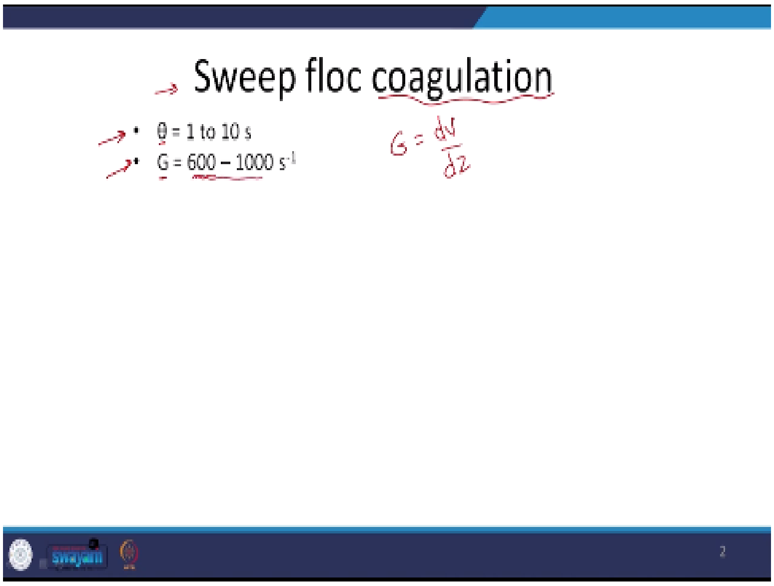
Water and Waste Water Treatment
Prof. Bhanu Prakash
Department of Civil Engineering
Indian Institute of Technology – Roorkee

Lecture - 38
Flocculation - I

Hello everyone, welcome back to the latest lecture session. We were looking at suspended solid removal and we know that gravity is our friend, but we want to help gravity to see to it that our job is done faster. So, what are we trying to do? We are trying to destabilise the stable system such that smaller particles come together and then they settle down. So, destabilisation coagulation and then bigger particles being formed after the initial coagulation, flocculation.

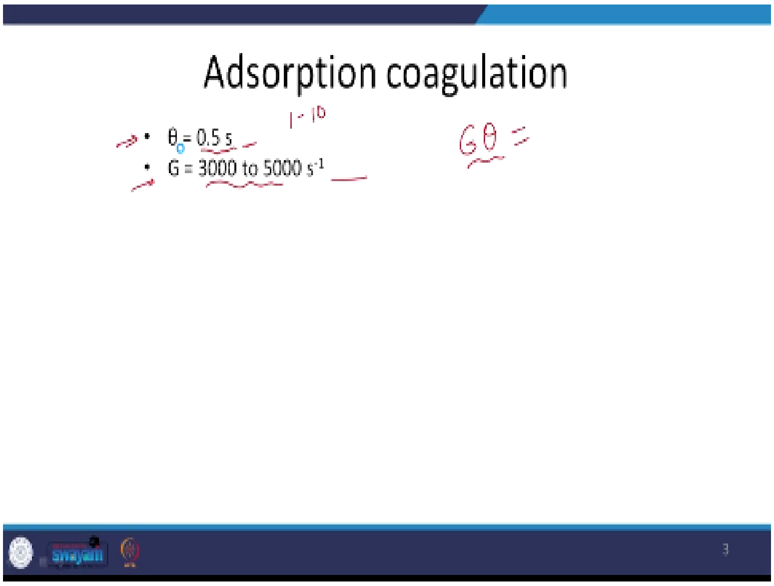
(Refer Slide Time: 00:57)



So, we are going to discuss the aspects related to coagulation, we looked at 2 primary variables; one is theta, how much time and how much mixing. So, let us look at the typical values. So, it depends on the type of coagulation you want. One is sweep, sweep coagulation. So, here theta is 1 to 10 seconds relatively higher compared to the other ones, we are going to look at.

And level of mixing, you can see that mean velocity gradient, it is G equal to dv by dz that is what we know. So, it is 600 to 1000 per second, relatively longer times and still high enough mixing but not very high, because you want to have precipitation also being formed, and adsorption taking place.

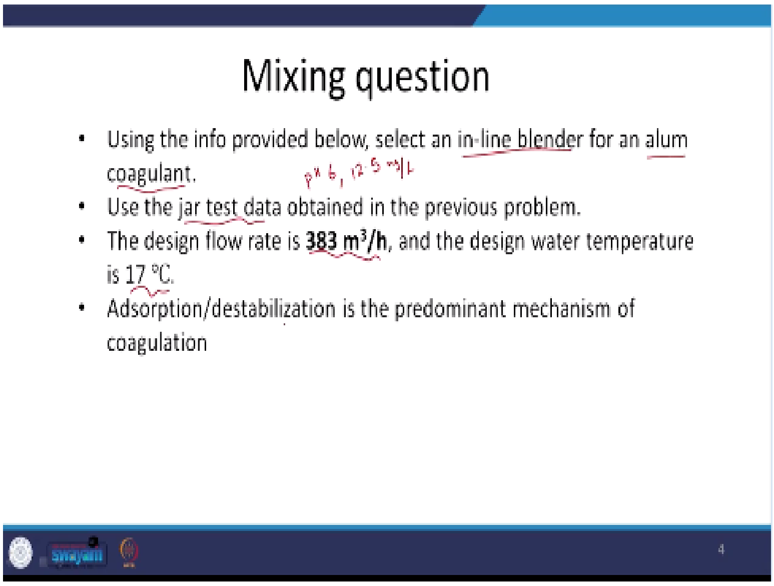
(Refer Slide Time: 01:41)



So, now you can compare that with respect to the adsorption coagulation, where charge neutralisation and maybe initial inter particle bridging is of great relevance or charge neutralisation primarily. So, here we see that the theta is much less. In the earlier case it was 1 to 10 seconds and G is also much higher. Earlier case, it was 600 to 1000. Here, it is 3000 to 5000.

So, much more intense mixing and relatively lesser time, . But in general, we are concerned with Gɵ. It is not that this is the same value, even though G theta for this adsorption coagulation might be comparable to the sweep floc coagulation. We also need to be concerned about G and ɵ, the independent variables too because that will also have an effect on the kind of mechanism and how effectively is it going through? So, that is something to keep in mind.

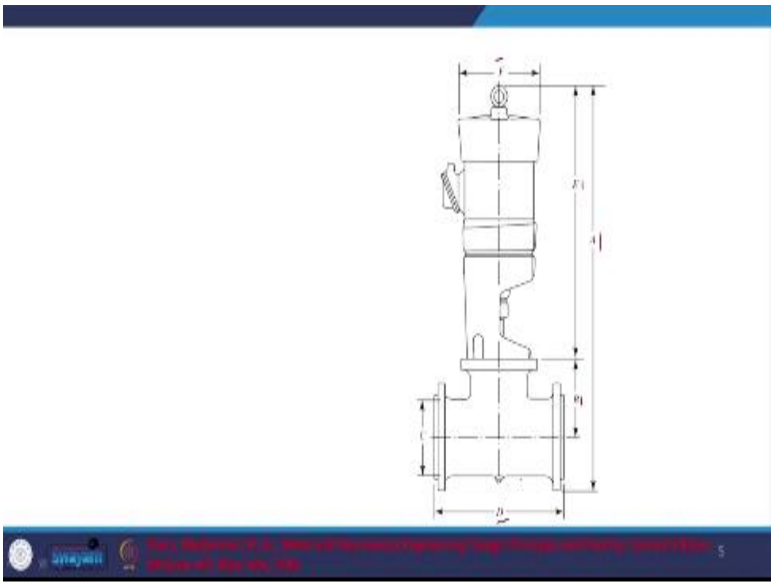
(Refer Slide Time: 02:40)



Let us go through. So, here we have a problem using the info which will be provided, we want to use or select an in-line blender, where we are adding coagulant. And what is the data? We are going to use the data from the previous case and that for that case, I think the pH was 6 in the last session and also something like 12.5 milligram per litre or such, but it should be presented in the succeeding slides and flow rate is given.

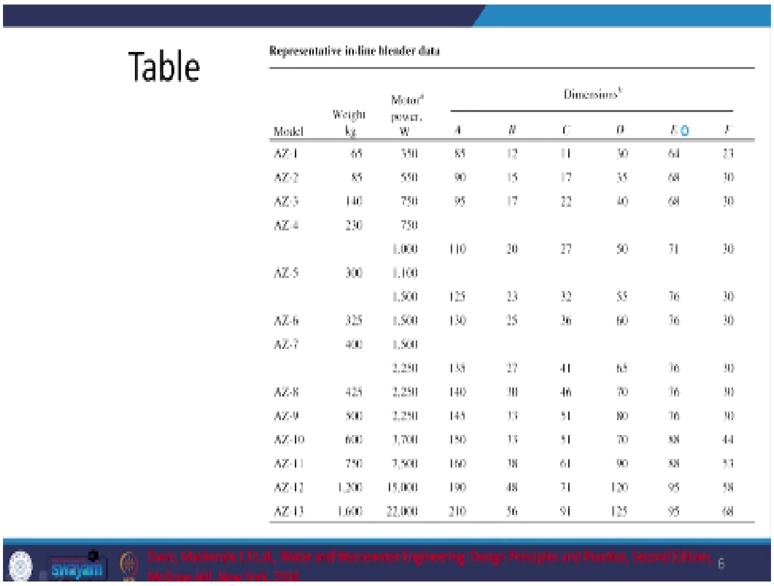
And water temperature, yes, is also a relevant aspect. And here, we are saying that it is adsorption and destabilisation is the predominant mechanism, not the sweep floc coagulation. So, that is what we want to have.

