Water and Waste Water Treatment
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Module No # 09
Lecture No # 44
Disinfection

Hello everyone, welcome back to the latest lecture session. Let us look at the bigger picture, what we are trying to do and what we have done so far so that we can understand what we need to do. We are looking at providing potable drinking water. We are not talking about water that is remarkably contaminated by specific contaminant, because if that is the case there are n numbers of contaminants that can contaminate the water, we are talking about general water.

Like surface water body, lake. In that case how do we go about it? We were looking at removal of turbidity, the suspended particles as being one of the major issues. We looked at combination of coagulation, flocculation to make the particles come together and then bigger and then removal by sedimentation. Then the relatively smaller particles which are still suspended or some of the bacteria which not settled down,

You look at filtration. We looked 2 aspects- Depth filtration and Membrane filtration. We removed most of the suspended particles. And if the water is ground water and has high hardness, we will look at that relatively later. Hardness meaning calcium and magnesium relevant issues, they are dissolved ions but we will look at that aspect later. What else do we need to look at? I removed most of the suspended matter which will cause relevant issues or provide sites for pathogens or bacteria.

I need to remove that other than the general issues with suspended matter too. By looking at the process so far, we have removed the turbidity or the suspended matter, what else? We are going to look at the primary aspect when we supply drinking water. We are talking about seeing to it that the population does not fall sick due to harmful bacteria or pathogens. Now we are going to look at the last step in traditional drinking water plant which is disinfection.

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Fig 1

Disinfection; We already looked at why we need it? This was in the context of waste water treatment so I will not go into great detail in this particular session. But I will skim through it and some of the slides, we are going to reuse them because they are applicable here too. Firstly why? we will cover that; Pathogens. This is caused especially in drinking water, we need to be especially stringent.

And we looked at some of the methods there, so a quick recap. Firstly, when I talk about methods what is the principle here? Here we are going to have cells. Either bacterial cells or with respect to viruses; RNA or DNA. I need to damage them or see to it that they become inactive such that they cannot replicate. Typically, they replicate pretty fast, I think we saw this via one example in waste water treatment.

Here, I want to see to it that either I damage them or such that primary aspect is I want to make them inactive or see it that they do not replicate. Different ways; One is by adding a strong oxidizing agent such that the cell wall of bacteria at least can be damaged. Cell wall- organic matter, oxidizing agent- electron acceptor. It will go and oxidize this relevant cell wall. Then cell constituents or such will come out and you are going to have relevant damage.

We look at a class of oxidizing agent or group of oxidizing agents as disinfectants. Based on the relevant dose, relevant time, we are going to have different kinds of effectiveness for certain

kinds of disinfecting agents. Different effectiveness for different disinfecting agents or oxidizing agents and another category is UV, it is UV radiation ultra violet radiation. And we looked at germicidal action based on radiating water width 253.7 nanometers, that is something we are going to cover today.

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Fig 2

Let us see, goal; We know that we want to kill, kill is the layman's term, inactivate pathogens or sometimes kill them too. While minimizing the formation of harmful products, when I say harmful products this is disinfection byproducts which is of great relevance in the Indian context.

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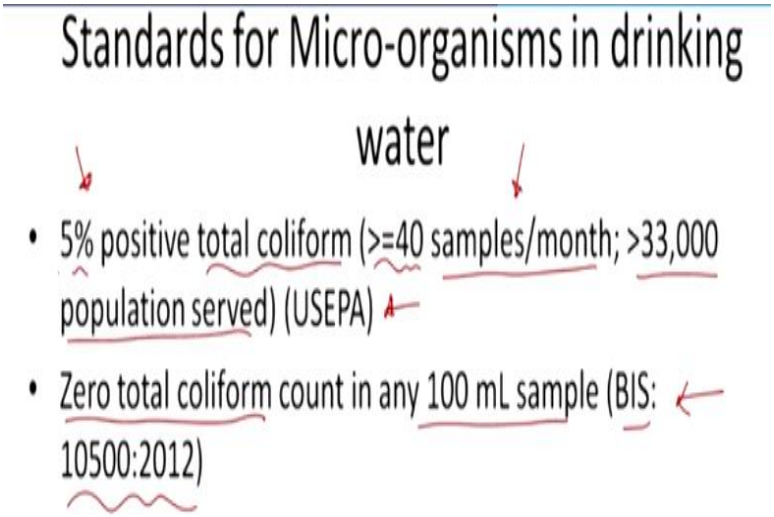

Fig 3

Let me move on, so in India for drinking water, what is the relevant standard? I think we also looked at this earlier when we were talking about water treatment. What is it we want? We want zero total coliform count, so they want zero in any 100 ml sample. Well keep in mind that it is not as if I take sample every day typically when I suspected it then I take it, there is supposed to be a regular testing but in India with infrastructure that we have and based on our needs.

We still are lacking in that aspect; we are increasing but what do we have? We have zero total coliform. Let us compare that with USEPA, so it is fine with 5% positive total coliform that seems a bit surprising. But the rider here is that you have to take more than 40 samples per month especially when the population is greater than 33,000, there are more details which we are not going into but here it specified about the number of samples per time and what is the acceptable positive here, that is something to keep in mind.

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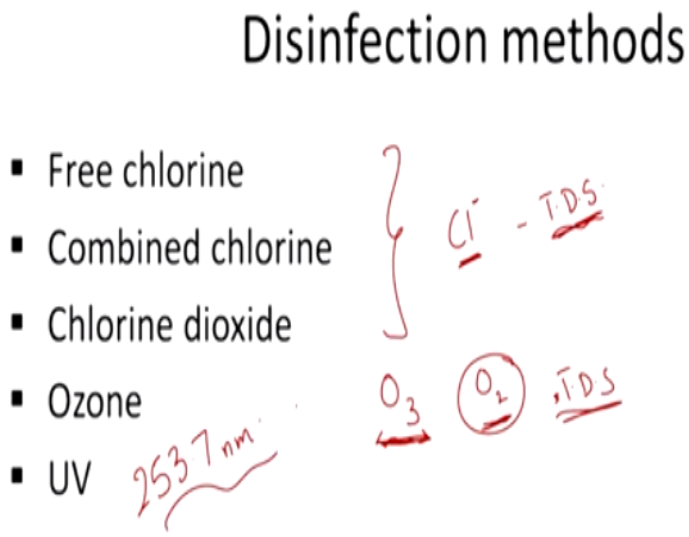

Fig 4

Disinfection methods typical oxidizing agents based on chlorine typically and then ozone O_3, reason for liking this or preferring this is it will increase the final oxygen in your water, other than that it will also not increase to any dissolved solids. All this, it will add to Cl^- and increase the TDS that is something you do not want to have in your system over time; Adding more and more results solids.

After oxidation and your existing agent being reduced to Cl^- you are going to have Cl^-, which is very much going to be dissolved in your solution. That is why I am saying it is going to increase the TDS. But with O_3, we are going to have oxygen as the final product and oxygen it is not going to lead to TDS issues, we want higher oxygen content in general. And then UV and the radiation or the wave length was 253.7 nanometers.

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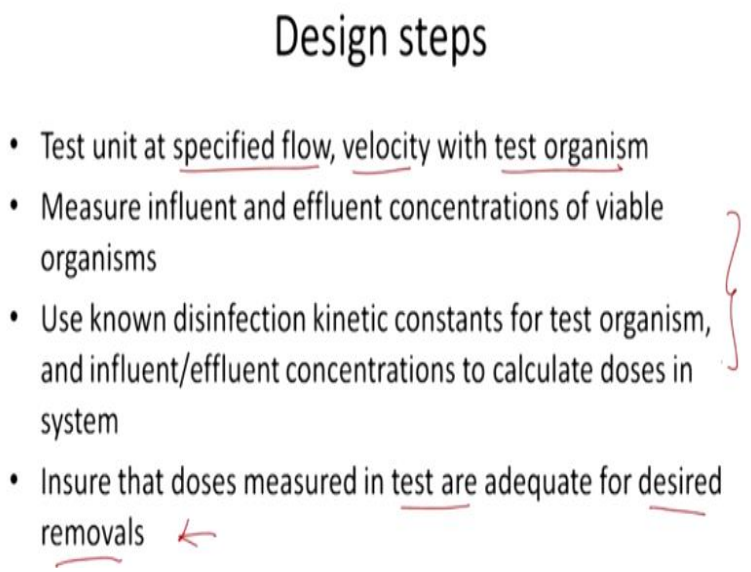

Fig 5

What are we concerned with? To test the unit at specified flow and velocity with test organism? And we covered these aspects and ensure that the doses measured in the test are adequate for desired removals, that is what it comes down to. These aspects we covered so I am going to skip this.

