Water Supply Engineering
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Lecture-31
Filtration Theory and Slow Sand Filters

Hello friends and welcome back so we will continue our discussion on conventional water treatment systems in the last few lectures we were discussing coagulation and flocculation. Earlier we discussed the clarification process which is sedimentation.

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Now although we are discussing in beds and pieces but when we arrange these systems like for depending on the source of water. Let us say if we are dealing with a typical surface water source like if you are withdrawing water from a river. So, it goes through the flash mixture and then flocculation and then clarification usually because we do not have screening and we may or may not use aerations and sedimentation also like pre sedimentation is generally not provided until unless water is too turbid.

If it is too turbid then we may have a like if the sediments or the suspended solids concentration is very high we may go for a pre sedimentation or plain sedimentation Otherwise we normally add coagulant and then flocculate it using a flocculator or in a clariflocculator and then clarify is the water or if we are not using clariflocculator we may send water to a clarification unit sedimentation units basically what we discussed last week.

And then the after that water is taken to the next unit. And that next unit is filtration so that is what we are going to discuss now. So, in this particular class we will be discussing about the basis basics of the filtration what is the filtration process, what are its objective what are the various contaminant removal mechanisms that take place in the filtration, what are the various types of filter. And then we are going to focus on the slow sand filters there design operation and maintenance.

The rapid sand filters will be taking in the next class so this particular class will be focused on slow sand filters. And then we will be concluding with the advantages and disadvantages of the slow sand filters.

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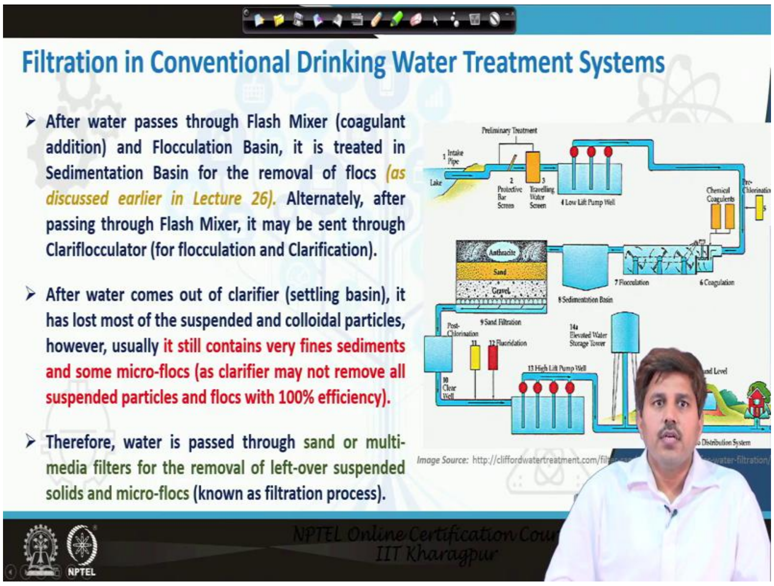

Now if again we see a conventional treatment systems so the water after like it is lift it comes then there is a coagulant added in a rapid mixed system and then it goes to a flocculation basin and then a sedimentation basin. So, we have discussed this in a last few lecture and we discussed sedimentation basins also earlier. Now after that the water typically comes to the filtration so like we mix first coagulant flash mixture then it will go to the flocculation basin and then it will be either like sent to a clariflocculator or sedimentation basin.

The water which comes out typically here the water that comes out of sedimentation basin may still contain very fine sediments and some kind of micro floc so that is because clarifier or clariflocculator does not work with 100% efficiency, there is like the sediment; these units may work well but it still like it is too much to expect 100% removal of these floc that these micro floc are these fine particles just by gravity settling.

So in order to overcome this in order to take care of the remaining leftovers we pass the water through a filter bed and this process is known as the filtration. So, that is what basically we will be discussing now the basic if we see the basic objective of the filtration process. so, when the water is coming to the filter means the inlet water does not in inlet water is not completely devoid of very fine sediments or the micro floc.

So, the basic objective of the filtration unit is the removal of these leftover suspended solids and micro floc in the water. Apart from that to an extent it actually treats the pathogenic contaminants as well it may remove certain pathogenic contaminant but again filtration does not guarantee complete removal of pathogens. So, filtration we do not consider or we do not design as a unit for pathogen removal.

But it does some it like it acts upon and it may remove quite a few of the pathogens from the water when water is passed through such filters. Now again that depends on what kind of filter layer or what kind of media layer we are using. Further in addition some organic compounds organically bound nitrogen phosphorus and undissolved metals may also be removed if we are going for a multimedia filter where there is like alongside sand we are using some other materials.

Those other materials can be like anthracite, granite or charcoal those kind of things are there which may help in the removal of the various other contaminants from the filter.

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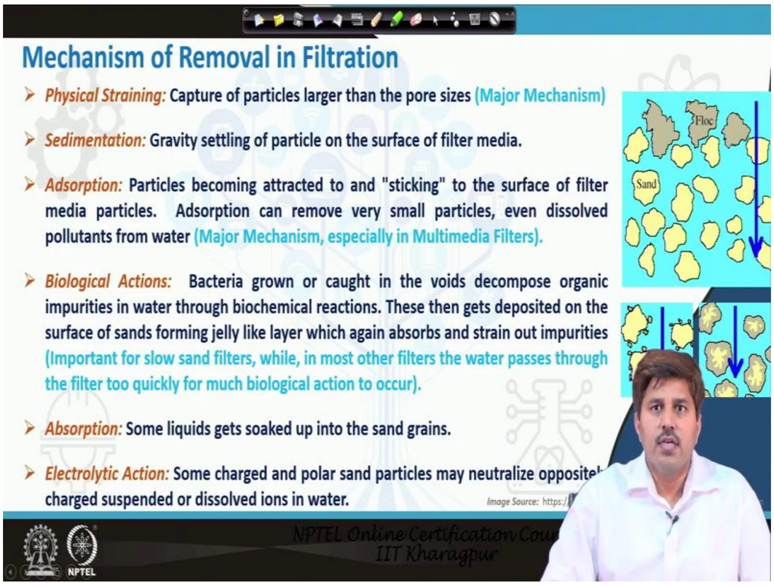

Now the removal mechanism is actually again there are multiple processes work up work on. So, the basic removal mechanism or one of the major mechanisms is the physical straining. Physically straining as in like when the water is passed through the filter media. Now if let us say we are assembling sand in a tank or in a in a chamber and then we are passing water through it so water is eventually passing through the pore spaces between the sand particles.