(Refer Slide Time: 03:20)



In-line blender, this is what we have. And you have different , dimensions . Yes, so, , let us go about and look at it. So, we know that we want to get the relevant G and theta values. So, that is the agenda of the day that is what we are concerned with.

(Refer Slide Time: 03:37)

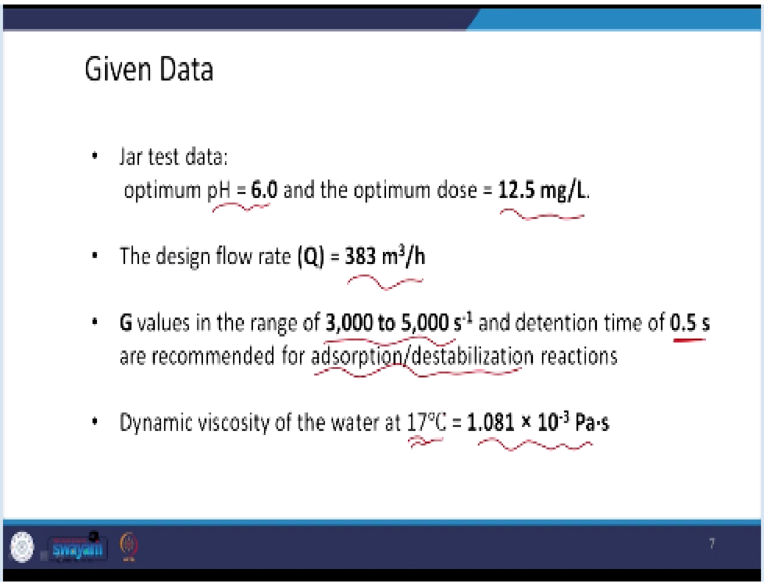


Representative in-line blender data

Model	Weight, kg	Motor[a] power, W	Dimensions[b] A	B	C	D	E	F
AZ-1	65	350	85	12	11	30	64	23
AZ-2	85	550	90	15	17	35	68	30
AZ-3	140	750	95	17	22	40	68	30
AZ-4	230	750						
		1,000	110	20	27	50	71	30
AZ-5	300	1,100						
		1,500	125	23	32	55	76	30
AZ-6	325	1,500	130	25	36	60	76	30
AZ-7	400	1,500						
		2,250	135	27	41	65	76	30
AZ-8	425	2,250	140	30	46	70	76	30
AZ-9	500	2,250	145	33	51	80	76	30
AZ-10	600	3,700	150	33	51	70	88	44
AZ-11	750	7,500	160	38	61	90	88	53
AZ-12	1,200	15,000	190	48	71	120	95	58
AZ-13	1,600	22,000	210	56	91	125	95	68

So, from here, I have different dimensions . I have the motor power given. So, you can choose one motor, , as a trial.

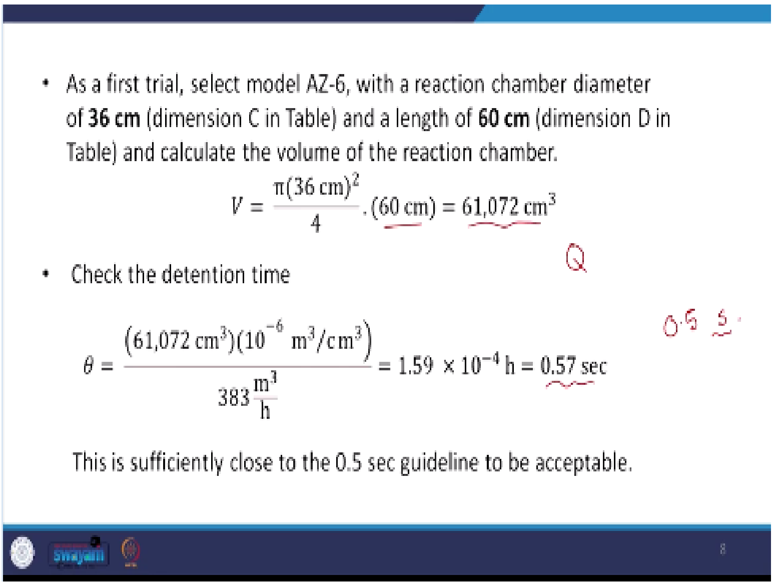
(Refer Slide Time: 03:44)



Initial one will be trial and from the jar test data from the previous or 2 sessions before, pH 6; optimum dose; flow rate is what we have now. And we know that for destabilisation or charge neutralisation based adsorption and destabilisation, we know that theta is less and G s relatively higher. And the temperature, why is it relevant? Because the viscosity of water changes with temperature.

So, this is the temperature from the, not this is the temperature, this is the viscosity at that particular temperature. So, this is what we have.

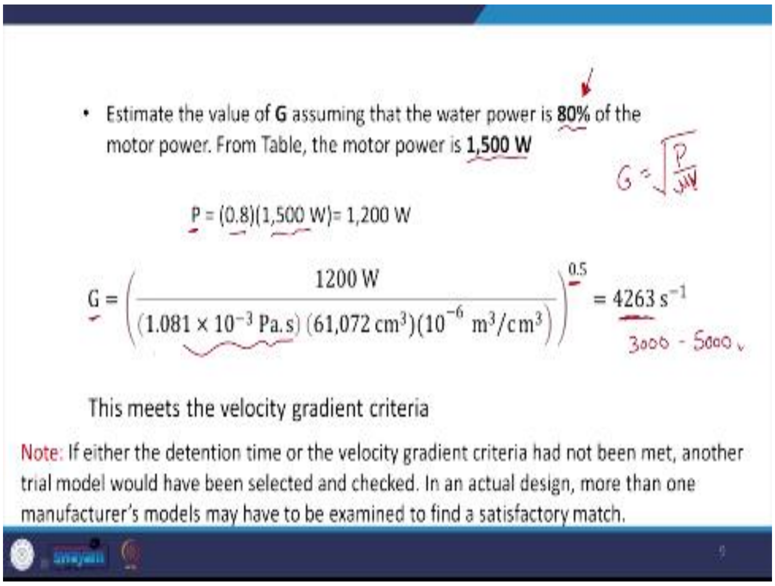
(Refer Slide Time: 04:22)



So, let us go ahead and look at it. So, trial, we are selecting something here and looks like the dimensions are C and D inside the chamber. So, now we can calculate the chamber, chamber volume by D square by 4 h, pi r square h and we get the relevant volume, . Let us look at the this thing once, C and D. So, this is the volume of the effect of volume of your particular system, .

So, that we got from the table and then the retention time, how will you calculate the retention time? We know that we have Q, so, ɵ is equal to V/Q. And that is what we have, you can play around with the units and it is 0.5 seconds. We know for what we want 0.5 seconds is what we want. So, it is more or less, fine.

(Refer Slide Time: 05:15)

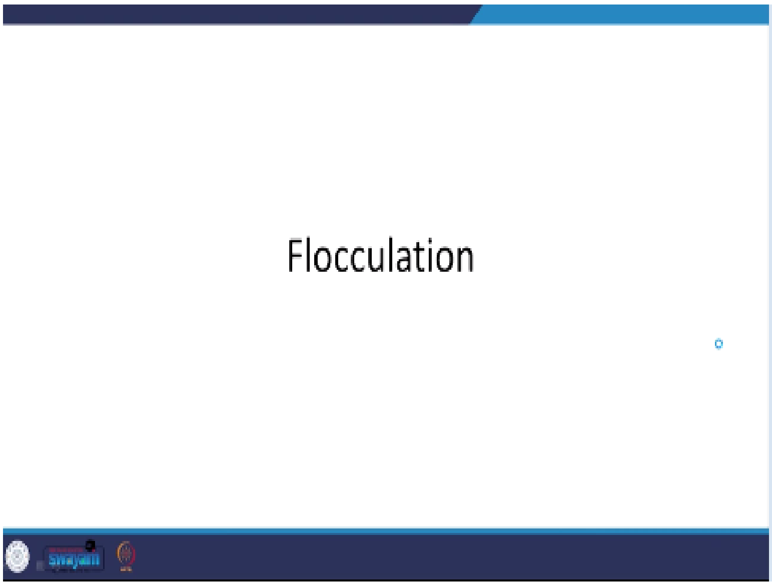


And what next G; we need to look at G. Here, we are assuming that not all the energy from the 1500 watt rated motor power is going to be transferred to the water, we are assuming that the efficiency is around 80%, . So, effect to P = 0.8 x 1500 watts. , these kinds of things will be from experience . If not, at least in the homework or exam, this will be given.

