Water Quality Management Practices

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Week-05

Lecture-24

Flocculation

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Bhowmick from the Department of Agriculture and Food Engineering. Today, we will be continuing with the module 5, which is the Physico-Chemical Operations and Processes part 2. We will be specifically discussing on Flocculation Processes, we will be discussing on the different mechanisms, the Perikynetic and the Orthokinetic Flocculation Systems, the factors which affects the flocculation and different design considerations and also we will solve one numerical as well. So, to start with we all know that from the term floc, we all understand that what is floc, it is like you know and conglomeration of some objects right. Same or other different other types of objects can conglomerate together and we can call it a floc.

So, in general in flocculation process what we do? We somehow adds by means of by mechanical or chemical I mean like by unit process or by unit operations by somehow we try to amalgamate, we try to you know conglomerate couple of different types of pollutants or same type of pollutant together and so that it will be easier for us to get rid of them by the forces of gravity it will settle down on the bottom and we can collect it as a sludge ok. So, this is the basic fundamental of flocculation process. So, in this flocculation process our target is to make the pollutant to cluster together agglomerate and form larger flocs isn't it. As you can see in the picture so that is what our target is to make them as a floc like structure.

What are the different mechanisms that involves in the flocculation systems? The first one is the perikinetic flocculations and the second one is orthokinetic flocculations. The first one in general like the in the first stage of operation happens in micro scale. In micro scale flocculation or in also known as the perikinetic flocculations what happen in this particular case different inter particle they collide with each other and because of the because of the Brownian motion as you know that the any colloidal particle they normally have a behavior they normally have a tendency to go for a very peculiar path of motions. So, this is what we call the Brownian motions. This Brownian motions because of that they collide each other and that is what the basic principle here.

So, we somehow try to you know in encourage this kind of collisions. So, in this kind of flocculation systems it commences immediately after the destabilization of the colloidal particles and it is generally driven by diffusion process. Aggregation of particles smaller than 0.1 micron diameter it occurs during the perikinetic flocculations and leading to a formation of flocs of a size of around 1 to 100 micron. The rate of change of concentration of this colloidal particles in suspension with respect to time due to the perikinetic flocculations can be denoted as J_B as you can see and it is estimated by using this equation the following equation ok.

$$J_B = \frac{dc}{dt} = -\frac{4\eta kTC^2}{3\mu}$$

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particle in suspension at any particular time t. The collision efficiency factor the k is the Boltzmann constant and the t is the absolute temperature in Kelvin. The next stage is the macro scale flocculation. What is happening in the initially we have the perikinetic flocculations or the micro scale now we are having the macro scale. In macro scale or the or also known as the orthokinetic flocculation it refers to a phenomena where the inter particle contacts are produced by laminar or turbulent fluid motions.

Here we target normally little bit higher or the larger sized particles like in greater than 1 micron and it normally happen due to the process of eviction or the bulk motion of the fluid. We normally introduce some velocity gradient which is induced in flocculation tank by via slow mixing by using some mixing phenomena mixing maybe it can be some orator it can be some normal mixture it can be vortex generator. So, by anyway we try to make a small mixing in the system ok. And we can actually provide different kind of mixture also we can provide some baffles along the basin that also kind of making it a kind of a the mixing possible. Higher velocity gradient in general it increases the number of contacts and between the particles and leading to the greater quantity of floc formulation ok.

The more time will be required to reach the optimum floc size at lower velocity gradient owing to the subsequent reduction in the number of contacts between the particles. Also the rate of reduction in the concentration of colloidal particle with time which is expressed by J_G can be expressed using the following equation.

$$J_G = \frac{dc}{dt} = -\frac{2\eta\Gamma d^3 c^2}{3}$$

Here if you see the it also it almost follows the same equation as the perichyretic flocculation, but only with the additional terms like d which denotes the diameter of the colloidal particle and gamma this the velocity gradient of the laminar flow. The negative symbol in general if you see in this equation we have a negative it actually used before to account for the decrease in the concentration of the particle due to the aggregation with time. So, what are the different factors which can affect the flocculation? First of all the concentration of the colloidal particle in the waste water, the higher the concentration of the colloidal particle more opportunity for them to in a contact with each other and agglomerate and form the floc.