So any sediment or any micro flock or any flock any leftover suspended materials which are larger than the size of the pore spaces will get trapped. So, that is what is the physical straining means it does a straining action so it captures the particles that are larger than the pore sizes and that is one of the major mechanism. Then sedimentation also takes place sedimentation as in like these particles will settle again although the water is coming from a clarifier but in order for water in order for these particles to settle in a clarifier they need to travel much larger distance.

They need to come to the bottom now very fine particle have very little settling velocity so in the given time in the clarifier they may not cover the entire distance and they may not settle. But here when we are having us a chamber filled with small sand particles so a particle like each pore space can act as a tiny sedimentation basin. And the particle may get settle in there because he let us say if you see in a larger point.

So say a particle is here now a particle needs just this much distance to settle if this settles here it comes into the surface and then it can actually be adsorbed or retained on the surface which is the next major mechanism. So, adsorption is basically the particles that are attracted to and stick to the surface of the filter media particles. So, like here if you can see that there are some particles at attract to the surface of this filter media particles sand particles.

Now this attraction could be like physical attraction out of van der Waal forces or as we said that if it is actually getting settled. So, after settling also it may come here and stick there. So, mostly these kind of physical or physical chemical attractions are important for this the adsorption process can remove very small particles like because it is attracting the particles. So, even let us say water is passing through here it is having some contaminant which gets attached that attracted to this particle so it can come and stick to the surface of these particles although by size that should pass.

Because the particle is very small but because of adsorption process it has come and attached to the surface and then it on the surface of the media particle itself so that the water that percolates through this end bed is divided of these particles. Then there are biological action now bacteria that may grow on the top of the filter layer if say we have this filter body here we have sand or whatever filter media particles we have fit in.

So on the top of this there is a possibility of a formation of bacterial layer and then this if a bacterial because we are passing water and particularly like if water is having certain microorganism they will get trap on the surface and then then if water is say carrying some organic material as well. So, then they get food also there and they proliferate and as a result they can form a biologically active layer on the top of the surface and when water passes through this so there is a possibility of bio absorption.

So, that this layer itself can adsorb a few contaminants present in the water there is a possibility of bio degradation or bio decomposition. So, these layer of microorganisms can decompose the organic impurities that are present through the result of certain biochemical reactions. So, that also is quite helpful and quite prominent in the slow sand filters where we keep on passing water through the same sand bed for over a much larger period of time.

Whereas in rapid sand filters or most other type of filter where the filtration cycle is too low. So, we generally like within a day or so we back we need to backwash the filter and those things it does not allow the microorganisms to grow on the surface. So, this biological action is not effective for any other type of filtration it is not effective for pressure filtration bacteria cannot sustain in those pressure mediums.

It is not effective for rapid sand filtration or very high rate filtrations it is only effective and in fact it is a very prominent mechanism in the slow sand filters. The next mechanism is absorption which is like the some liquid gets soaked into the sand grains again not too prominent mechanism a very tiny contribution might be there of an absorption. And then there is a possibility of electrolytic action as well where some charged and polar sand particles neutralize the opposite charge suspended particles. So these are the major mechanisms.

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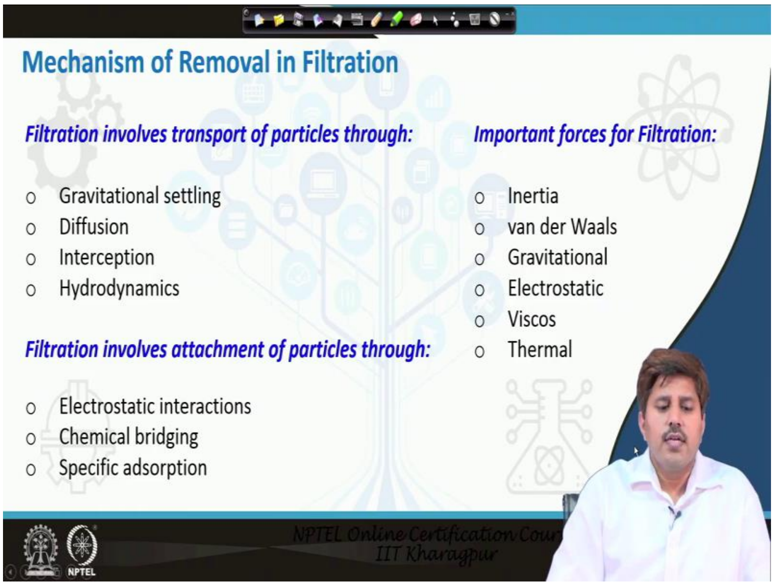

Now for these processes to happen there are like the transport of particles maybe through gravity settling, through diffusion, through interception or through the hydrodynamic movements. Like diffusion is important for the adsorption process gravitational settling will be there for sedimentation interception is important for physically straining process. Similarly this it will involve the attachment of the particles media particles attach these contaminants through either electrostatic interactions or chemical breezing or specific adsorption or physical adsorption kind of thing.