So, we know that I think, G was equal to square root of power by mu into V if I am not wrong. You can correct this variable. So, that is what we have square root of P/ mu. And what else is this? V is volume, . Let me just check that.. Now to check that is what we have volume out here. And from that, we will get the G value. This will give us an idea about the mixing.

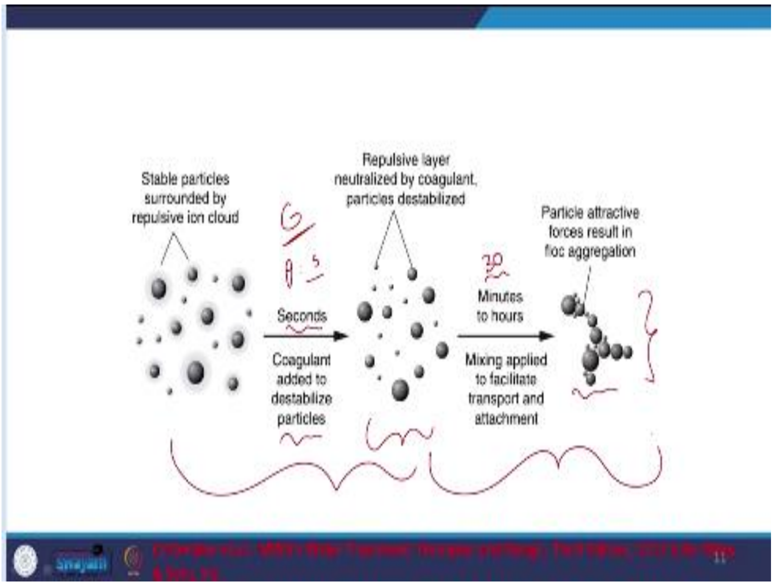
So, this is acceptable, I think we were looking at 3000 to 5000 for our particular case. So, this is acceptable from that point of view. So, we looked at or we are more or less done with coagulation.

(Refer Slide Time: 06:27)



So, once I am done with coagulation, , provide enough intensity of mixing and enough time for the particles to be destabilised. What do they want to do? I do not want to continue that further. Why? If I continue that further, the flocs or these colloids are not going to come together. So, we are going to look at flocculation.

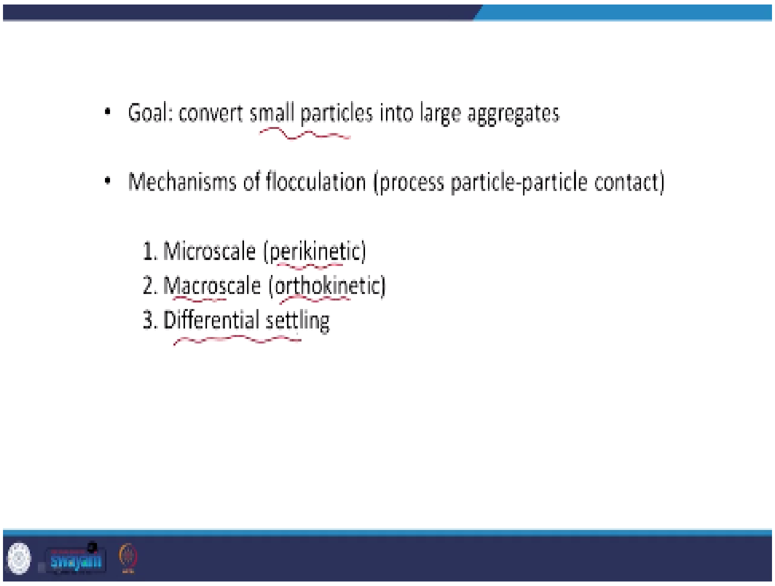
(Refer Slide Time: 06:47)



So, to take a holistic view, so, initially we have a repulsive ion cloud electrical double layer, this is what we have, after adding coagulants we destabilise them and different ways. So, repulsive layer is neutralised by the coagulant and particles are destabilised, they are destabilised. , theta was 1 to 2 seconds or 0.5 to 10 seconds, . So, it is order a few seconds that is what we have here.

And then we want the flocs to come together. If we still hold very high G values or very high intensity of mixing, the particles are not going to come together. So, here you want to give greater retention time, , typically 30 minutes or such and then you will have particles aggregating together and flocs being formed. So, coagulation and then flocculation. So, that is what we have out here. So, let us move on.

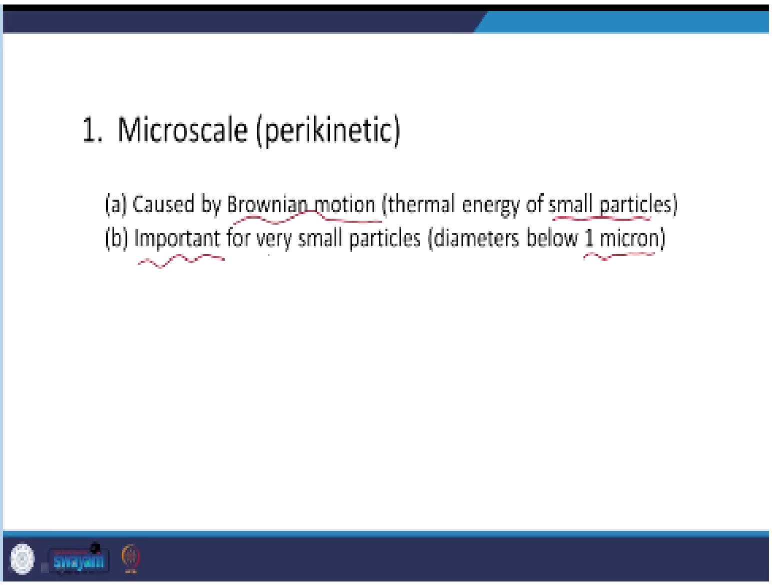
(Refer Slide Time: 07:42)



So, what is our goal? , we want to convert or see to it that the smaller particles aggregate and form bigger flocs that is what we have. How does it come about? now, these particles have to come close together. How is it now? Now, they are not any more stable, they do not have that repulsive layer or relatively less, take the repulsive layer, but now they still need to come together. So, what are the different ways?

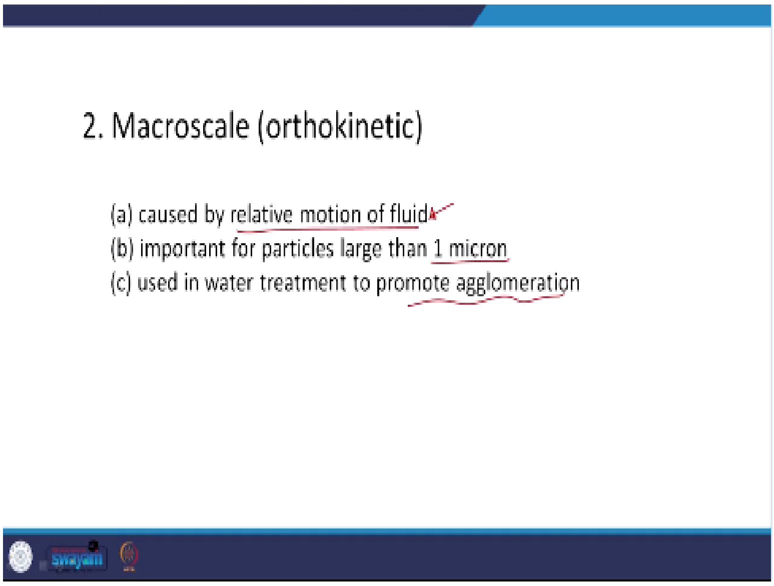
We looked at one figure earlier where in energy transfer from large Eddies to smaller Eddies and then to the micro scale, it is similar. So, micro scale, perikinetic macro scale, ortho-kinetic and differential settling, . So, these are the 3 mechanisms by which different particles can come in contact.

(Refer Slide Time: 08:29)



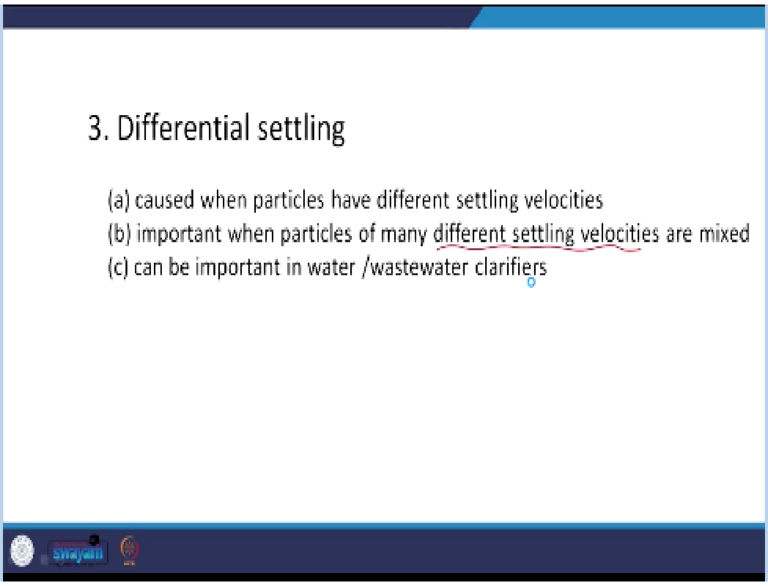
Micro-scale, so, Brownian motion , diffusion relevant aspects , Brownian motion, this is due to the thermal energy of small particles, we are talking about very small particles, one micron , almost wider size . So, important not wider size, relatively higher than wire size. It is important for very small particles. , it is caused by Brownian motion.

