Water and Waste Water Treatment
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Lecture -28
Disinfection

Hello everyone welcome back to the latest lecture session. Until now we have been discussing how to treat wastewater in that context we looked at various aspects first removing the bigger particles, clothes, rags where the coarse screen. And then the grit relatively inert but bigger particles which can be relatively easily settled out and we looked at sedimentation as our friend in that case our gravity as our friend and we looked at sedimentation.

And we looked at different kinds of sedimentation type one two three four are different types of settling in the context of sedimentation. Then we moved on to primary treatment where we wanted to remove the suspended solids, yes. Two issues one to decrease the load on your biological system and also if you have any inert content it is easier to do that but not all wastewater treatment plants do that.

We discuss this elsewhere. Sedimentation we look at that gravity is our friend and then we moved on to secondary treatment or biological treatment. In that context the principle was that you had organic content which is relatively reduced form of carbon. So that acts as an electron donor. If you if you have an electron acceptor which is oxygen in this case you can have the relevant redox reaction and the byproducts or the products of this reaction will be carbon dioxide.

But this reaction is too slow. So what do we do we are going to use nature or the microbes to help us catalyze or fasten the kinetics of this reaction. How do we fasten it or how do the microbe's fasten it? They fasten it by releasing enzymes and why do they want to do that they need to have a reason for that because they want to grow they need energy they are going to degrade our waste and gain the energy.

And also they are going to use our waste for cell synthesis. You they need to form cell mass so they are going to use that or use the waste for cell synthesis and also for energy production. And after we do that we saw that floc forming microbes are what we want to form because you want to separate that from the water. So clarification and then thickening at the bottom of that sludge why because you want to have sludge with higher solid concentration and less water, why?

Easier to recycle and also easier to treat the sludge later economical too, so we are done with that organic part and then we started looking at nitrogen and phosphorus. Nitrogen principle is the same you have an electron acceptor donor you want to try to play around so that you can remove nitrogen. Then we moved on to looking at phosphorus, phosphorus it was a bit more tricky not as straightforward as removal of nitrogen where ammonia was oxidized to nitrates and nitrates were reduced to nitrogen gas and removed.

In the case of phosphorus we saw that we want to put the system under stress or the microorganisms under stress so that a particular kind of microorganisms thrives and the conditions are anaerobic and aerobic. In anaerobic the organisms release phosphorus because they need that particular energy which is given out when polyphosphates are degraded or transformed and in during that process you have phosphates being released that energy is used by the microbes to store carbon.

Carbon and electron donor sources and when they go to the aerobic phase they use this stored carbon a stored electron donor to out compete the other microbes. They thrive much better than the other microbes. And in during this process they are going to try to store or form polyphosphates but to form polyphosphates you need to take the phosphorus from the water. If you look at the anaerobic and aerobic phase net there is an accumulation of phosphorus.

We can then remove these phosphorous accumulating organisms from the system via the sludge removal like us. We were done with that. And the last aspect is disinfection we are still left with some enteric pathogens or enteric microorganisms or pathogens which you want to degrade or if I may say so inactivate. So that they don't lead to propagation or transmission of disease once they are let out into the receiving water BOD. So let us go forth and look at that so disinfection.

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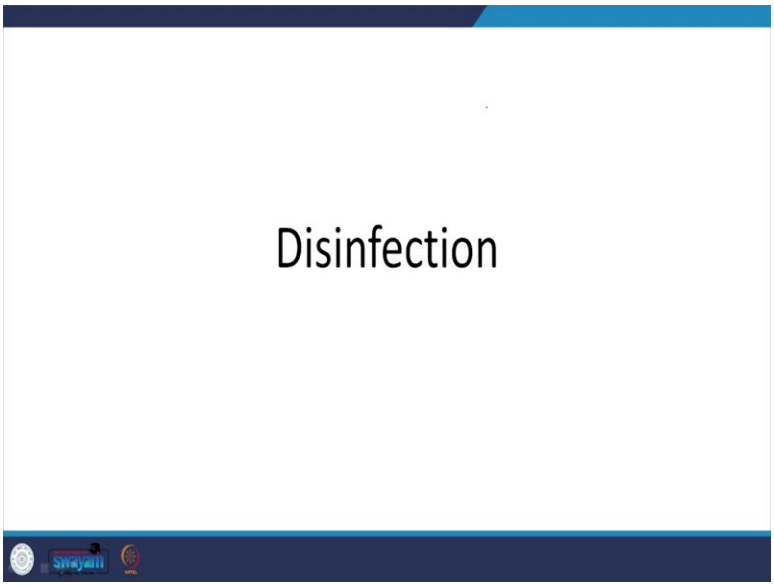

What were we done with until now we removed the relatively bigger particles and then we removed grit we removed the suspended solids most of them and then we removed organic content which we measure by BOD. So preliminary treatment primary treatment secondary treatment and then nitrogen and phosphorus the nutrient removal this is the tertiary treatment. And finally we need to take care of the pathogens.

So when we talk about wastewater this is what we are typically trying to do. So, preliminary primary secondary tertiary and then disinfection, so some treatment plants especially the older ones will not have nitrogen and phosphorus removal but then you can look at upgrading them. So in the context of disinfection we have different ways to go about it some are cheaper but they do not are not effective st all kinds of pathogens.

Some are relatively more effective but they are relatively expensive and difficult to not difficult to there is greater technological know-how required to be able to maintain the system. So it is a balance between what you are trying to achieve let us go forth and look at what we have. What is the goal?