Second is the slow mixing, the higher mixing intensity in flocculation can induce a shear effect and it may actually disintegrate and disperse in the water again. So, slow mixing is more important ok. The intensity of mixing is very important here. We normally denote the we it is a very important term this capital G if you can see here the temporal mean velocity gradient with a unit of second inverse normally 10 to 75 second inverse is standard like in general we takes a anyway. So, this temporal mean velocity gradient is normally used in coagulation and flocculation process for measuring the intensity or mixing by the following equation.

$$G = \frac{v_1 - v_2}{x}$$

This V 1 and V 2 are the velocities of colloidal particle A and 2 having a distance of x in between them ok. So, this is called the temporal mean velocity gradient or with the G ok. So, it you can understand it has a unit of second inverse and so, this is very important please remember this term temporal mean velocity gradient. So, we need this value we need this notation when we will be discussing the numerical. In general the mixing basin it it this mixing is induced by creating a turbulence by as I was mentioning either by using some mechanical or the mechanical means or by you can simply put some baffles as you can see in this picture they put a different kind of baffle walls different I mean like like 5 number of baffle walls.

Because of this baffle walls this inflow it reaches it creates a certain turbulent turbulence and because of that what this mixing is happening. So, this kind of mixing can be either called like I mean like this can be called the around and end type there is another type over and under type is also there. So, this over and under type mixture is also there and you know there are this around and end type is also there. So, it depends upon the position of the baffle walls in the either it is a horizontally placed or the vertically placed ok. So, and also the mechanical mixer also sometimes we use like radial or the axial axial flow impellers with shaft and pedal arrangement as you can see in the bottom the mechanical mixer.

So, those are slowly they are moving and they are rotating on the surface either vertically or the horizontally horizontally placed. So, what they are doing they are making a certain mixing arrangement inside in the in the water. So, it will actually encourage the flocculation process to occur. So, what are the base major factors which affects the flocculation? The first one is the mixing time. As you can easily understand the maybe from your basic understanding we can say that you know the more the mixing time the more the better the system right.

So, it was not only it is that that is not the only factor ok. In general in like in usual wastewater treatment practices the mixing time required for flocculation ranges from 20 to 30 minute to ensure the proper floc formations. Most of the flocculation tanks are designed with the hydraulic retention time t considering the requisite mixing time criteria. Product of velocity gradient you know the what is the velocity gradient here? The velocity gradient it is like you know dc by dt or dc by dx here I would say like you know dv by dx here ok. So, that means, the velocity in terms of I mean like in terms of distance.

So, because of that it has a what will be the unit of it second inverse or the time inverse multiplied by the hydraulic retention time time. So, it becomes the conjugation opportunity we call it this this gt it has it is a dimension less than ok is not it you understand. The velocity gradient which normally it is like you know having a second inverse the unit and the hydraulic retention time if you multiply it will become unit less. So, this unit less this term conjugation opportunity what we call it gt is very important. It is normally it is often used as most important design criteria for flocculation tank.

So, please remember this term gt capital gt which is used for which is also known as conjugation opportunity and this will be very useful for us to understand the process ok. In general the parameter g normally directly affects the density of the flocs whereas, the detention time t is responsible for the determining the size of the floc formed ok. So, remember the g the the g is it you remember the g we discussed about in the temporal mean velocity gradient g this mean velocity gradient is actually giving us an idea that what will be the density of the flocs ok. The higher the g the higher the denser the floc the dense the floc will be. However, the lower the g the lighter the floc will be ok.

As you can see in the and also it depends on the detention time also if the t is less that means, small floc formation if the t is more than more and more opportunity for the this pollutant particles colloidal particles you know agglomerate. So, the size will be larger. So, t is higher is already known to us the t if it is high then the size of the floc will be larger if t is less the size of the floc will be small. The g is high that means, it is a dense it is will be quite dense the floc as the if the g is low then the it will be quite lighter in the in in nature. So, based on that if you see in the picture there the inflow and outflow we normally design it in asuch a way that we add multiple mixer.

We suppose need to design 1 cubic meter of flocculated flocculation tank. What we do we divided into 2 part half meter cube each ok. Then in the first mixer what we do we do it in a little bit faster mixing. In the second one little bit slower mixing zone. So, because of this faster mixing zone what is happening there the small flocs, but more dense so that means, more amount of particles can get agglomerate there.