(Refer Slide Time: 08:52)



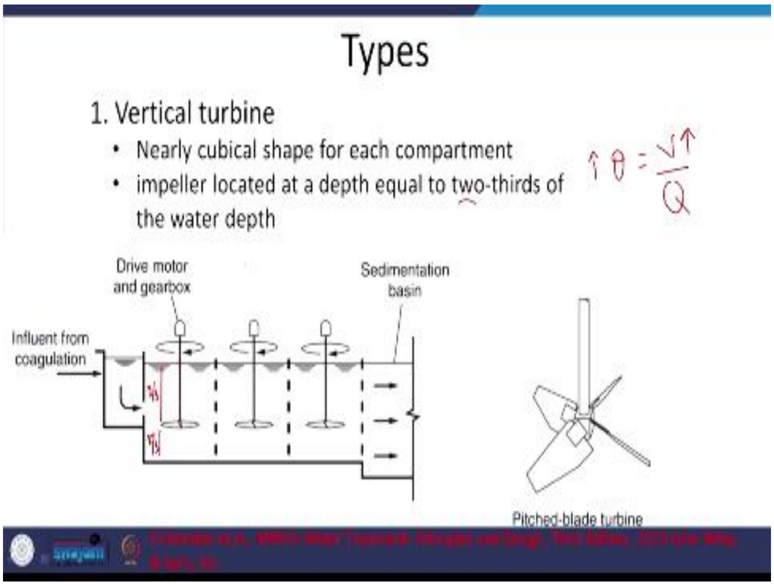
So, macro-scale, this is based on the fluid flow, macro-scale, bigger or not bigger, macro-scale. So, it is for bigger particles and we want to use it to promote agglomeration too.

(Refer Slide Time: 09:09)



And differential settling, different particles have different settling velocities, I think, we looked at it in sedimentation . And then they can come in contact and also when we have different fluid velocities being imparted to the water, , these differential settling velocities will also play a role. So, differential settling macro and Micro-scale mixing, . So, that is one aspect to consider.

(Refer Slide Time: 09:37)

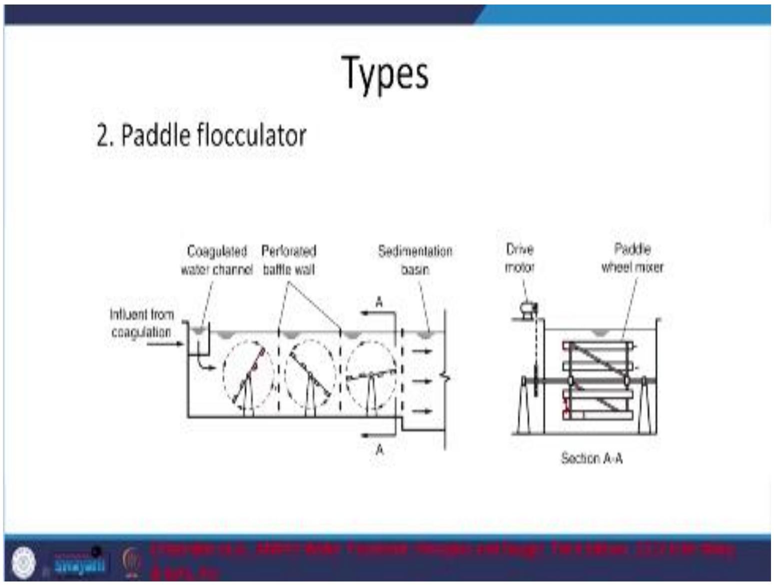


And different ways of flocculation mixing, earlier we looked at in-line static mixers , but here you are going to have relatively bigger systems at play. Why? Why is it that we have bigger systems at play? It is because that the retention time is not in the order of a few seconds. Now, it is in the order of a few minutes or even half an hour, sometimes even one hour.

So, , for the same flow rate, if the water has to spend more time, you need bigger volume; theta is equal to V/Q. Theta(ɵ) is equal to V/Q, if theta increases, V also has to increase. So, cubical shaped, typically cubical shape, where we have the vertical turbine, this is the vertical turbine with the drive motor . Impeller located at a depth equal to 2 thirds of the water depth, 2 thirds of the water depth.

So, 2 thirds of the water depth, so, gentle , flow of water coming in and then you are going to have gentle mixing out here. Yes, and then it is going out to the sedimentation basin here. We are trying to form the flocs here, vertical turbine.

(Refer Slide Time: 09:37)

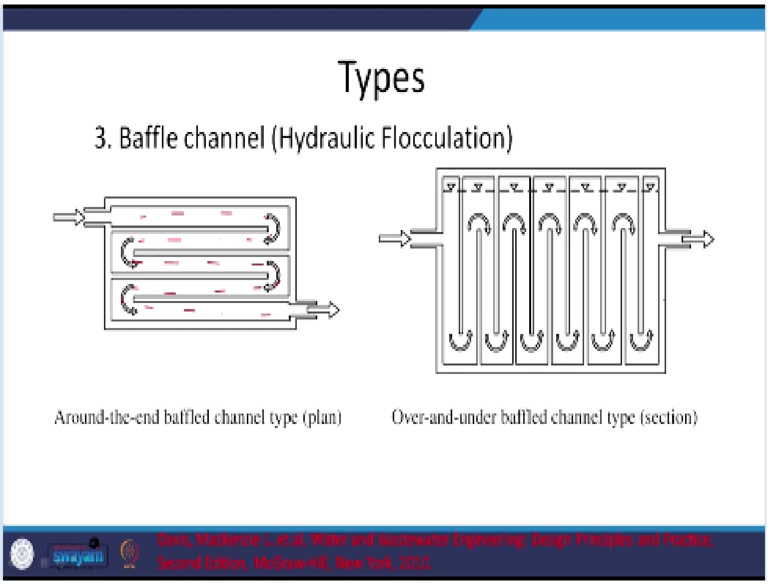


Then you can have the paddle flocculators. You can see now that this is the side view. Even earlier, it was the side view. And here you have the paddle flocculators. So, by rotating in this way and that different velocities because velocity of this what we say, paddle here will be lesser than the velocity of this paddle here. So, you are going to have differential velocities being imparted to the fluid. And then you are going to have mixing, .

, water coming in water channels so, that there is less short circuiting and also gentle flow of water coming in. And perforated baffle wall to create the ideal flow conditions. So, that to prevent short circuiting in general and then it goes to the sedimentation basin. So, if I cut it at this section and look at it this way, so, this is what a paddle looks like. I am looking at it from this way.

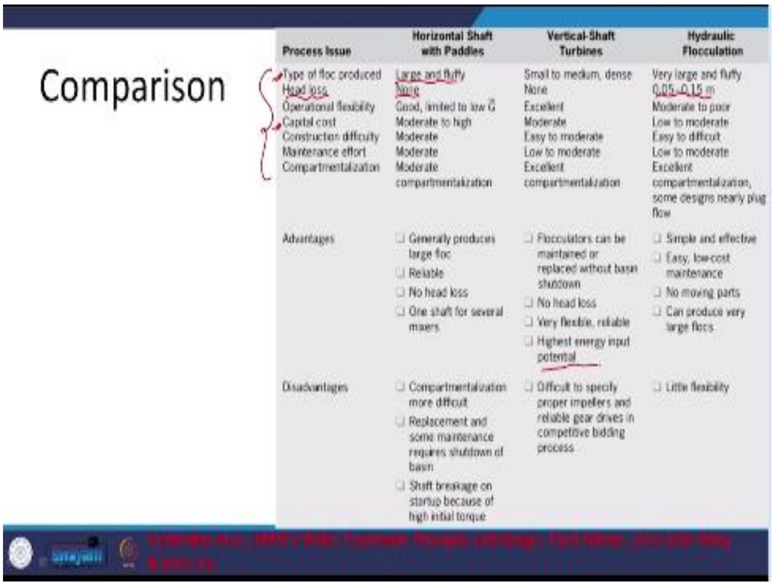
So, it is mounted and you have the drive and you have the paddles. So, you need to be able to design these what is the width of this; what is the distance between 2 paddles; how many paddles because that will lead to this energy from the motor or the power from this motor being transferred. Why are the paddles into the water? So, that is why you need to be able to design these aspects.

(Refer Slide Time: 12:04)



What else? Other than that you also have baffled channel or hydraulic flocculation. So, you just have baffles, water taking the flow and then relevant mixing, . So, here it is also over and under, over and under water comes in. This is the level and you are headed going to go over and under tank. So, different kinds of flocs, .