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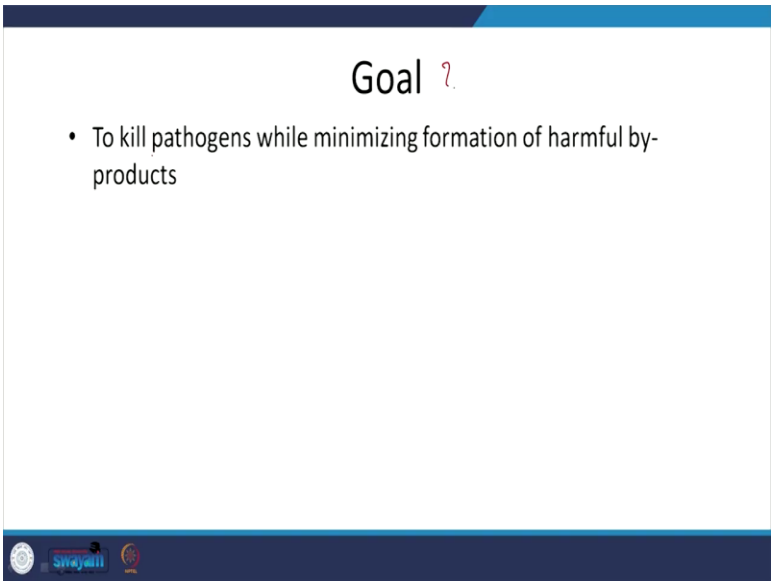

The goal is to kill kill is a layman's term pathogens while minimizing the formation of harmful byproducts anything that we do I take a medicine I am going to have side effects maybe the analogy is not a great analogy here but when I add a compound to water it can also be toxic by itself or it can lead to formation of harmful by-products. These by-products are typically called disinfection by products.

So you want to kill the pathogens but want to minimize the formation of these DBP's so how we can go about that.

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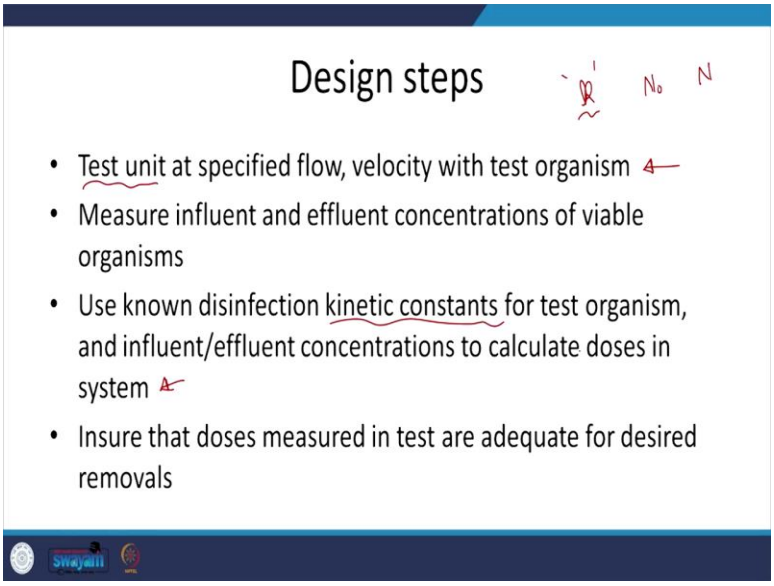

Design steps so you are going to test the unit at specified flow and velocity with test organism. One aspect to note is that models fine but when you build the system you are going to have considerable or short circuiting. So water that has to spend a certain amount of time would not probably spend as much time in that particular system. But unlike the case of organic removal where you can have some variation you do not want to have pathogens being released into the environment.

So here with respect to disinfection we need to be much more careful about the variation in the quality of the water. Especially in the context of drinking water treatment that is much more of a concern maybe not as much a concern in wastewater treatment. So that is one thing. So why did I mention that because you want to test it at the unit or on the unit with relevant flow .

Measure influent-effluent concentrations of the viable organisms, use known disinfection kinetic constants for test organism and influent-effluent concentration to calculate doses in the system. So what is coming in microorganisms what is going out and if you can find the rate constants or such where the disinfectant will degrade or kill if I may say so these pathogens you can more or less come up with a model to calculate the dose in the system .

We have to ensure that the doses measured in the test are adequate for desired removals. So some safety factor but that goes into the design .

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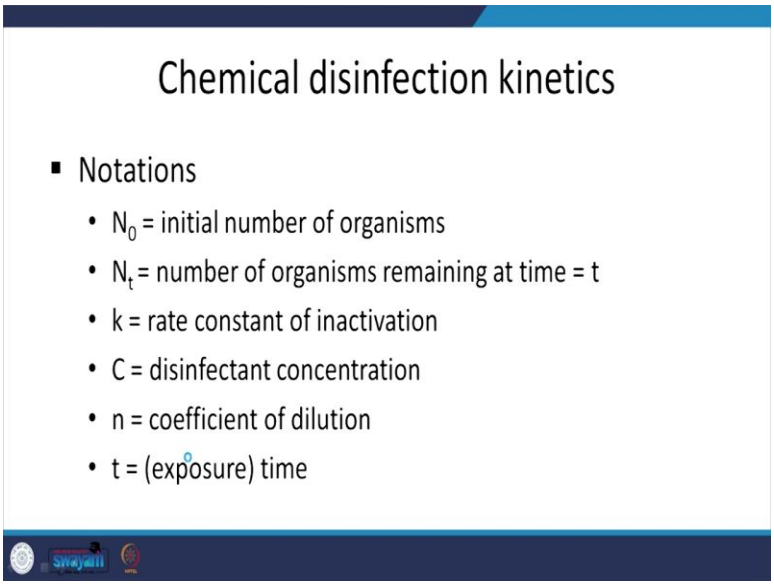

So chemical disinfection kinetics in general before we go further what do we know we know that A goes to products first order reaction first order. Rate is always dependent only on the reactants so rate of this reaction is depend upon the concentration of A and the rate constant of that reaction. And how is the rate of the reaction going to be equivalent to rate of A; r_{rexn}= k[A]. So because it is loss you can say A by stoichiometric coefficient of A stoichiometric coefficient of a here is 1. $r_{rexn(losss)} = -r_A/1$

So here similarly in the context of disinfection kinetics we use similar principle. So what are some of the notations that we are going to come across let us look at that. N_0 initial number of organisms initial number of pathogenic are the indicator organisms that you are trying to measure that are coming into the system, number of organisms remaining at time t, rate constant of inactivation so maybe that is a better word as we see rather than kill.

