Water and Wastewater Engineering
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Lecture # 15
Disinfection

Last few classes we were discussing about various processes in water treatment to remove the solids present in the water and we have seen plain sedimentation coagulation flocculation and even softening to remove hardness and we discussed in detail about filtration. Today we will discuss about disinfection. because even if we remove the solids the physical and chemical characteristics of water is very good, the water is not fit for drinking unless the bacteriological quality is safe or bacteriologically the water safe. We have already discussed that bacteriological quality is the most important water quality parameter. The reason is, if a single pathogen is present in the water and if it enters in our body there is a chance of getting diseases. So it is very very important that the water whatever we are supplying or whatever we are drinking is bacteriologically safe. So, for that purpose only we are going for disinfection. So we will see what this disinfection is.

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Disinfection is the process in which pathogen organisms are destroyed or inactivated. Disinfection is only destroying the pathogenic organism but it is different from sterilization. Sterilization means killing all type of organisms whether it is pathogen or non-harmful microorganism we are killing everything in sterilization so there is a distinct difference between disinfection and sterilization.

But though we tell that in disinfection all the pathogens are killed but most of the time it is nothing because we don't have any measures to see whether all the viruses are getting removed from the water.

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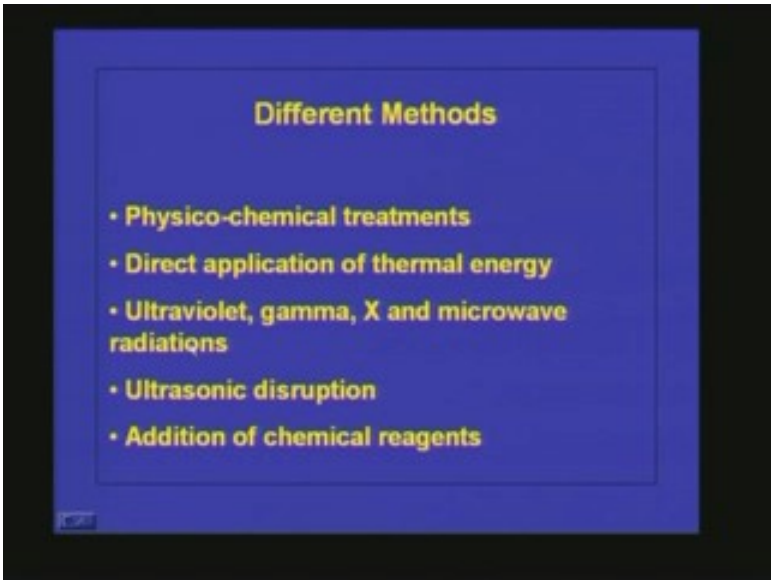

So now we will discuss the different methods of disinfection. We can remove the microorganism by various processes because we have seen various unit operations and processes in water treatment. The physico-chemical treatments: in each and every unit removal of bacteriological or microbial cells will be taking place but we won't be able to achieve hundred percent removal in any of these processes. That's why after a series of treatment processes we have to go for disinfection separately.

Then another method of killing the microorganism is direct application of thermal energy. This process was being used in age old days. Another one is ultraviolet, gamma, X-rays and microwave radiations. You know that if you open the water to the sunlight and keep in for long time it will be getting disinfected. The reason is, the ultraviolet rays whatever is coming from the sun is responsible for the killing of the microorganism. Another method is ultrasonic disruption. These ultrasonic rays will be going and disrupting the cells in the microorganism. The other method is addition of chemicals. This is the one most commonly practiced in water treatment plants. Then there are other things. If you keep the water for long time in some storage tanks then the microorganisms will not be having contusive environment for their growth so natural death will be taking place. This we will discuss in detail when we come to wastewater treatment. There we have some polishing units especially to kill the e-Coli and the pathogenic organisms. What we do there is we allow the water to stand for long time under sunlight for example in oxidation ponds. So what will happen is the oxidation pond will be getting exposed to sun light and sun light you know it is having UV radiation so because of that one the microorganisms are getting killed.

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I have already told that there is a distinct difference between disinfection and sterilization. Sterilization is the process in which complete destruction or inactivation of micro organisms are taking place. And disinfection, only pathogenic organisms are getting killed.

Now we will see, there are various methods for disinfection or killing the microorganism from the water. What is the property that makes a good disinfectant? These are the properties.

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The disinfectant should be able to kill all pathogenic organisms and it should be effective in a wide rage of pH and mineral compositions because we will be coming across various types of water with various degrees of pollution and various pH conditions and mineralogical conditions. So if the disinfectant or the chemical or the method whatever we are selecting if it is applicable only for a narrow range of values of pH and mineral compositions then it is not a good disinfectant because if we want to have hundred percent efficiency we have to bring the entire water to that specified composition. So a good disinfectant is the one which is able to remove or kill the microorganisms for a wide range of conditions.

The next point is, there should not be any toxic byproduct produced during the disinfection process because mostly chemical agents are there so when it acts with the water or when it reacts with the microorganism and inactivates that one during that time it should not form any byproduct which is toxic. And the fourth point is there should be some residual affect of disinfectant after the disinfection process is over. This is required because after the disinfection or after the complete treatment what we do is we usually put the water in the distribution system so there are chances of bacterial entrance or pathogenic entrance into the distribution system so we have to keep the water free of microorganisms or pathogens till it reaches the receiver or the consumer so, for that there should be some residual disinfectant property left over. Therefore, these are the four important properties to select a good disinfectant. Now we will see what is the mechanism of disinfection.

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Though the mechanism of disinfection is not completely clear one thing is very very sure. The disinfectant whatever we are adding either it is chemical, terminal or any other radiation it will be acting on cell protein to inactivate the critical enzyme system essential for microbial life. So once it is inactivating the microbial system the microorganisms will not able no more able to survey or support the life so naturally they will be dying, so, that is the mechanism.

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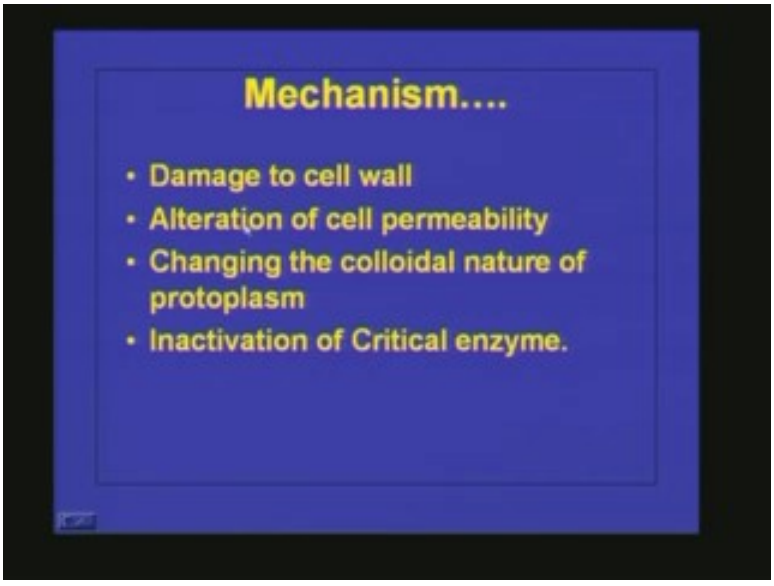

Or in detail we can tell like this; it damages the cell wall and it alters the cell permeability. Thus, when the cell permeability is altered the cell material whatever is

present inside the cell wall will be coming out of the cell so that will be destructing the cell availability. The third one is changing the colloidal nature of the protoplasm because these chemicals will be acting with the protoplasm material and it will be changing the colloidal nature of that one or it will be inactivating the cell material and the last and most important one is that the disinfectant will be inactivating the critical enzymes. The critical enzymes are those enzymes which are responsible for all life supporting reactions or all life supporting functions of the cell. Now we will see the entire steps involved.

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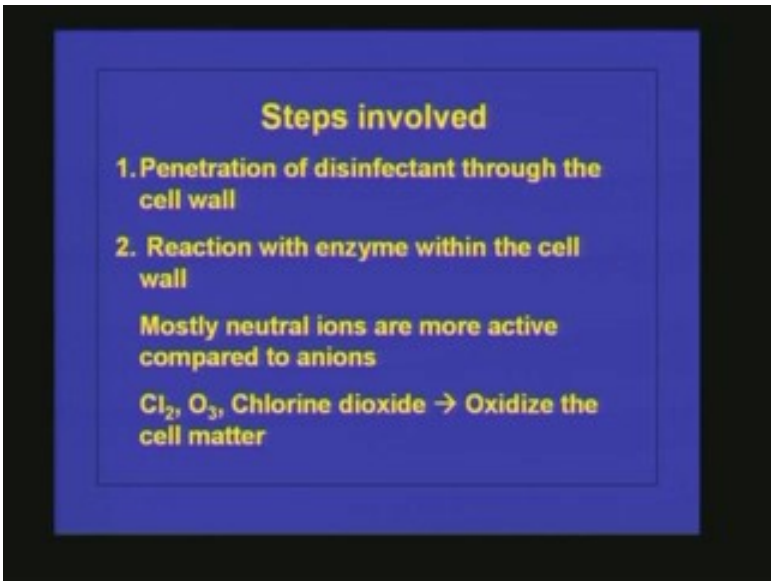

If these are the mechanism either they will be altering the cell permeability or attacking the cell or reacting with the critical enzymes. We know that one chemical is present and the microorganisms are their in the same water so that first the chemical has to come and reach the cell wall and it has to penetrate through the cell. Unless it enters in the microbial cell it cannot deactivate the cell component. So the first step is the chemical coming close to the cell and entering through the cell wall and second step is, once the chemical has entered in the cell it has to react with the cell components and inactivate them. These are the two major steps of disinfection.

From this one it is very clear that the disinfectant or the material whatever we are using if it is not having any charge then it will be having high chance of getting penetrated to the cell. Whenever the bacterial cells are present in medium it will be having a negative charge. So if you are disinfectant is a negatively charged iron there will be a repulsive pore between the cell and the disinfectant so that iron will not be able to penetrate through the cell wall. Unless it is penetrated through the cell wall the chemical will not be able to deactivate the cell. That is the reason; either cations or the irons without any charge are the best disinfectants. So mostly neutral irons are more active compared to anions that is why chlorine, ozone, chlorine dioxide etc or being used as good disinfectants.

The ozone and chlorine dioxide when they enter into the cell they have a very high oxidizing capacity so they oxidize the cell matter beyond inactivating the critical enzymes. Now we will see the most commonly used chemical disinfectants.