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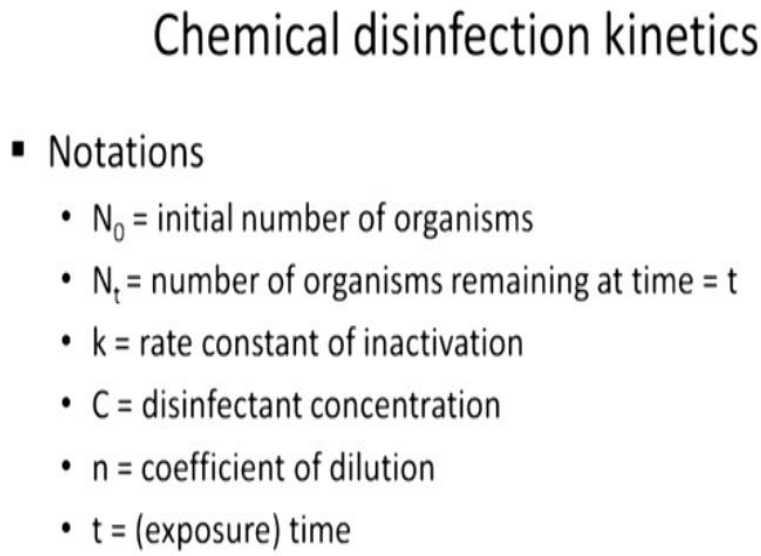

Fig 6

And we looked at different laws and the first law we looked at was only considering the concentration of the microbes and saying that the rate is going to be dependent upon the concentration of the microbes; Chicks law.

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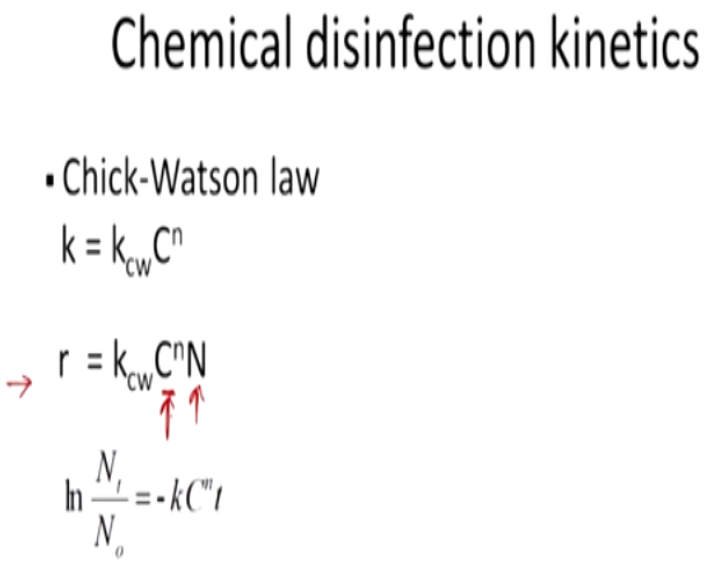

Fig 7

But in general, people know that the concentration of your oxidizing agent or the disinfecting agent is also important, that is why you are going to have the Chick Watson's law which also takes into account the concentration of the relevant disinfecting agent. Here Chick Watson's law;

It takes both the microorganism concentration and also the concentration of the relevant disinfecting agent into account and we discuss this.

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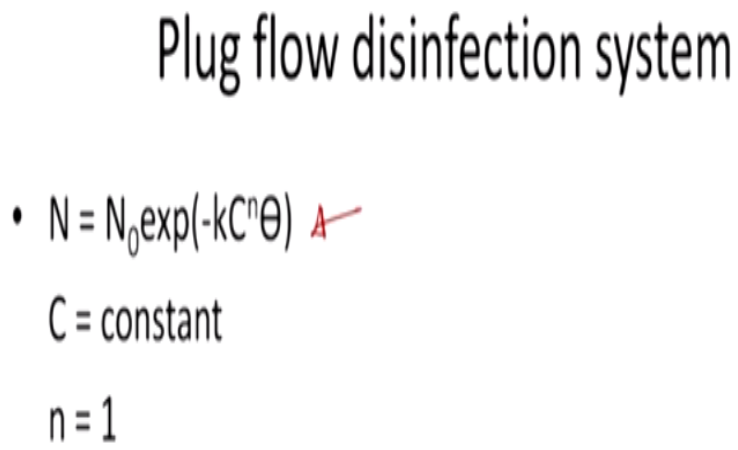

Fig 8

And we also looked at Plug flow why that is better and how to come up with this equation?

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Fig 9

Typically Plug flow is what we look for and we looked at the actual pictures of some of the disinfecting systems.

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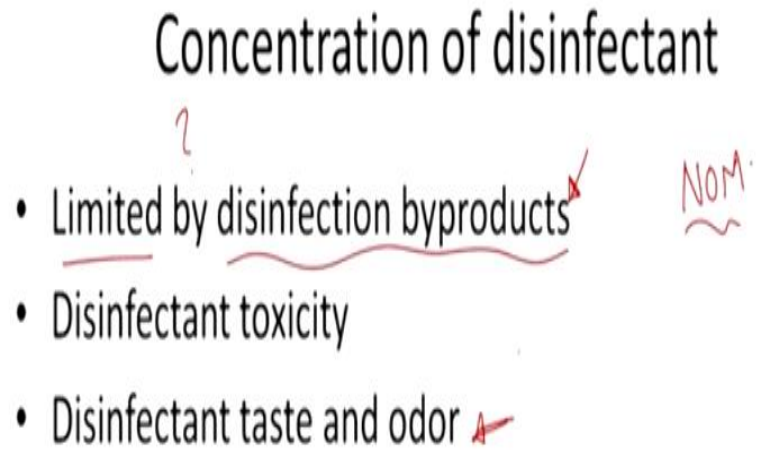

Fig 10

Primarily variable; Concentration of disinfectant is one aspect, it is should not be too high why is that? Because then it is going to react with NOM and form these harmful disinfection byproducts which we are going to discuss later. And disinfectant itself might be toxic at high concentrations, it can lead to odor and taste, this you would have seen in India especially sometimes when people had high chlorine at the treatment plant.

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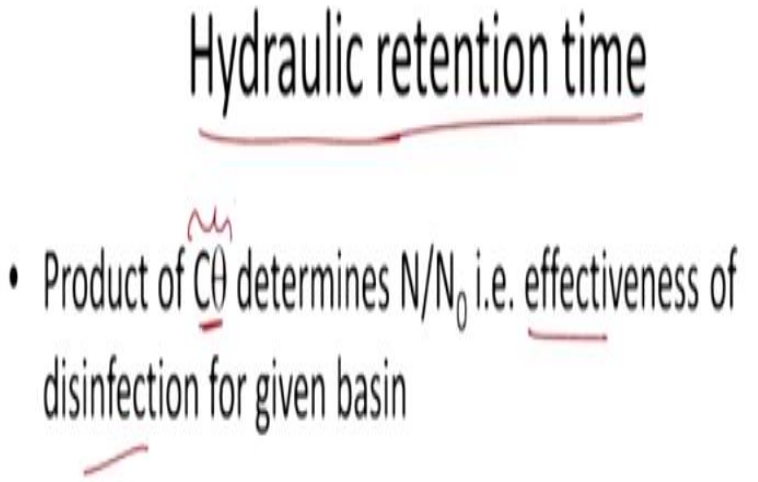

Fig 11

Retention time, we know that how much time the disinfecting agent is in contact with your particular pathogen or the water will certainly play a role that is why we also look at theta,

hydraulic retention time theta. The product of C theta determines the effectiveness of the disinfection, that is the called the dose approach; C theta.

