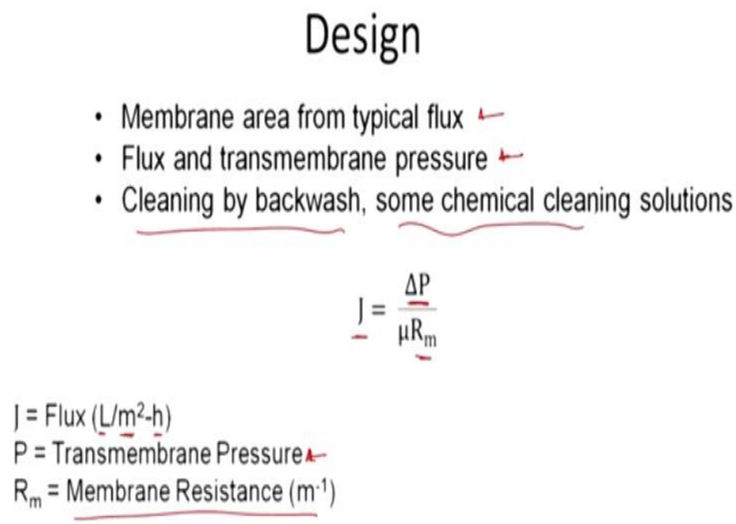

Fig 40

Design, what it is that I am concerned with? This is the flux; Flux is the volume of water per meter square surface area of my membrane per hour. It is going to be dependent upon the trans-membrane pressure, the difference in pressure, how much am I going to apply. And also, this membrane resistance, that varies from one particular system to the other. Membrane area from typically flux. Flux and trans-membrane pressure, we just looked at that, cleaning by backwash and sometimes chemical cleaning.

With that I will end this session and in the next session we will talk about disinfection and disinfection by products but because we discussed that in waste water treatment, we will be very brief. Before we wrap up the water treatment related aspects and move on to looking at process that are now coming into greater work as in adsorption, ion exchange, reverse osmosis, advanced oxidation process but that is enough for today and thank you.