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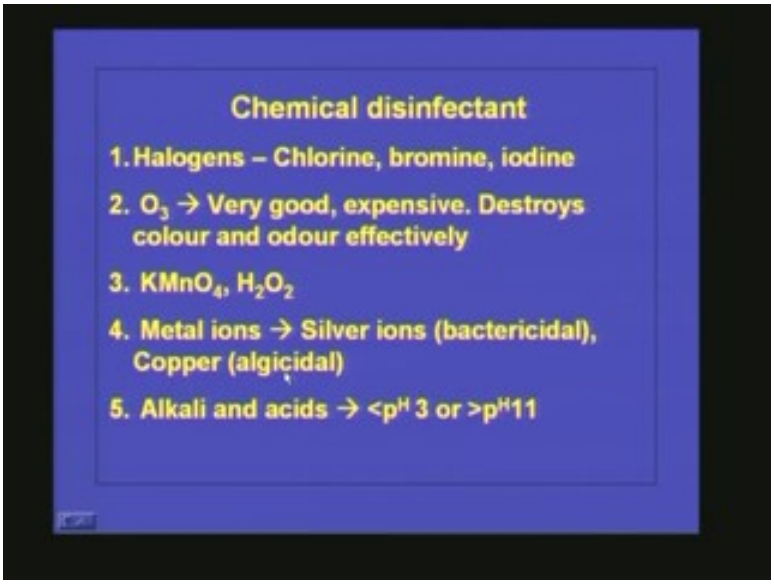

We can use halogens. the most commonly used halogens is chlorine because in India we practice chlorination as the most commonly used disinfection method and bromine and iodine are being used in some places and ozone is a very good disinfectant but the problem is it is expensive and it also destroys color and odour effectively. But another disadvantage of this ozone is, it will not be having any residual effect.

Other oxidizing agents like KMnO4 and H2O2 are also being used as chemical disinfectant. Then metal irons for example silver irons it is acting as a bactericidal and copper can act as algicidal and fungicidal. Copper sulfite is being used in swimming pools to control algal growth. In India nowadays most of the households use water purifiers, in most of the water purifiers the adsorbent or the activated carbon which is used for removing the turbidity and color and odour it will be coated with these silver irons to remove the pathogens. So silver is being commonly used in such domestic water treatment units.

Another method is using alkali and acids. You know that the microorganisms are able to service under a particular pH value. If you reduce the pH to less than three or if you increase the pH above eleven then the environment will not be contusive for the growth of microorganism. So this one we can use for the disinfection purpose. That means if you can decrease the pH les than 3 by adding from strong acids or if we can increase the pH by adding from strong alkali the medium will be or the water will be free of microorganisms.

Now we will see what are all the factors influencing chemical disinfection. We have seen what all are the mechanisms of disinfection and what all are the various chemicals we can use for disinfection. So it is very very important to know what all are the factors that effect the disinfection. Unless we know that one, we will not be able to achieve hundred percent disinfection.

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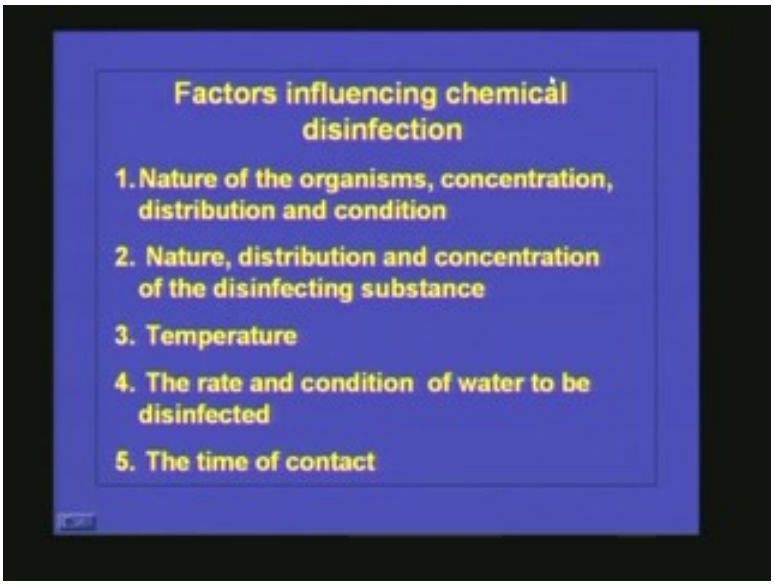

Therefore, the first and most important one is nature of the organisms and concentration and distribution of the microorganism in the system. the nature of microorganism means if it is in colloidal form or if it is present as discrete particles in the water then it is very very easy to destruct them because the chemical can attack them directly. But if the microorganisms are in the form of flocs the microorganism which are present in the outer surface of the floc will be getting exposed to the chemical but whatever is there sitting inside they will not be getting exposed to the chemical that much. Hence, unless the chemical dose is very very high the microorganism whatever is there in the center of the floc will not be destroyed that is one reason.

Another one is, each cell will be forming a cyst, cysts are highly resistive to this chemical so if the microorganisms are of cyst forming nature then naturally it will not be getting destroyed or destructed using any of these chemicals. And if you have very high concentration of the microorganism then also it is very difficult to achieve hundred percent disinfection unless we add very high dose of disinfectant. So the nature, concentration and distribution of microorganisms are very very important. Second one is nature, distribution and concentration of the disinfecting substance.

Hence, what is more important is how well we are distributing the chemical, what is the concentration we are providing and what is the nature of the disinfectant. if you are giving the chemical dose lower than required for killing the microorganism then naturally the microorganisms are not going to get destroyed.

Similarly, if the chemical or the agent whatever we are adding for disinfectant is not very stable it will get disassociated immediately and will fail be to be an effective disinfectant. Third one is the temperature. We know that for any chemical reaction or biochemical reaction temperature is very very important because as the temperature increases the activation energy of the reaction will be increasing so definitely high temperature will be preferable for high rate of disinfection.

The next one is the rate and condition of water to be disinfected. Because, if the water is having lot of turbidity what will happen is this turbid particle will be acting as a protection for the microorganisms. What will happen is the microorganism will go and get attached to these turbid particles and when the chemical is applied these microorganisms will not be getting exposed to the chemical completely so destruction of the microorganism becomes very very difficult. This is one of the reasons why there is a standard for or there is a limit for turbidity present in drinking water.

We know that it is one NTU. If the turbidity is more, disinfection will not be effective. Another one is if the water is highly contaminated with organic matter or some inorganic compounds like ferrous, manganese etc the chemical reagents whatever we are adding…… we have seen that most of the chemical reagents whatever we use for disinfection are all having high oxidizing capacity so when we add these chemicals to the water the chemical will be used by the organic matter or the inorganic compounds present in the water so the chemical will be completely utilized for the oxidation of these compounds so the microorganism will not be getting exposed to high concentration of these chemicals so naturally the disinfection will not be proper.

Hence, if you want to have a high efficiency of disinfection the water whatever we are subjecting for disinfection should be clear of turbidity organic matter and other pollutants. The last thing is the time of contact. If the microorganisms are getting exposed to a toxic compound for longer time definitely the rate of killing will be more so time of contact is also very very important.

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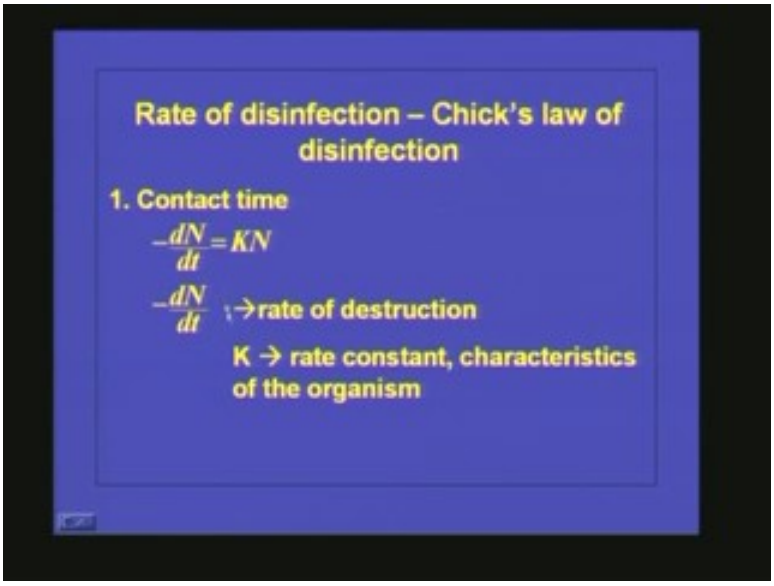

Now we will see how we can find out the rate of disinfection. The most commonly used law or the most famous law of disinfection is this Chick's law of disinfection.
How can we relate the contact time and the rate of disinfection? This is the relationship Chick has given; minus dN by dt is equal to K into N or rate of kill is proportional to the number of microorganisms present. So here dN by dt is nothing but rate of destruction and K is the rate constant and it is the characteristics of the organism. So this K is not a constant it will be varying with respect to the reagent or the disinfectant as well as the microorganism.

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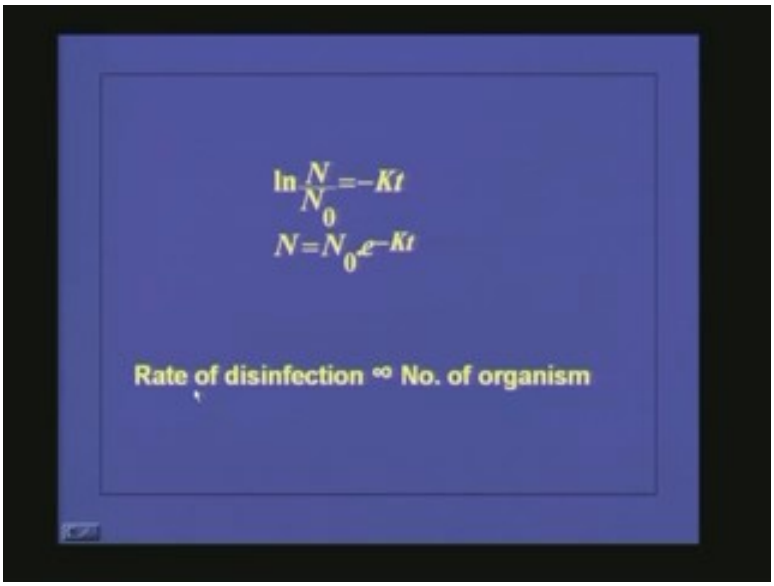

So if you integrate the expression then we will get; ln N by N_0 is equal to minus K into t where N_0 is the initial number of microorganism present in the system and N is the number of microbes present after a time t or we can find out N whatever is the remaining number of microorganism that is equal to N_0 into e raised to minus K into t or Chick's law of disinfection is telling; rate if disinfection is proportional to number of microorganisms present. It is not giving any relationship between the concentration of the disinfectant or the nature of the organism, everything is taken care by this K. But this statement is true only if all the microorganisms present in the system are having uniform susceptibility to the chemical. That means all the microorganisms are having the same resistance or same toxicity for the chemical.