Disinfectant concentration that you are trying to put in or maintain typically you will maintain a constant disinfectant concentration. And is the coefficient of dilution which we will look at later t is the exposure time. How much time are the relevant pathogens being exposed to that particular concentration in that particular reactor. So exposure time or contact time.

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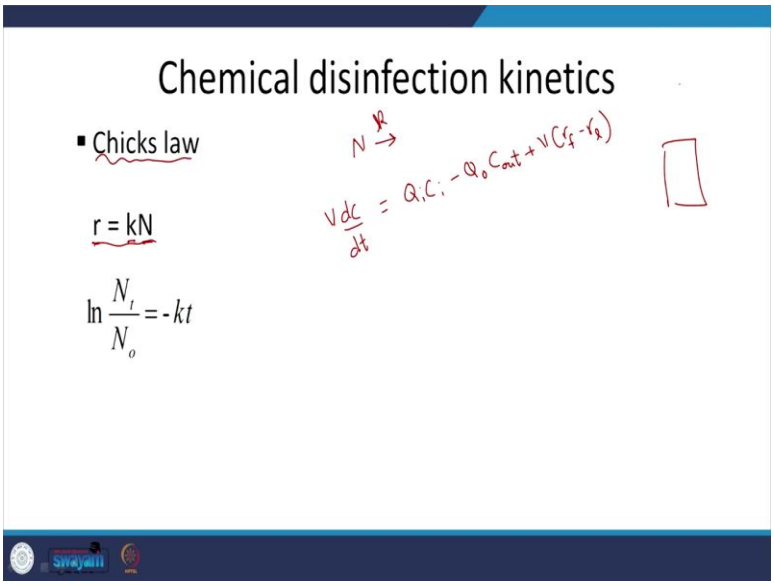

So long ago Dr Chick or Chick's law tells us that the rate of inactivation is depend upon that particular rate constant for inactivation and the number of microorganisms so N goes to products; $N \xrightarrow{k} P$

You can think of it this is an analogy this is not a chemical reaction here, the rate is like this. So if you put that into a batch reactor or batch for a batch system that for batch system what is the mass balance VdC/dt is equal to $Q_{in}C_{in}$ - Q_{out} C_{out} + Volume x rate of formation minus rate of loss of that particular compound.

$$V\frac{dC}{dt} = Q_iC_i - Q_{out}C_{out} + V(r_f - r_l)$$

Here if I am applying it on a batch reactor on microbes which are initially at a concentration of N_0. No flow coming in no flow going out and rate of formation of the microbes is also zero. So dC/dt is equal to - rate of loss

$$\frac{dC}{dt} = -r_l$$

and I know that the rate of loss (r_l) is equal to kN. So dN/dt

$$\frac{dN}{dt} = -kN$$

I am concerned about the concentration of the microbes so instead of C, I am using the term N and is giving me the concentration of the microbes at a given time in the system is equal to -kN. {C = -KN}

So I integrate this I will get N_t our natural logarithm of N_t/N_0 initial this is not out equal to -kt

$$ln\frac{N_t}{N_0} = -kt$$

so that is what we have out here. So that is why we looked at mass balance earlier in the class. So we understand this you can apply this for a batch reactor for a continuously stirred reactor or for a plug flow reaction reactor system but for plug flow you will not look at retention time you look at I mean you will not look at time you look at hydraulic retention time.

I think we will look at that later. So here as you can see we are not really considering the concentration of the disinfectant but the concentration of the disinfectant will play a role is not it, it cannot be such that even at zero it is going to happen or even at a dose of 100 mg/L of chlorine you are going to have the same kinetics .

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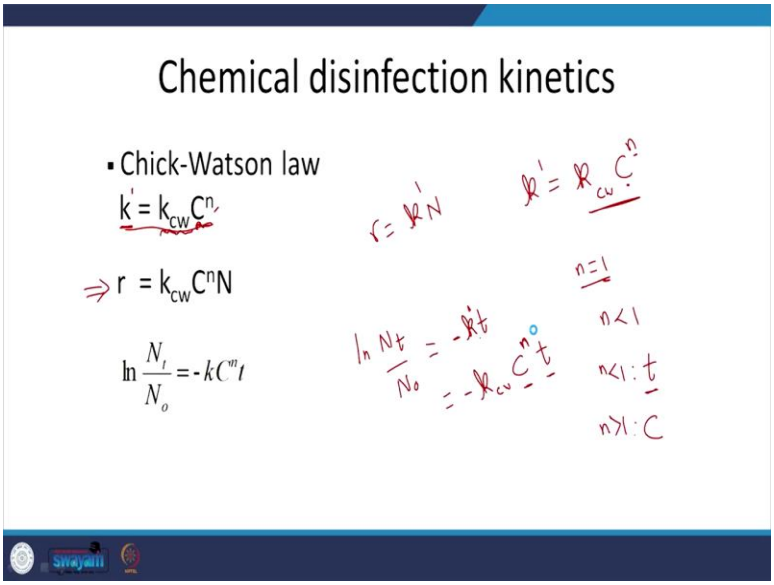

For example consider the case when we have one milligram per litre of chlorine a common disinfecting agent and 100 mg/L of chlorine. But as we saw earlier from Chick's law it is was equal to the rate of inactivation was equal to k times N{r=kN) there is no term that takes into account the concentration of the disinfectant C. So that is what is rectified in this Chick Watson law. So we had the rate constant earlier so that rate constant is depend upon k_{cw} the inactivation rate constant.