In the next one it is larger floc because the time is high, but what what is happening the floc sizes larger, but there is a chance that it will it will also be quite denser as well ok. If you can see in the first mixing zone what is happening the g is higher. So, the g once the g is higher and if you see the t the time is low. So, what is happening here? So, because of the higher detention time I mean like the detention time is less, but if you have the higher like the g value is high. So, because of that what will happen will happen in denser small floc, but in case of slow mixing zone if you see it will be having the g value is less and the time is high.

So, because of that it may have the larger flocs, but it may be much lighter than the fast mixing zone ok. So, this is the basic difference between these two ok. So, this is this is the why why we install multiple like you know stack of mixer and we divide the flocculation chamber in couple of bifurcated in couple of different zone. So, that will increase the efficiency of the flocculation process. There are some design considerations I would like you to remember the first thing is the flocculators are normally designed for a peripheral velocity of around of this paddle blades in the range of 0.1 to 0.9 meter per second. The relative velocity with respect to the adjoining water near to the external tip of the paddle is maintained below 1 meter per second to prevent the excessive velocity gradient for avoiding the disintegration of the floc. The total paddle blade you know the paddle wheel when we use it this paddle blade area should be 15 to 20 percent and or like you know 10 to 15 percent of the flocculation basin cross section basin sectional cross sectional area based on the the the Droste gear 2018 and the CPHEU manual in 1999. The minimum and the maximum area of the blade should be 10 percent and 15 25 percent for sufficient mixing respectively. The depth is generally 3 to 3 4.5 meter when mechanical mixers are installs for baffled flocculators depth of 1.5 to 3 meter is ah 3 times the distance ah between the baffle ah with a minimum distance of 0.45 ah meter between the baffle is enough. Hydrodynamic retention time in general we keep it around 10 to 30 minute. So, please remember the value of g t the value of g t we ah we take it in the range of 10^4 to 10^5 and ah based on the CPHHU recommend they recommends the this value should be somewhere around 2 to 6 into 10^4 for aluminum coagulants and 1 to 1.5 to the power ah 10^5 for ferric coagulants ok.

So, ah we normally take the aluminum coagulants only in general. So, for that we take the value of 5 to 6 into 10^4 that is a standard procedure. So, let us go ahead let us do one ah numerical. So, it will be you know ah easier for us to understand the flocculation chamber and how it is to be design and the whole concept in details. So, in this question it is asked that a flocculation basin is to be designed to handle 60 60 million liter per day MLD 60 million liter you remember million liter means 10^6 liter per day.

So, 10^6 means liter means 10^3 meter cube day means divided by 886400 it will be easily converted into meter cube per second ok we may need that value anyway. So, 60 million liter per day of waste water flow ah for this particular flocculation basin has to be designed. The basin should have 4 compartments each equipped with a vertical mechanical mixture with a shaft and paddle arrangement having a motor and brake efficiency of 90 percent and 75 percent respectively. The shafts are to be fixed horizontally at mid depth along the width of the tank perfect has and has a gradually varying g to provide tapered flocculation as your as you remember I was telling it will vary with time the faster mixing then the little bit slower then little bit slower at the end it will be the slowest one ok. And the kinematic viscosity of the water ah is given as 1.31×10^{-6} m^2/sec ok. If you want to convert into dynamic viscosity simply you multiply it with the ah density ok so, which is 1000 kg per meter cube you know. So, ah in general the you are asked to to calculate the dimension of the flocculator the power required for driving each mixer the rpm of paddle wheel etcetera. We first is they also ask that please provide 2 flocculators operating in parallel and 2 power blades per ah power wheel for with one on either of the arm ok with a coefficient of drag CD as 1.8 and depth to width ratio of the flocculator as 1 ok.

