Basic Environmental Engineering and Pollution Abatement
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Lecture: 26
Treatment of Surface and Ground Water for Drinking Water Generation

Hello, everyone. Now we will discuss on the topic, treatment of surface and groundwater for drinking water generation. So, as you know, the drinking water quality should be very pure and very good quality it should have, so that we can use it for our drinking purpose, unlike other applications like say, bathing, washing etc. And also, the sources which are used for the production of safe drinking water, those are also basically pure and less contaminated.

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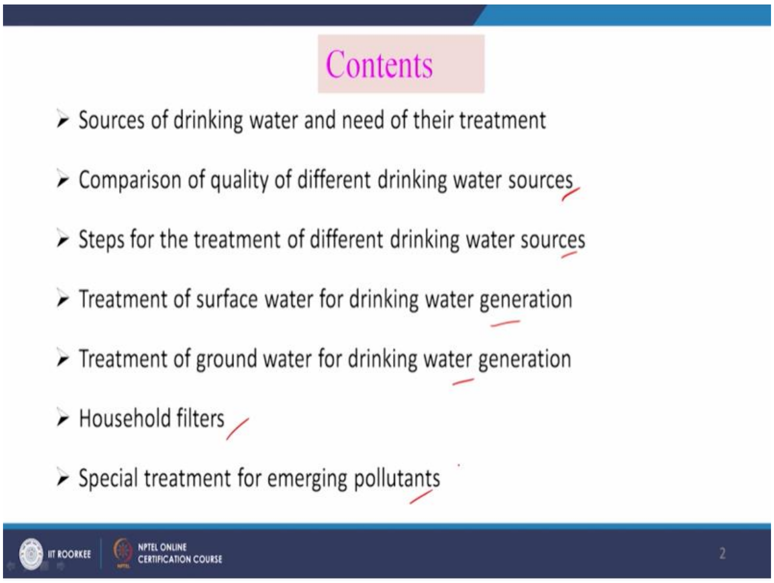

Now, we will discuss here are the sources of drinking water and need of their treatment and comparison of quality of different drinking water sources, then steps for the treatment of different drinking water sources, treatment of surface water for drinking water generation, treatment of groundwater for drinking water generation, household filters and special treatment for emerging pollutants.

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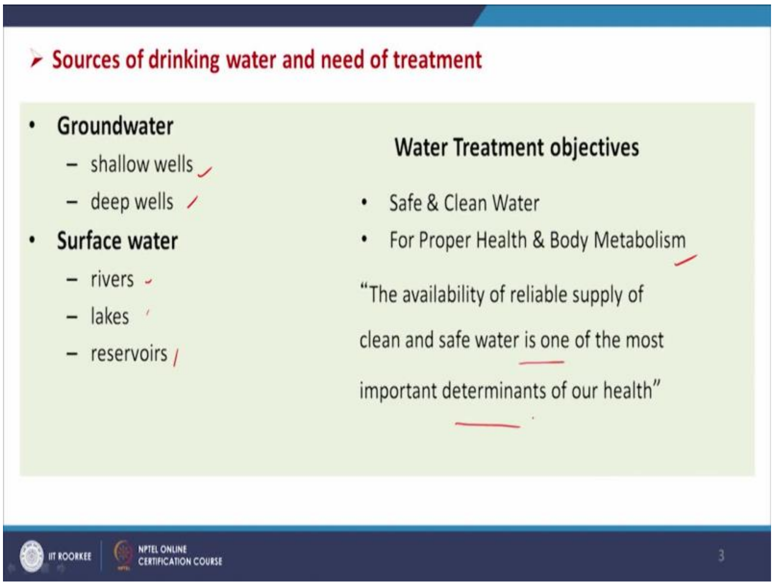

If we see the sources of drinking water, then we see that either the surface water or the groundwater is used. And mostly in our country the groundwater is used and when the surface water is not that contaminated, in that case surface water can also be used. And rivers, lakes and reservoirs, these waters are used for the drinking water production and from groundwater, shallow wells or deep wells, both sources are available.

And if we increase the well deep, if we go deeper, the wells normally becomes more safer and require less treatment and shallow wells water normally contains more contamination like arsenic, fluoride, etc. and requires more treatment.

And the main objective of the water treatment for the drinking water generation is to make the water safe and to provide clean water for a proper health and body metabolism. So, this is the objective, the availability of reliable supply of clean and safe water is one of the most important determinants of our health.

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➢ Comparison of quality of different drinking water sources

Characteristics	Groundwater	River	Lake/Reservoir
Safety (bacteriological)	Generally safe	Not safe	Better than river
Composition	Constant	Varying with season	Relatively constant
Hardness	Present	Variable	Variable
Turbidity/SS	Nil	Present	Very Less
Minerals	Present	Variable	Variable
Iron & Manganese	Sometimes	Nil	Variable
Color	Low /nil	Less/Nil	Present
Nitrate	Sometimes	Less	Less
Hydrogen Sulphide	Sometimes	Nil	Nil
Sulfates & Carbonate	Present	Variable	Variable
Taste & Odor	Sometimes	Less	Summer

Now, if we see now, there are basically some sources, one is your groundwater, then river and lake or reservoir. So, in these cases, if we consider the characteristics, then you see that bacteriological count that is in groundwater, generally it is safe and river water not safe, the more chance of contamination. So, that we are just discussing that the safer source are preferably used for drinking water generation.

So, groundwater is used in higher extent, but when the river water is not that contaminated, certainly it is used and lake and reservoir water are less contaminated than river water and mostly used for drinking water. And if we see the consumptions, hardness, turbidity, minerals and iron and manganese, then color, nitrate concentration, hydrogen sulfide and sulfates and carbonate and taste and odor, we will see that these are not equal for all three cases, that means the quality of the water source is different.

And in case of this groundwater, we will see that the hardness and the different types of ions mostly available in most of the cases and the TSS, etc and odor taste is also sometimes it is available that is sometimes odor and taste we also get. And TSS is normally not available in groundwater whereas, this is available in river water and in reservoir water also this is less.

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➢ Steps for the treatment of different drinking water sources

Steps	Surface Water	Hard Groundwater
1	Screening/Microstrainer	Aeration
2	Pre-Sedimentation/Pre-Chlorination	Oxidation/Prechlorination
3	Rapid Mixing (Coagulation Tank)	Rapid Mixing (Lime & Soda Addition)
4	Slow Mixing (Flocculation Tank)	Precipitation
5	Sedimentation	Sedimentation
6	Filtration	Recarbonation
7	Adsorption Optional for organics removal for better taste/color/odor)	Filtration
8	Disinfection	Disinfection

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Now if we see the steps for the treatment of different drinking water sources, then surface water and hard groundwater, if we see the almost similar steps are there, but in in case of surface water the screening or microstrainer is used. But, in case of hard groundwater this is not required, but in some cases aeration is required because by providing oxygen some reduced form of different ions can be converted to oxidized form and can be removed easily from the groundwater.