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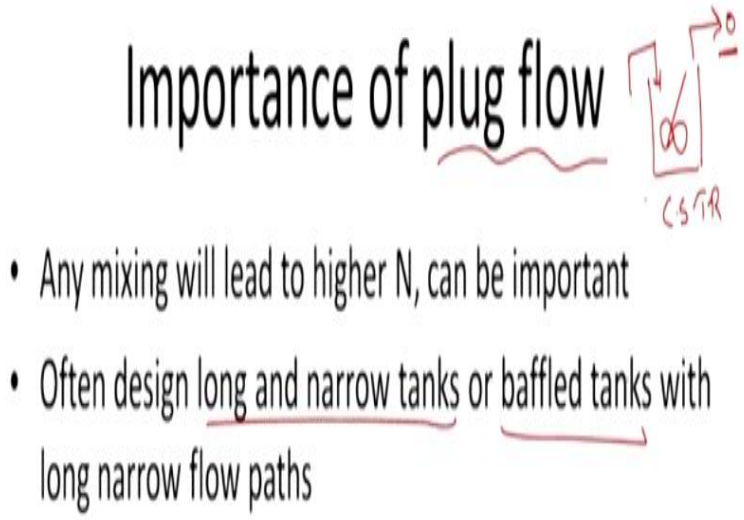

Fig 12

Plug flow, why in general? We saw that you if it is CSTR assuming that it is completely mixed. Whatever comes in if it is immediately being mixed, this is my water with reasonably high pathogens coming in and this is my effluent (refer Fig.12). Here at least Indian standards, what is it? Standard is typically pretty low, it is zero. We know that the effluent has to be zero but if something comes in and is completely mixed, it cannot really be zero.

That is why you are going to move away from the CSTR kind of systems and try to achieve plug flow systems. Typically, long and narrow tanks or baffle tanks (Plug flow systems), this is something that we discussed.

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Fig 13

Two aspects to consider; One is primary aspect which we discussed until now, we want to inactivate the relevant pathogens. Secondary to maintain disinfectant residual, why? So that you will have some oxidizing or disinfectant capacity in your distribution network so that if there is any microbial growth, it can be taken care of it or if there is any pathogen entry into the distribution network then also this disinfectant residual can take of that particular aspect.

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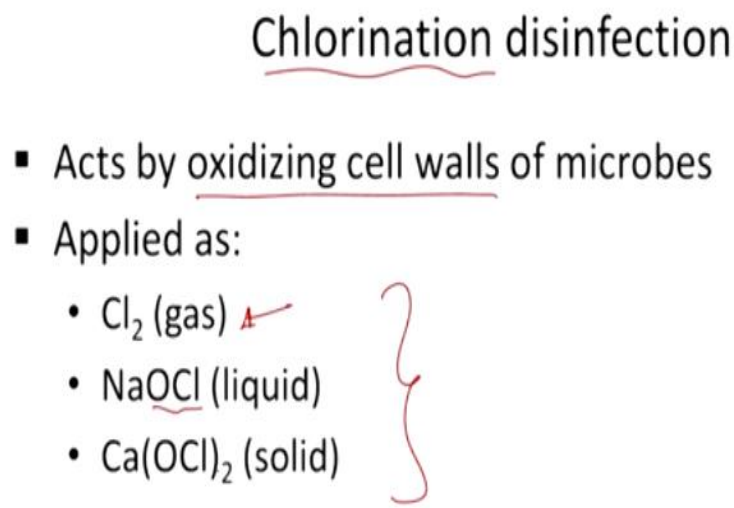

Fig 14

What is the mechanism by which chlorination gets this disinfectant done? It is by oxidizing the cell wall of the microbes typically and it can be applied in various forms as per gas itself or OCl^-.

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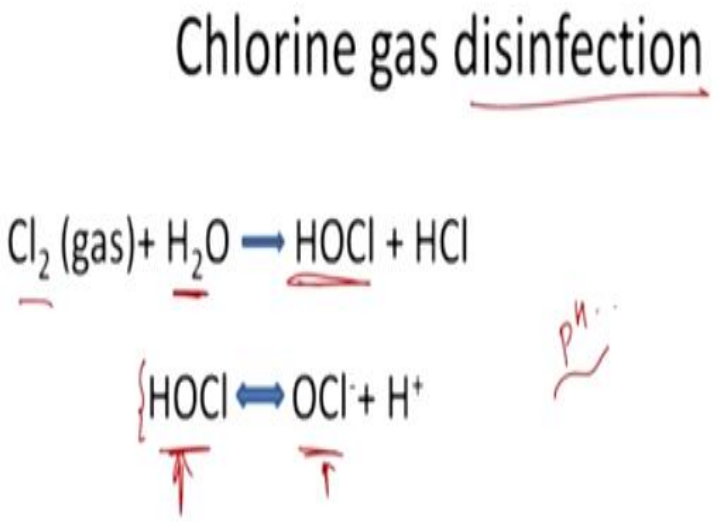

Fig 15

We will discuss this again; Chlorine gas once it is dissolved in water, it will from HOCl. HOCl is an acid and as we know it will stay in equilibrium with the deprotonated form which is OCl^-. But in general, we know HOCl is about 80 to 90 times more powerful oxidizing and disinfecting agent then OCl^-. Typically, you need to look at the pH and pKa to see to it that you have relatively reasonable HOCl without the pH dropping low, that is something to keep in mind.

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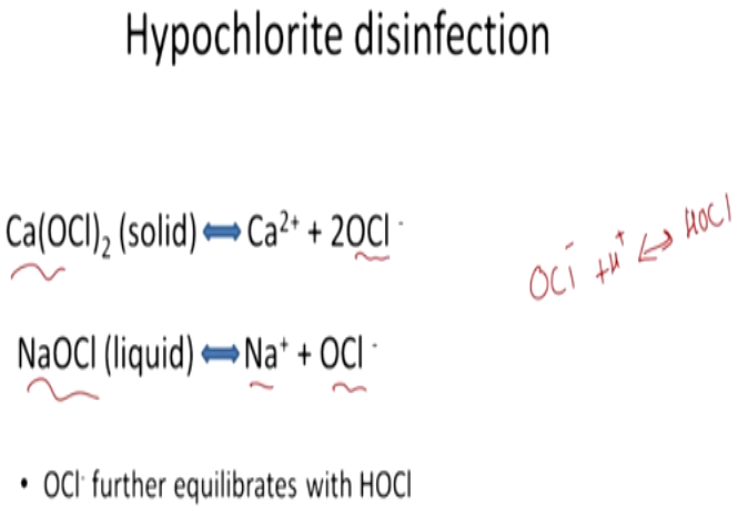

Fig 16

Hypochlorite; If I add this, as you can see after you dissolve, you are adding OCl^- and NaOCl too, Na^+ and OCl^-. OCl^-, we know it will be in equilibrium with HOCl. In effect we are trying to add the oxidizing agent HOCl, that is what we are trying to do.

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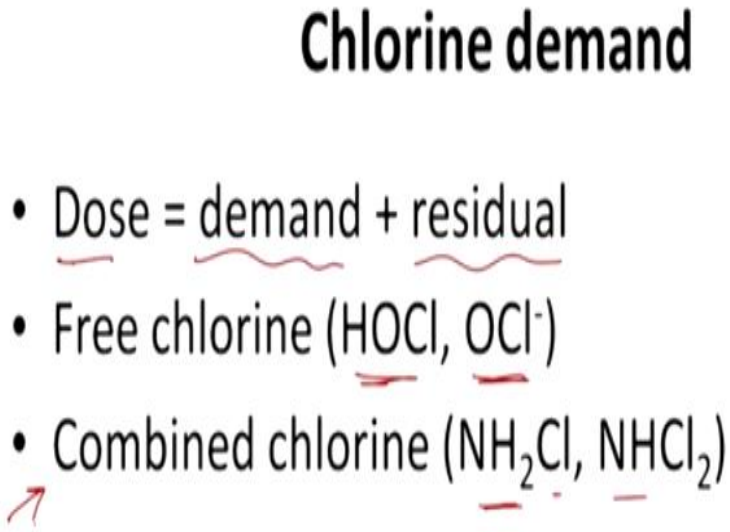

Fig 17

Chlorine demand, what is the dose equal to? The demand plus the residual. This will be the aspect the with dose, so free chorine, we are going to mention that as HOCl or OCl minus. Combined chorine, if it is combined with NH_2Cl or $NHCl_2$, we are referring to that as combined chlorine.