And the concentration of the disinfecting agent which you are holding or assuming to be constant in that system and N is the dilution factor that we considered earlier. So you can say that r equal to k dash N

$$r = k'N$$

where k dash is equal to this inactivation constant times the concentration of the disinfectant raised to the power of n, n was the dilution factor.

$$k' = k_{cw}C^n$$

So what is the relevance of n when n is equal to 1 both concentration and time are equally important.

So maybe we will look at this here and then discuss that. So this is our k dash let me say k dash and r is equal to this and similar to the case earlier where we had in the Chick's law. From chick's law we know and we derived that for the batch system it was equal to $-k_t$

$$ln\frac{N_t}{N_0} = -kt$$

So but now k is $k^/$ which is equal to this so that is equal to $-k_{cw}\ k^/$.

So that is equal to k_{cw} C (to the power of n) x t

$$ln\frac{N_t}{N_0} = -k_{CW}C^n t$$

So when n equal to 1 both concentration and time are equally important when n is less than or far less than 1 time or the contact time is relatively more important. When n is greater than 1 the concentration is relatively more important. So these are aspects that need to be looked at in the context of the dilution factor n here. I think that is what we call n or refer to coefficient of dilution fine. So this is an aspect let me see what else we have.

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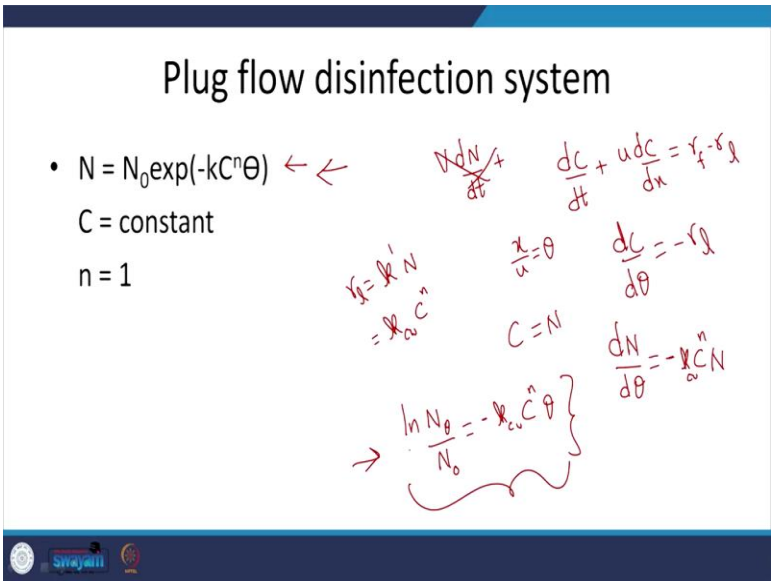

For a plug flow system in general you would like to have a plug flow system that is something we already discussed why do we want to have a plug flow system. In general it is more efficient for the same volume of the system. If you can maintain plug flow system your effluent concentration is going to be relatively lower compared to a CSTR or such. So we looked at that earlier so how do we come to this apply the mass balance.

So v dn/dt I am applying the fundamental mass balance equation dc/dt plus u dc by dx is equal to say plus or minus things which is rate of formation minus rate of loss.

$$\frac{dC}{dt} + u\frac{dC}{dx} = r_f - r_l$$

So I will end up with at steady state and x by u is equal to theta. So dc by d theta is equal to minus the rate of loss.

$$\frac{dC}{d\theta} = -r_l$$

The microorganism concentration dN/dθ is equal to - r_l which is equal to k times the microorganism concentration.

What is k? k is nothing but k_{cw} x C to the power of n that is something we saw r_l was equal to $k'N$ where k' is equal to k_{cw} x C to the power of n. What do you get this is what you get please note that it is similar to what we had earlier as a natural logarithm of n at time theta by n naught

or initial n this is n naught let me make that clearer. So n theta to n naught or n initial is equal to minus k_{cw} x C (to the power of n) theta.

$$ln\frac{N_\theta}{N_0} = -k_{CW}C^n\theta$$

So if I take this raise it to the exponential that is what I am going to get and that is what we have here for a plug flow system. But you see the parallels between the batch reactors equation and the equation from the mass balance for the plug flow system. So that is what we have this is for a plug flow disinfection system. So depending upon how well you can make the system behave like a plug flow you can go ead with it.

But depending upon your type of mixing you can sometimes end up having a series of CSTR this is especially the case with plug flow reactors in context of disinfection . Why is it because if I am trying to bubble in through bubble through ozone which is a strong oxidizing agent which can degrade the cell walls and thus leads to disinfection. maintaining or more the system will typically behave like a CSTR.

So to be able to approximate our achieve plug flow reactor system I will have it in series or there are different ways to go about it with baffle walls too. So that is one aspect to keep in mind.