So that is how they can retain and attach with those contaminants present in the water the important forces that are important forces for the filtration process could be the inertia van der Waal forces gravitational forces electrostatic forces then viscous or thermal forces may also play some role in there.

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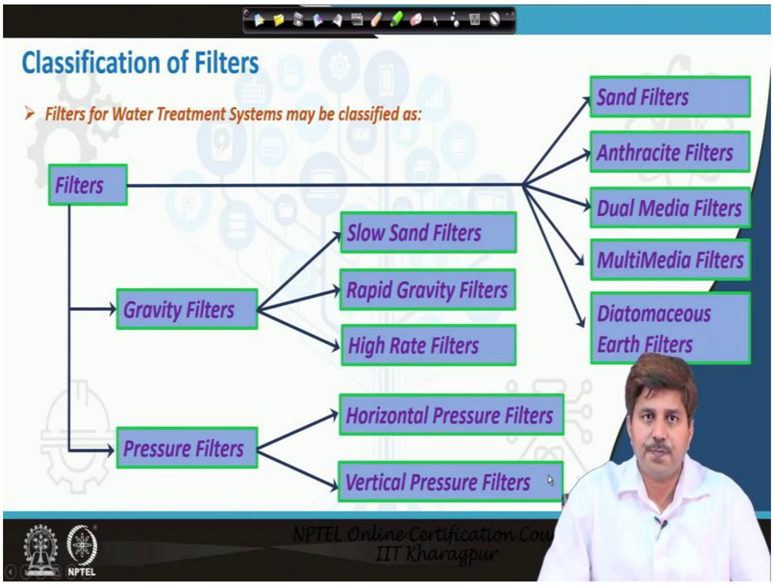

Now filters are classified based on different criteria's and one of the major criteria is what is the deriving force. So, if it is derived by the gravity so these are called gravity filters if it is derived by the pressure means we are applying pressure for filtration to take place then we call that pressure filters. Pressure filters can be horizontal pressure filters or vertical pressure filters depending on how we assemble them and gravity filters could be the slow sand filters rapid gravity filters or high rate filters.

Then based on the material or the media that we are using again we can fighting in two different types of the filter like the sand filters then anthracite filters when we are using anthracite medium. The dual media filters when we are using more than one medium like sand and anthracite both. The multi media filter when we are using more than two or the dynamics earth filter so these are some of the like different type of filters.

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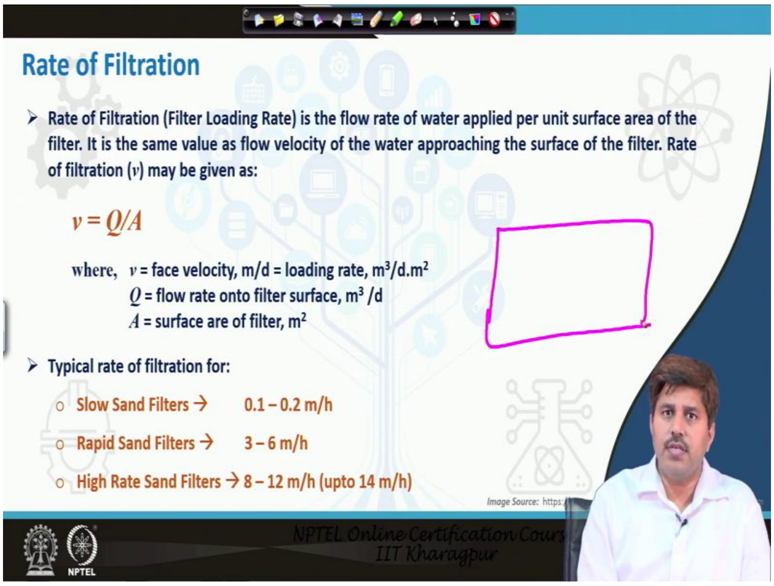

Now the rate of filtration which is actually the filter loading rate is one of the very important parameters in the filter design and establishment. So, let us say we have this as a filter bed whatever kind of filter bed it may be if this is our filter bed the rate of filtration is we are loading certain discharge on this filter bed. So, if the discharge is Q and the area is A, so rate of filtration is Q by A. Now this rate of filtration that weighs kind of approach velocity with which velocity the water is approaching the surface of the filter so that is what is the; rate of filtration.

Now we classify these different type of filters based on these rate of filtration primarily. Typical rate of filtration for slow sand filters would be 0.1 to 0.2 meter per hour actually unit of the rate of filtration because we are talking about discharge which is say in meter cube per day or meter cube per hour and then area which is in meter square. So, the unit becomes meter cube per day per meter square or we can simply say is meter per hour when we say that it is kind of approach velocity to this surface.

So, how much water is loaded on per unit area in per unit time that is what is basically the rate of filtration. So, for slow sand filters it is 0.1 to 0.2 meter per hour range for rapid sand filters it is 3 to 6 meter per hour range. And for high rate filter it is 8 to 12 meter per hour range. So, that is the typical range.