And some pre-sedimentation and pre-chlorination and here oxidations and pre-chlorination in case of groundwater is needed, just to have mentioned to convert some ions to the oxidized form that can be easily removed. And then, rapid mixings are applicable for both the cases and then slow mixing and then sedimentation filtration are used for surface water and where we can go for precipitation, sedimentation, recarbonation.

So, recarbonation is required here, because in this case, as we are using lime and soda additions, you will see here in case of rapid mixing for the surface water, coagulation tank and rapid mixing lime and soda additions in case of groundwater. So, here the pH is increased to carbon dioxide is again sent to reduce the alkalinity or increase the pH or to reduce the pH.

Then filtration is common for both the cases and adsorption optional for organic removal for better taste, odor etc. When we are considering the river water or reservoir water, so BOD, COD may be available in this but normally in hard groundwater BOD, COD is not available. So, in that case, adsorption maybe made optional for organic removal for better taste and odor and color.

And disinfection is common for both the sources. Disinfection is must because the water which will be drinking that must be free from pathogenic microorganisms, so, disinfections is mandatory for all types of drinking water generation.

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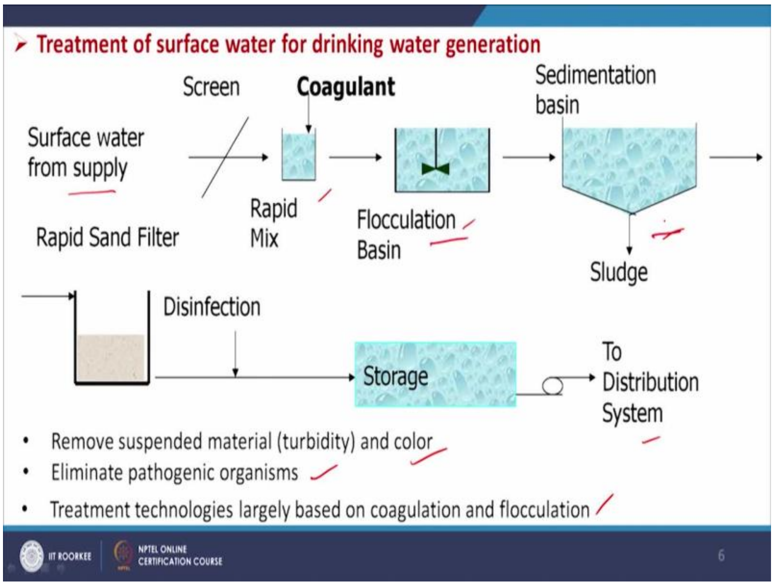

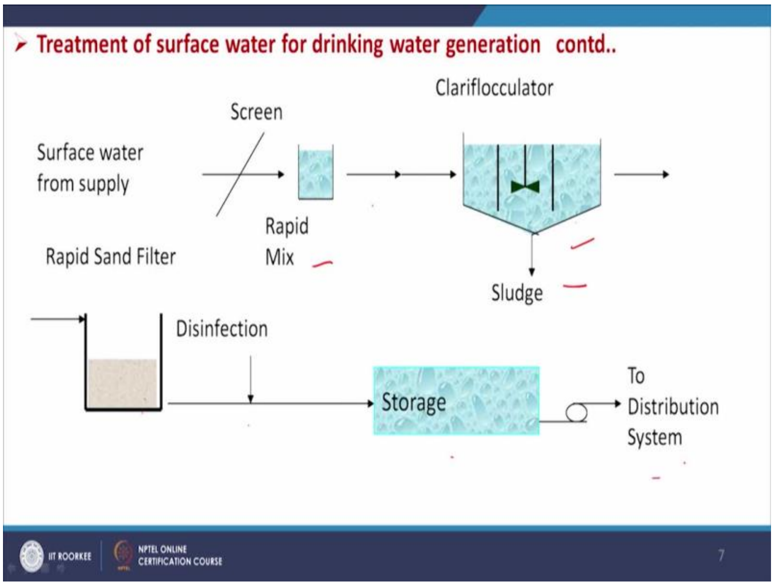

Now we will see the surface water treatment for drinking water generation. If we see the first surface water from supply, then we have a screen the removing of say floating materials like the leaves or paper or piece of papers or anything like this. So, then after that it will be coming to coagulant, so we will be adding some coagulant so that the BOD or COD if it is available, or if some suspended solids and the dissolved solids will also be settled.

And then, we will be adding some flocculation basin, so the tiny particles, the colloidal particles will be given an opportunity to collide each other and to make into a bigger firm and settle. Then we are coming to sedimentation basins, we will be providing sufficient time so that the clogs which we are forming, so, that can be settled.

And then it is coming to a rapid sand filter. So, sand filters will be there then it will be purified and then the water is ready almost for its applications, but before that disinfection is necessary to kill all the microorganisms present in it, then it will be stored and to be distributed. So, this the general flow sheet for the treatment of surface water for drinking water production.

And main objective of this treatment is to remove suspended material, that is turbidity and color and then eliminate pathogenic microorganisms and treatment technology is largely based on coagulant and flocculation. And here, we have seen that flocculation and sedimentation, two different divisions, but in some cases, we can use the single unit that is clariflocculator.

In that case, other units are same, like say screen, rapid mix, and then this is your clariflocculator, no separate flocculation's and sedimentations only clariflocculator unit is also used. Then it will come to rapid sand filter, then disinfections and then it will come to storage and then to distribution system.

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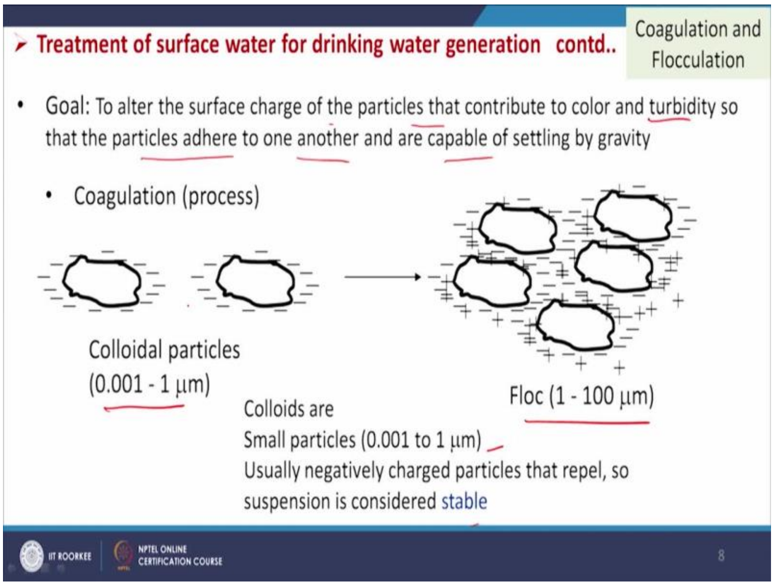

Now, coagulation and flocculation is an important part for the treatment of the surface water as you have mentioned, so what are those methods? Let us see, so, and the goal of this method is to alter the surface charge of the particles that contribute to color and turbidity so that the particles adhere to one another and are capable of settling by gravity.