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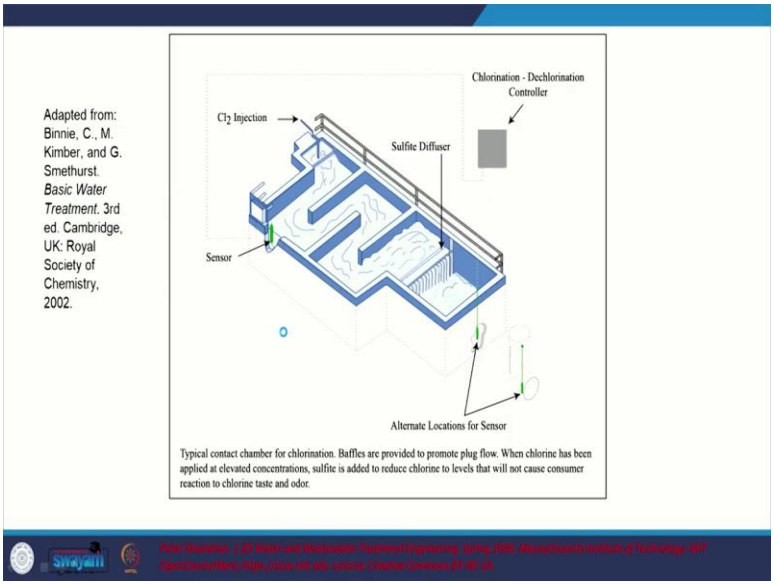

So here what do we have this is for chlorination simple or typical system. Chlorine is being injected here Cl_2 is being injected here we have sensors and different controllers for chlorination and dechlorination we will look at why we need to dechlorinate the system. So what do we have out here it is a typical contact chamber for chlorination. Baffles are provided to promote plug flow.

You want a plug flow reactor as much as possible because for the same volume the r_{net} for loss is typically higher. When chlorine has been applied at elevated concentration the concentration of chlorine at the effluent will also be high. And in general I am not sure if people experience this now at least when I was a child back in my hometown some days we used to get this water and it used to have a pungent smell and we were worried that there was something off yes it was off but it is not something that could we have not been able to remedy at home.

It was that the municipality was pumping in more chlorine than was necessary. We will look at why they add more chlorine in the first case. If the chlorine is too high you want to de-chlorine it so that is why you want to add a reducing agent to be able to reduce this oxidizing agent which is chlorine so that is what you see typical plant.

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So plug flow disinfection system there are different ways to promote it but this is with respect to typically chlorination. If it is origination you are not going to keep it open to the relevant surface.

So different ways to promote this plug flow we do not want to achieve completely mixed. So different baffles you see the different baffles to be able to achieve a plug flow system here or narrow long channels which are divided so that they behave like a plug flow system. So that is what it looks like typically .

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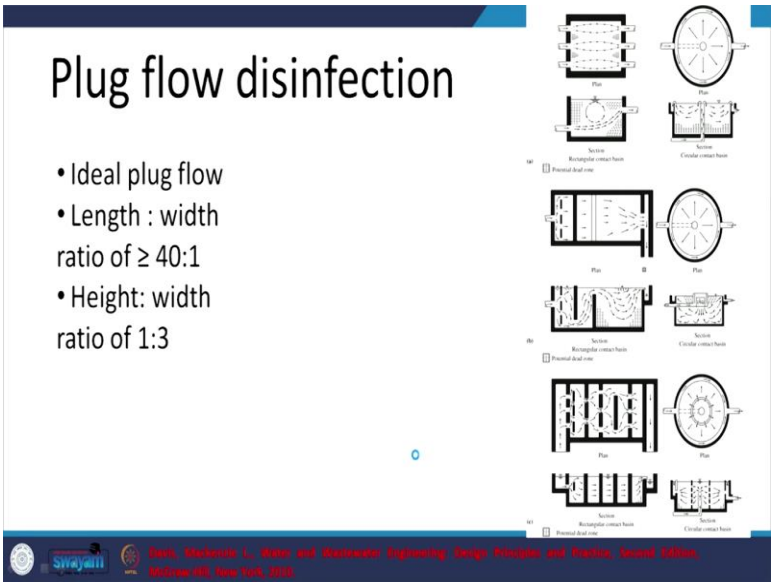

And different plants let me not go into that in detail but with respect to ideal plug flow you want to have length much greater than the width. And ratio is typically greater than 40 is to 1 height to width 1 is to 3. Fo for example an example of this particular case was seen out here. but with the baffles or baffle system you can try to get around that, yes. So here you see with baffles not here. So there is not a great picture here but the previous ones were better pictures of the baffle based system to achieve plug flow reactors.

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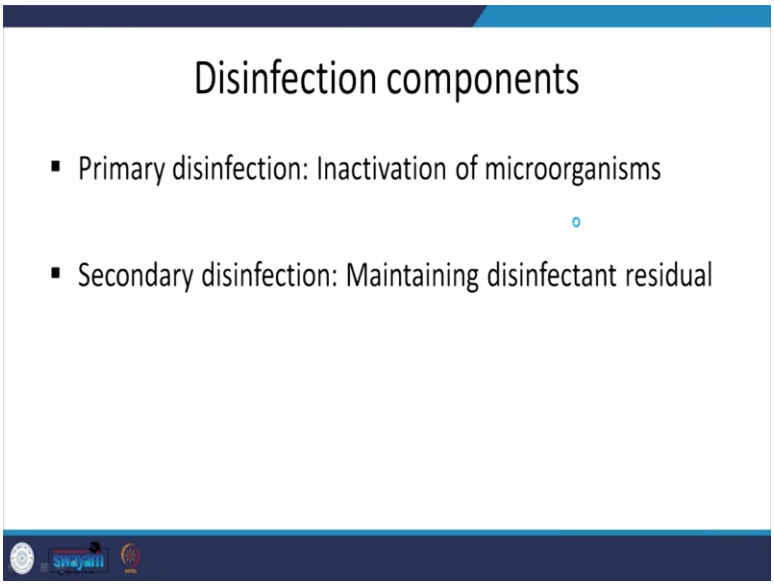

So disinfection components what are we trying to do. So why is it that the municipality was adding chlorine in the first case they want to kill the or inactivate the microorganisms present. But in the context of my hometown that was with respect to supply drinking water here we are talking about it in the context of wastewater . So I want to inactivate the microorganisms. I am discussing this, these is relevant to the water aspect but let us go ead and talk about it in general .