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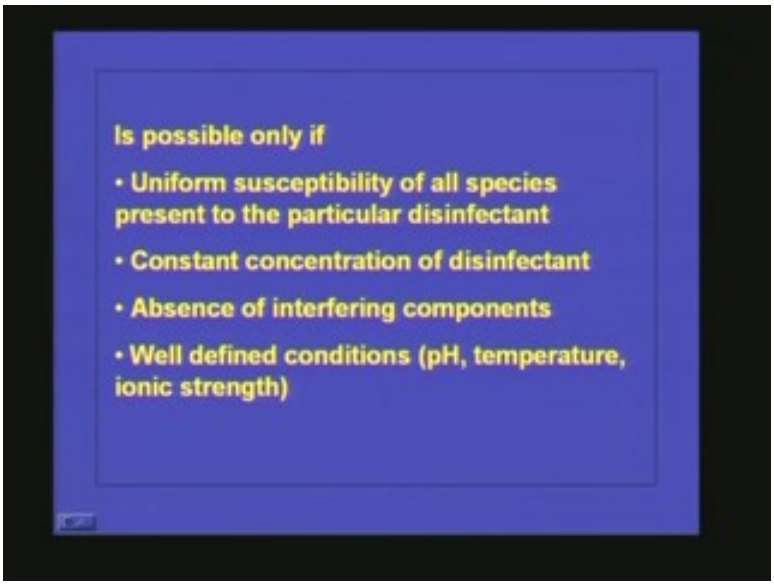

For example, if we take water we know that pathogens are present and escherichia coli which we use as indicator organism will also be present in the water. But if you consider these two types of microorganisms or bacteria the pathogens are having less resistance to chlorine compared to E.coli so naturally if you apply a particular amount of chorine to that water and if you see the number of microorganisms separately naturally the pathogenic organisms number will be getting reduce at a faster ray compared to E.coli.

Therefore, Chick's law is valid only if uniform susceptibility of all species present to the particular disinfectant and the second important point is constant concentration of disinfectant. But we know that when we add the disinfectant to the water with respect to time the concentration of the disinfectant or concentration of the chemical will be getting reduced. So at a reduced concentration the effect on the microorganism will be less so Chick's law is not considering that effect also. But that law is considering whether the concentration of the disinfectant is remaining the same or concentration of the disinfectant is not having any effect on the disinfection or rate of kill but that is not true.

The third one is absence of any interfering components. For example, if organic matter present or iron or manganese is present in the water certain amount of the disinfectant will be used for the destruction of those materials and the remaining only will be available for disinfection so that is also not being considered in Chick's law of disinfection.

Another one is well defined conditions; example pH temperature and ionic strength. These parameters are also not considered in Chick's law because if pH is different then the effectiveness of the disinfectant will be different. Similarly, temperature; for high temperature the activity will be more compared to low temperature and ironic strength also is having a comparable effect on disinfection.

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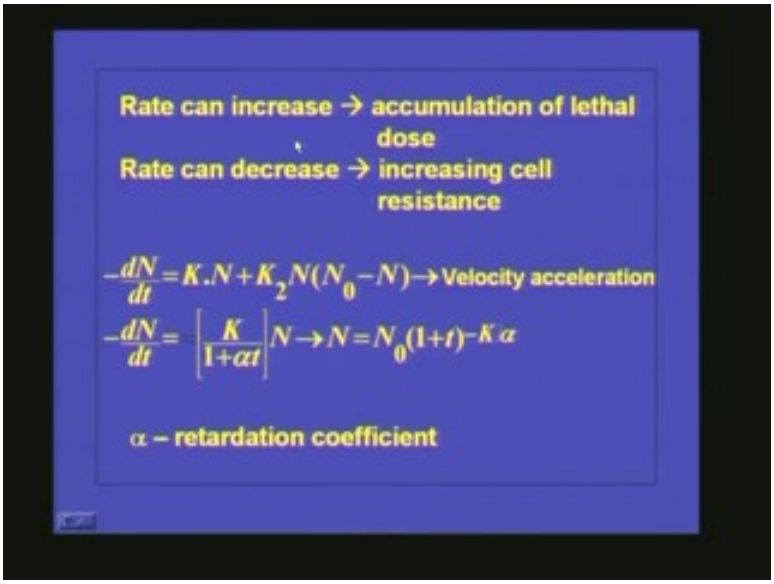

Till now we have seen that rate is a constant but rate can increase or rate can decrease. When the rate can increase?
For example, initially the concentration of the disinfectant is less with respect to time the microorganisms are there in the same water and the disinfectant is there in the water so with respect to time the chemical or the disinfectant will be getting accumulated in the cell wall. So it will keep on be getting accumulated and at a certain stage the concentration of that chemical will be exceeding the maximum permissible concentration which the body of the microorganism can withstand. Once that concentration is reached the microbial destruction rate will be increasing. That's why rate can increase when accumulation of lethal dose takes place.

When can the rate decrease?
The rate can decrease when the cells increase the resistance to that particular chemical. We all are aware that if you keep on giving certain medicine the microorganism will not be responding to that medicine some bacteria or some microorganism will be developing resistance for certain disinfectant or certain chemicals. So if the microorganism can

develop the resistance in a short period of time what will happen, initially it will be getting killed at a faster rate but with respect to time as they have already developed a resistance for that chemical so the rate of kill will be decreasing so we can modify the Chick's equation like this; minus dN by dt is equal to K into N plus K_2 into N into N_0 minus N. So this is the velocity of acceleration.

Or we can write it in another way; minus dN by dt is equal to K by 1 plus alpha t into N or N is equal to N_0 into 1 plus t raised to minus K by alpha. So here alpha is the retardation coefficient. That means if the cell already develops some resistance what will happen to this K? This alpha is a number which is more than zero then what will happen is this K value will be getting reduced. But if the cell is not developing any resistance then what will happen is this value will be zero so you will be getting the same equation; minus dN by dt is equal to minus K. So this term will be taking care of retardation (Refer Slide Time: 25:30) and this will be taking care of the velocity acceleration because we know that depending upon whatever value N is, that one will be varying. This is the one which takes care of the velocity acceleration and this is the one which takes care of the retardation coefficient. So the rate of kill may not be or need not be a constant always.

We have seen that Chick's law is taking care of only the number of organisms present. But the concentration of disinfectant is also very very important.

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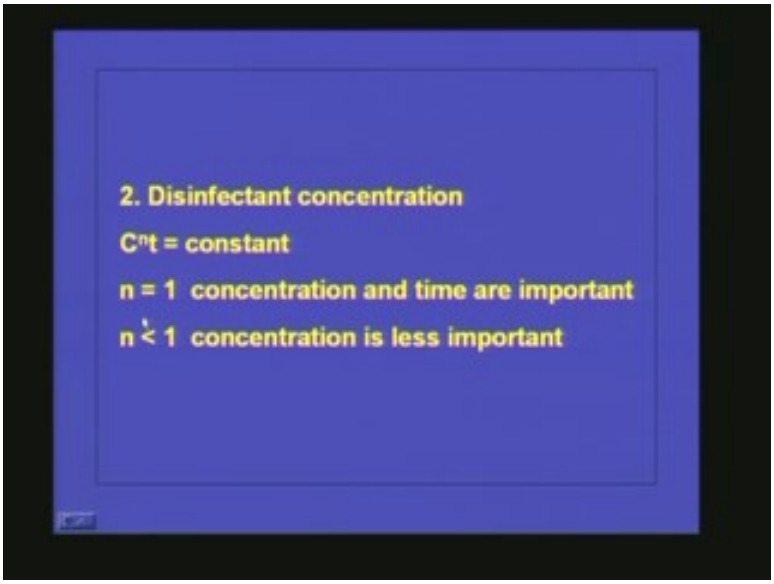

That we can represent using this formula; C raised to n into t is a constant. So this n can have any value between zero to one or above that one. If n is equal to 1 that means concentration and time are very very important for disinfection, if n is having a low value less than 1 then concentration is less important compared to the contact time and if n is greater than 1 then concentration is more important than the contact time. We will discuss about this in detail and about other chemicals whatever we are using as disinfectants and how their behavior is.

Now we will see how the temperature effect is coming into disinfection. We know that as a temperature increases the activation energy of the reaction also will increase so the rate of disinfection will be changing or increasing with increase in temperature.

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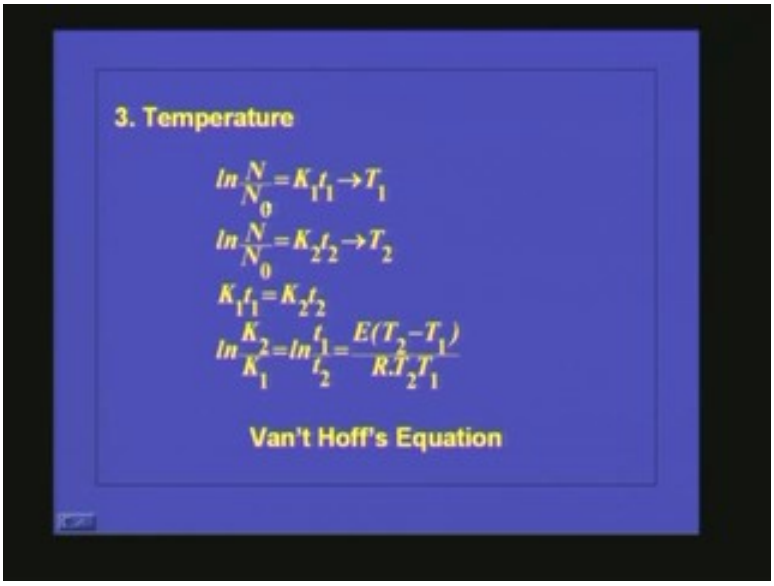

So this equation shows that one. Temperature ln N by N_0 this is the number of microorganisms present at any time t and (Refer Slide Time: 27:10) this is the number of microorganisms present when t is equal to 0 that means before the disinfection. That we can write like this K_1 into t_1, K_1 is the constant and t_1 is the time. This is a time at a temperature T_1 degree Kelvin and same is written here for a temperature T_2. So this rate constant is changing and contact time is changing. But we know that in both the cases this term is same so we can equate K_1t_1 equal to K_2t_2 or ln K_2 by K_1 where K_1 and K_2 are the rate constants at different temperatures that is equal to ln t1 by t_2 that means the contact time which is equal to E into T_2 minus T_1 by R into T_2T_1 where R is the universal gas constant so this is very very important.