So, we have some particles, normally these particles are having negatively charged. So, if two particles both are having negatively charged so, that they will not be able to come closer to each other and to make a bigger one so, that that can be settled, so very fine particles will not be able to do, so in water solution or in the water.

But if we add some coagulants or flocculants then these charge neutralization can take place and the particles will be able to come closer, if we make some slight agitation, then it will come closer and the bigger agglomerate will form and that will be settled and this is the mechanism for this. And colloids are small particles such as 0.001 to 1 µm.

So, after this coagulation process, we are getting 1 to 100 µm. So, say 100 times incrementing the size so, now that small particles will be able to settle. So, usually negatively charged particles that refill, so, suspension is considered stable. So, normally these particles are stable, but when we add the coagulant, so this stability breaks and it falls.

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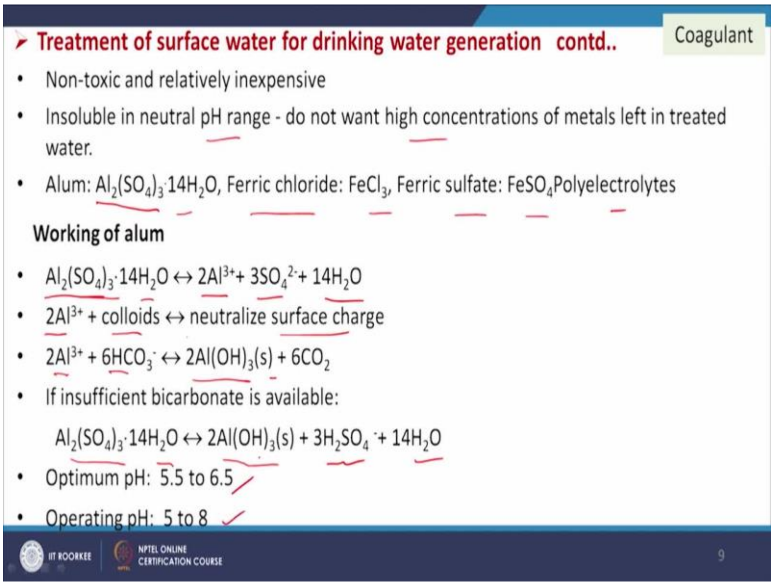

Now, coagulant how they work, we will see here and some common examples of these coagulants like say $Al_2(SO_4)_3 14H_2O$ that is alum and ferric chloride, $FeCl_3$, ferric sulfate, $FeSO_4$ and polyelectrolytes. So, these are the different materials which are used and then these are normally nontoxic and relatively inexpensive, if it is toxic, we will never use it for the treatment because that will be dangerous for the health.

And insoluble in neutral pH range do not want high concentrations of metals left in treated water and we will see the working here.

$Al_2(SO_4)_3{\cdot}14H_2O \leftrightarrow 2Al^{3+} + 3SO_4^{2-} + 14H_2O$

$2Al^{3+}$ + colloids $\leftrightarrow$ neutralize surface charge

$2Al^{3+} + 6HCO_3^- \leftrightarrow 2Al(OH)_3(s) + 6CO_2$

If insufficient bicarbonate is available:

$Al_2(SO_4)_3{\cdot}14H_2O \leftrightarrow 2Al(OH)_3(s) + 3H_2SO_4^- + 14H_2O$

And operating pH is 5 to 8 and optimum pH is 5.5 to 6.5, so, this is for coagulation.

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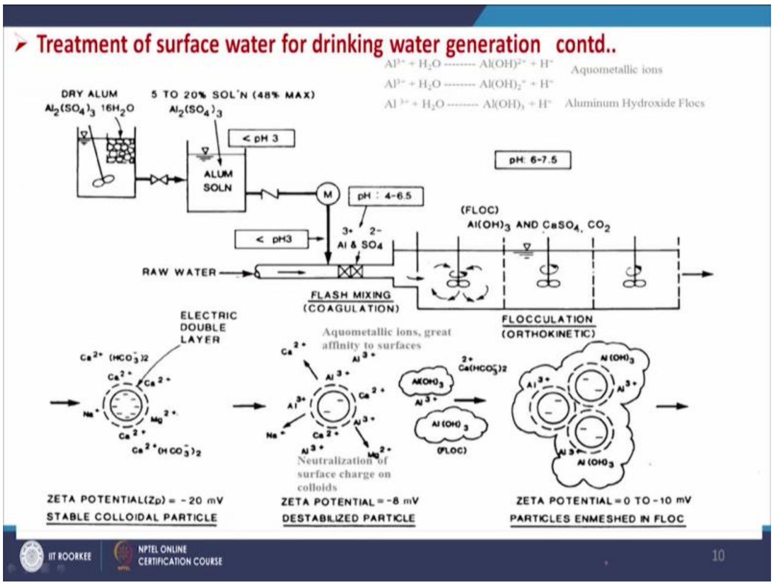

And we see here, when we are adding alum here, alum solutions here coming to this raw water and here we are giving some slight agitation. So, initially the flocculation takes place, so flocculation then the particles becomes closer and this say, this is a colloidal particles, negatively charged and some positive ions present in the water makes a double layer here, so this is a stable one.

So, now if we add some aluminum sulfate, so that will be converting $AlOH_3$ and then some Al^{3+} ion also so that will disturb these. So, the particles will be able to come closer and then in this case you see the more number of particles are coming here and a flock is formed by this aluminum hydroxide, so, this flock and then it settles. So, very tiny particles are able to settle here. So, both flocculation and coagulation take place in this unit.