So secondary disinfection, primary disinfection is what we are looking at in the context of our wastewater in the context of water we have to kill the microbes and also ensure residual chlorine maintaining the disinfectant residual why is that? For example at least in the Indian context this is my water treatment plant not the sea waste treatment plant. Why am I also discussing this here because we will need to discuss this infection later rather than doing it in parts.

I am discussing that here now maybe we will look at it briefly later on. So in the context of the water treatment plant this is not the sewage treatment plant the water will have to be pumped over long distances to different locations . So you can have microbial growth though you apply some chlorine here to kill the microbes here because of this long contact long traveling time. By the time it comes to my home I can maybe at least in Indian case this is always the case especially in the joints I can have sewage from the nearby sewage lines coming in contact with the distribution network are penetrating the distributed water distribution network and thus contamination of the water.

So if there is no residual chlorine or residual disinfecting agent it is going to lead to what we say transmission of disease or transmission of or propagation of pathogens. So that is the reason why I want to have some residual disinfectant. In India it is especially important because our water distribution networks are relatively poorly maintained. So that is why sometimes you see that you get much more what we say chlorine than is typically acceptable because.

if I am living out here and there is one person living far out. But they are going to apply the same chlorine dose. So by the time this water travels here the chlorine dose might be less, 0.2 mg/L is typically acceptable. But here it might be pretty high why the travel time is less. So there are different ways to look at it. So primary disinfection at the point of disinfection secondary disinfection to rule out microbial re-growth and contamination of the water later on that two aspects.

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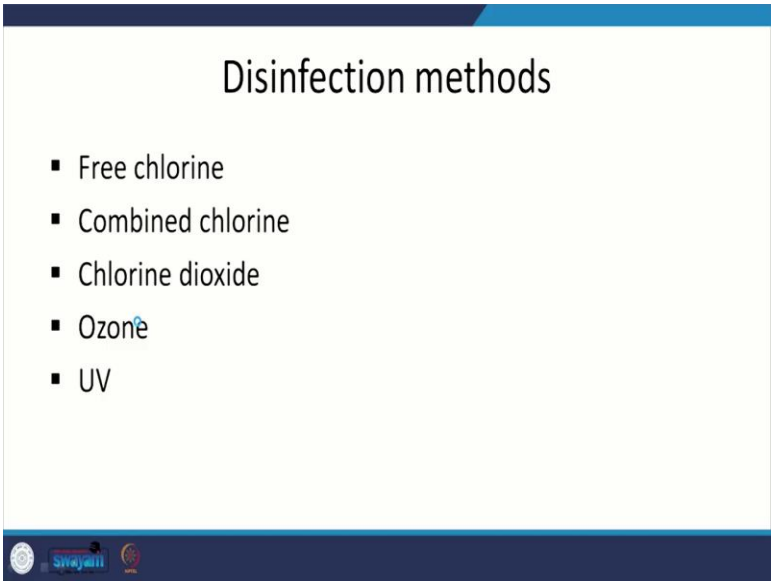

So different disinfection methods so free chlorine combined chlorine. We look at that chlorine dioxide strong oxidizing agent ozone a remarkably strong or the strongest oxidizing agent among these chemical oxidizing methods or chemical oxidants and UV ultraviolet, ultraviolet disinfection. So let us look at the aspects before I go further one aspect to consider is that as I mentioned oxidizing agent. So when I say oxidizing agent or oxidant what is it that I am trying to say now.

Even in the context of what is this? The microbial degradation of the organic matter we came across this electron donor electron acceptor. Electron acceptor oxygen oxidant or oxidizing agent so strong oxidant would want to strongly want to accept the relevant electron. So typically it can degrade organic matter cell mass is also organic matter. So that is why you are going to add the strong oxidizing agents which can what we say degrade the cell components or the cell wall .

So different ways to bring about the inactivation of the microbes we will go about that but as can be seen one common aspect among all these top four oxidizing agents' top four disinfection agents is that they are all oxidizing agents or oxidants. I think we will discuss this now.

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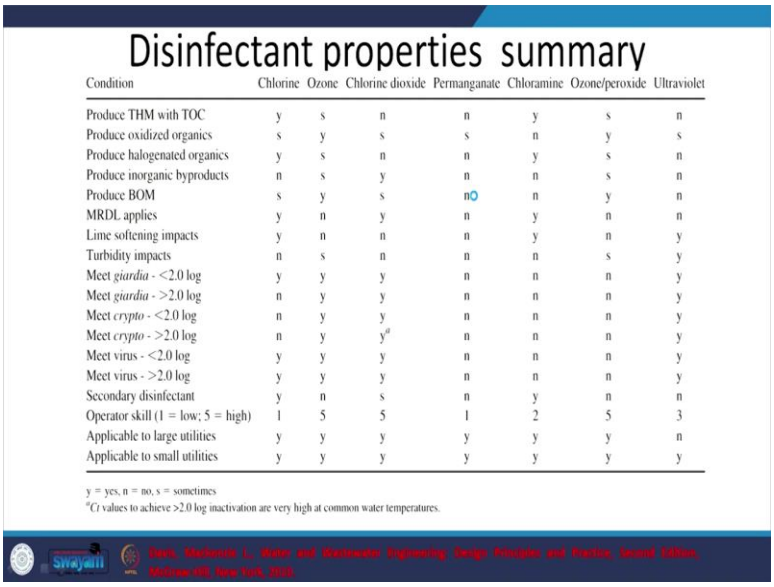

Before I go further so what do we have chlorine, ozone, chlorine dioxide, permanganate, chloramine, ozone and hydrogen peroxide ultraviolet. So here we have different conditions that we want to meet . Produce trihalomethanes when total organic carbon is present these were the harmful disinfection byproducts that I discussed about. So you do not want to have these formed. So what are some of the ways or types of disinfecting agents which can lead to formation of these harmful disinfection byproducts chlorine and chloramines, yes.