Hence, the rate of kill is the rate of the rate of disinfection varies with respect to temperature. And if you know the rate of disinfection at a particular temperature
We can find out the rate of disinfection at another temperature using this formula; (Refer Slide Time: 28:24). This is the famous Van't Hoff's Equation.

Now we will discuss about the disinfection by chlorine because chlorine is the most commonly used disinfectant in India. In developed countries chlorine is banned because of various reasons. The major reason what they are telling is that chlorine can create carcinogenic compounds with the organic compounds present in the water so most of the chlorinated organic compounds are carcinogens.

If organic matter is present in the water when we apply the disinfectant what will happen they will be forming chlorinated organic compounds. These compounds will be present throughout the water so when we drink the water these compounds will be getting accumulated in our body and most of these compounds are cynabiotic in nature that means very very difficult to destruct. What will be happen is it will be getting accumulated in our body and it can cause cancer. That is the reason why chlorine is banned in develop countries but in India it is being used now also.

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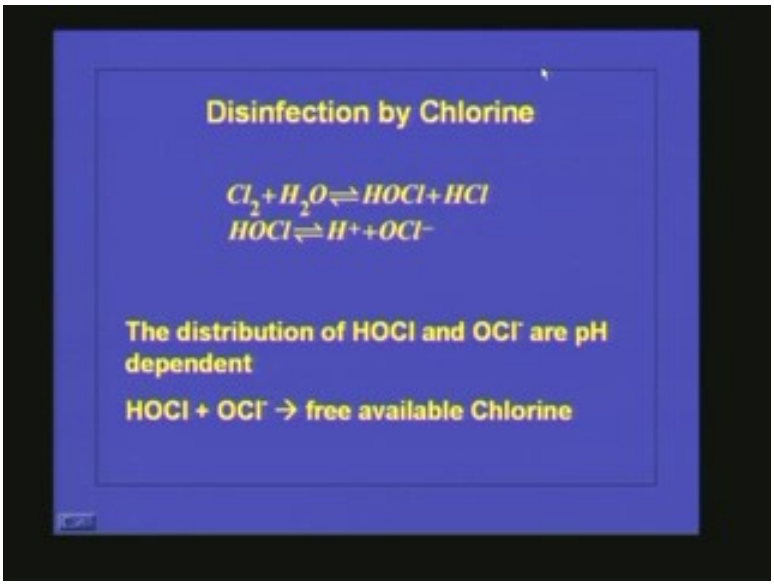

We have seen that the risk involved because of the carcinogenic nature of the compounds created by chlorine is much negligible compared to the disinfectant characteristics of the chlorine. That's why we are using chorine very commonly in India. First we will see the reaction that takes place when chlorine combines with water, this is what is happening; chlorine reacts with water to give HOCl plus HCL Hypoclorus acid and hydrochloric acid and HOCl now can disassociate as HOCl that is H plus and OCl minus, this reaction is very very important.

We have seen that when we talk about disinfection neutral molecules is more effective compared to charged one especially if it is having a negative charge. Most of the microorganisms will be having a negative charge. So when HOCl disassociates to OCL, OCl is having a negative charge that will not be able to penetrate the cell wall as effective as HOCL. So HOCl is very very important as for as chlorine disinfection is considered. That's why the pH is very very important. What will happen is, at low high pH HOCl will be disassociating to H plus and OCl minus and OCl concentration will be very high whereas HOCl concentration will be less. But at low pH what will happen is HOCl will be predominant compare to OCl minus so disinfection will be more effective. That's what I have written here; the distribution of HOCl and OCl are pH dependent and the sum of HOCl and OCl whatever is present in the water is known as free available chlorine. So here again I have given the reactions Cl_2 plus H_2O gives HOCl plus HCl so we can find

out what is the equilibrium constant for that reaction HOCl into H into Cl minus by Cl_2 so this is the equilibrium constant for that reaction and this is the reaction with HOCl.

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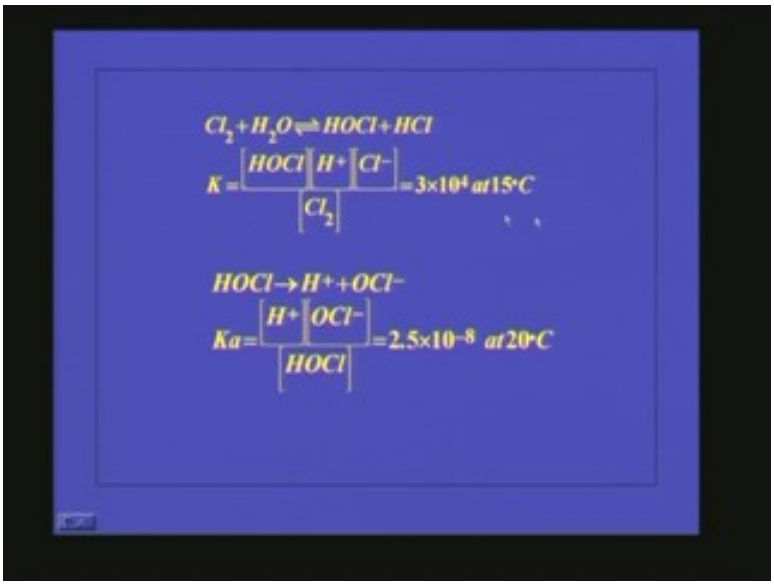

HOCl disassociate to form H plus and OCl minus and k_a equilibrium is 2.5 into 10 raised minus 8 at 20 degree centigrade and we know that it is a function of pH because H plus ion is coming here. Or if you know the pH of the water and if you know the total amount of HOCl present in the system then we will be able to find out the percentage HOCL. Also we know that HOCl is having hundred times lesser disinfecting power than OCl minus. This is also very very important.

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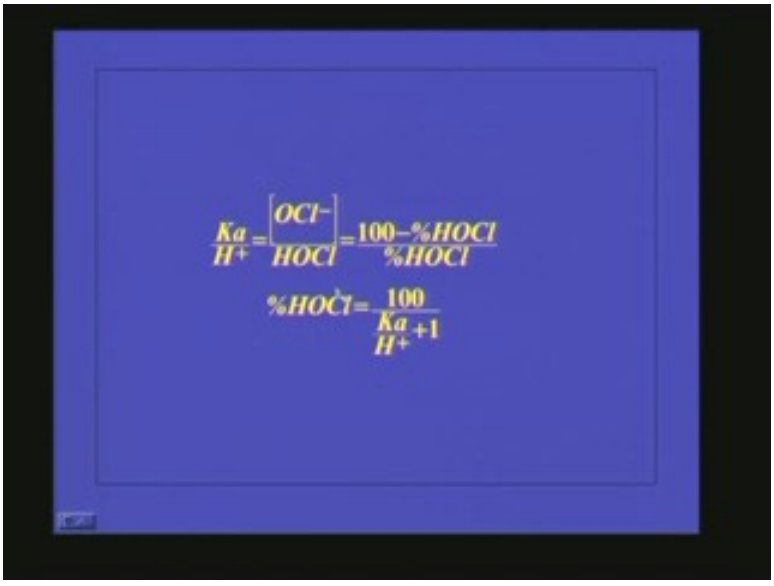

Our aim is to maximize whatever is the HOCl component present in the water compare to OCl minus. This graph shows the HOCl and OCl distribution with respect to pH. We can see that. At around pH7 both HOCl and OCl will be almost equal but if the pH is slightly lower then almost all will be in the in the form of HOCl but if the pH is higher than 9 then everything will be in the form of OCl minus.

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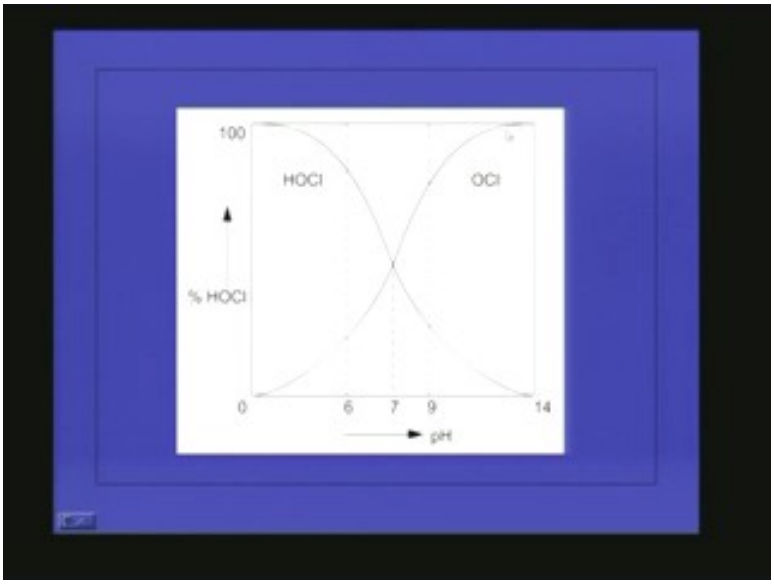

So, in water if the pH is in alkaline side the disinfection efficiency will be very less compared to acidic range and this chlorine can react with ammonia present in the water also so this reaction is also very very important. Thus the ammonium iron whatever is present in the water is combined with water to form ammonia and H plus so this is the reaction.