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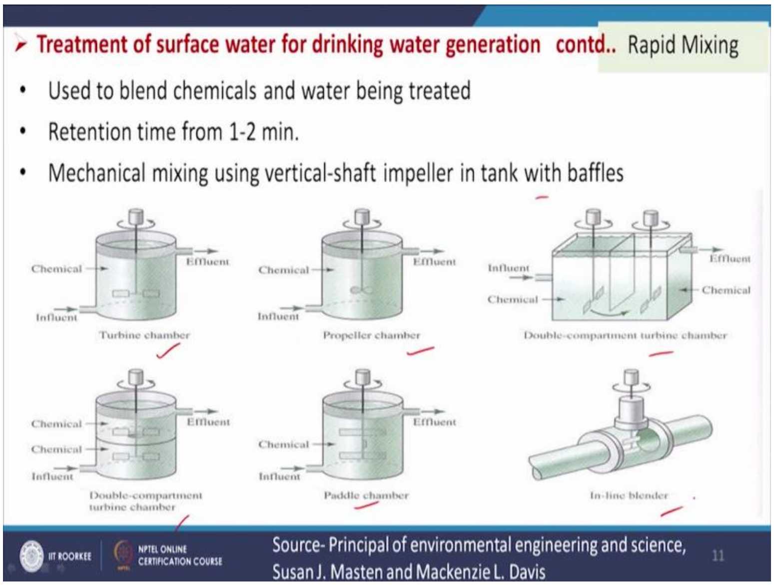

And then rapid mixing show this is used to blend chemicals and water being treated. So, rapid mixing is required within a small span of time, the mixing will be then, then coagulation, flocculation will take place, then sedimentation will take place. And retention time for this is 1 to 2 minute, and mechanical mixing using vertical shaft impeller in tank with baffles these are commonly used. So, different types of rapid mixing arrangement, you see this is turbine chamber, propeller chamber, paddle chamber and maybe double compartment turbine chamber, and here double compartment turbine chamber, and inline collector is also there.

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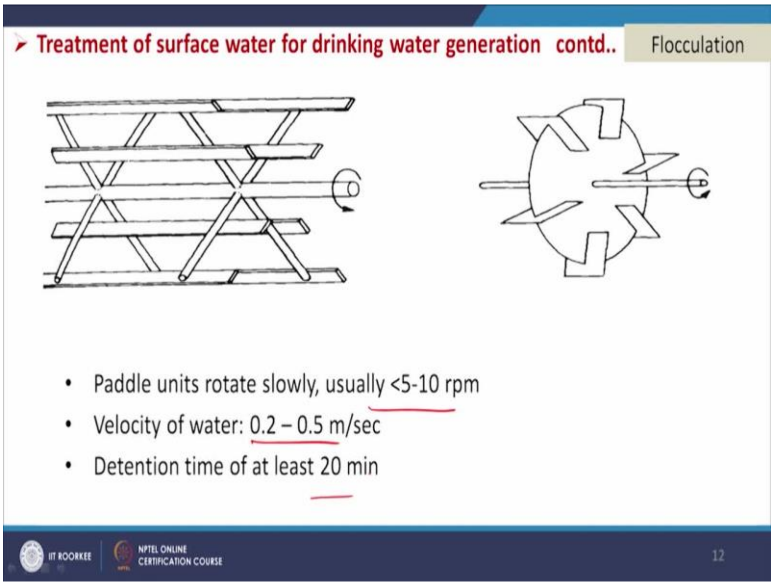

So, if we see here, the paddles are like this. So, this is our central shaft. So, these are our paddle, so paddle units rotate slowly usually less than 5 to 10 rpm and velocity of water is 0.2 to 0.5 m/s and detention time of at least 20 minutes. So, this is the conditions for flocculation.

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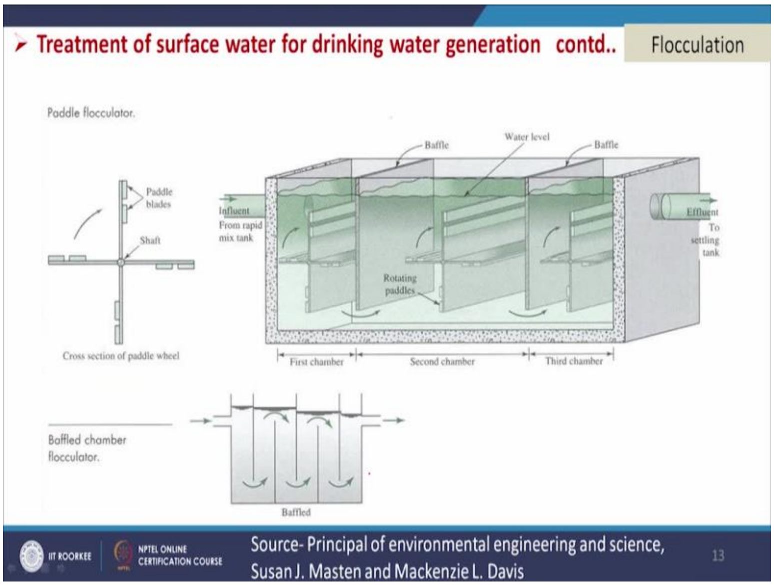

And then, this is one say cross section of paddle wheel and this is baffled chamber, flocculator also is used. So, the baffles are put inside the chamber and then say here water is coming, it will go like this like this. So, that way the efficiency improves, just we have discussed in case of micro settler in case of sedimentation unit, so similar way this incorporation of these baffles also increases the removal of the particles.

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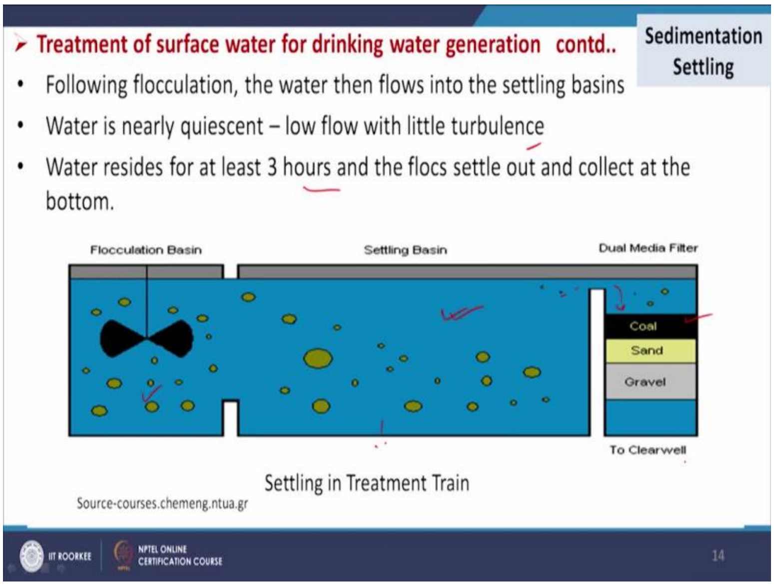

Then we are coming to sedimentation settling or tank. So, after flocculation the water then flows into the settling basins. So, water is nearly quiescent, low flow with little turbulence, water resides for at least 3 hours and the flocs settle out and collect at the bottom. So, this part is our, this is flocculation, so then it is coming to settling basins. So, flocculation, settling basins then it is coming to further filtration either we can use sand, we can use multimedia or dual media filters.