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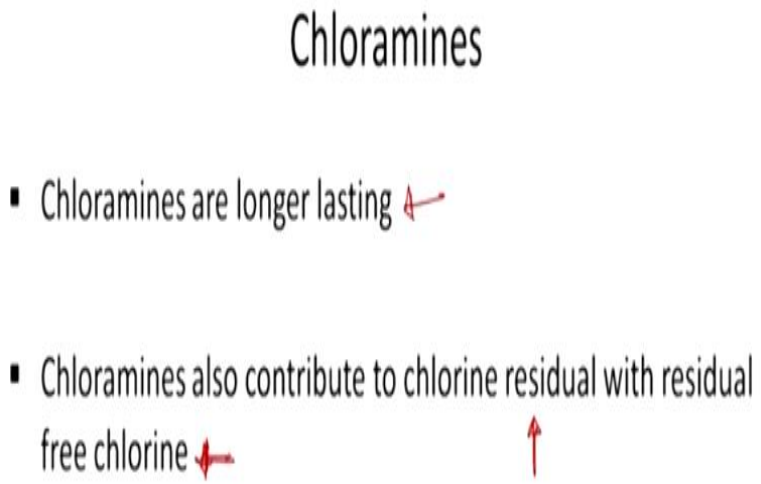

Fig 18

And chloramines, combined chloramines, typically they last long but their disinfection lethality is relatively low. Chloramines also contribute to chlorine residual with residual free chlorine as I mentioned because they are longer lasting for residual chlorination this is relatively decent.

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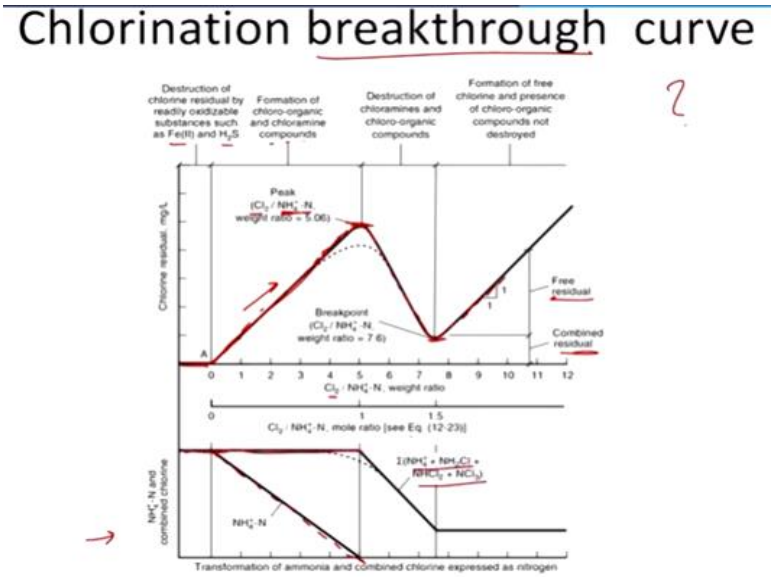

Fig 19

And one aspect we mentioned was or we discussed earlier which I am not go into great detail now is the chlorination breakthrough curve. What is this about? In water it is not just the pathogens that there, there are many compounds that can be oxidized by your oxidizing agent and your oxidizing agent is not specific, it is not going to go and disinfect what you want, it is going to oxidize whatever it can come in contact with.

You have to take care of all these other scavengers. If you have a Fe^{2+} or H_2S, which are reduced compounds, they will be oxidized by your chlorine, they will take up some of the chlorine that is what we have out here. And after that we were going to have formation of these chloramines let us see. Depending on the concentration of chlorine, you are going to have different ratios and that is what you have.

But after a certain peak or concentration of chlorine has been added, what is going to happen? You are going to have destruction of these chloramines. The final one that is going to be formed is going to be unstable so you are not going to have any chlorine left after a certain point. That is

going to decrease, that is why you see that chlorine residual is decreasing. And this is the break point (refer Fig.19) and after that whatever you add will stay as free chlorine, so that is something to keep in mind.

Free residual and combine residual, that is something to keep in mind. Why is this increasing? I discussed this well enough in the waste water relevant aspect. Here we are having the chloramines being formed and after certain point due to stoichiometry and relevant aspects the chloramines will be forming another kind of compound which is going to be unstable.

That is why it decreases. In that context, we saw this for ammonia, it depends on NH_4^+ present. Reaction of Cl_2 with ammonia, that is why NH4 plus is decreasing and here we have all the types of chloramines. Typically, that is constant and then the unstable compound is formed and that is why it decreases.

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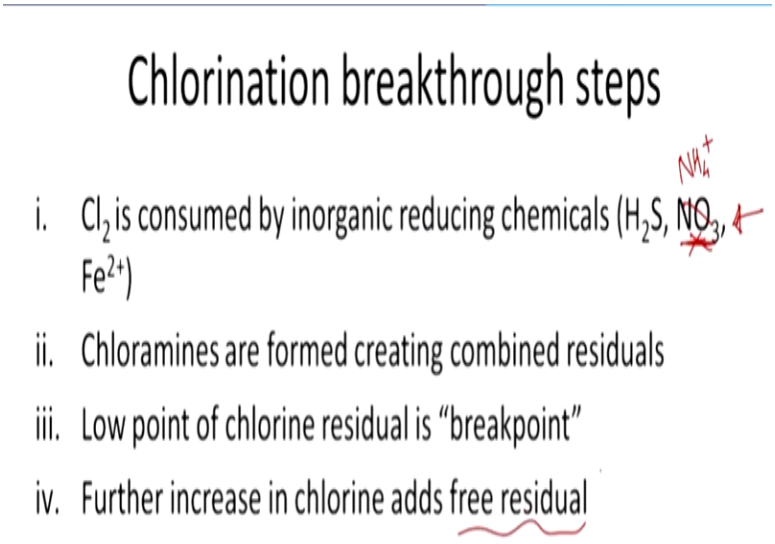

Fig 20

Chlorination break through steps; We mentioned this already, whatever reduced compounds are there, not nitrate though, H_2S and Fe^{+2}, nitrate it already oxidized compound, chloramines are formed creating combined residuals, maybe an NH_4^+ is a better option, low point is break point and after that whatever I add will stay as the free residual, that is something to keep in mind. Depending on your relevant limits you have to add that.

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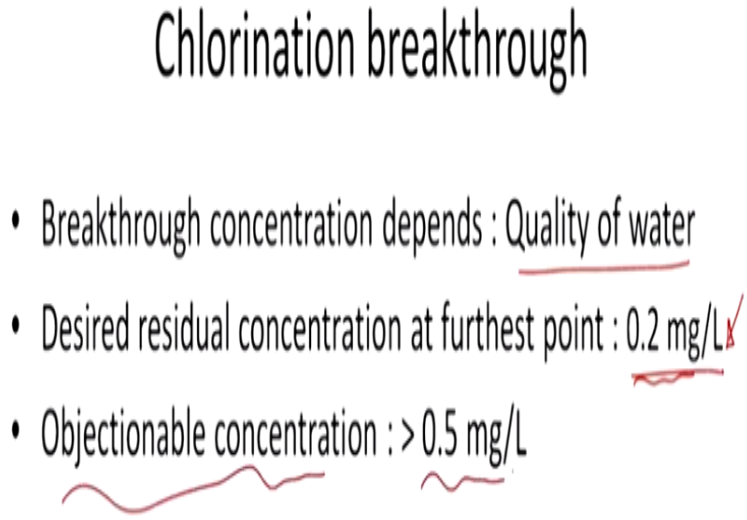

Fig 21

Chlorination breakthrough, we are done with that. What is the concentration that I have to add depends on the type of water sample from one place to other, it is going to vary. And typically, we want 0.2 at the furthest point, for example in IIT Roorkee, it was built up over time. Sometimes things pass by and there are certain sections where water or the distribution network is at a dead end.

The water spends a lot of time in that particular section no fresh water comes through unless it is used vigorously in that particular house or along the houses in that road. Here the residual chlorine might be pretty less so you have to be aware of these kinds of aspects, at least that is something I wanted to mention; Dead zones. But it is objectionable as in the chlorine residual it is higher than 0.5 milligram per liter, it becomes objectionable.