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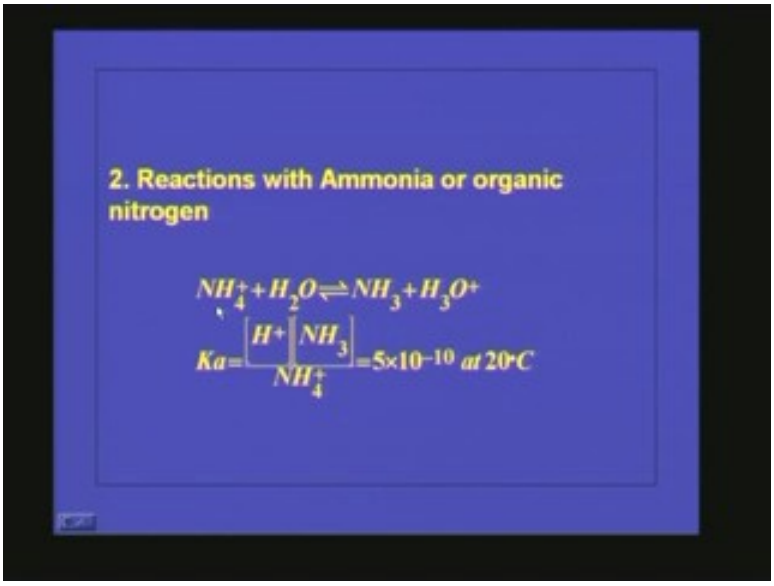

Now, whatever ammonia is present that will react with the chlorine to form chloramines. So first is ammonia, one hydrogen ion will be replaced by chlorine ion so we will be getting NH_2CL which is known as monochloromine.

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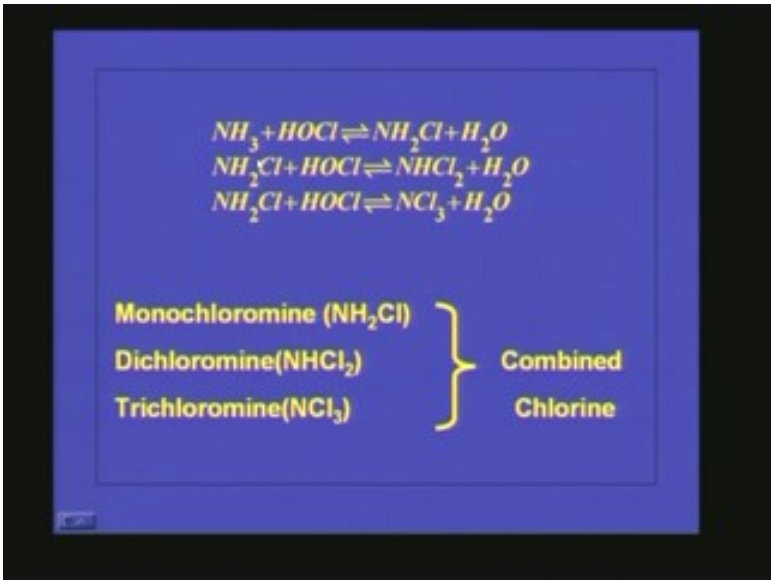

And after that one what will happen is this monochloromine will be reacting with another molecule or another atom of chlorine to form $NHCL_2$ or dichloromine, it is having two chlorine and again it will be reacting with three chlorine to form trichloromine.

So if you further or chlorine then this will be disassociating and chlorine will be regenerated and N_2 gas will be escaping from the system. So if you have ammonia present in your water then we have to add more chlorine to remove the ammonia. If you add chlorine to water and if you measure the residual chlorine and added chlorine and if you plot it we will be getting a typical curve like this (Refer Slide Time: 34:39) known as the breakpoint curve it is very very important.

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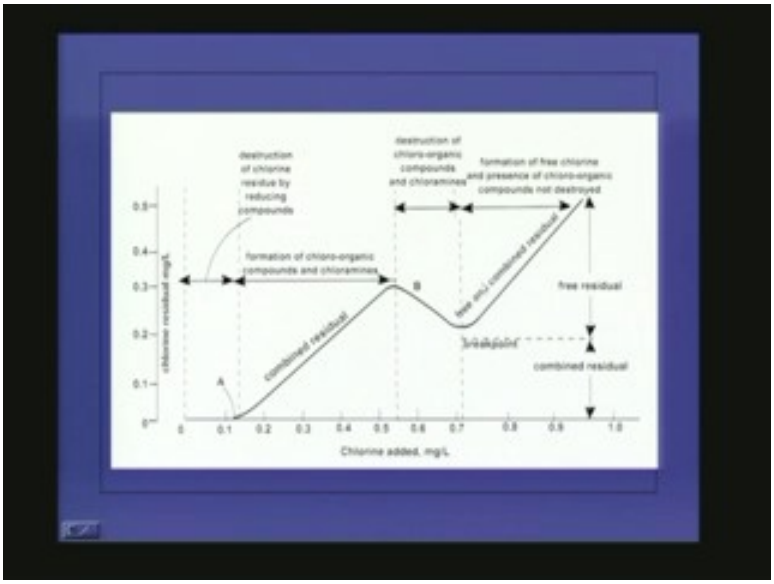

Initially what is happening is up to here the residual chlorine is almost at nil. So this is used for the destruction of other compounds whatever is present. We have seen that if organic matter is present it will be used for the destruction of organic matter then if microorganisms are there that also will be getting destructed so some amount of chlorine will be use for the destruction of the organic compounds present in the system so there will not be any residual chlorine at all.

So, after sometime what will happen is all those things are destructed then ammonia is present in the system hence further what will happen is the monochloromine, dichloromine, trichloromine and all those things will be formed in a stepwise manner. So if you find out the residual chlorine you will be getting a curve as something like this. Residual chlorine will be a sum of HOCl OCl and monochloromine, dichloromine and trichloromine.

Now at this point B what will happen is all the ammonia whatever is present in the water is already converted to trichloromine that means NCL_3 so if you add some chlorine at the time what will happen this trichloromine will be disassociating and nitrogen gas will be going out and chlorine will be coming so your combined residual chlorine will be coming down because NCL_3 is getting destructed from the system so this is the breakpoint that means all the chloramines and chloro organic compounds are getting destructed from the system.

Here (Refer Slide Time: 36:30) whatever you see up to this point is the combined residual chlorine so some more chloramines whatever is present in the system that we can get from here and this portion from here to here gives you the free residual chlorine and this is the breakpoint chlorine. This break point is very very important. So if you want to find out the disinfectant concentration required what we have to do is we have to prepare this breakpoint and we have to add chlorine up to this breakpoint and add little more to maintain the residual chlorine as prescribed by the standard. So this is the typical curve for water if it is having ammonia.

Now, if you have only distilled water and if you add chlorine how the curve will look like?
It will be of a line at an angle of 45 degree because whatever you are adding will be available as chlorine residual so it will be a 45 degree line. But if you have a solution which contains some glucose or something like that then initially some chlorine will be utilized for the destruction of the organic matter or the glucose solution then again it will be raising at an angle of 45 degree, you will not be getting this type of a curve. This is typical of the presence of ammonia.

But sometimes in water treatment system what people do is, this combined residual chlorine is much more stable compared to the free residual. So, if you want to maintain the residual chlorine effect for a longer time then after treatment is completely over little ammonia will be added to the system before chlorination therefore some combined residual chlorine will be there so that will be remaining in the system for a longer time.

What is the mechanism of chlorine disinfection? We have already discussed the mechanism so we can see that once again.

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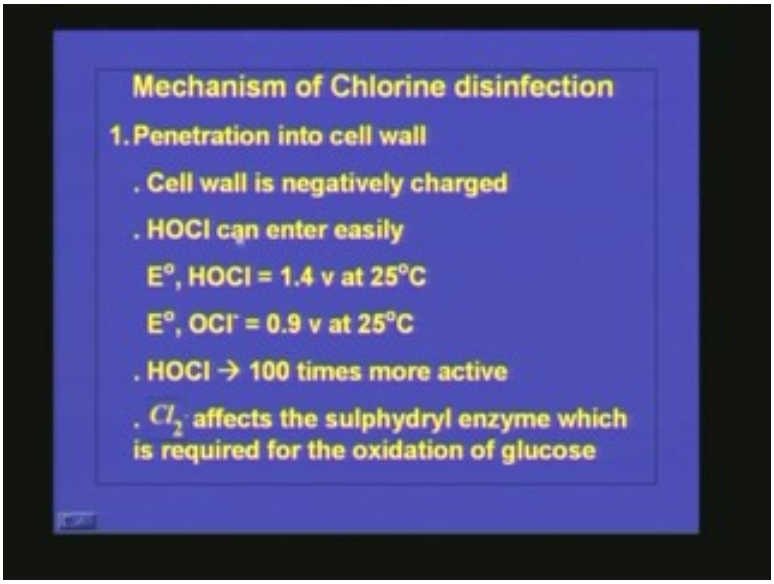

Penetration into the cell wall: Cell wall is negatively charged so we can see that HOCl can easily enter in the cell whereas OCl will be having some resistance that is why HOCl is hundred times more active than OCl minus and CL_2 affects the sulphydryl enzyme which is required for the oxidation of glucose. sulphydryl enzyme is the one which generates the energy. So the chlorine will go and act on that enzymes so the energy generation system will be getting affected and it also inhibits the respiratory enzymes and also inhibits the phosphate uptake and permeability of the cell membrane is altered and leaching of the cell material will be happening. So chlorine is having all these properties so in all these ways it will be destructing the cell. That means permeability changes, phosphate uptake is getting affected, prescribly enzymes are getting affected, sulfiteral enzymes are getting affected so this cell will not be able to survive at all.

Now we will see what are the different types of chlorination. We can classify the chlorination into basically five categories depending upon the point of application.

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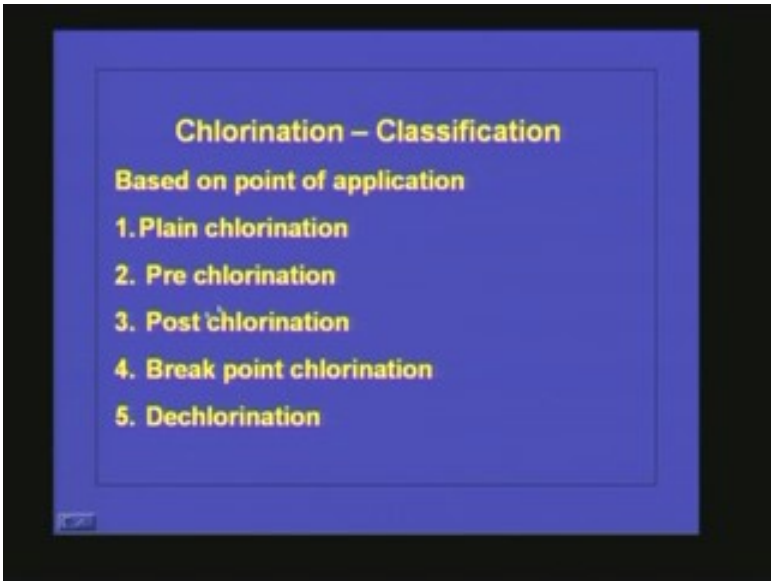

First one is;

- Plain chlorination
- Pre chlorination
- Post chlorination
- Break point chlorination and
- Dechlorination

By the name itself it is clear. What is plain chlorination?
Plain chlorination is the one where no other treatment is there only chlorination is given after treatment to the system.