(Refer Slide Time: 12:30)

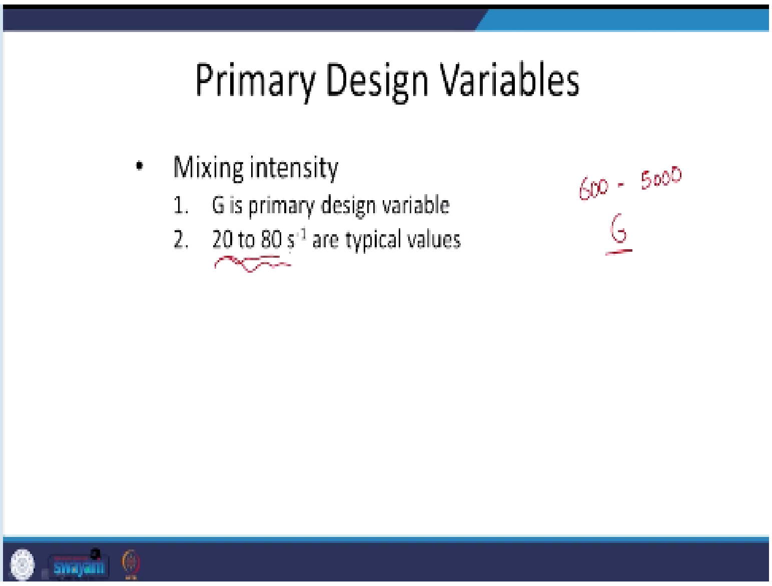


Process Issue	Horizontal Shaft with Paddles	Vertical-Shaft Turbines	Hydraulic Flocculation
Type of floc produced	Large and fluffy	Small to medium, dense	Very large and fluffy
Head loss	None	None	0.05–0.15 m
Operational flexibility	Good, limited to low G	Excellent	Moderate to poor
Capital cost	Moderate to high	Moderate	Low to moderate
Construction difficulty	Moderate	Easy to moderate	Easy to difficult
Maintenance effort	Moderate	Low to moderate	Low to moderate
Compartmentalization	Moderate compartmentalization	Excellent compartmentalization	Excellent compartmentalization, some designs nearly plug flow
Advantages	❑ Generally produces large floc ❑ Reliable ❑ No head loss ❑ One shaft for several mixers	❑ Flocculators can be maintained or replaced without basin shutdown ❑ No head loss ❑ Very flexible, reliable ❑ Highest energy input potential	❑ Simple and effective ❑ Easy, low-cost maintenance ❑ No moving parts ❑ Can produce very large flocs
Disadvantages	❑ Compartmentalization more difficult ❑ Replacement and some maintenance requires shutdown of basin ❑ Shaft breakage on startup because of high initial torque	❑ Difficult to specify proper impellers and reliable gear drives in competitive bidding process	❑ Little flexibility

So, horizontal shaft, vertical shaft and hydraulic flocculation, what are the advantages ? Let us look at what are the primary aspects of concern. In general, we are concerned with type of floc. How much is the head loss? If the head loss is too much, , initially it to pump the water to a higher head. So, I do not want that to be higher. So, operational flexibility, what is the initial cost and relevant aspect?

In general, you see that horizontal shaft with paddles is best or pretty good and vertical one so, so and hydraulic flocculation also pretty fine, but there is head loss too. So, these are the aspects you will need to consider when you try to balance between your requirements, . So, highest energy input potential, , you can import a lot of energy with respect to this vertical shaft. So, you have greater control looks like. We will not go into it in detail though.

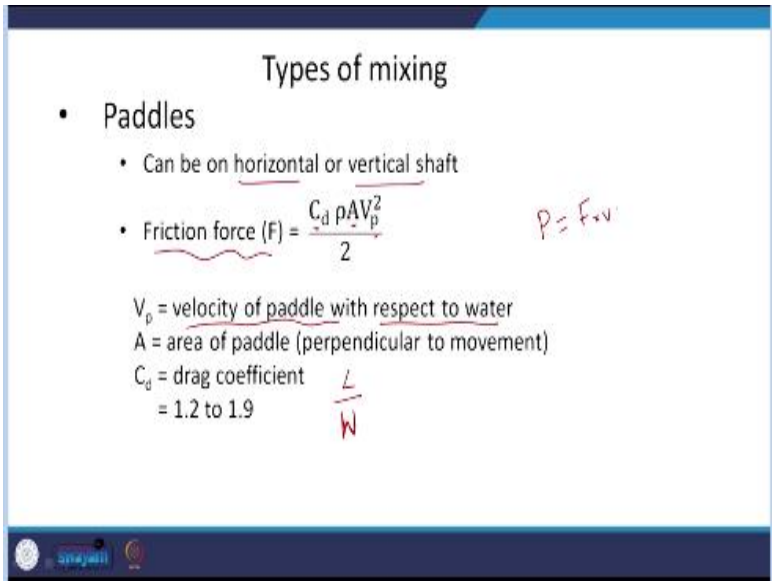
(Refer Slide Time: 13:31)



So, primary design variables; , what is it I am concerned with? I am concerned with imparting enough energy through the motors and then the paddles or the hydraulic flocculation chambers such that there is enough turbulence, but not a lot, such that the flocs come together or flocs are formed. And here , theta is a primary aspect. Earlier in coagulation, it was the order of a few seconds and here we know that it is in the order of a few minutes.

And as you can see here, G values are remarkably less. Earlier, we were looking at ranges from 600 to I think 5000 G values. Here, though you can see that the values are or the level of mixing is relatively less. We are still going to have mixing but it is not at all rapid. If we have or continue with this level of mixing, what is going to happen? All the particles are going to , break up or the flocs are going to break up. Let us move on.

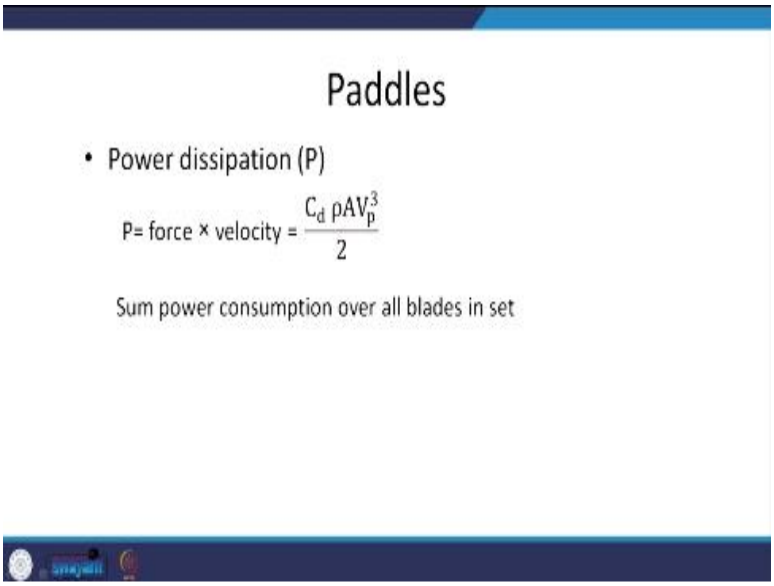
(Refer Slide Time: 14:27)



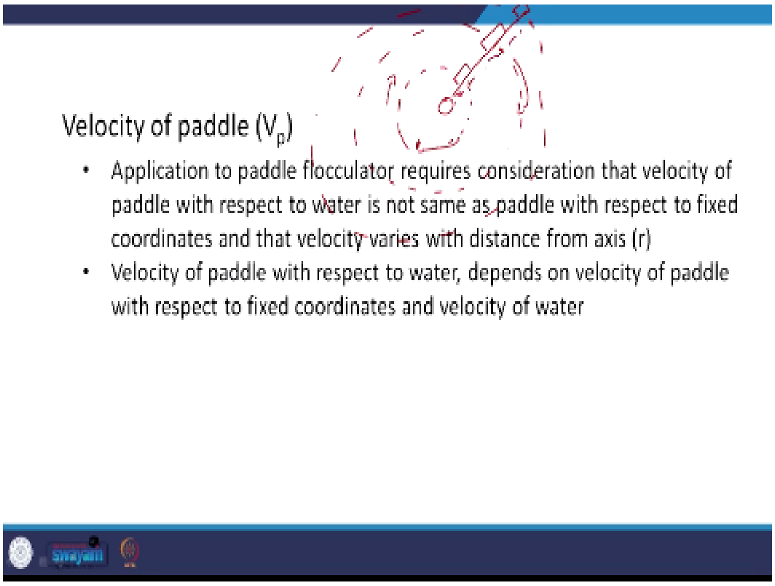
So, types of mixing based on paddles as we saw, can be horizontal or based on vertical shaft. So, what is of concern? How is it the energy transfer will take place? So, here it is friction force. This is coefficient of drag area . Let us see what we have velocity of the paddle with respect to water. And area of the paddle, velocity of the paddle, area of the paddle and coefficient of drag which will be depend upon length to weight ratio not weight, length to width ratio.

So, that is something you can get from the relevant tables, this will be the friction force. How will I be able to what is that get power? It will be forced into velocity as we looked earlier and the velocity of the paddle, so, force into velocity.