So, here just like say coals, sand, gravel is shown that is your multimedia filters. So, this part is with related to settling, so, we provide more time. So, after addition of the coagulants and flocculants, we are giving some time for the settling. So, then all solids are settled here. So, liquid is coming in this part where we are having some sand filter or multimedia filter or dual media filter. And then you will get the pure water.

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So, circular clarifiers are used in real life plants as shown in this figure. So, these are the clarifiers, we provide sufficient time to settle all the particles from this and from the top we collect the supernatant liquid for further treatment.

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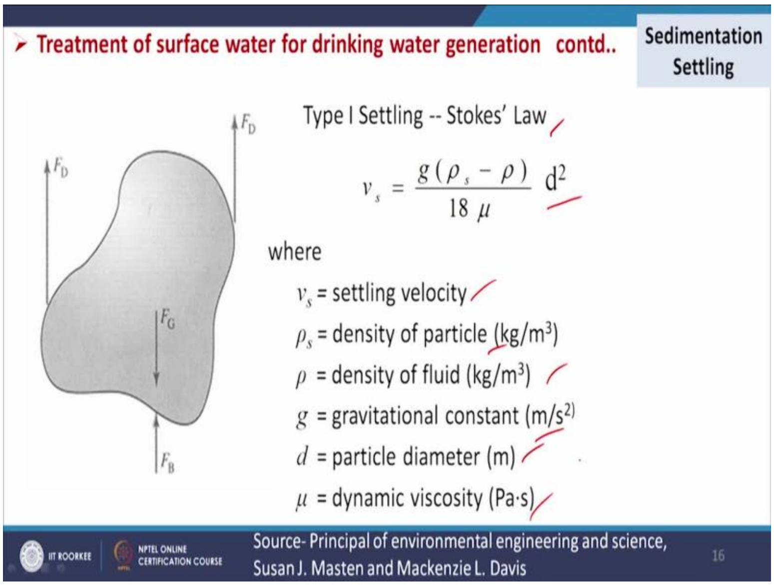

And in the sedimentation, if we want to understand the force balance, already we have discussed in our previous classes for gravity settler for air pollution control, the similar mechanism is also applicable here. So, Type I settling the Stoke's Law or Laminar Flow Zone, consideration if we have so, then

$$v_s = \frac{g(\rho_s - \rho)}{18\mu} d^2$$

So, Vs settling velocity, ρ_s density of particle, ρ density of fluid, g gravitational constant, d particle diameter, and μ dynamic viscosity, so already we have discussed this, this can be used to understand whether a particle will be settled or not.

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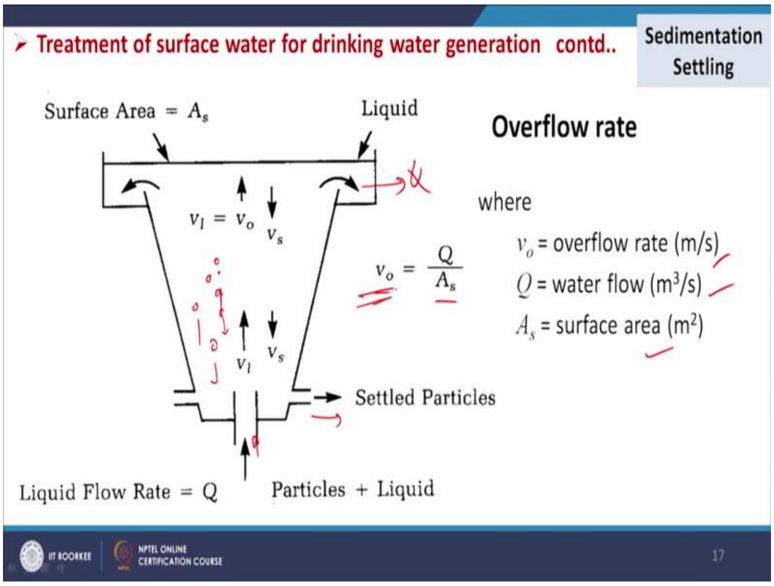

And then, overflow rate is very-very important. So, if we have a sedimentation unit in the previous class we have discussed that. In a sedimentation unit, you see we have particles + liquid is coming from this end. So, the particles liquid will go up and will be out from this and particles will settle. So, we got smaller bigger particularly settle fast and that can be collected here.

So, this, the inlet flow will give some upward movement to the particles, this particle will get some upward movement and its gravity is also working on it and that will give its terminal settling velocity. So, that the condition is that for the settling, the terminal settling velocity should be greater than this velocity is provided by this liquid velocity.

So, then that is overflow rate which we are taking that is equal to Vo,

$Vo = Q/A_s$

If you have cross sectional area As, then As*Vo, the upward direction that is equal to volumetric flow rate. So, this Q may come out. So, this Q is also going in that direction also, see if our cross-sectional area is As, so As*Vo is equal to your Q. So, this is the formula, where Q is water flow, and As is the surface area. So, this Vo is very-very important parameter, this is the design parameter of the settling chamber or sedimentation unit.

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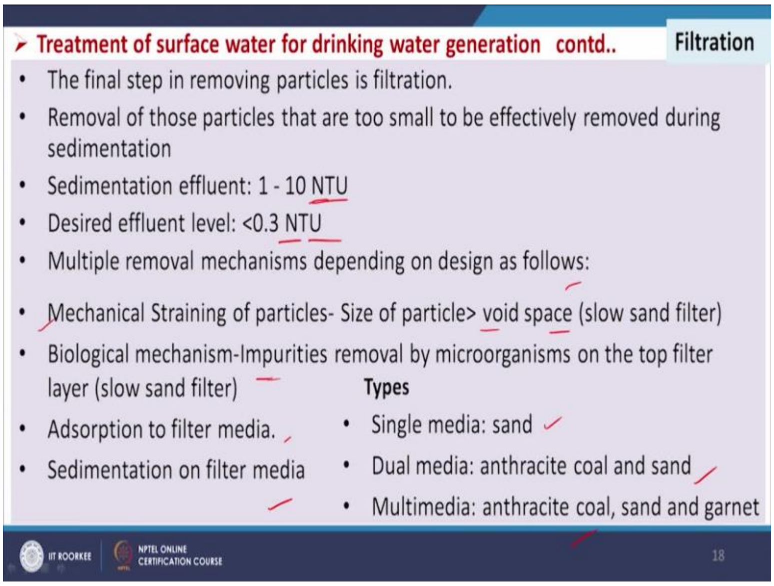

Then, after sedimentation we need a filter that we have discussed that and in this case all the tiny particles are if remaining that can be arrested in the pores, and then we will get the, we will get the clear water. The final step in removing particles is filtration, the removal of those particles that are too small to be effectively removed during sedimentation. So, sedimentation effluent is 1 to 10 NTU and then desired effluent level less than 0.3 NTU.