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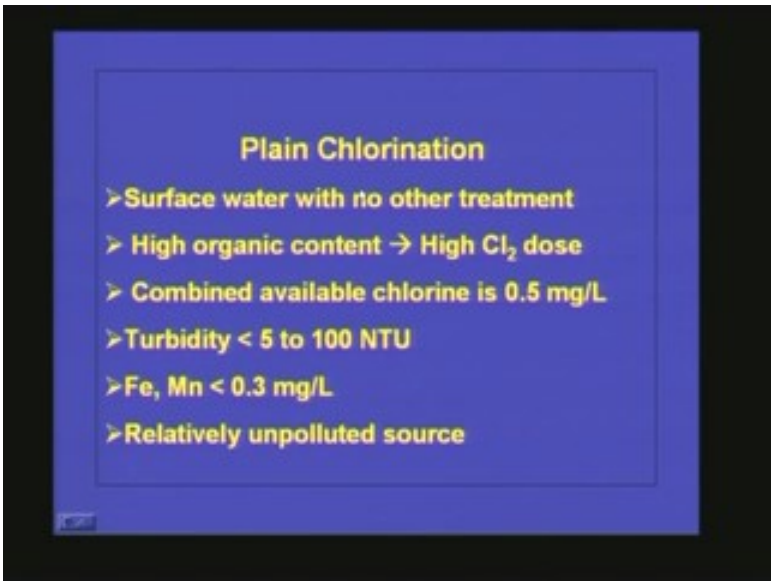

This is practiced mostly in case of emergencies. So the water treatment system is not working at all so what one has to do is we have to make sure that the water whatever we are supplying is free from pathogens. Because if the water is not safe chemically or physical appearance-wise it can be tolerated for a short period of time. But if the water is not safe bacterialogically it cannot be tolerated even for a single hour because what will happen is if pathogens enter into our body it can cause diseases. So whatever be the condition we have to make sure the bacterialogical safety of the water. So in emergency purpose or if your water source is very very clean or it is unpolluted then we can only go for plain chlorination we don't have to go for any other treatment.

Thus, plain chlorination we have surface water with no other treatment. In such cases what will happen is if high organic content is there high chlorine dose is required and when we go for plain chlorination we have to make sure that a combined available chlorine of 0.5 milligram per liter is available after the chlorination and after the contact time and the turbidity should be less than 5 to 100 NTU or preferably 5 NTU because if more turbidity is there the disinfection will not be effective and Fe and Mn should be less than 0.3 milligram per liter. So, if the concentration of Fe and Mn is higher what will happen is this will be utilizing the chlorine which is a strong oxidizing agent for the oxidation of Fe2 plus 3 Fe3 plus and manganese. So whatever chlorine you are adding mostly it is used for the oxidation of the other pollutants that is why we tell that plain chlorination can be applied only to relatively unpolluted sources.

The next one is prechlorination. prechlorination is nothing but the application of chlorine before any other treatment. It is having certain advantages. It improves coagulation. Especially if you are collecting the water from some stagnant water bodies as they will be having lot of algae so removal of algae by coagulation flocculation is very very difficult

or we have to add excess alum dose to remove the algae. But if you chlorinate the water and kill the alga then it becomes very easy to remove, thus, improve coagulation.

The next one is, if some organic matter is present and if you chlorinate it chlorine can oxidize the organic matter so it reduces the taste and odour of water. So, by reducing algae and other organisms keep the filters and cleaner otherwise these microorganisms will be growing on the filter sand and filtration will not be effective especially the rapid sand filtration and its effectiveness depends upon the residual chlorine concentration available.

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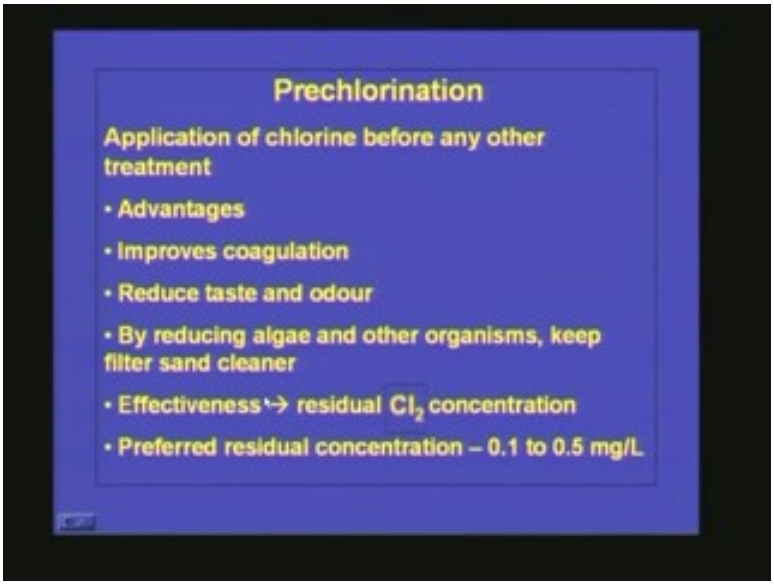

If you have sufficient residual chlorine then all the treatment units will be protected from bacterial growth and preferred residual concentration is in the range of 0.1 to 0.5 milligram per liter. So, if the residual concentration is low then it will not be having the effect so it is always advisable to keep a residual chlorine concentration at 0.1 to 0.5 milligram per liter. Now the other one is post chlorination. That means addition of chlorine after all other treatment.

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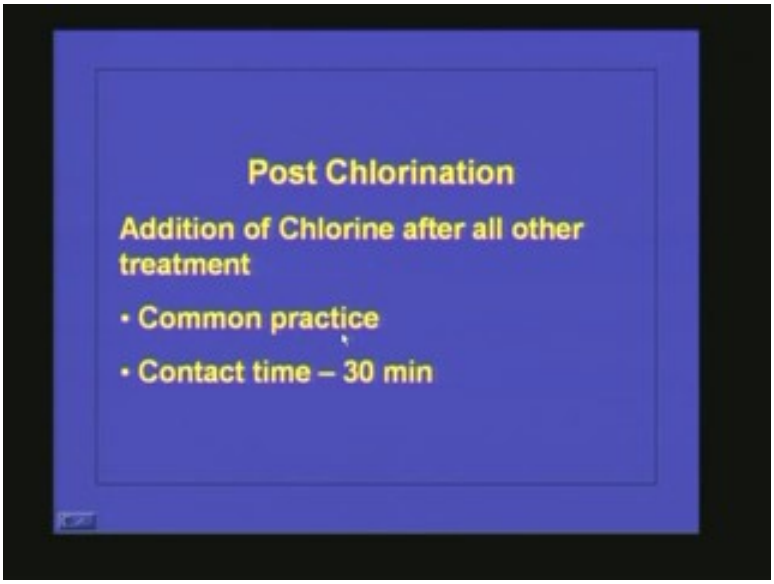

This is the most commonly practiced one. What we do here is, after the filtration or after the end of all the treatment units we are adding chlorine to the clean water coming out of the treatment unit and we allow it to stand for 30 minutes because the usual contact time given in chlorination unit is 30 minutes so whatever microorganisms are present here in it will be killed. This process is known as post chlorination. This is the most commonly practiced one.

In post chlorination if you want to find out the dose we have to find out the break point and add some dose which is slightly higher than the break point so that the required chlorine is present.

Now we will see what dechlorination is. Dechlorination is practiced when we need quick disinfection. When the water is highly contaminated we know that the water is having lot of pathogens present in that so at the time what we have to do is we have to add heavy dose of disinfectant to that one so that all the pathogens will be getting killed very fast then take the water for entire treatment but after that if you taste the water it will be having lot of this disinfectant taste so it will not be acceptable by the public. Therefore it is higher in residue and it is not advisable to send it into the distribution system.

So if high residual is present then we have to go for dechlorination. That means we are going for high dose of chlorine and the residual chlorine dose is very very high so we have to remove the excess chlorine whatever is present so we are going for dechlorination. Now we will see what are the methods we can practice for dechlorination.

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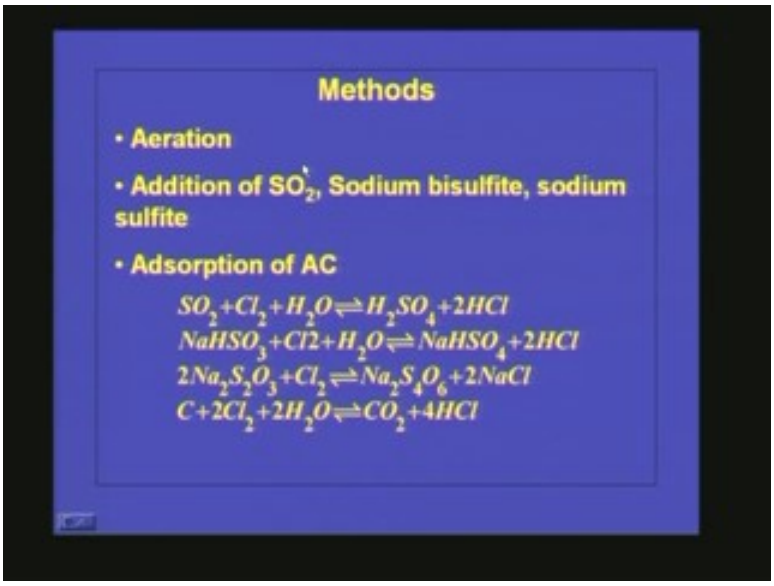

One is aeration. When we do aeration whatever are the dissolved gasses it will be going out so we can use this in method for removing the excess chlorine and another one is addition of sulfur dioxide, sodium bisulfite or sodium sulfite. You know that all these things are reducing agents. So sulfur dioxide is a reducing agent so it will be getting oxidize to sulfite; similarly sodium bisulfate and sodium sulfite. And you know chlorine is a very strong oxidizing agent so chlorine will be getting reduced to chloride and these compounds will be getting oxidized to the corresponding compounds. So these are the reactions.

Another method is adsorption on activated carbon. So SO_2 and chlorine react to give H_2SO_4 and hydrochloric acid. Similarly, sodium bisulfate and sodium thiosulfate all these things can be used for removing chlorine or as dechlorinating agents. Now we will see the disadvantages of chlorine. This I have already mentioned in the initial slides. One is formation of chlorophenols. If the water is having phenols then this chlorine will be reacting with the phenols to form chlorophenols; it is having a very bad smell; fishy smell. So if phenol is present in the water and if you go for disinfection using chlorine you will be getting taste and odour.