(Refer Slide Time: 15:14)



(Refer Slide Time: 15:20)

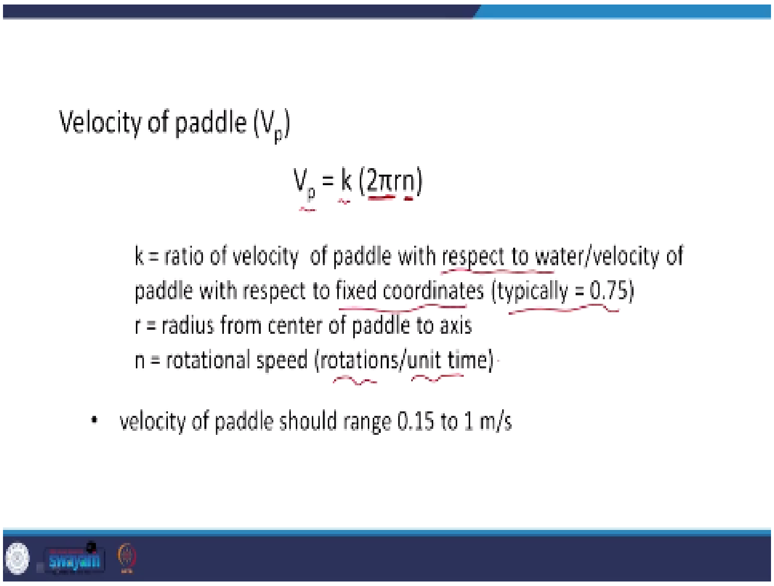


So, that is what we have earlier we had square and now we have cube here. And if there are different blades or such, you are going to sum them up; some power consumption over all blades. So, per blade, if this is the consumption, what is the consumption over all the blades, you will just sum them up. So, velocity of paddle looks like we need to be aware of one aspect. earlier, we saw this if this is the shaft and this is the paddle holder. These are the paddles. So, , velocity here relatively less higher, higher.

It is going to rotate in this direction, and look at the distance being taken by this; look at the distance being taken by this and look at the distance being taken by this; all within the same time. So, the velocity is different that is what I think we are trying to say here. So, application of paddle flocculator requires our understanding or consideration that velocity of paddle with respect to the water is not the same as paddle with respect to fixed your coordinates. That is one thing to keep in mind.

Why? Here, what is V_p? It is the velocity of paddle with respect to water, not with respect to fixed coordinates that is something to keep in mind. And that velocity varies with distance from access. And as you can see, it varies from distance from axis . Velocity of paddle with respect to water depends on velocity of paddle with respect to fixed coordinates and now , velocity of water, that is what we are trying to see.

(Refer Slide Time: 16:45)



So, what is it depend upon? This is the ratio of velocity of paddle with respect to water to velocity of paddle with respect to fixed coordinates. So, , we are taking into consideration both the fixed coordinates and also the velocity of water, . Typically 0.75 and 2 π r, is the perimeter, . And n is rotational speed rotations per time.

So, this is the distance and this is rotation speed, . Or , this will give me unit of watts now. Rotations per time, distance per time so, that is what it gives me an idea about. So, typically, k value is 0.75, velocity of paddle seems to be that this is the range out here. So, let us move on.

(Refer Slide Time: 17:33)

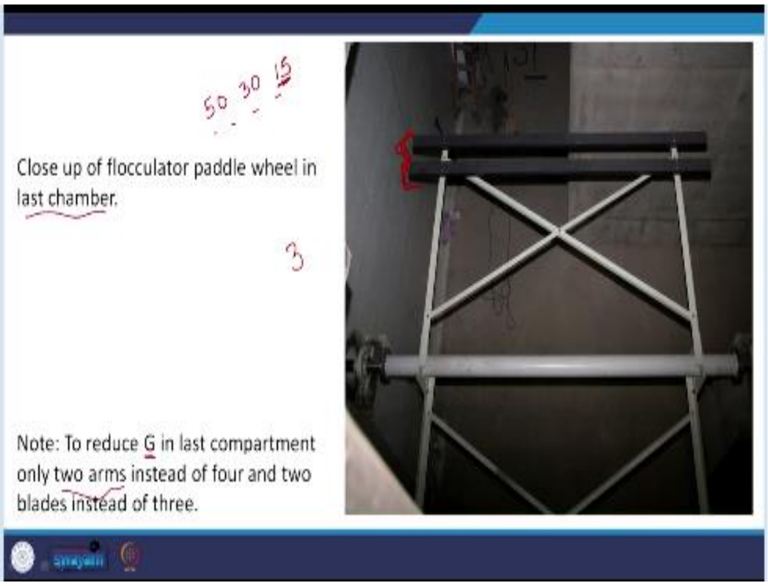
And , this is a good figure, you can see the paddles, you can see the paddles and water is flowing in this direction, horizontal shaft. And you have the relevant paddles, you can observe the spacing, there are different spacings, you need to be aware of. The spacing between the wall and here, between the floor and the what is the lowest point of it. And also, this spacing and then spacing between the paddles and also the width of the paddles and the length of the paddles.

So, these are the dimensions that you have to be aware of when you design it. Let us see how we will design it. But , this is how paddle flocculator looks like, .

(Refer Slide Time: 18:19)

So, here, we see that there are 3 boards per arm, as I mentioned, the distance between the boards, pedal, is the term that encompasses all this setup and then the width and the length, these are the aspects we are going to look at. So, this is going to go over and above and over and above that how it is going to keep mixing.

(Refer Slide Time: 18:40)

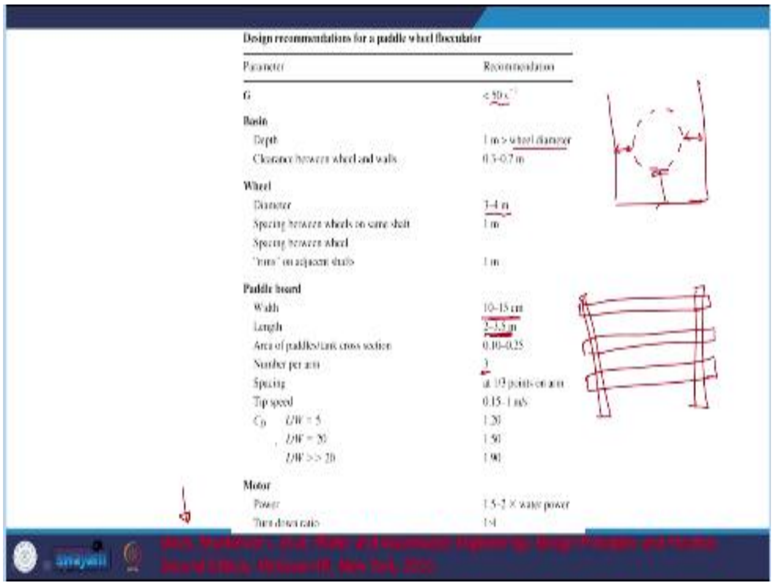


So, at the end, though, close up of flocculator paddle wheel, in the last chamber at the end, when the water is about to exit, to reduce the G in the last compartment, there are now only 2 instead of the usual 3. And in general, , you are going to have multiple compartments it is not going to be only one compartment with uniform level of mixing. So, initially relatively higher G may be 50 and then maybe 30 and then maybe 15.

So, this is how it is going to go. So, that is why here they are saying that in the last compartment, they have less, , a close up, what is this to reduce the G or 2 arms, that is the term I was using or thinking of. So, they have only 2 arms rather than 3 arms. Why? They want to decrease the G. So, that is something to keep in mind. As you can see here, the area, the area plays a role; area of the paddle.

So, if you decrease the area, you are going to decrease this power. So, that is how and , that power is proportional to the G value. G is square root of P by mu volume. So, if you decrease the power, you can do that different ways. So, you can decrease the area let us that is what they were trying to do in that particular context.