So, 1 to 10 NTU, now it is less than 0.3 NTU. And multiple removal mechanisms depending on the design as follows, so different mechanisms can work, let if say mechanical straining of particles. So, size of particles greater than void space that means mechanically it will be arrested and then biological mechanism. So, if we have any multimedia filter you need a dual media in that case with time microbial film will also grow and that microbes will also be working on the degradation of the pollutants and that is biological mechanism.

And then adsorption to filter media, it can be the pollutants can be adsorbed on the materials used in the filter and sedimentation on filter media. So, these are the different mechanisms which are applicable for the removal of very-very small particles available in the water after sedimentation. And then, this type of filters maybes, single media filter like sand, dual media, anthracite coal and sand and multimedia anthracite coal, sand and garnet.

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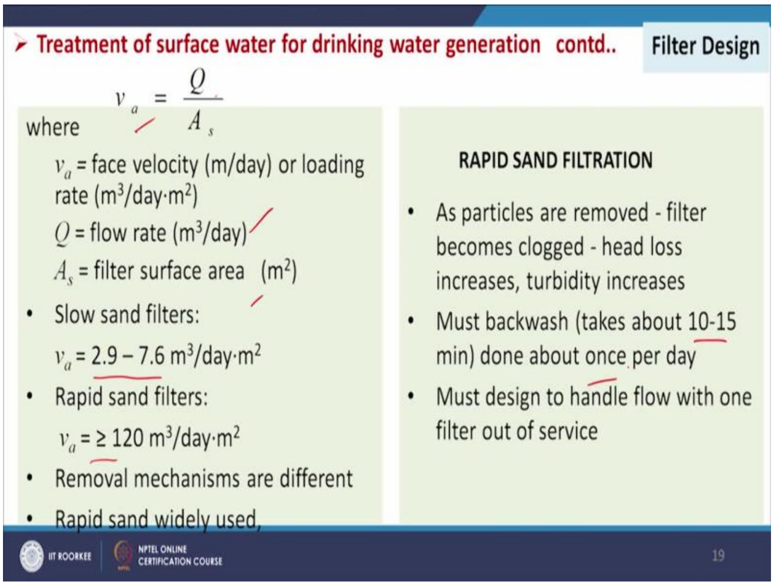

And here again we have Va

Va = Q/A

Va face velocity and we have flow rate and then As filter surface area. So, in this case, Va value normally 2.9 to 7.6 m^3/day-m^2 and for rapid sand filters, this is Va equal to greater than equal to 120 m^3/day-m^2. For slow sand filters Va equal to 2.9 to 7.6 m^3/day-m^2.

And removal mechanisms are different, rapid sand filters are widely used. As particles are removed filter becomes clogged, as when the filter unit will be used for a longer period the pores will be blocked, and there will be head loss and turbidity also increases and so, backwashing is must in this case, and that can takes about 10 to 15 minutes and done about once per day. And must design to handle flow with one filter out of service that is always some standby system is required.

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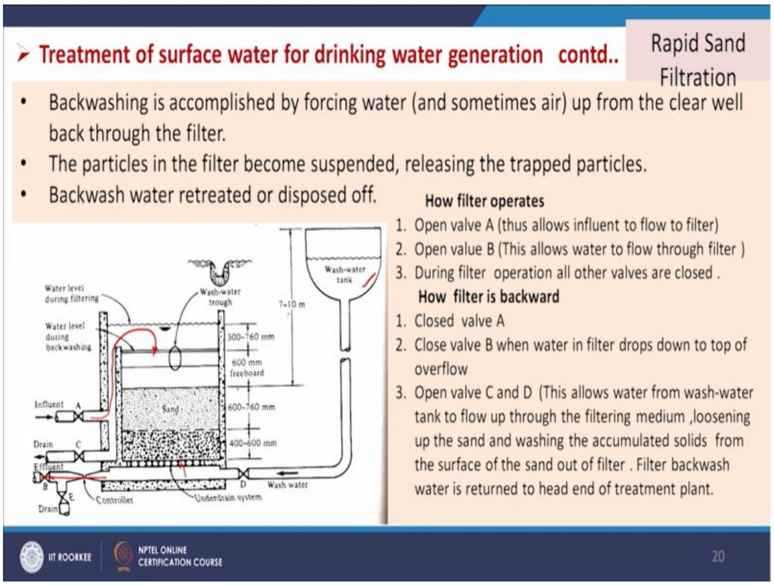

And now for the washing you see say, if we have a sand filter here, so, this is our influent it will come here and it will go through it and after treatment, it is going through this, that is B. So, this is our normal course of operation. But when we will see that some pressure drop has occurred, and we need to wash it so, we will be taking wash water, so, it will be closing this valve now and this valve will open.

So, water will be going through this and in opposite direction water will go and again it will come here and it will be going out to this, that is drain. So, this is the way, the filter unit is designed so, that the backwashing can be done with certain interval.

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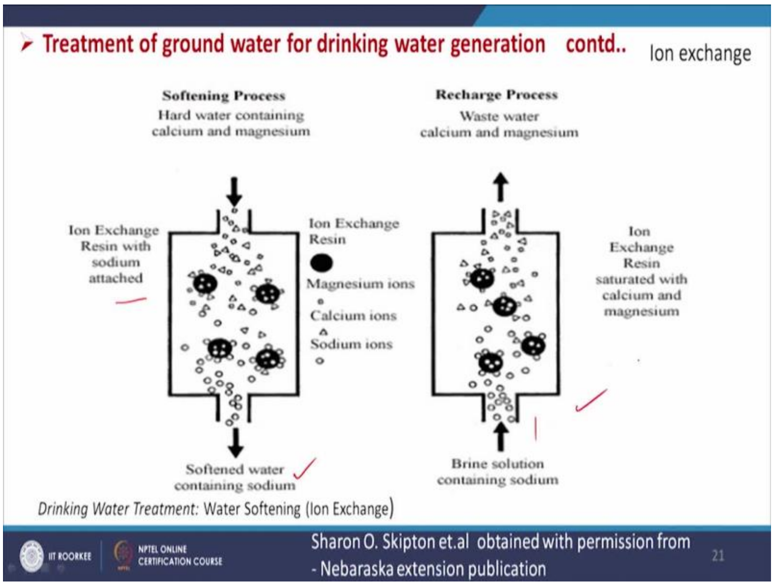

And some cases ion exchange process is also used. So, in that case hardness removal basically in case of groundwater treatment, where hardness is there in surface water also. So, this sometimes ion exchange can be used. So, in this case, so for the softening purpose water will pass through a column that is resin column.