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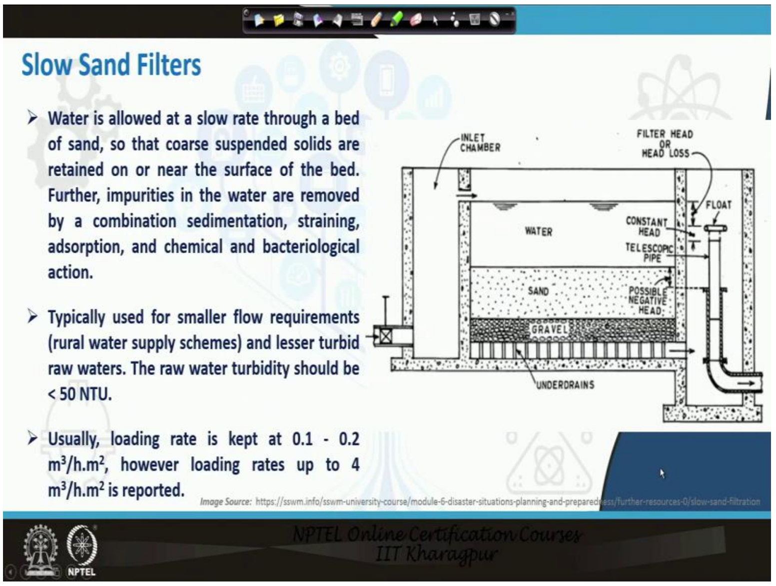

Now the most basic type of the filter is slow sand filter or although the applicability is not that much its rapid sand filters or rapid gravity filters are far more popular than slow sand filters, we will be discussing that in the next class that why they are more used. But slow sand filters are pretty good system has very good efficiency. But only demerit is that they need a much larger area. Now water is allowed to basically at very slow rate in this through a bed of the sand it is a sand filter.

So, generally slow sand filters will have only sand we do not have multi media or dual media filters in slow sand filter cases, so sand filters are primarily the sand filters. So, what will happen that we have a sand layer and we allow water to pass through this sand layer at the bottom we will be having a gravel which is basically for the support purpose and then underdrains in a system which will collect the water which passes through this which passes through this media.

And then it will be transported to some chamber for further uses. So, the process is simple the water is put in an inlet chamber and then loaded from the top so it is a gravity filter flow will be downward of course because all these filters works on gravity based only apart from the pressure filter which may have a like up flow. The all the gravity filters work from top to bottom, so they are all down flow filters.

Typically slow sand filters are used for smaller flow a requirement which is good for rural water supply schemes and the water should not have turbidity more than 50 NTU. So, we do not like slow sand filters are not used for treating highly turbid water. The reason behind that these are slow sand filters the particle sizes are small the rate that we get through these through the filter bed is very low and if we are using too much of turbidity like the suspended solids concentration is very high or the particles are very bigger it will block those filter pores in very like less time whereas we want these filters to run for much longer durations.

So, usually loading rate as we said that 0.1 to 0.2 meter cube per hour per meter square is used; however loading rate up to 4 also is reported in the slow sand filters.

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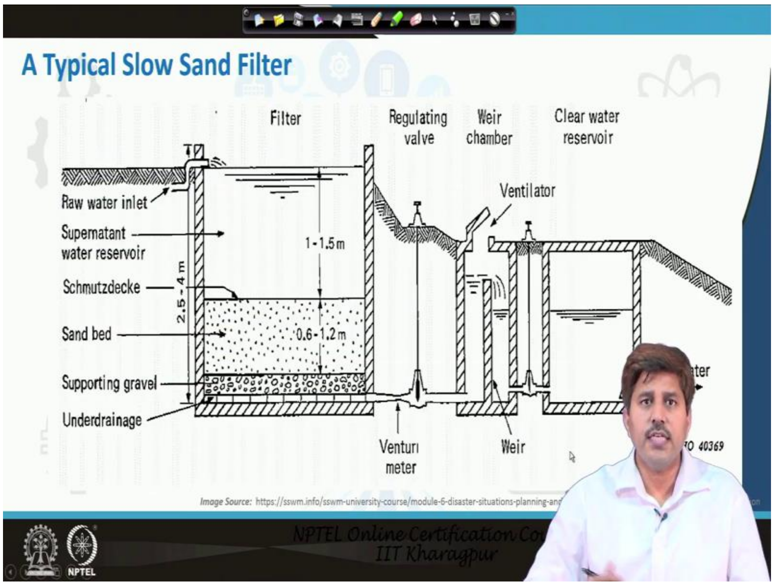

These are typical cross-section of slow sand filter again the process are same that water is put in the top then it percolates through a sand bed and then gravel supporting gravel bed and then 200 in it system it comes in a clear water chamber and from there it can be taken for further uses.

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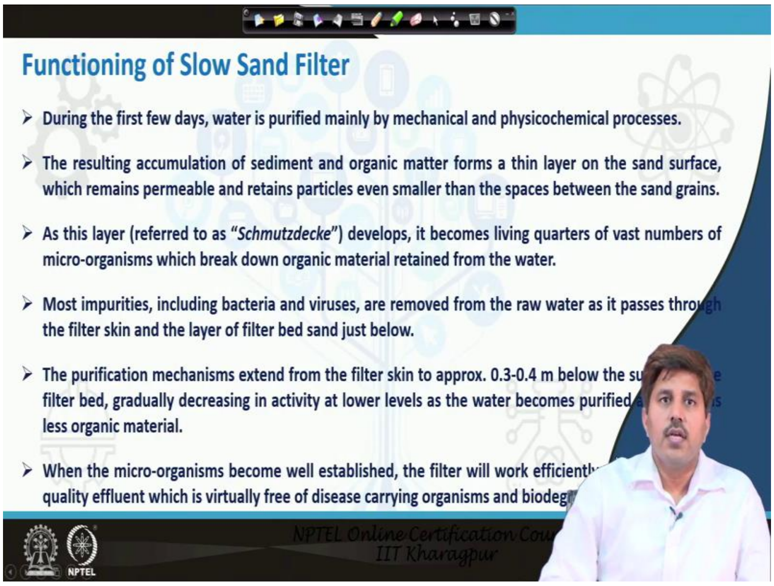

Now how this slow sand filters function so during the first few days water is purified mainly by mechanical and physical chemical processes, those process that we were just discussing so there is physical straining and adsorption which plays the major role during the first few days of the filter operation. Now as the filter keeps on working there is an accumulation of sediment and organic matter which will form a thin layer on the sand surface as just we were discussing.