(Refer Slide Time: 19:57)



Design recommendations for a paddle wheel flocculator

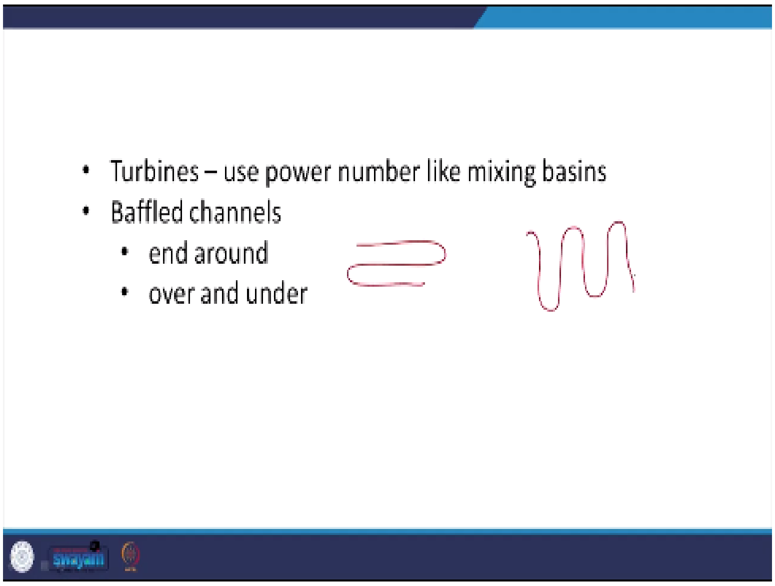
Parameter	Recommendation
G	< 50 s^{-1}
Basin	
Depth	1 m > wheel diameter
Clearance between wheel and walls	0.3–0.7 m
Wheel	
Diameter	3–4 m
Spacing between wheels on same shaft	1 m
Spacing between wheel "rims" on adjacent shafts	1 m
Paddle board	
Width	10–15 cm
Length	2–3.5 m
Area of paddles/tank cross section	0.10–0.25
Number per arm	3
Spacing	at 1/3 points on arm
Tip speed	0.15–1 m/s
C_D L/W = 5	1.20
L/W = 20	1.50
L/W >> 20	1.90
Motor	
Power	1.5–2 × water power
Turn down ratio	1:4

So, in general, you have the recommendations , if this is asked in the exam, this will be given. If it is asked in the homework, you can look this up, . G, we know that it is what 20 to 50 per second that is what we have. So, different relevant aspects, depth should be one metre greater than the wheel diameter. So, we know that this is the wheel. So, the depth should be greater than one metre, or total depth should be one metre greater than the wheel diameter.

And , clearance between the wheels and walls, so, we have the clearance. So, this clearance is a relevant issue. And wheel typical diameter is 3 to 4 metres. Spacing between wheels on the same shaft . So, we have different wheels, this is one wheel and this is one wheel. So, we need to have some spacing between wheels, . And that is what they were talking about this spacing between the wheels on the same shaft, rims on adjacent shafts.

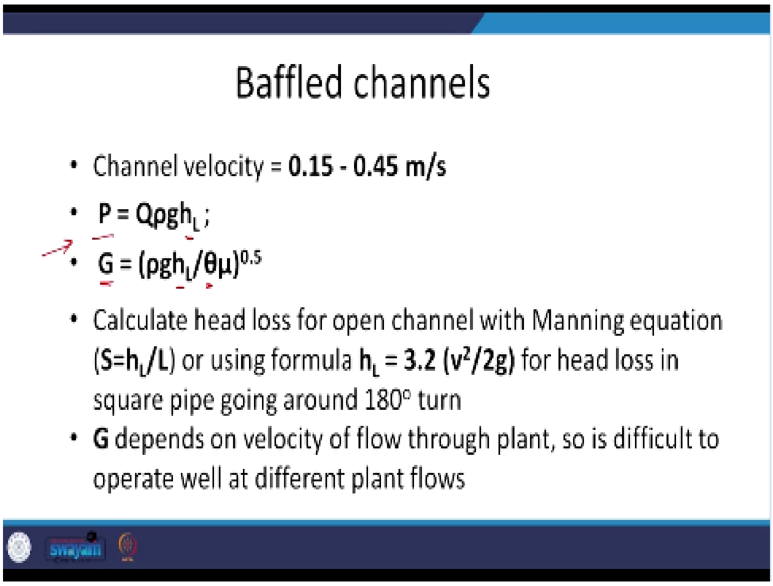
And paddle width, typical width, typical length, typical width, centimetre. This is what typical length 2 to 3.5 metres. Yes and area of paddles per tank cross section number per arm, usually 3; spacing is usually given at 1/3 points on the arm, but it can vary. So, 1/3, if this is the total. So, that is what they are saying 1/3 on the arm and length by width . So, these are the general aspects which we will look at when we try to design it.

(Refer Slide Time: 21:30)



So, let us look at the other aspects to turbines, they use power number like the mixing basins, baffle channels, we already looked at looked at it and around or over and under; over and under This will create the gentle mixing conditions. Baffled channels.

(Refer Slide Time: 21:48)

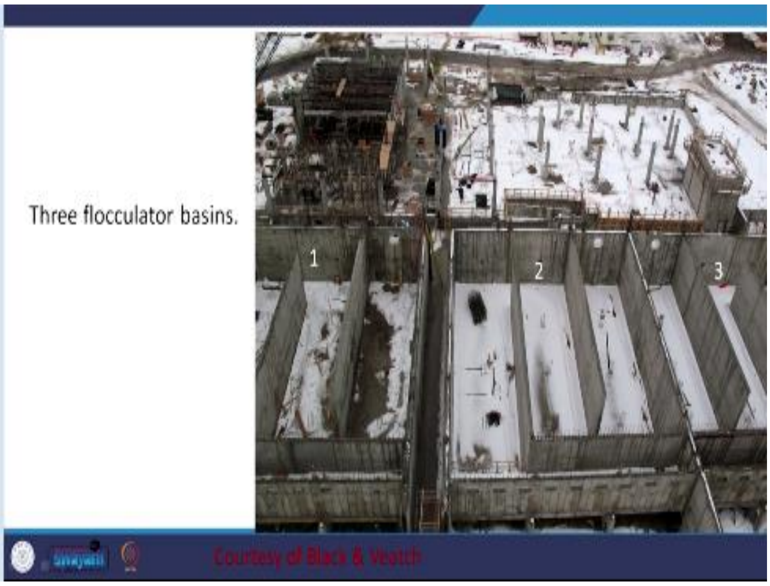


So, you have channelled velocity, power and depending on head loss, you can equate them. This is something we already looked at for the static mixers, when we looked at the power dissipation. So, from that you can equate the level of mixing to the head loss and the retention time. So, that is something that you can get. So, how do we get this head loss or such?

We have the Manning's equation for open channel flow or from this formula, . Where for head loss in square pipe going around 180 degrees turn , 180 degrees, , so, 180 degrees turn. So, that is the relevant aspects. So, you can have that formula, . So, G depends on velocity of flow through the plant, this is one aspect to keep in mind. So, it is difficult to operate well at a different plant flows.

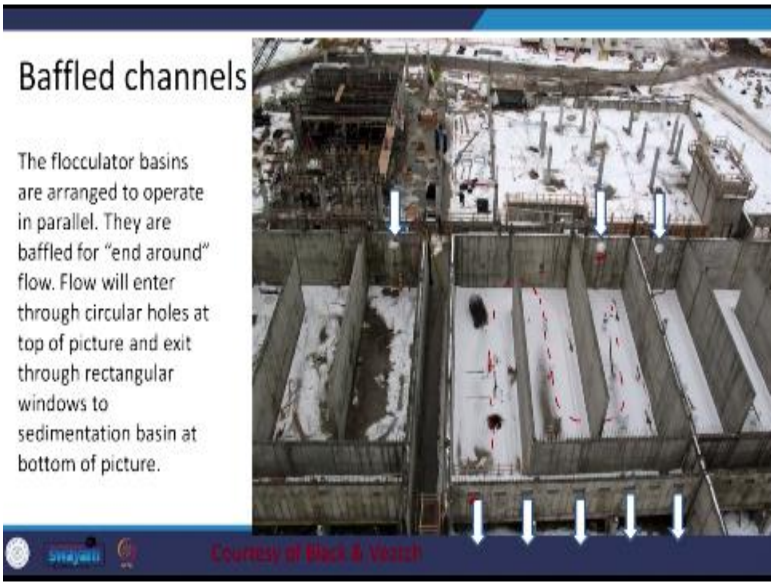
For hydraulic or these baffled channels, the issue is that G depends upon the velocity of flow through the plant. So, if it is varying a lot, G will vary a lot. So, you cannot control it very much if the flow is very low. So, that is something to keep in mind. So, you have to maintain a very narrow range of velocity especially when you are looking at this baffle kinds of , baffle channels . So, that is something to keep in mind (23:05).

(Refer Slide Time: 23:05)



So, 3 flocculator basins. So, you can see them one here, 2 and 3. These are baffled type, , not baffle I think, these are not baffle type. Both baffle and with respect to the horizontal shaft mixing.

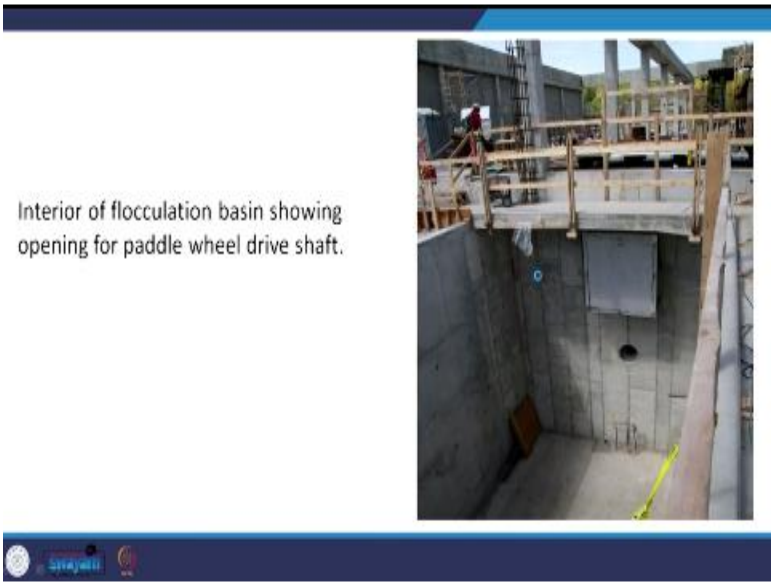
(Refer Slide Time: 23:24)



So, baffle channels let us see. The flocculator basins are arranged to operate in parallel, all 3 are parallel. They are baffled for end around. They are going to end and around. Flow will enter through the circular holes at the top of the picture and exit through the rectangular windows to sedimentation basin at the bottom of the picture. You can see this. Flow is coming through here; water will come this way and end and around and then it will exit here.