So, that resin is basically ion exchange resin with sodium attached with resin part and then when it will pass through it calcium, magnesium will be captured and we will be getting the softened water. And for regeneration, this brine solution will be sent and this calcium magnesium will be removed and sodium will be added with the resin and this is called a regeneration, so that way, we can do.

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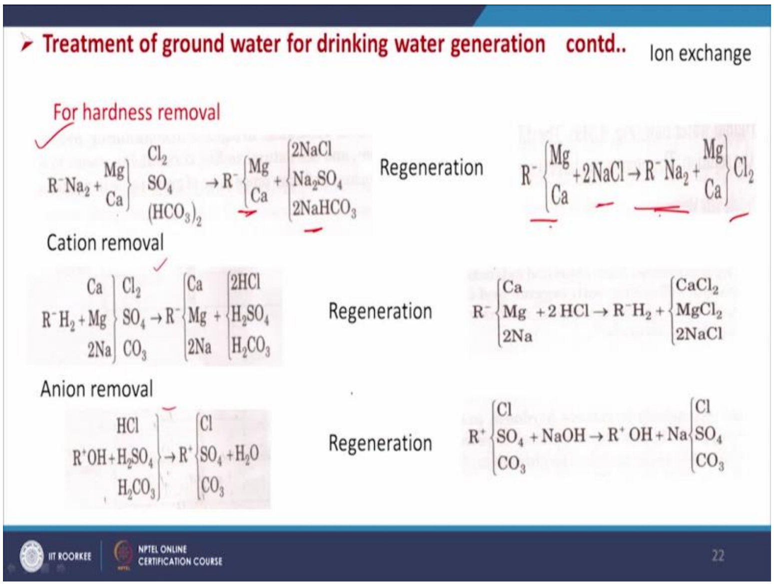

So, here the hardness removal, this is normal operation. So, sodium is replaced by calcium, magnesium, it is converted to this form and we are getting this one in the solution. And for regeneration we are getting calcium magnesium, we will be adding brine solutions and we will get this. This form again regenerated and we will be getting these into the solution.

So, this is for hardness removal. And for cation removal and anion removal also if we want to get more purity water, so these ion exchange method can also be used and these are the conventional operations and these are the regeneration, these are the normal operations and these are the regeneration operation.

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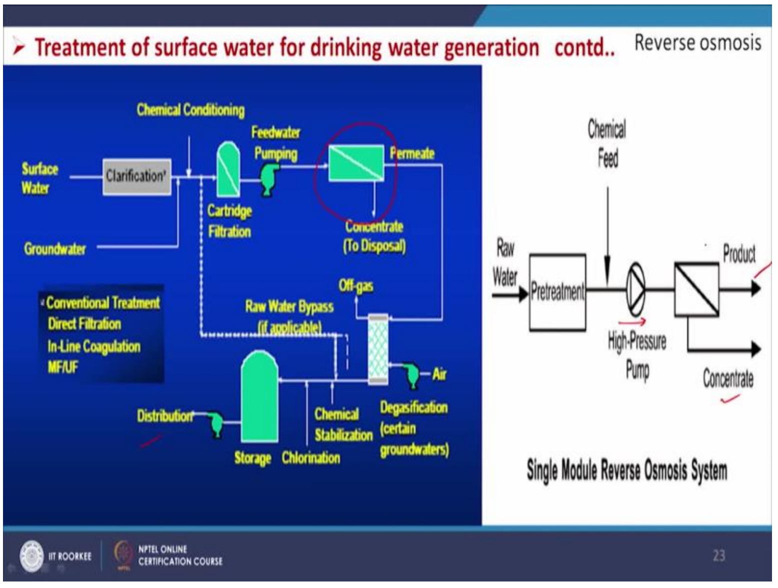

Next reverse osmosis is another method that is a tertiary treatment as you know in this case, the water after clarification it is coming and then cartridge filtered and then RO, so it is coming here, so when permeate and this is concentrated will reject it and this permeate is coming and then off gas air is passed to remove any gas remaining in the water to make it odor free. And then it is coming for the chlorination or disinfections and sent to the distributor.

So, this part, which we are considering here that is reverse osmosis. So, in this case, we are sending it through some high-pressure pump and then some membranes are there, so, these we are heating the condense it and product. So, this product is our free from all pollutants and this is concentrated one, so, this is our interest, we are interested to get this one this will be further disinfected.

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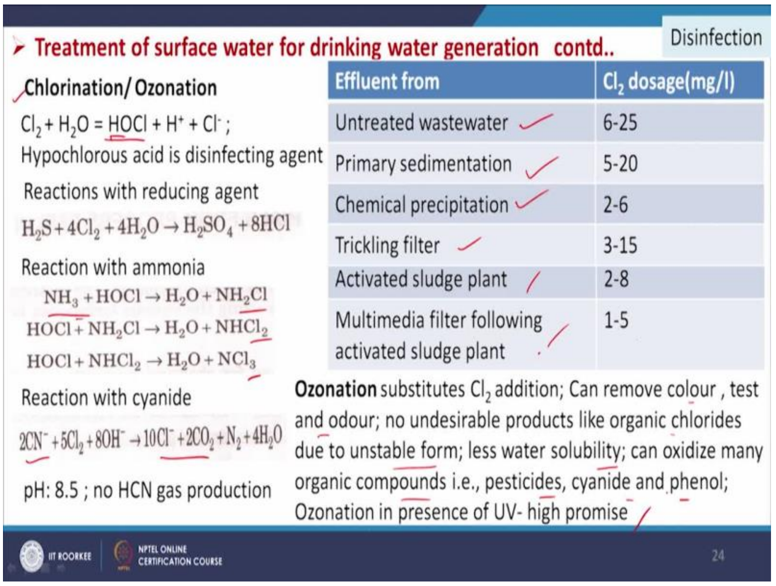

And disinfection is normally done by chlorine or ozone addition, if we add chlorine, the chlorine may react with water and may produce HOCl that is hypochlorous acid. And this hypochlorous acid reacts with NH_3 or these will kill the microorganisms and it can also react with ammonia and from this different compounds and it can also react with CN and so, this can form like this.

So, the main disadvantage of this chlorination is that, if chlorine is added in higher dose, so, HOCl produced will be in higher concentration that will be harmful to the human health as well. And some recommended doses is provided here for untreated wastewater, primary sedimentation, after chemical precipitation, after trickling filter, after activated sludge plant, and after multimedia filter, following activated sludge plant, so, then these are the chlorine dose.

As we see, as we are going to the end of the flow sheet then our chlorine dose requirement is also reducing. So, to avoid the negative impact of these chlorination, this process is normally banned in advanced countries and now ozonation is being in practice. And if we use ozone, then that problem of chlorine can be removed, ozone can remove color, taste, and odor and no undesirable products like organic chlorides due to unstable form and less water solubility can oxidize many organic compounds that is pesticide, cyanide and phenol. And ozonation in presence of UV light is a promise.