So, it is practically there for the formation of biological layer. So, if this is our filter this is say our sand bed, so a thin layer will be formed over the sand bed and then this layer remains permeable. So, water passes through this but various particles are retained by the adsorption or by the other mechanisms. So, as this layer further develops this layer particularly is a biological layer. So, it becomes living quadrate of the vast number of microorganisms generally bacteria mostly and then they break down the organic matter material which is retained in the water.

So that way it helps in the treatment of some organics present in the water as well. Most impurities like particularly the living one bacteria and viruses are also removed as the raw water passes through because this layer will effectively retain the bacteria and virus as well when the water passes through the skin of this layer. And purification efficiency enhances as this layer starts working you know like full stage or full fledge.

Now this progressively what happens that the purification initially starts from the top if this is say the total sand bed depth. So, of course the major retention is going to be on the top in the beginning and then purification mechanism progressively extend to the filter skin to approximately 0.3 to 0.4 meter below the surface of the filter bed. And then it gradually decreases in the activity of the lower level and water becomes purified containing less organic material. So, the lower layers are still not that contaminated.

Majority of the contaminant is retained in the top 0.3 to 0.4 meter layer. Now when these microorganisms become well-established the filter will work very efficiently and produce very high quality effluent which is virtually free of disease-carrying organisms and biodegradable organic matter as well.

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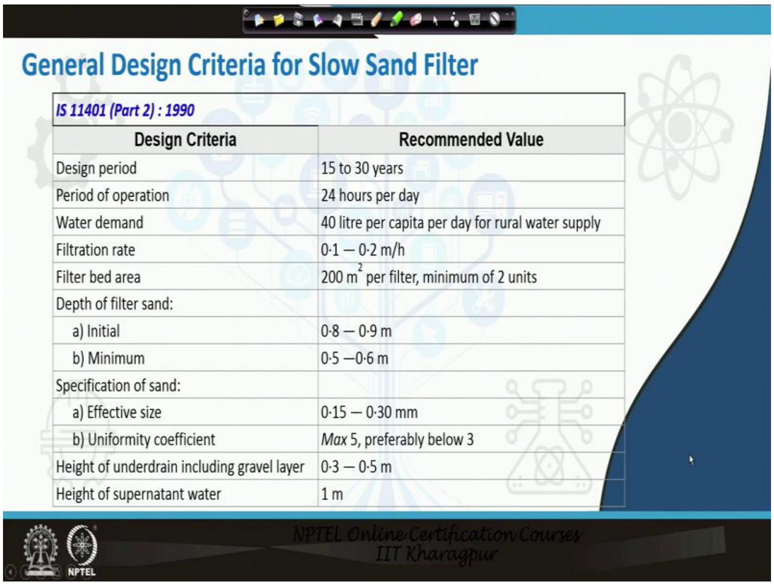

Design Criteria	Recommended Value
Design period	15 to 30 years
Period of operation	24 hours per day
Water demand	40 litre per capita per day for rural water supply
Filtration rate	0·1 – 0·2 m/h
Filter bed area	200 m^2 per filter, minimum of 2 units
Depth of filter sand:	
a) Initial	0·8 – 0·9 m
b) Minimum	0·5 – 0·6 m
Specification of sand:	
a) Effective size	0·15 – 0·30 mm
b) Uniformity coefficient	*Max* 5, preferably below 3
Height of underdrain including gravel layer	0·3 – 0·5 m
Height of supernatant water	1 m

So, that way the growth is very helpful in there, now what happens like for design purpose actually if we see for design purpose so the design criteria this is the as per is 11401 the recommended design period is 10 to 15 year, 15 to 30 years the period of operation it will operate round-the-clock it can operate 24 hours a day, it can serve the water demand of around 40 liters per capita per day for rural water supply scheme.

The filtration rate as we said that it is preferable between 0.1 to 0.2, meter per hour the filter bed area would be 2000 meters square per filter and minimum 2 units we must provide. So, this is the maximum area in fact we can go for a smaller filter bed area as well. The depth of the filter sand that we keep so initially it is 0.8 to 0.9 meter and minimum it should be 0.5 to 0.6 meter. So, we start with a height sand death and then during maintenance we may lose some sand we will discuss that how we do that.

And then the depth of the sand may reduce but it should be minimum maintain as 0.5 to 0.6 meter. The specification of sand effective size has to be 0.15 to 0.3 meter and the uniformity coefficient should be preferably below 3. The height of underdrain including the gravel layer should be 0.3 to 0.5 meter and the supernatant water should be around 0.1 meter.

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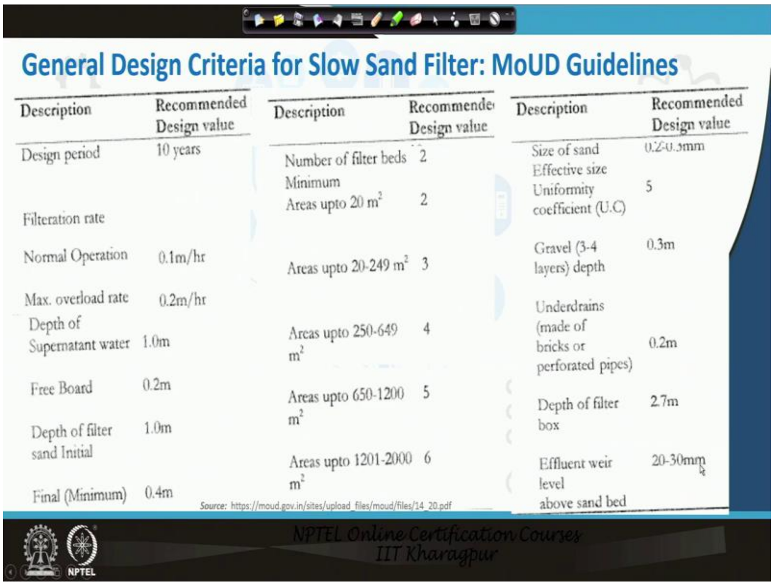

This is another design criteria as per MoUD guidelines Ministry of Urban Development guidelines ok. So, again they also like they say the design period should be around 10 years the filtration rate at normal operation 0.1 meter per hour maximum 0.2 meter per hour. The depth of supernatant water again 0.1 meter freeboard could be 0.2 meter depth of filters and initially we can have 0.1 meter final like the minimum could be 0.4 meter.