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Fig 22

Then disinfection byproducts, so you can never have too good an aspect of anything, too much of anything is bad. That is what you have. If you add too much disinfecting agent and you also have organic matter, you will have in water called as disinfectant byproducts.

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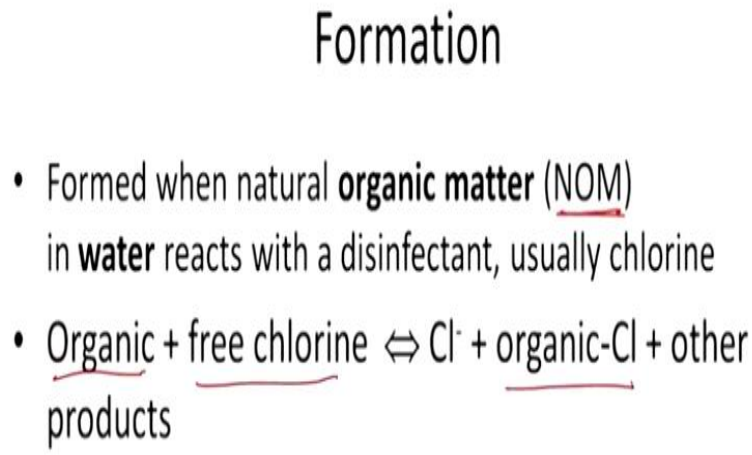

Fig 23

Formation; We discuss with this aspect more importantly. Organic matter, typically people call it as natural organic matter but India the organic matter could also be due to human causes. And then free chlorine, you have relevant organic and Cl compounds being formed.

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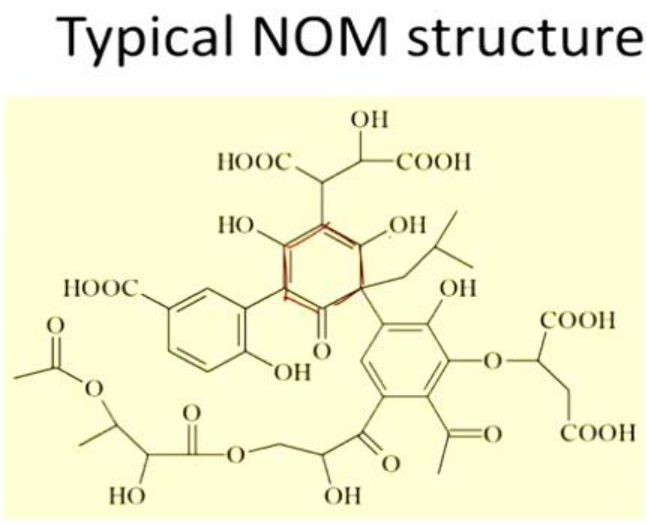

Fig 24

Typically, NOM structure (refer Fig.24) you see this aromatic structure and remarkably complex too.

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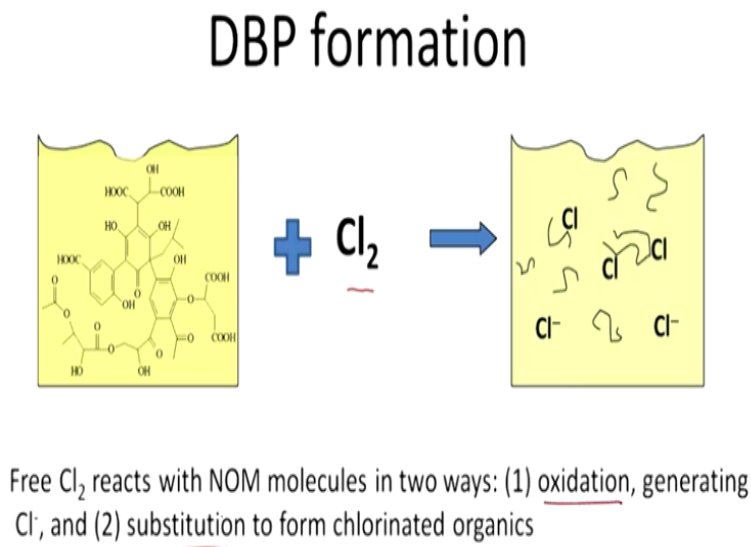

Fig 25

And so with that, you are going to have the relevant DBPs being formed. We looked at this path way earlier so I am not going to go into great detail here, oxidation and substitutions are the relevant primary steps.

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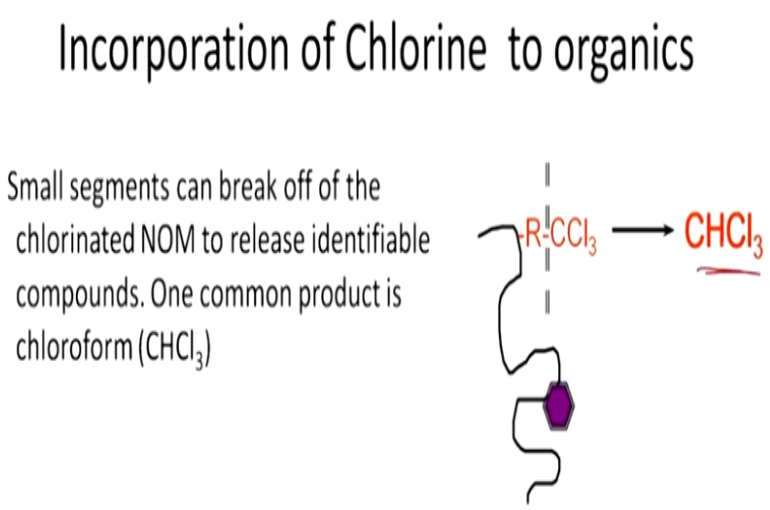

Fig 26

Incorporation of chlorine to organics and then finally we will have this like chloroform being formed (refer Fig.26).

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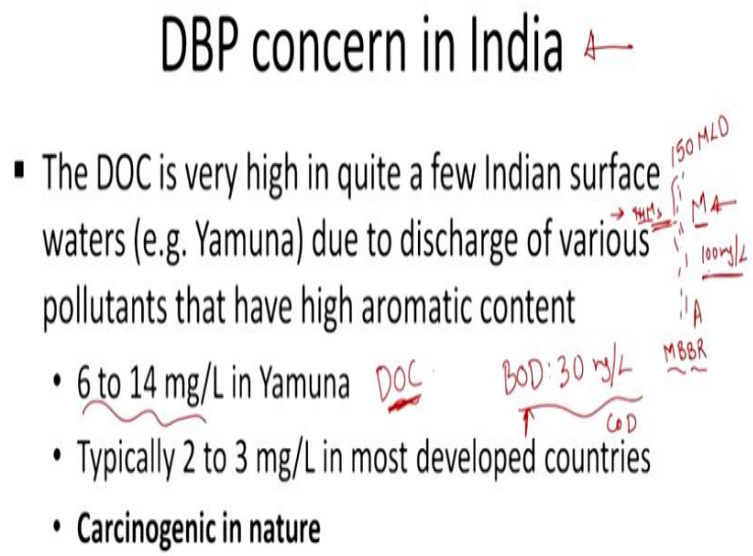

Fig 27

And as I mentioned this, I mentioned in the case of waste water but I should have mentioned this in the case of water, why do I say so? I should give the background here and spend some time. Here I have Mathura and here I have Agra and we have 150 MLD treatment plants here and what is the issue here? Downstream of Delhi due to various reasons historical, explosive growth, infrastructure not being able to cope up with the relevant population influx.

And also, the kind of technology is being used and more importantly people also not contributing to laying the distribution and sewerage network, we have Yamuna being relatively polluted. This water being taken up at Mathura, it has high organic content- 6 to 14 mg/L DOC (Dissolved Organic Concentration). BOD is around 30 mg/L and COD will be relatively higher.

And the Fecal coliform or total coliform will be in lakhs if I am not wrong, it is pretty high. What is happening? The traditional one as in based on the steps, we discussed until now coagulation flocculation, sedimentation, filtration and disinfection, it leads to considerable THMs or Trihalomethanes or disinfection byproducts being formed. But I was told that mostly the people use it not for drinking but for other purposes, for drinking they have other sources.