So that is one thing to look at sometimes with ozone but that is when there is bromide. So let us not go into that for now but chlorine and chloramine which is pretty cheap to use and add the

issue is that you have formation of these disinfection byproducts. In India people do not consider that to be a huge issue because if you look at the number of deaths especially of the infants all or the vulnerable population you will see that most of us most of the deaths are considerable fraction of deaths are due to diarrheal diseases.

So greater priority is to kill the microbes and we will think of these aspects which will have long-term issues though like sometimes DBP's are classified as carcinogens according to US EPA. So we will maybe as a country once we develop then we will start looking at that. So that is one aspect to consider though. So they can produce oxidized organics we will not look at that for now.

And these are different types of pathogens here yes protozoa, viruses log 2 is it 99.99 removal or such. So log 2 that is what it is talking about. So as you can see here chlorine they are not able to achieve a great level of removal for what we say quite a few of the pathogens of interest . So that is something to keep in mind not every disinfectant is effective st the range of pathogens that we come across. So that is one thing to keep in mind.

So secondary disinfectant I am assuming that it is about the relevant residual disinfecting properties. So chlorine yes ozone and UV certainly not chloramine. So if I want to have a residual oxidizing capability in my water I need to choose chlorine or chloramines. So if I add too much chlorine I know these toxic disinfection byproducts will be formed.

So it is a trade-off how I want to go about it but sometimes you can have ozone to kill the microbes and the trace organics and then you can add some chlorine so that the DBP concentration will be less but you will have enough residual chlorine available . So let us dig deeper into this aspect .

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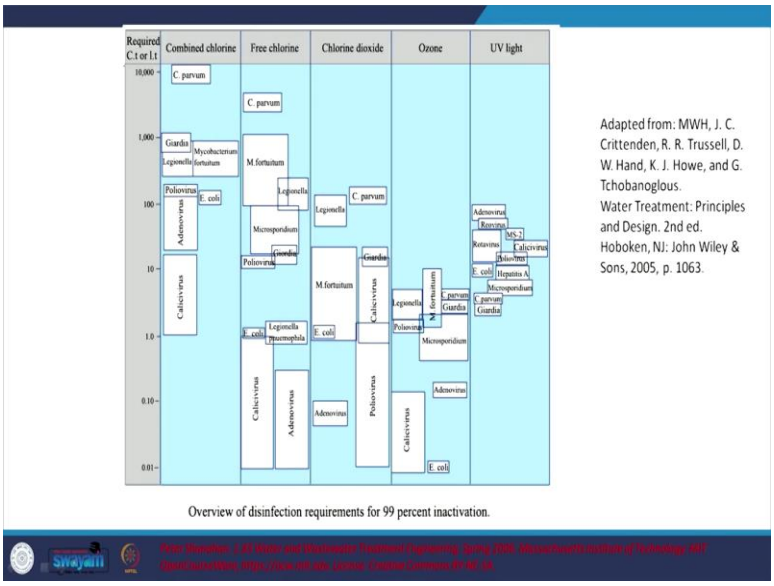

Overview of disinfection requirements for 99 percent inactivation.

So here we see Ct or intensity time so earlier people used to maybe just mention concentration or just mention the time required for disinfecting a particular kind of microorganism or pathogen based on applying a particular kind of oxidizing agent. But now as we know both concentration and the time are relevant so here it is this is called the Ct approach. So it will give an idea about how much concentration and the contact time is required.

So that is the approach that is widely accepted. So for combined chlorine you see that with respect to a range of viruses' yes it is doing fine but with respect to Giardia and there is something else that should be missing out here so I will come back to that. So there are some kinds of pathogens that lead to diarrheal diseases major cause of deaths in India. A major cause so, for that you need to have a lot of contact time or high concentrations and high contact times as you can see here.

But within acceptable times and concentration Ct values you see that most of the viruses are or a few viruses can be inactivated. So fully free chlorine the issue is that most are compared to combined chlorine it can inactivate a range of pathogens but the issue is that you will need to have high Ct. So more contact time is required. So that is an issue chlorine dioxide you see that relatively lesser contact time.

But it cannot look at Giardia, microsporidium if I am not wrong and these are typical aspects though we mentioned Giardia it is not particularly effective. But with respect to ozone and UV and this is the advantage you see that they are effective st a range of pathogens and that too at relatively less Ct values. So contact time is particularly or relatively less out here. So this is an advantage because to kill a range of pathogens I can I need not spend a lot of time meaning a lot of resources and space.

But I can what we say do this within a smaller time and also that will affect the size of the system but one aspect when we are designing small reactors is that it is easy for the water to bypass the relevant treatment path and short circuited from influence to the effluent meaning it does not spend enough time in the reactor. So short circuiting can happen in shorter or smaller a reactor that is one thing to keep in mind.

But ozone and UV relatively more expensive and but one aspect to keep in mind is that with UV the cost capital costs are coming down because more and more people even in India are using that or trying to adopt it. For example it is similar to the cell phones earlier the costs were high now they are coming down because there is more demand and thus the logistical change and infrastructure is prepared so that the cost per what we say cell phone comes out.

So this is for 99% inactivation. , ozone and UV they are remarkably good at inactivating Giardia and microsporadium which is not the case with typically combined chlorine, chlorine dioxide and free chlorine that is something to keep in mind let us move on.