So we can see that there are little variation in the guidelines like earlier guidelines were suggesting that minimum depth of the sand bed should be 0.5 to 0.6 meter whereas this allows to go till 0.4 meter. Now number of filter beds minimum we must have to filter beds if the total area is up to just 20 meter square we will be just writing to filter beds. Area is like the total area will be determined based on the discharge.

So, let us say if you want to treat 100 meter cube per day flow, if say we want to treat 100 metre cube per day flow and we are say 10 meter cube per hour flow. Let us say we want to treat 10 meter cube per hour flow and then we select the rate of filtration as point as 0.1 meter per hour. So, the as just we are saying this is our rate of this thing. So, this is equal to Q by A so our area is going to be equal to 10 meter cube per hour divided by 0.1 meter per hour.

And this will lead to 100 meter square area so that way we can determine the area. Area can be simply determined by dividing the dividing discharge with the rate of filtration what we have assumed. So, if we assume rate of filtration as 0.1 it is going to be the 10 times of the discharge in our hourly discharge. So, if hourly discharge requirement is 10 meter cube per hour area is 100, if our early discharge requirement is say 50 meter cube per hour then area required would be 500 meter squares.

So, if area is up to just 20 meter square we need still minimum two units for area up to 20 to 49 meter square we should provide 3 units for area up to 250 to 649 we should provide 4 units for area up to 1200 meter square 5 units and for area greater than that up to 2,000 we provide 6 units. And then these are some other parameters like the uniformity coefficient which is actually the ratio of D 60 to D 10.

The effective size of the sand which is actually D10, so D 10 means the if we are saying that effective size has to be 0.2 to 0.3 that means that all the particles at least 90% of the particles should be of size this or bigger. Only 10% of particles could be of smaller size. So, the gravel depth 0.3 meter then underdrains 0.2 meter depth of filter box 2.7 meter and then we are gravel 20 to 30 mm. So these are some of the other design specifications.

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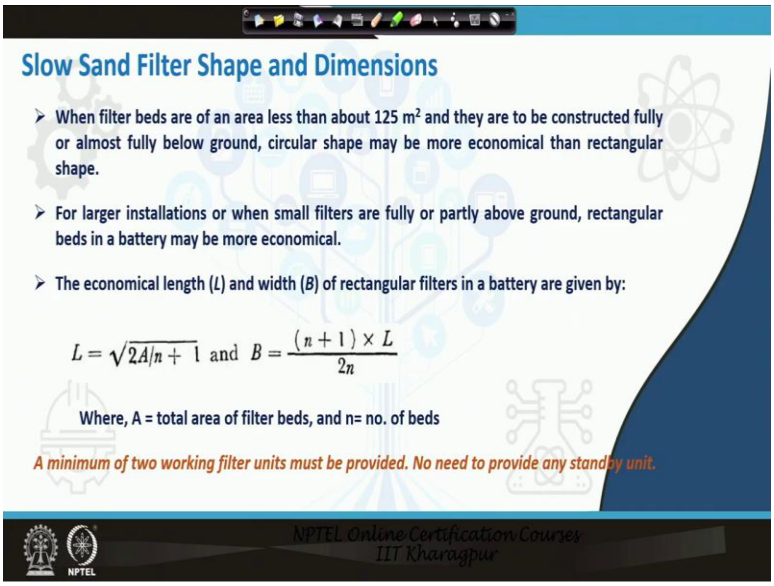

For shaping and dimension again when filter beds are of an area less than about 125 meter square they are like able to construct fully or almost fully below the ground however larger may be constructed half partly above ground or maybe completely above ground. Generally circular shape may be more economical than rectangular say for smaller area basins.

However for larger installations when we are partly considering below ground and partly above ground it is the rectangular shape which is arranged generally in a battery mode considered more economical.

So, battery mode means if say we need 3 filters so like we arrange the batteries we can arrange 3 filters like this or if say we need 4 filters. We can arrange a, 4 filters like this also so these are the kind of a 4 filters we can arrange like this. so, we allow the water to pass through these 4 filters or we allow water to basically pass through these 4 filters. So, that way we can arrange the different filter beds the most economical length and width of a rectangular filter beds in a battery mode.

So if we know the total area we want to determine what length and what width we can keep. So, if the total area is A and n is the number of beds that we decide, so length is going to be a square root of 2A by n + 1 and width is this so this is empirical formula which gives the most economical length and width when we try to arrange them in a battery mode. Minimum of 2 filters unit must be provided we do not need to provide any standby unit here.

Particularly in the slow sand filters we want to operate all filter units however we must design at a lower load. So, let us say like we must design at a loading rate of 0.1 meter per hour. So, that and if you are having say 2 beds only 2 beds and we have designed it for 0.1 meter per hour if say one bed goes under maintenance or for some other reason it is not working. So, our second bed can be run at a higher loading rate up to 0.2 meter per hour.