So, these are the information that is ah given to us. So, what we need to do the first thing that we need to do let us take some assumptions. The step one is since the flocculation basin should have the 4 component with the varying g value you take the different g value standard practice is. So, take like 60 second inverse it should be minus 1 ok please correct it those should be minus 1 60 second inverse in the first compartment then the next one is 45 second inverse the next one will be the 30 ah second inverse and the fourth one will be say like 15 second inverse. So, how we can get the ah average ah g average now? So, 60 plus 45 plus 30 plus 15 divided by 4 that is 37.5 second inverse say that is the g average for you. Now, you assume the g t value if you remember we say that g t value in generated by CPHHU CPHEU manual that ah they recommend that g t value should be somewhere around 2 to 6 into 10^4 for aluminium coagulants ok. So, this g t value is so, we have taken for this problem 6 into 10^4 ah and as you have as you remember it is unit less is not it because it is a product the multiplication of velocity gradient into hydraulic retention time. So, this ah the g t value we know the we already assume that 6 into 10 to the power 4 and also the the g average is also known to us the velocity gradient is also known to us ok.

So, which is given as ah 37.5. So, we can easily calculate the ah detention time because detention time is nothing, but the detention time or hydraulic retention time whatever it is it is it is it is the same is the nothing, but the you can easily find out by conservation opportunity divided by the velocity gradient. So, the velocity gradient is known to us 37.5 and that we also know the g t value. So, g t divided by velocity gradient you will get the retention time, hydraulic retention time or the retention time. So, hydraulic retention time is come over 6 into 10 to the power 4 divided by 37.5 equal to 26.67 minute or say let us let us say 27 minute. So, the volume of the flocculator how you can calculate the volume of the flocculator just try to understand. So, there is a certain inflow there suppose there is a one chamber you design one small tank. So, in this tank there is a say 100 meter cube per hour inflow is coming ok. So, you know that you only want your the water the the the detention time of your reactor should be half an hour ok.

So, what will be the volume? So, for half an hour your I mean like you know the 100 meter cube per hour is the inflow rate. So, for in half an hour what will be the total inflow 100 into 0.5 that is 0.5 50 meter cube. So, 50 meter cube should be your should be the volume of your reactor reactor same way we can also design the volume of flocculator also.

How because we know the inflow which is 60 into 10 to the power 6 that is that much of million liter that much liter divided by 10 to the power 3 it will become meter cube divided by 60 divided by 24 it will become in minute and the as the detention time we already know the 27 minute. So, if you multiply that this this much of this value in the left multiplied by 27 minute you will get the total volume of the flocculator you need ok which is coming as 1 1 2 5 meter cube. Now, there are 2 flocculator that we need. So, each floc each tank should have a volume of 562.5 meter cube. Now we know that the the depth to width ratio is 1. So, if you take a depth of 4.5 meter in general that is the standard practice for mechanical if you see it is given in the yes if you can see the fourth point the depth is generally 3 to 4.5 meter when mechanical mixtures are installed ok.

So, 4.5 is a standard practice. So, we will take a depth of 4.5 meter including 0.5 meter of free board on the top in case of you know over spilling and to reduce to reduce the chances of over spilling or not. So, total depth will be 5 meter and as you know the depth to width depth to width ratio is 1.

So, that means, if you are taking depth as 4 4 4.5 meter your width will also be 4.5 meter. So, now, you know the width 4.5 meter you know the depth. So, what will be the length? Because we know length into breadth into depth is equal to the volume the volume is 562.5. So, how you can find out the length 562.5 divided by 4.5 into 4.5 is not it. So, this way the value is coming as 27.78 meter or 28 meter.

So, that means, this is the length total length. So, now, they are asking you to divide the whole flocculator into 4 chamber 4 compartment. So, each compartment will be having a length of 7 meter 28 divided by 4 7 meter each ok. So, the each compartment having a dimension of 4.5 meter × 4.5 meter × 7 meter ok. So, that is the dimension of the easily you can find out. Now, again the value of g or the like if you want to find out the value power requirement it can be easily find out by the following the equation that is given here.

$$G = \sqrt{\frac{p}{\mu V}}$$

So, here if you see this dynamic viscosity you need to find out first the dynamic viscosity or mu this value you can easily find out kinematic viscosity is given multiplied by the density 1000 meter 1000 kg per meter cube. So, it will you can easily find out the kg per meter per second you can see the first point

$$P_1 = \mu V_1 G_1^2 = \frac{(1.31 \times 10^{-6} \times 10^3)\frac{\text{kg}}{\text{m s}} \times (4.5 \times 4.5 \times 7)\text{m}^3 \times (60\,\text{sec}^-)^2}{0.9 \times 0.75} = 990.36\ \text{W}$$

So, earlier the so, your the unit will become kg by meter per second ok kg per meter per second. Now, the the next is the the volume volume we know volume what is the volume 4.5 by 4.5 by 7 ok. So, also we need to find out the g g value for the first chamber what is the g value g 1 60 second inverse remember.