But one aspect is THMs, the primary root via which it affects is not just drinking water so when I take hot water shower, skin is also relatively warm, it is can permeate through my skin and affect my body. But in India there are lots of other issues to be concerned about so as of now THMs or DBPs are not at in great priority. But soon as our standards improve, I am sure that these aspects will come into the picture.

But I am only mentioning couple of plants, there are many other plants and one has to measure them. In Agra though, they were not using a traditional one they were using a MBBR or moving bed biofilm reactor. That was doing a very good job with respect to by removal of BOD and COD. But even there I saw that the DOC was pretty high and the DBP concentration was still remarkably high as compared to or as much high as the one in Mathura where they had the traditional treatment plant.

That is something to keep in mind and the chlorine dozes that they were having at Mathura, that was required was pre-chlorination, they were chlorinating it at almost 100 milligram per liter think of that initial chlorination so that that they would not have microbial growth in their relevant sedimentation tank; 100 milligram per liter. You can understand the dozes that they are having.

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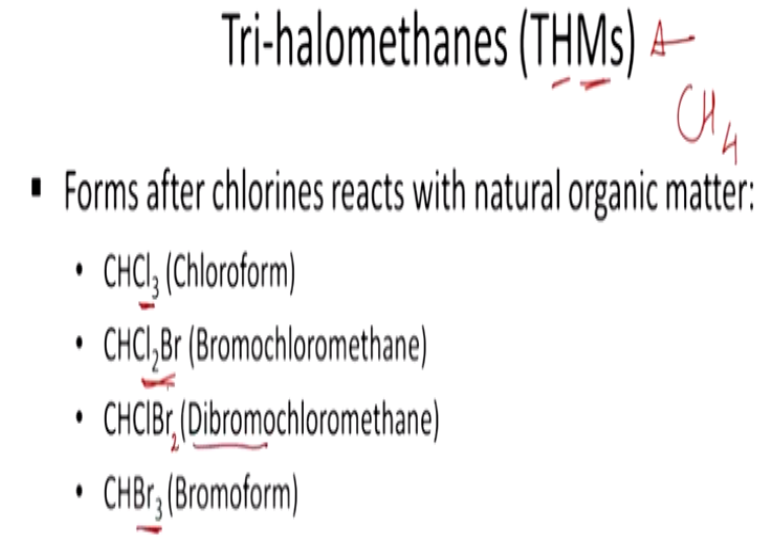

Fig 28

Types of DPBs; The ones that are regulated in India are the trihalomethanes, CH4. when you have trihalo, let us just look at it, so halo means 3 halogens, same case 3 halogens. This should have been up to dibromo, so 3 halogens trihalomethanes, so this is one thing.

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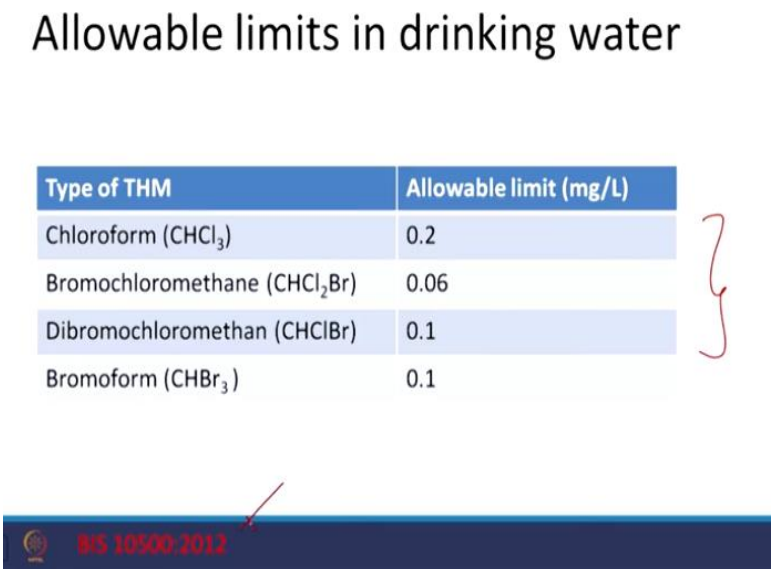

Fig 29

And in India we have the standards for this, this is from BIS as mentioned here.

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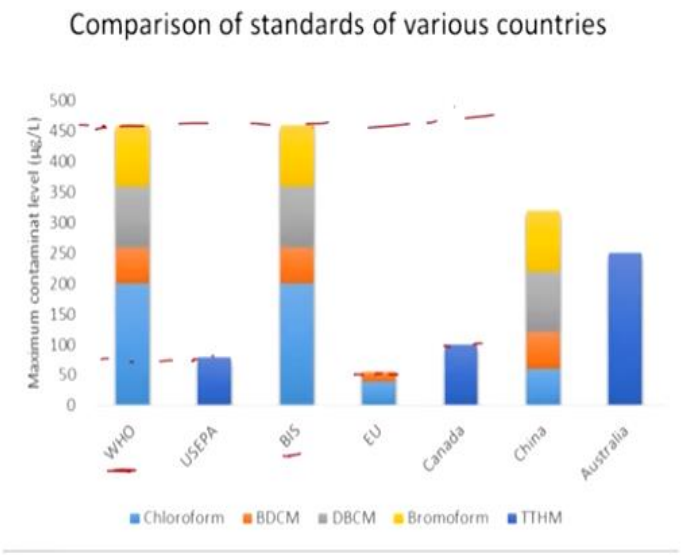

Fig 30

But in this case one aspect to consider is I am just comparing the standards of the relevant DPBs as given in various countries, what did we adopt? We adopted whatever WHO is suggesting as you can see that is the highest that people are following 40 PPB and USEPA what is it like? 50, 75 or something EU much lower and Canada too pretty low, Australia too. You see that we do have standards but our standards relatively more lags.

But we are developing country, there are many priorities, so that is one thing as technology comes in people can afford it and we have the capital for the relevant expenditure, we will have to look at it. But one aspect is to have citizens and students who are more technically competent and more aware, that is the job we are trying to do here.

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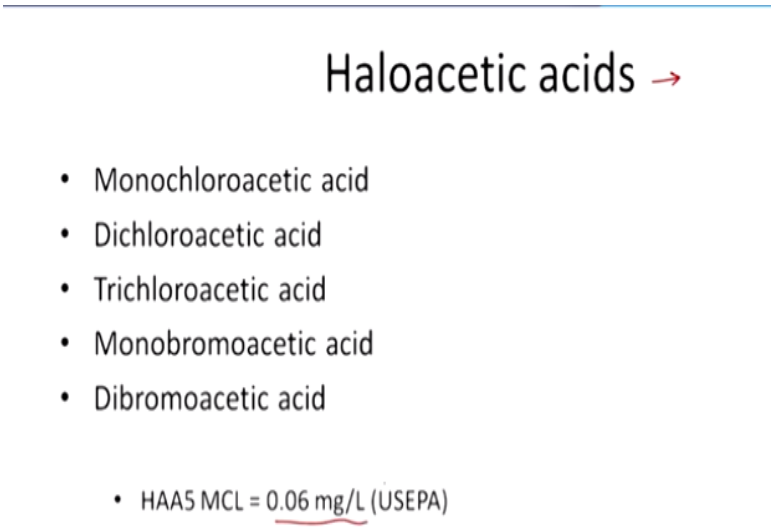

Fig 31

And another set of DBPs which is typically not regulated in India, that are the Halo acetic acids. monochloroacetic acid, dichloro, trichloro, monobromo and so on but in India they are not regulated, in the US and other countries they are though. And as you can see it is pretty low; 60 PPB or 0.06 milligram per liter.

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Fig 32

Chloramines and combine chloride let us come to that.