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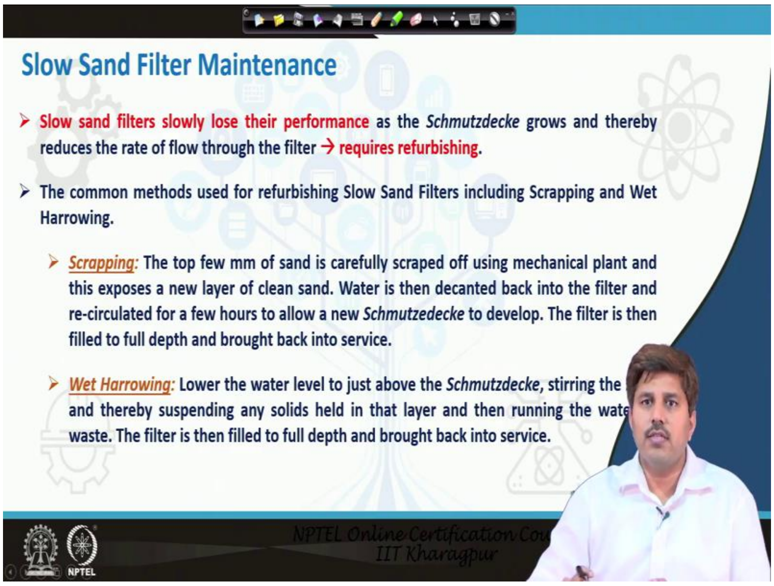

So but we do not need to provide standby units because you know if we are keeping a standby so that the growth of biologically active layer is not going to happen. Now these filters will lose their performance as that biological layer grows initially it works very well but as that layer goes think there will be mass transfer limitations come in and it kind of the major problem is that it generates lot of head loss as well.

So in that case either the performance will be poor or the like flow through the filter will more or less stopped or very little flow will pass through. So, in that case our filter particularly needs refurbishing. So, we need to maintain we need to send that filter bed for maintenance purpose. Now the common methods for refurbishing slow sand filters include two approaches one is scrapping. So, scrapping is simply like the top few millimeter of the sand we scrapped off using some mechanical plant.

And then we expose a new layer of clean sand and then again the water that we have decanted from the filter we pull it back and recirculate it for a few hours so that the new biological layer develops and the filter is then filled to full depth and back like is again brought back to its normal service run. The other approach is the wet hollowing. So, wet hollowing is like instead of making the filter completely drained out and then scrapping the sand what we do is we like lower the water level just like if this is the say sand bed.

So we lower the water level just above the sand bed and then we stir the sand and then suspend whatever the solids that are trapped in here that will come into the suspension. And then we kind of drain that water and let the sense and settle back into the system and then we fill the filter to the full depth and bring it back to the normal run. So, that process is known as wet hollowing.

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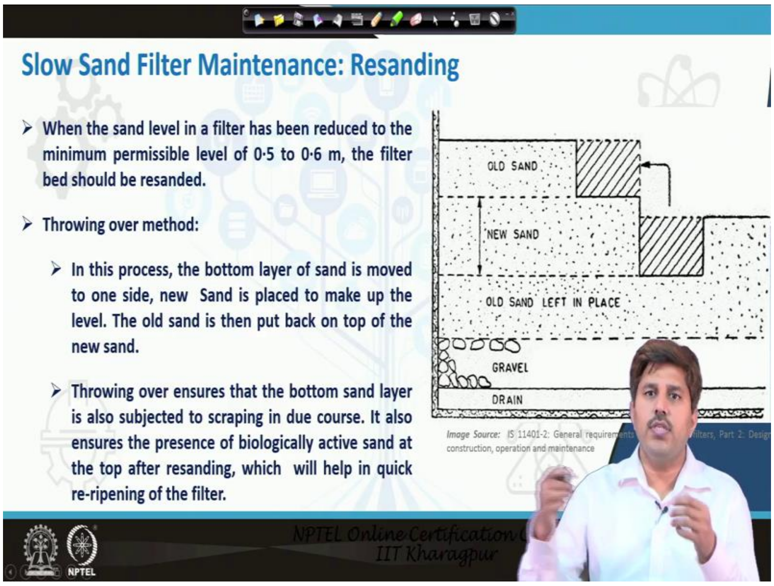

These two have simple concept in one we just strap make the filter drained out completely and scrap the top layer which is sort of have a retained majority of the contaminant and has been blocked because of that so we read we scrap of that layer a new layer is exposed and filter will start working normally. The other approach is that we reduce the water level just above that and then kind of steer it so that whatever impurities are trapped in the bed come into the suspension and then we drain that out.

The other like so if we are doing scrapping like wet hallowing and work for some time and then we may need to go for scrapping also if like if say the too much impurity has been trapped on. So, wet hollowing might not work properly so we need to scrap it so then we need to go for scrapping and as just we were discussing so what happens when we scrap some depth some depth of the filter layer or sand layer the depth of the sand layer which we have started let us say at 0.8 or 1 or 0.9 keeps on reducing.

So, after like 3, 4 maintenance cycles we may see that depth has come down to around level of 0.5 or 0.4 so as we were just seeing that different guidelines suggest different numbers. So, if level has been fallen to that level that means we need to resend that filter means we need to put more sand into the filter. So, that process is known as resanding, so we need to resand that filter and for resanding purpose generally the throwing over method is used.

So, while resanding we kind of it is not that we put fresh and on the top of that because in that case whatever biological organisms has been developed in the filter surface top level will actually be of no use because water again fresh and has been put in the top so that way it will actually it is further going to be like act as a new filter new run. And then developing of that biological layer will again going is probably going to take again a lot of time.