So, this will become 67 inverse. So, 60 second inverse that also the value should be in like it should be square the value. So, you will get the value of power requirement to be as to be 990.36 watt.

$$P_2 = \mu V_2 G_2^2 = \frac{\left(1.31 \times 10^{-6} \times 10^3\right)\frac{\text{kg}}{\text{m s}} \times (4.5 \times 4.5 \times 7)\text{m}^3 \times (45\,\text{sec}^-)^2}{0.9 \times 0.75} = 557.08\ \text{W}$$

$$P_3 = \mu V_3 G_3^2 = \frac{\left(1.31 \times 10^{-6} \times 10^3\right)\frac{\text{kg}}{\text{m s}} \times (4.5 \times 4.5 \times 7)\text{m}^3 \times (30\,\text{sec}^-)^2}{0.9 \times 0.75} = 247.59\ \text{W}$$

$$P_4 = \mu V_4 G_4^2 = \frac{\left(1.31 \times 10^{-6} \times 10^3\right)\frac{\text{kg}}{\text{m s}} \times (4.5 \times 4.5 \times 7)\text{m}^3 \times (15\,\text{sec}^-)^2}{0.9 \times 0.75} = 61.90\ \text{W}$$

Same way for the next one you put the value the the dynamic viscosity 1.31 into 10 to the power minus 6 into 10 to the power 3 kg per meter kg per meter per second multiplied by 4.5 by 4.5 by 7 meter cube multiplied by 30 because g 45 g 2 value is 45 45 second inverse. So, g square. So, 45 second inverse square all square divided by 0.9 into 0.75 what is this 0.9 into 0.75 if you remember in the question it is given that the the efficiency see the motor efficiency and the brake efficiency is given. So, once you know the motor efficiency and the brake efficiency you will be able to understand you will be able to calculate the exact power that is required ok removing the the considering the efficiency of the of your motor and the brake as well. So, if you divided by 0.9 divided by 0.75 you will get the actual power requirement ok. So, for the first one you need 990 watt, second one 557 watt, third one 247 watt and the fourth one 61.9 watt. So, likewise this is the power requirement for your aerator. So, this is how we normally we go ahead with the designing different the aerator flocculation systems and all. I would still suggest like you know once you go through it go through this lecture material once more to understand it more in a to you know kind of imbibity you know in your brain plus you go through some literatures and where it will be more easier for you to know just simply search for in Google that a design of different flocculation chamber and go through the different scholarly articles.

It will be very good for you to understand this you know important design thing is and all ok very good. So, I you can see in the top this is how we will be designing the flocculation chamber will look like with a individual mixing system with you know paddle wheel paddle wheel mixture. So, one wheel on the both the side ok on the other side of the arm I would say ok. So, in general we in this particular lecture we understand the mechanism the influencing factors and the design considerations of flocculations which is essential for optimizing the wastewater treatment processes and ensuring the effective removal of contaminants. We understand about the perikinetic flocculation driven by the Brownian motion and also orthokinetic flocculation induced by the fluid motion play a distinct role in the formation of the flocs.

We also understand the concentration of the colloidal particles slow mixing and intensity of mixing are one of the key factors which influence the flocculation systems. So, this is a very important you need to understand this basic funda because the most of the questions will be asked from your basic understanding of the subject only ok. The control mixing particularly in flocculation tank is crucial to prevent the disintegration and ensure the effective floc formation and proper design considerations as we just did for flocculators include the peripheral velocity of the paddle blade, relative velocity and the hydraulic retention time is very important for us to understand when we design a flocculation chamber of the flocculators ok. So, we will be continuing with the different other types of flocculation systems in the coming lecture. So, this is the different references I would really request to go through each one of this ok.

And we will discuss more in more about the flocculation systems in the coming lecture and we will be concluding the primary treatment units in the coming lecture as well. And I hope you will get to know more I mean like more in details about how this flocculation different other types of flocculation chamber works and all ok. Thank you so much for the time being. See you in the next lecture.