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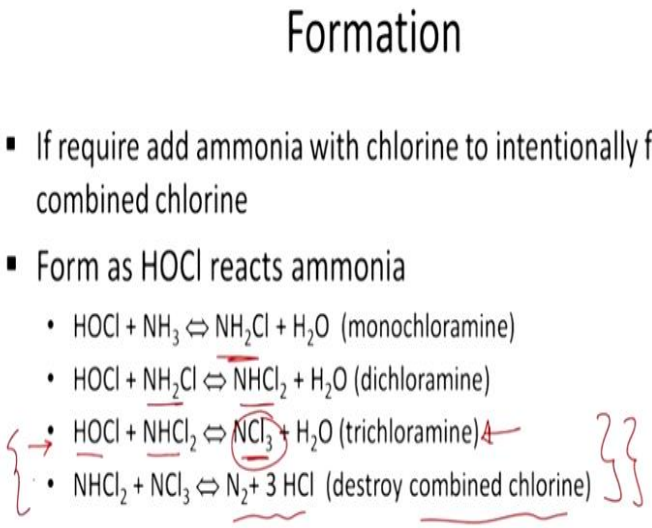

Fig 33

I discussed this earlier, so if you require add ammonia with chlorine to intentionally form combined chlorine. Anyway, this we discussed so how do I do that? I can do with mono-chloramine, we will typically add these as the relevant oxidizing or disinfecting agents. Here we have that, but we also mentioned the aspect, this (NCl_3) is the one that is unstable.

I will come back to that at breakthrough curve, so if I increase the chlorine concentration or HOCl concentration beyond a certain point, it is going to start reacting with $NHCl_2$ and form NCl_3 which is remarkably unstable and it is going to destroy the combine chlorine, that is something to keep in mind. The concentration at which you are going to maintain it is important.

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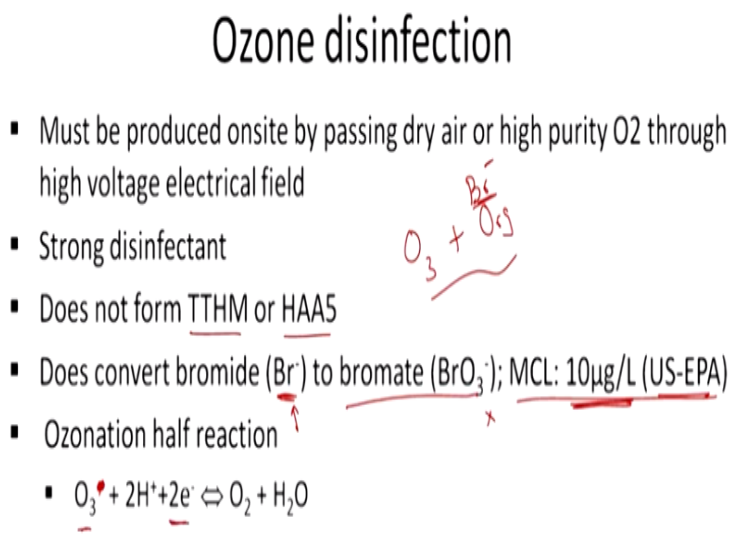

Fig 34

As I mentioned it is pretty weaker, particularly for viruses we discuss this earlier but one advantage is it does not form the trihalomethanes. But it is unstable, this is an aspect; Combine chlorine residual often added before distribution. Looks like this is unstable it will not provide long lasting residual so combine chlorine residual has to be often added before distribution.

Or a different type of chlorine has to be added here, that is something to keep in mind when looking at these chloramines. Ozone disinfection, we mentioned this one advantage is it does not form trihalomethanes or Halo acetic acids but forms something else which is harmful. It converts bromide if it is present in water, if bromide is present in water. It is not the issue of ozone reacting with organic content though. It is ozone reacting with Br^-.

If Br^- is present, we need to be concerned about bromate but in India we do not have any standard for this but this is toxic compound if not carcinogenic, we can check that. But USEPA does regulate that and as you see it regulates it at 10 PPB which his pretty low. Ozonation one of the strongest oxidizing agents out there probably the second strongest. This is the relevant half reaction (refer reaction on Fig.34), very strong electron acceptor.

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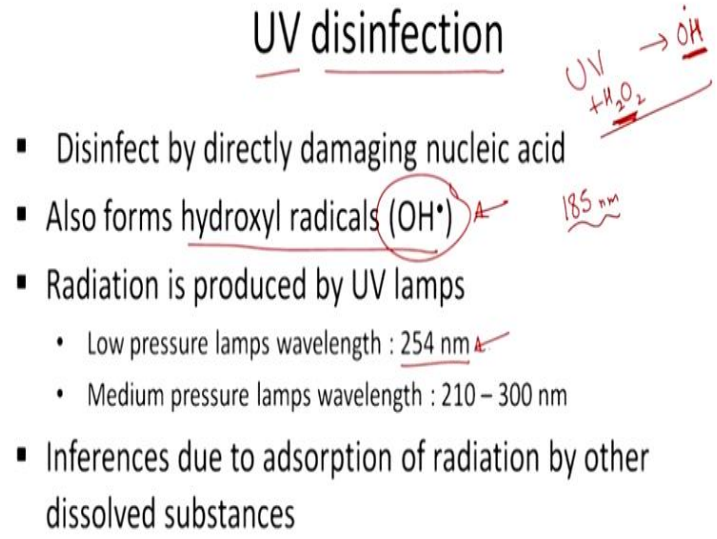

Fig 35

The next kind of disinfection is not based on oxidizing agent but ultra violet radiation. And low-pressure lamps, monochromatic, they emit radiation at 254 nanometers. And this particular wavelength is absorbed by the RNA or DNA of viruses and you are going to have inactivation of these viruses, the process or the mechanism, we explained earlier when we were talking about waste water treatment.

And though we say that it can also form hydroxyl radicals, it forms hydroxyl radicals when you have 185 nanometers wavelength but this is rarely used. But UV can also lead to formation of hydroxyl radicals, the strongest oxidizing agent known probably when we add hydrogen peroxide but that is a different aspect but I wanted to mention that, why am I mentioning this?

If you want to remove any of the persistent organic pollutants then you will have to add this hydrogen peroxide which will lead to formation of this very strong oxidizing agent which can degrade this persistent organics but that is a different aspect but I want to mention that; Typically, we look at low pressure and 254 nanometers.

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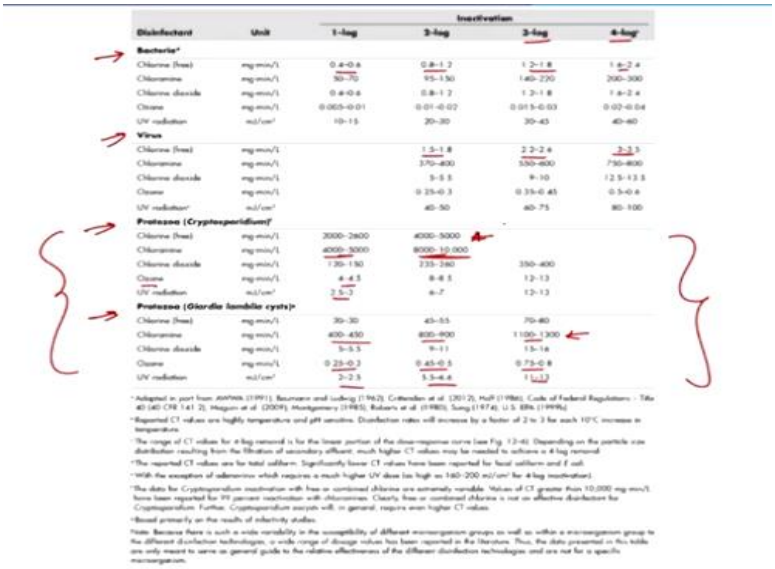

Fig 36

As you can see here, we have bacteria and virus. Here we have different disinfectants and comparison here (refer table Fig.36), we already looked at this earlier but one aspect to keep in mind is the relevant lethality. For example, look at ozone, this is 1 log 99.99% removal. For Protozoa and Cryptosporidium that is of conceptual issue in India and Giardia Lamblia.

You see that it is relatively lethal; Ozone or even UV but with chloramine, one of the weakest, you see remarkably high doses which are almost impossible to add. The choice of your disinfecting agent should certainly depend upon what it is you are trying to achieve. If you are concerned with the protozoa then chlorine or chloramine certainly are not maybe a great way to go about it.

With viruses, you see that chlorine does a decent job and even for bacteria it does a decent job. But with respect to protozoa which again is pretty prevalent in Indian context, chlorine as you can see does a great job with respect to Cryptosporidium.