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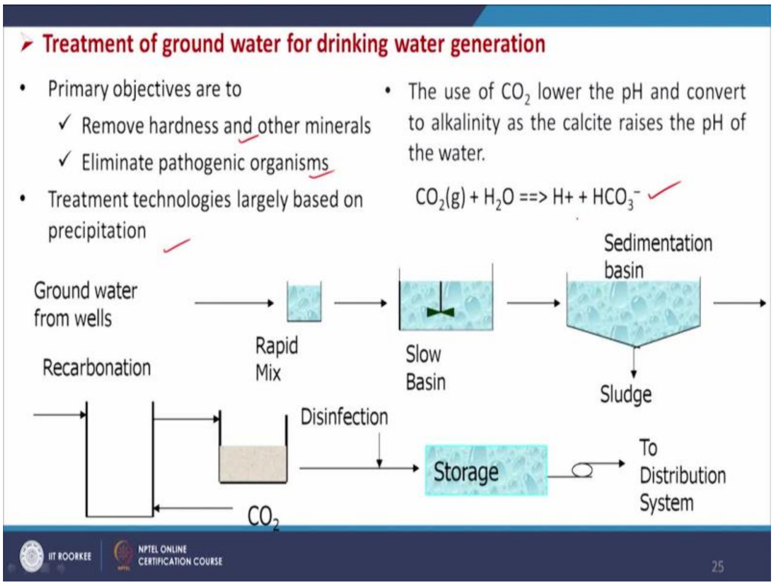

Now, treatment of groundwater for drinking water generation. So, far we are discussing how the surface water can be converted to drinking water. Now, we are concentrating on how that groundwater can be converted to drinking water in more purified form. So, here our main removal is hardness and other minerals and eliminate pathogenic organisms and treatment technology largely based on precipitations the similar flow sheet is also shown here like two surface water treatment, but here carbon dioxide addition is needed. As you have mentioned that in that case, some alkali addition takes place, so then to reduce the pH again CO_2 is needed.

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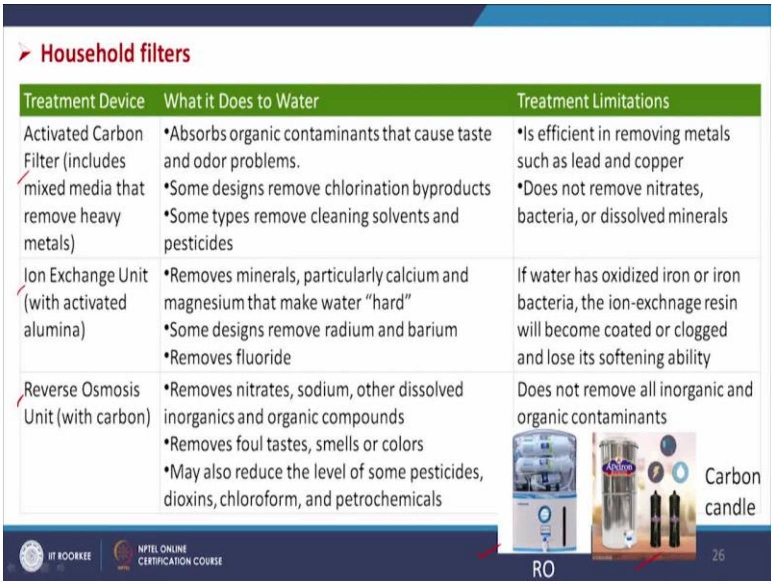

And all those discussions which we have made so far that is basically for the large-scale productions or community scale applications. Apart from that, point of use applications, that is application in each and every household, we can use some small filter units. So, those are basically activated carbon filters or maybe ion exchange units or reverse osmosis units. So, these units are also used in individual households for the treatment of groundwater.

So, they have different efficiency and as you see in this figure like RO and this is carbon candle filter. So, all these filters are available and people use for the removal of different types of inorganic and organic impurities to control the taste and odor etc. And RO is very-very superior, it can remove the dissolve TDS even to 5 or 10 ppm, but that is not recommended at least 100 ppm of TDS should be there for good health.

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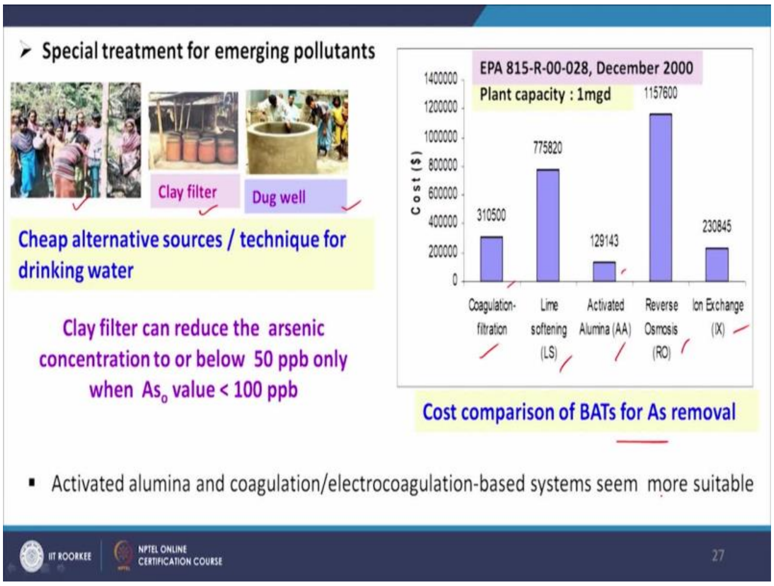

And another most important aspect of groundwater treatment is that the presence of emerging contaminants. Day by day new pollutants are being identified in the groundwater which is being contaminated by different human activities or from the natural sources like say arsenic, fluoride, pesticides, uranium etc. So, all those chemicals are emerging in nature and we need to have some special treatment apart from the discussions which we have made, those treatments may not be applicable or suitable for the treatment of this type of pollutants.

And if we see the literature, then we see that for a particular arsenic and fluoride removal. For arsenic removal, in India, people offer for different low-cost technology, but these technologies are not that efficient, and best available technologies are available as our EPA.

That is coagulation and then lime softening, activated alumina, reverse osmosis, and ion exchange these five are identified as the most promising.

And out of these, we see activated alumina and coagulation or electrocoagulation, these two techniques are very-very important and it seemed that these systems may be more suitable for the treatment of contaminated groundwater, particularly when these the emerging pollutants are available, and it can be affordable to the common mass of the poor country also. So, up to this in this class, thank you very much for your patience.