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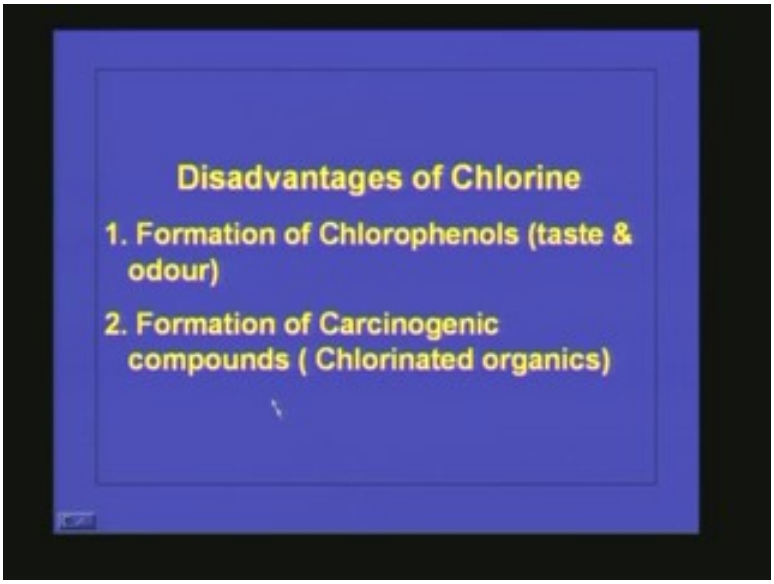

Another one is formation of carcinogenic compounds which are chlorinated organics. These are the major problems with chlorine. Now we will see what are the non chemical methods of disinfection. One is thermal method. This is direct application of heat energy. Naturally if you go for this nearly complete sterilization takes place.

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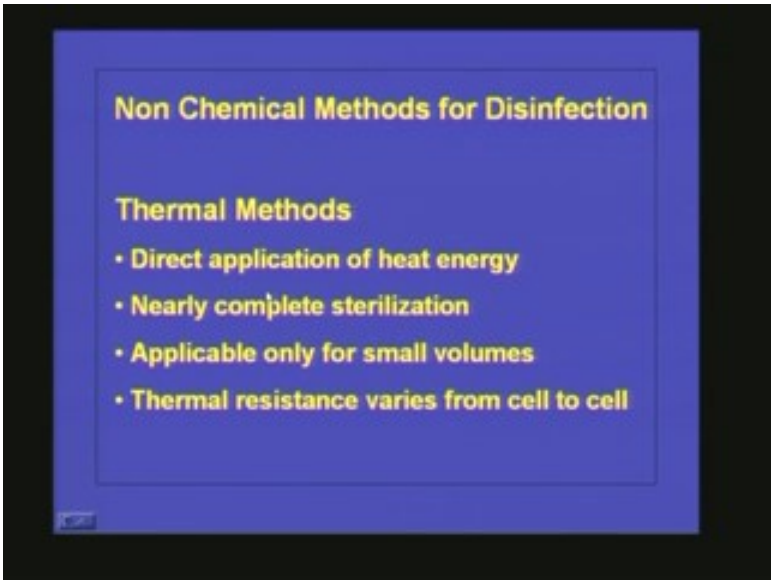

We know that the energy involved in this process is very very high so it is applicable only for small volumes of water. Thermal resistance varies from cell to cell. So even if

you boil the water and keep it boiling for sometime certain cells will not be getting destructed. The next method is UV radiation.
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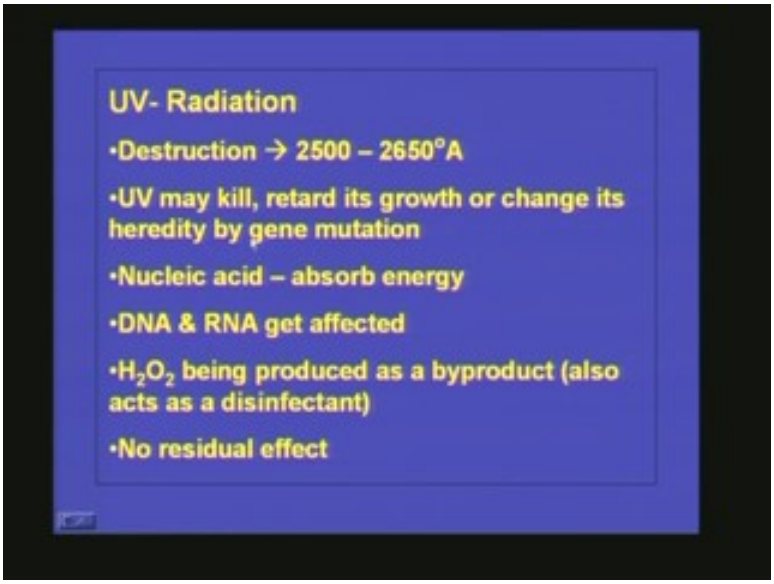

UV can destruct the cells. UV may kill the cell, retard its growth or change its heredity by gene mutation. So these are the actions on how the UV radiation is killing the cells. It will be acting on the nucleic acid and you know that in nucleic acid DNA and RNA are there so what will happen is this DNA or RNA will be getting affected so UV will be directly affecting DNA RNA resulting in nutrition of the gene that will take place and it can retard the growth and when UV radiation is acting on water it can produce H_2O_2 so H2O2 is a strong oxidizing agent so this oxidizing property of this H_2O_2 is also one of the reasons of destruction.

The major disadvantage of UV radiation is there is no residual effect and it is costly compared to chlorination. Another one is gamma and X ray radiation. Any electromagnetic radiation can kill the cells and it can penetrate and destroy the cells. But again it is very very costly so not usually practiced in water treatment plants.

Now coming to ozone, ozone is a very very good disinfectant. But here we can see that ozone is having a peculiar nature; it will not be having any disinfection property up to a certain concentration and once it reaches that concentration the disinfection or the efficiency increases drastically.

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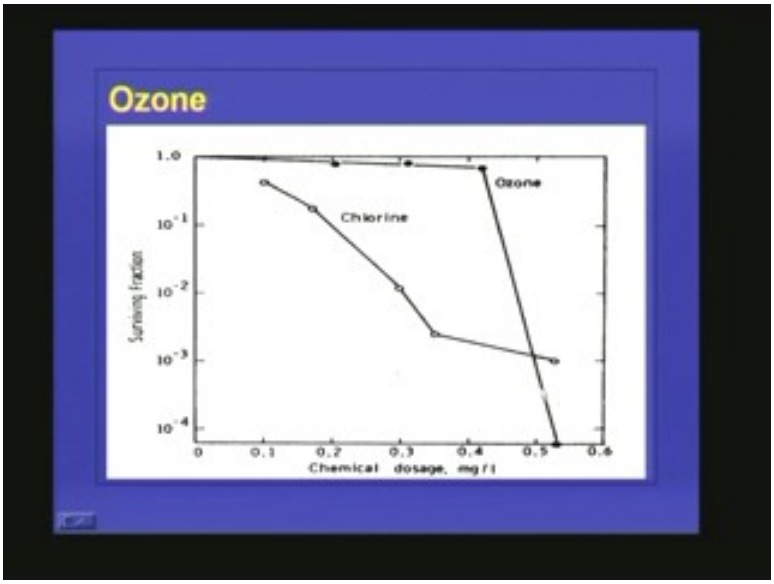

This is the surviving microorganism; this is the chemical dosage. So it is having a no or complete effect. That is the case of ozone. But chlorine you can see that at low concentration itself it is having sun disinfection concentration and it will not be having hundred percentage like ozone.

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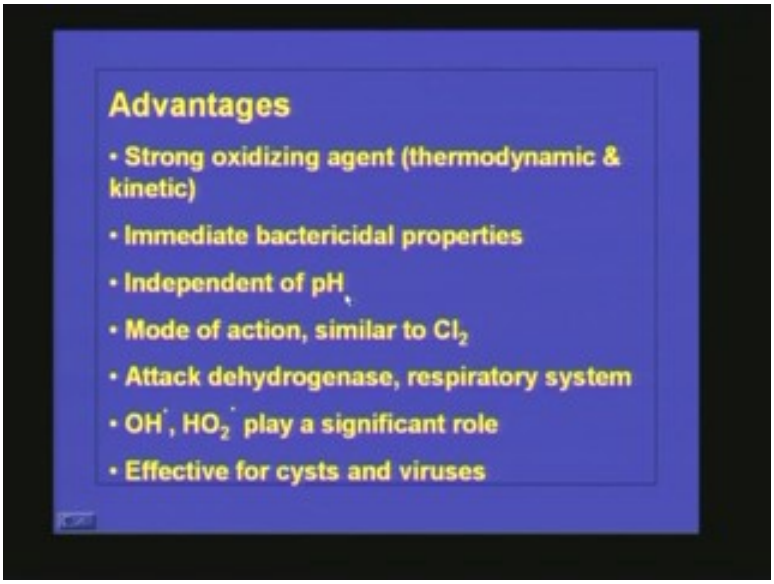

Advantages of ozone:

It is a strong oxidizing agent and immediate bactericidal properties are there and it can work on any pH. We have seen that chlorine can work only on that acidic range ozone can work under any pH condition. The mode of action of disinfection is similar to chlorine and it attacks dehydrogenase and respiratory system and when ozone reacts with water it produces radicals are HO_2 radicals and this plays a significant role in disinfection and hence it is effective for cysts and even viruses but again it doesn't have any residual property.

How can we add chlorine? Chlorine can be added to the system by addition of a weak solution prepared from bleaching powder, addition of weak solution by electrolyzing a solution by brine or by addition of chlorine as gaseous form.