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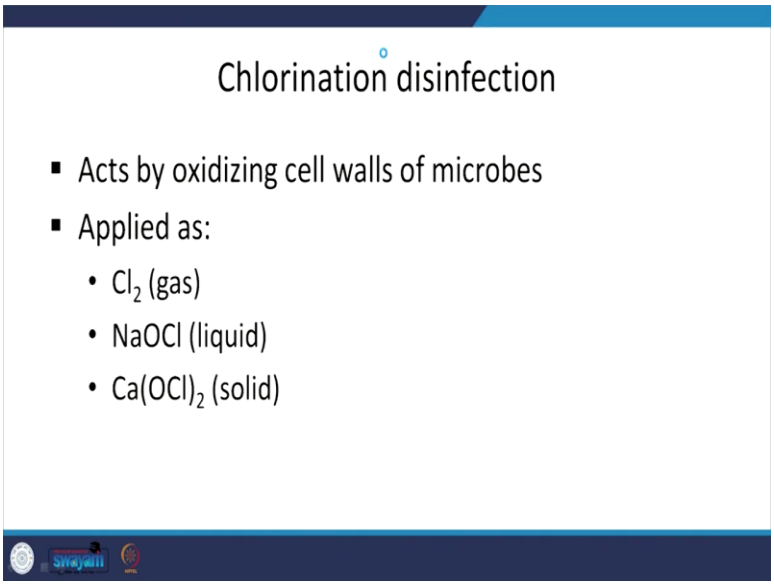

So chlorine as we mentioned is an oxidizing agent it acts by oxidizing the cell wall of the microbes. cell wall organic matter so you have organic matter which is relatively more reduced. Reduced meaning it can give electron or it can donate the electron and you have chlorine which is a strong oxidizing agent it wants the electron. So thus it can if I use the layman's terms eat away the cell wall.

By eat having away the cell wall the contents of the cell they are going to come out and then the relevant pathogen depending on the type of pathogen because not all pathogens have cell walls they will not be able to thrive or function. But one aspect to keep in mind is when we were looking at bacteria forming of flocs we saw that. And during the endogenous phase we saw that bacteria have a slime layer.

And if there is slime layer that acts as a protective layer or coating for the relevant microbes st chlorine. Chlorine has to eat away all that or oxidize all that slime layer before it can get to the cell wall. So, endogenous phase typically occurs later. So relatively older microbes if I can say so older microbes they need higher concentrations or higher contact time before they can be inactivated. These are the aspects you need to be aware of especially when looking at oxidizing agents like chlorine .

So what do we have it the primary action is oxidizing cell walls and then damage to the relevant cell ingredients. It can be applied in different forms Cl_2 remarkably cheap but one issue is it is a fire hazard toxic hazard to the people. There so the kind of application is going to depend upon what we say how well you enforce the fire hazard standards.

In India maybe not a lot that is why people go for this and it is pretty cheap or it can be applied as NaOCl or $CaCl_2$. So let us look at the relevant reactions.

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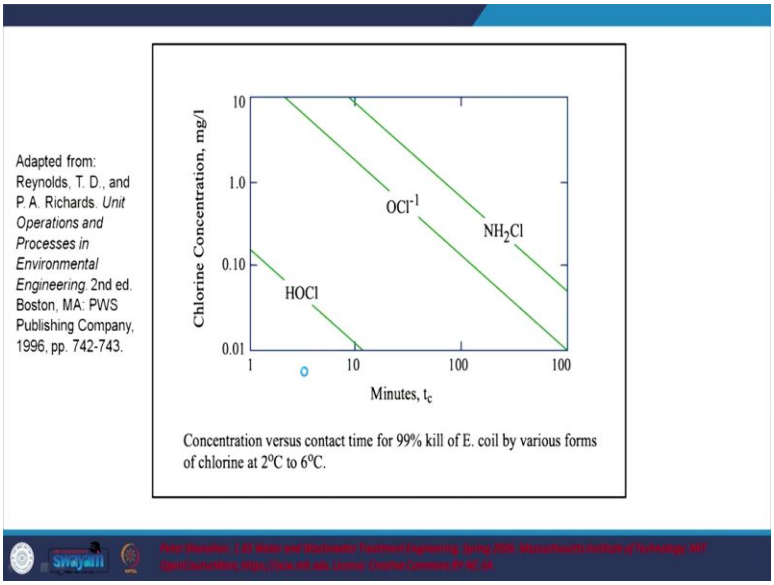

Before I look at the relevant reactions let us compare the effectiveness. Here when I form NaOCl or add NaOCl to water what is it going to form it is going to form OCl^- and Na^+. And this OCl^- will be in equilibrium with HOCl. So HOCl is a much more stronger oxidizing agent when compared to OCl^- it is depend upon the pH we will look at this later but just to what do we see convey the information or message that HOCl is a much more stronger oxidizing agent we have this graph.

So here we have the effective chlorine concentration on the y-axis and the contact time or minutes on the x-axis chlorine concentration versus contact time to achieve 99% kill of the E. coli by various forms of chlorine. As you can see for a particular concentration let me say this you can see HOCL requires very little time OCL requires a lot more time and this combined chlorine NH_2Cl, chloramines require much more time .

This should have been 1000 because this is logarithmic scale 1, 10, 100, 1000 each time it is 10 times higher. So you can see that HOCl is remarkably effective and for a given time 10 minutes you can see that the concentration of HOCl required is much lesser compared to the concentration of OCl^- that is required. So we have to play around with the pH to maintain what we say favourable concentration of HOCl but you cannot bring the pH too far down .

I am almost out of time or rather exceeded my time limit. So I will end today's session and continue this in the next session, thank you.