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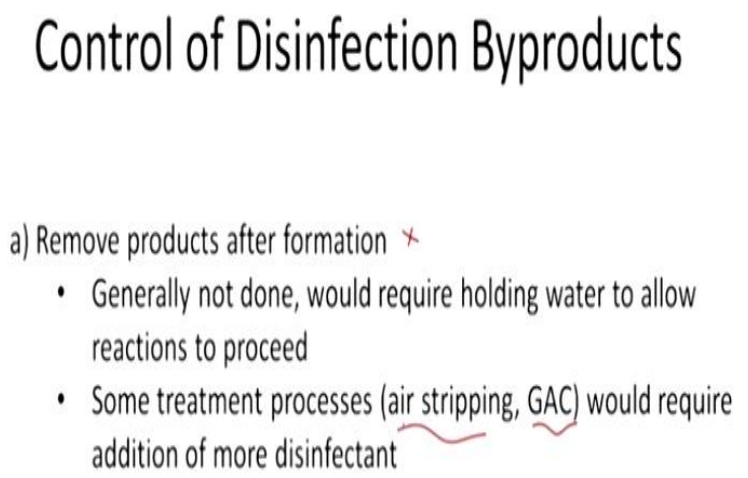

Fig 37

Control of DBPs; After forming the trihalomethanes or Halo Acetic acids, it is difficult to remove them. Typically, you can have organic compound or hydrophobic compound, adsorption onto GAC but that is like creating a problem and then trying to solve it. Typically, this is not done. Generally, what do we do? Air stripping, GAC, addition of more disinfectant, that is not something that is usually done, what do we do?

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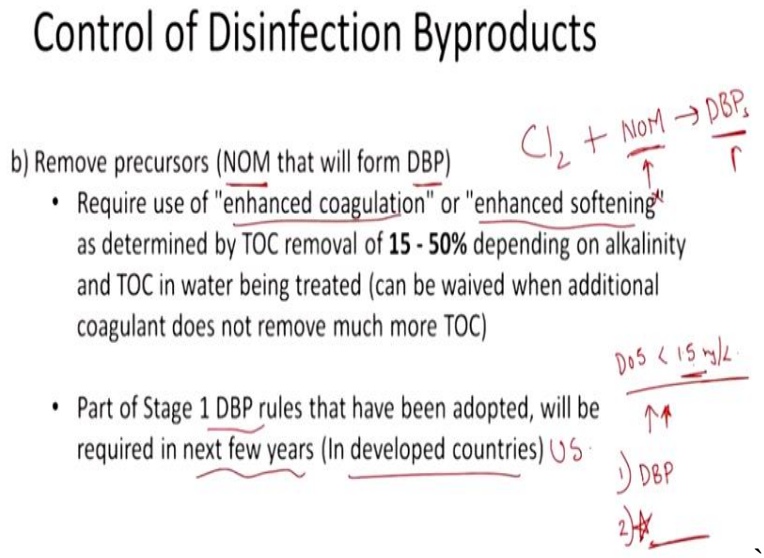

Fig 38

We remove the cause or one of the building blocks for formation of DBPs, we know that Cl_2 or the disinfecting agent and NOM or organic matter will lead to formation of DBPs, so rather than

trying to tackle this, people try to tackle this and remove this, that is what we do, Remove the precursor. And here there are different ways; One is enhanced coagulation or enhanced softening which will remove some TOC.

That is one thing to keep in mind. Different 1 one rules, in developed countries especially in US. They are going to implement more stringent conditions with respect to NOM rather they are already implemented it and they talk about DOC being relatively less than 2 or 1.5 milligram per liter which is not the case in India. But in India, I think this should be adopted because of 2 reasons.

One reason is if it is high then the DBPs concentration will be high and secondly and this is pretty important. In India, now we have these persistent trace organic compounds which are synthetic in nature. For example, I am taking a pharmaceutical compound, only 20% is used 80% goes through (depends, I am just giving an example). And that is not good for either the aquatic ecosystem or even if it goes to the food particle and enters the food chain

And enters my system, it is not good for me either. For removing them, typically DOC is a better parameter. But we are yet to catch up in that aspect.

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	TOC Removal (%)		
	Source Water Alkalinity (mg/L as $CaCO_3$)		
Source Water TOC (mg/L)	0 - 60	60 - 120	>120
2 - 4	35.0	25.0	15.0
4 - 8	45.0	35.0	25.0
> 8	50.0	40.0	30.0

Fig 39

Depending on the alkalinity, your TOC removal also will be dependent. But just some thumb rules out here. If the source water is this and relevant alkalinity, what is the TOC percentage removal you will expect.

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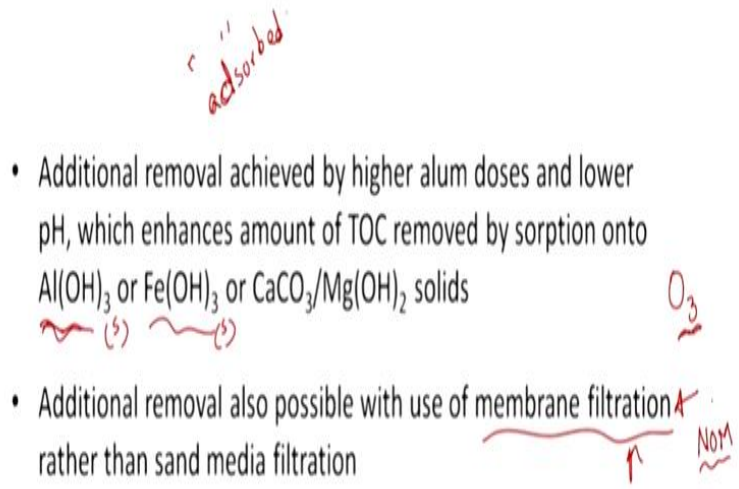

Fig 40

And some will be removed when we are looking at formation of the relevant precipitate because organic carbon or TOC will be adsorbed onto this solid, that is something to keep in mind. Or you can use membrane filtration rather than sand media filtration but one issue with membrane filtration which we already discussed earlier was, if we add have high NOM it will lead to fouling considerably.

That is one aspect and that is why as I mentioned I like ozonation but in India, yet to come up in fine great acceptance. But ozone will degrade the NOM, that is one reason why I like usage of ozone.

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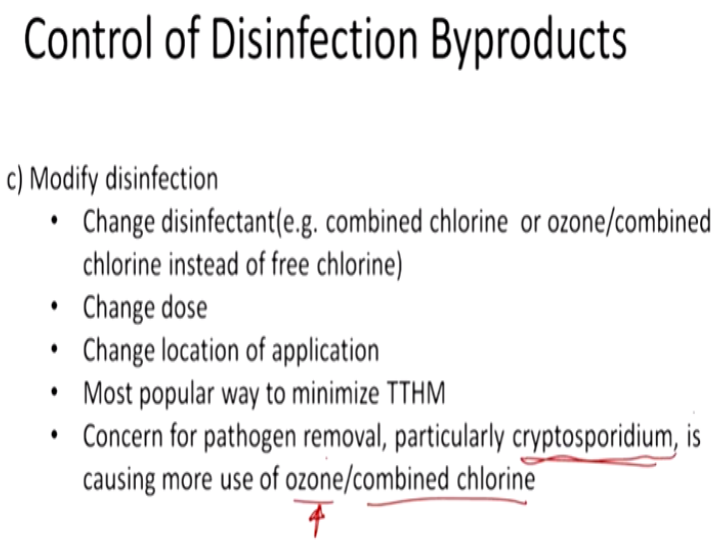

Fig 41

You can modify the type of disinfection, change the dose but not a great idea; Change the location of application and concern for pathogen removal, particularly Cryptosporidium is causing more use of ozone or combined chlorine. But typically with ozone, that is what I mentioned for Cryptosporidium protozoa in Indian context. With that I am done with disinfection and we are done with the traditional water treatment plant trying to treat surface waters.

But what else are people trying to do? Because now the challenges are not what we faced earlier, we have multiple other challenges and technologies tries to catch up with these challenges and so these are aspects we will look at it in from next session but before we go into the more or relatively recent advances or not very recent though, they have been invoked since one decade or two if not, we will look at lime soda softening especially relevant when we are talking about hard ground water. With that I will end today's session thank you.