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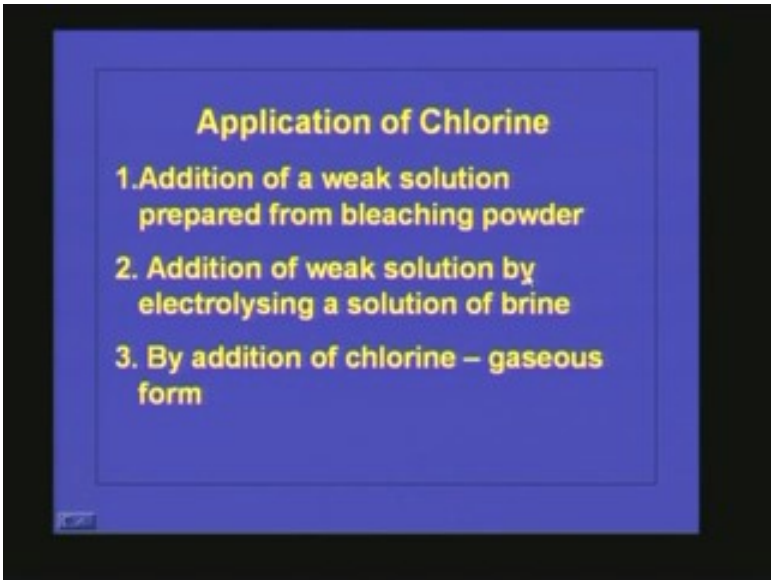

So there are different forms by which we can add chlorine and most of the times the water treatment plants use chlorine gas so we have to be very very careful when we handle chlorine because it is very toxic. So cylinders should be stored upright and ready access and easy removal is possible. You know that chlorine is very dense compared to air so the chlorine storage rooms should have proper ventilation and the ventilation should be placed in the lower side of the room. The reason is it is heavier compared to the air so all the chlorine will be getting accumulated in the bottom so if you want to remove that one effectively the ventilators should be placed in the bottom of the row.

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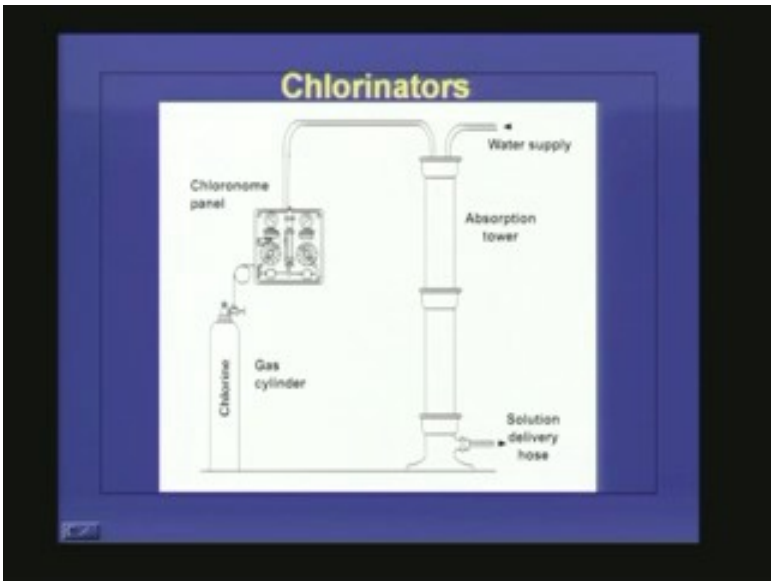

Then this is the commonly used chlorinator. You can see the chlorine; this is the meter which adjusts the flow rate and all those things. Some water is coming here and chlorine gas is coming and this is an adsorption tower (Refer Slide Time: 52:20) so what will happen here is the chlorine will get mixed up with the water and we will be getting a weak solution of chlorine which will be going to the water.

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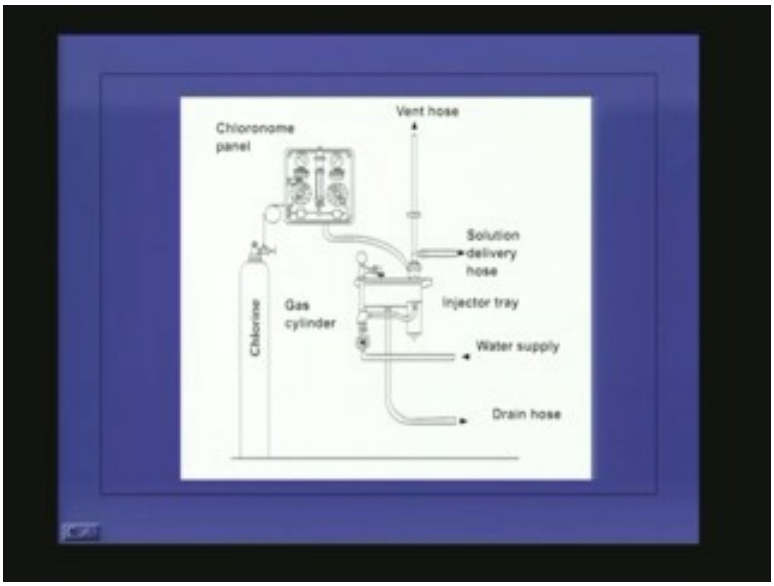

This is another chlorination panel, another method. Here an injection tray is there and vent hose is there and this is the water coming (Refer Slide Time: 52:42) so it will be coming here and will be mixing with the chlorine and whatever mixed chlorine solution is coming out will be going to the tank which is meant for disinfection. Here, this is the gas whatever is generated so we can mend through this hose. Now we will see what are the most commonly used chlorine compounds in India.

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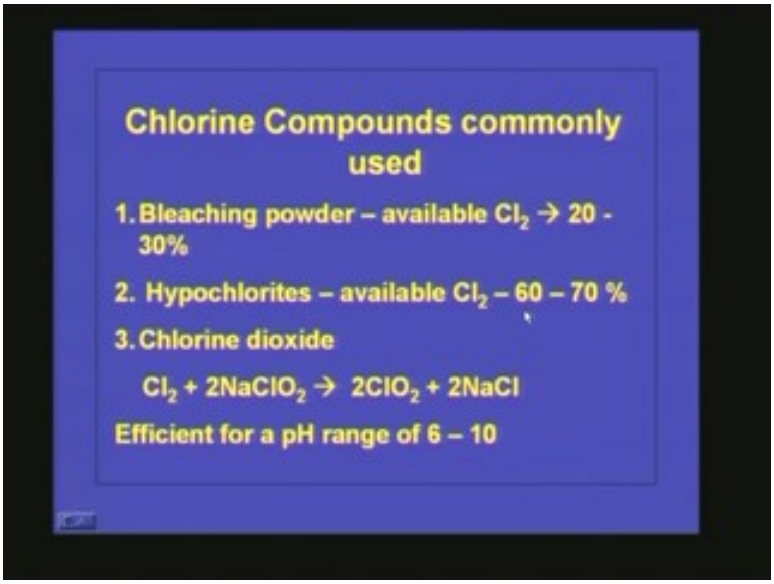

Bleaching powder: Bleaching powder is very very commonly used and in bleaching powder the available chlorine is only 20 to 30%. So when we make the calculation of the dose we have to be very very careful because the available chlorine is only 20 to 30%. Another one is hypochlorites, here the available chlorine is 60 to 70% and another one is chlorine dioxide. Chlorine dioxide is having one advantage; it is efficient for a pH range of 6 to 10. So, if you have high alkaline in water and if you want to disinfect that without bringing the pH to 7 or lower then we can go for chlorine dioxide.

We know that we have to maintain chlorine residual in the distribution system because we have to take care of the microorganism whatever can enter in the distribution system. So according to the standard we have to maintain 0.3 to 0.4 milligram per liter of residual chlorine in case of prechlorination and 0.5 milligram per liter in water works especially when the cysts of E-hystolytica is present that means cyst cannot be destructed by low concentration of chlorine and 0.5 milligram per liter of prechlorine is present for one hour in which it can inactivate viruses and 0.4 to 0.5 milligram per liter for 6 hours can inactivate nematodes.

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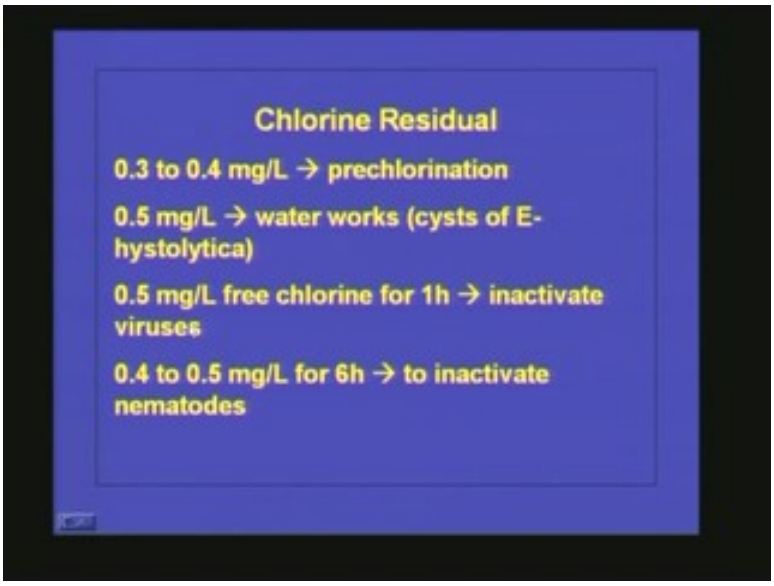

Now we see what are the things we have discussed today. We know that disinfection is a very very important treatment for water distribution because water should be free from microorganism or bacteriological safety is the most important water quality parameter because their effect will be immediate compare to chemical parameters and physical parameters. Disinfection can be done by various methods like any of the physical chemical method it can remove a certain amount of microorganism but the removal is not hundred percent. It can also be done by direct application of heat, UV radiation, ozone and chemicals. Chemicals; we can go for any halogens; chlorine, bromine, iodine then potassium permanganate H_2O_2 ozone etc and we have seen the mechanism of disinfection. What is happening is the chemical will be penetrating into the cell and deactivating the active enzymes which are responsive for the life supporting reaction. So that is the mechanism of almost all the disinfectant.

And we have seen that the most commonly used disinfectant in India is chlorine because chlorine addition is cheaper and it makes hundred percent deactivation of the pathogens and the efficiency of chlorination is depending upon the pH of the water, chlorination will be effective at acidic pH because when chlorine combines with water we get HOCl and HOCl is stable under acidic conditions. In alkaline condition OCl will be formed which is one by hundred times efficient compare to HOCL. Then ozone is another important and good disinfectant but the disadvantage of ozone and UV is it cannot maintain any residual effect.

And we have seen that if you want to find out the dose of chlorine required we have to find out the break point chlorination and add chlorine slightly above the breakpoint doors so that we will be having enough residual concentration. So depending upon the

condition whether viruses are present or nematodes are present we can change the residual concentration. So the recommended residual chlorine dose in the distribution system is 0.2 to 0.5 milligram per liter and chlorine can be added in different ways either as gas or bleaching powder or chlorine dioxide.