So in order to avoid that we use throwing over method and in this process the bottom layer of sand is move to one side, we move just bottom layer of sand old sand to one side and then put a new layer of sand and then again put the bottom layer of sand on the top of that so we do it like in a way that in a way that it is partially shifted that way. So, it ensures that bottom sand layer is also subjected to scrapping in due course of the time first thing it is not that the bottom sand is as it is and we are only just top layer top layer of sand is scrapping.

And it also ensures that the presence of biologically active sand at the top after resanding which again will help in the quick formation of the biologically active layer and that may ensure the filter coming back into its normal operation.

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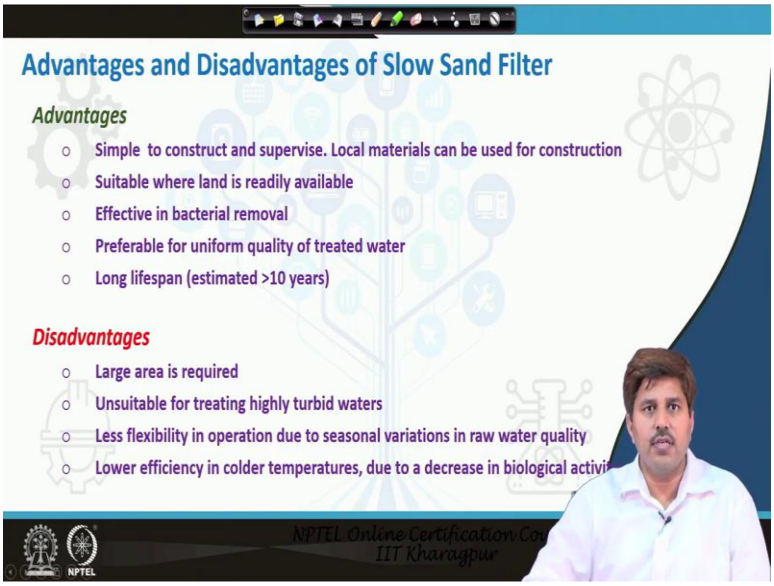

Now the major advantages and disadvantages of the slow sand filter are pretty like usual. So, the major disadvantage is that large area is required. We are working with a very low rate of filtration 0.1 or 0.2 meter as opposed to rapid sand filter which say work at 4 or 5. So, let us say like simply if you see that the area required is equal to the discharge divided by the rate of filtration. Now if our rate of filtration is 0.1 or it is 5 in case of rapid sand filter.

So this is this is kind of 50 times less area would be needed if we go for a rapid sand filter. A slow sand filter would require 50 times more area than a rapid sand filter. So, in order to like see that particularly in the cities where land cost is too high we cannot use slow sand filters the huge amount of area would be required. So, that is why it is unsuitable for treating large flow. Because with a large flow again you will require very large amount of area and that much area are getting that much area in a city is very challenging.

And there is a huge land cost associated with that so that is why these are not considered suitable for very large flow. It is also considered unsuitable for highly turbid waters as we were just discussing because. We let this filter run for 3-4 months usually and then once the water is too turbid it is going to block this filter and then we will not be able to operate it effectively for that longer period.

It has less flexibility in operation due to seasonal variation in raw water quality and it may have lower efficiency in colder temperature due to decrease in the biological activity. Biological activity plays a significant role in the removal of contaminants in a slow sand filter and if we are using it in a low temperature reasons so the biological activity will be decrease and filter performance may get affected.

However on plus side this is very simple to construct and supervised and we can use local materials for constructing this. It is suitable where land is readily available particularly in a rural areas for smaller flow so smaller flow land requirement would also become and a lot of land may be available in rural areas. So, slow sand filters are more popular for the those places. It is very effective in bacterial removal as well it is preferable for uniform quality of treated water and it has a long life span. More than 10 years, so these are the major at want the slow sand filters.

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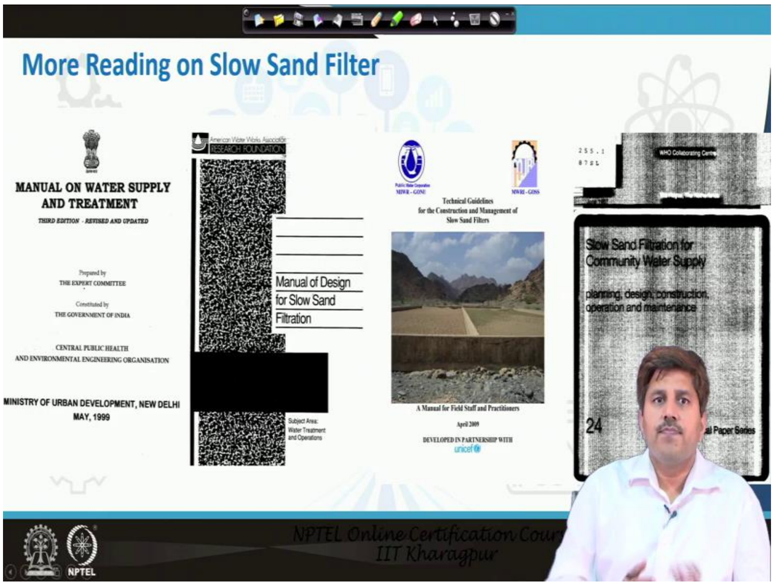

So, these are the like some other documents where far more details can be obtained so there is a American Water Works Association manual of design on the slow sand filter. There is a again like UNICEF has a manual on the construction and management of slow sand filters. There is again WHO guidelines on slow sand filter our CPHO manual also has a section on the slow sand filters.

So, these are the documents which can further be referred for more details on the slow sand filters. So, with this we conclude this lecture thank you for joining and we will continue discussing the filtration process in the next class. And will take up the role of media and how they work in a rapid gravity filters. So, thank you for joining see you in the next class.