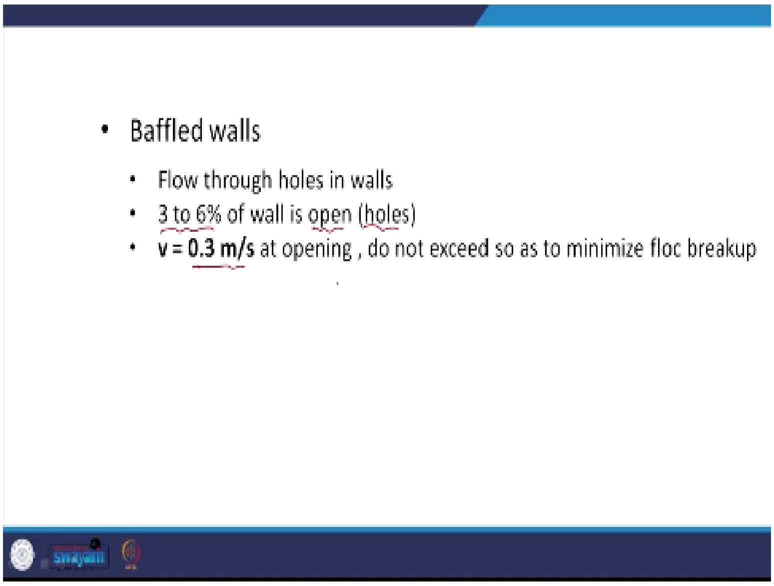
This is only for baffled; I thought they were also going to have the shafts here looking at this particular holes but maybe I was mistaken, .

(Refer Slide Time: 23:04)



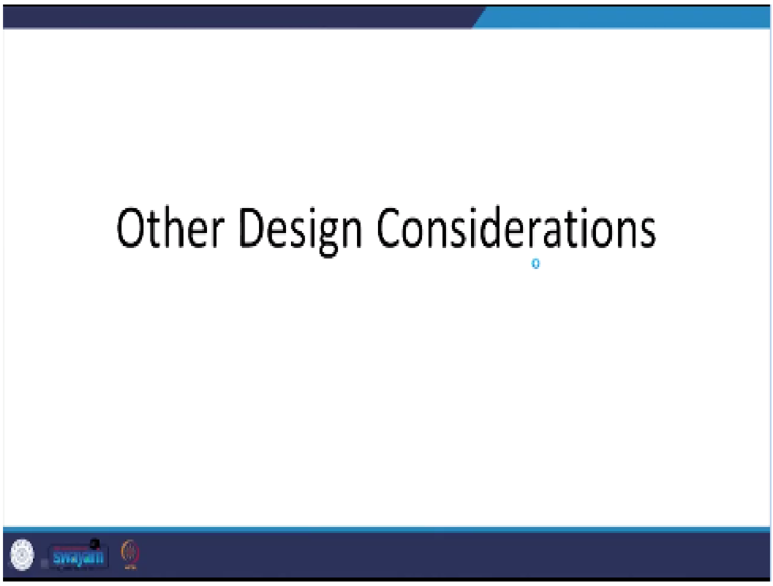
Interior of flocculation basin showing opening for paddle wheel drive. So, paddle wheel drive shaft this is what so, you have the opening for the paddle wheel drive shaft.

(Refer Slide Time: 24:17)

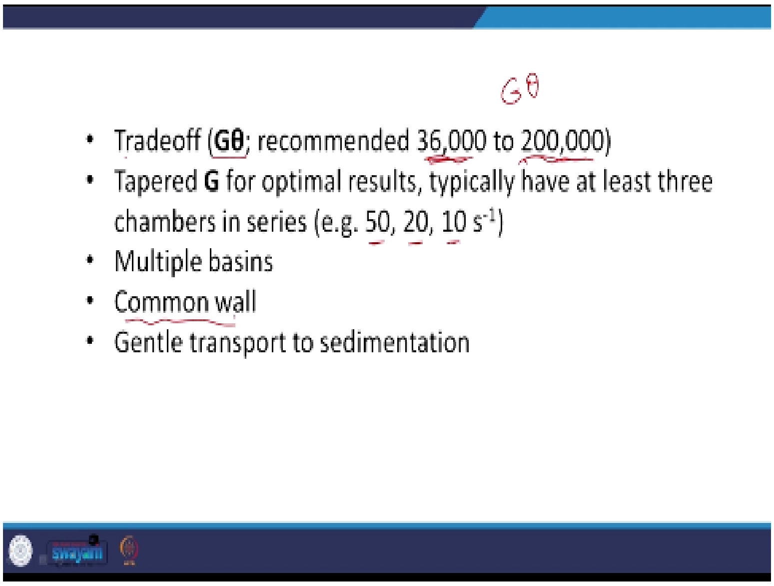


So,, baffled walls flow through holes, typically the percentage of holes is such that 3 to 6 percentage of wall is open holes and velocity is relatively less 0.3 metres per second at the opening. We do not want to exceeded. For example, , initially area is this and now it is coming through a particular relatively less area, then velocity can increase if you do not design it well. But the issue is if velocity increases, then you are going to have floc breakup that is what it is that people are referring to here.

(Refer Slide Time: 24:52)

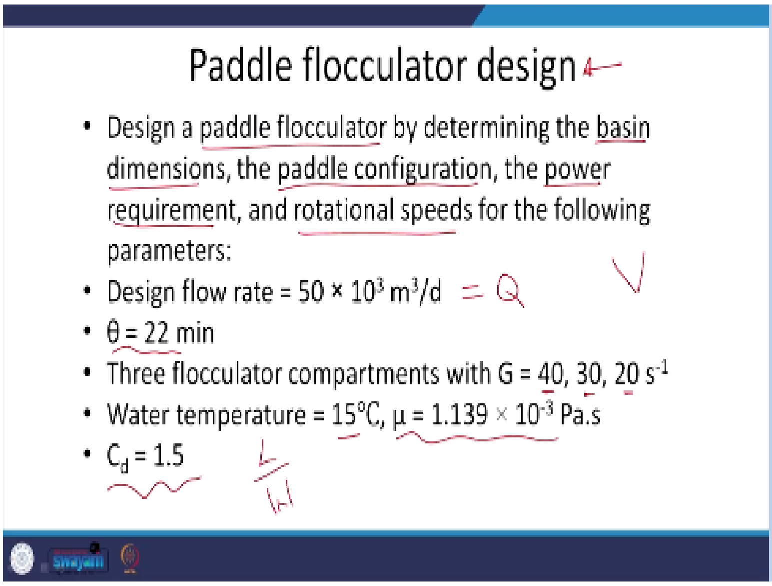


(Refer Slide Time: 24:54)



So, types of mixing and other design considerations trade off. If you look at G theta , this is for your relevant case of flocculation. So, you can go from one end to the other. Take a G for optimal conditions. This is what we mentioned. So, initially high and then slow and slower, or lower and lower, . You can have multiple basins . Or you can have combinations that will allow for common wall and then transport to sedimentation, .. So, that is something to keep in mind.

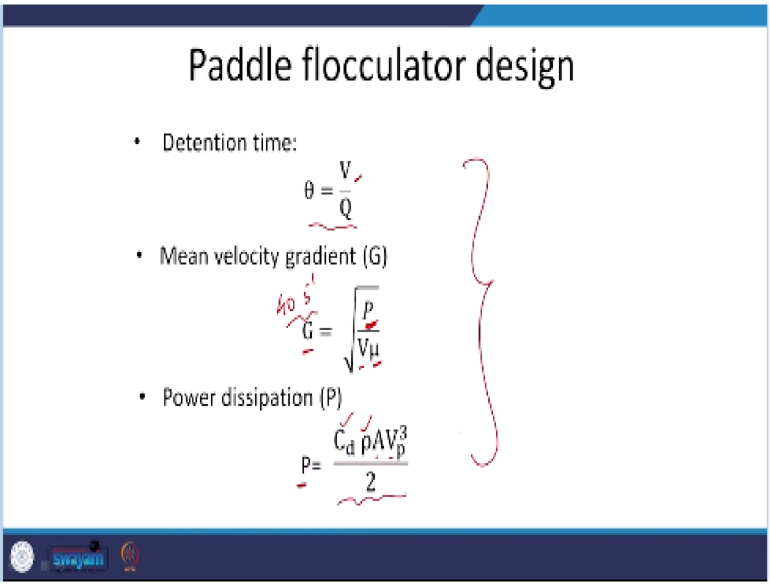
(Refer Slide Time: 25:27)



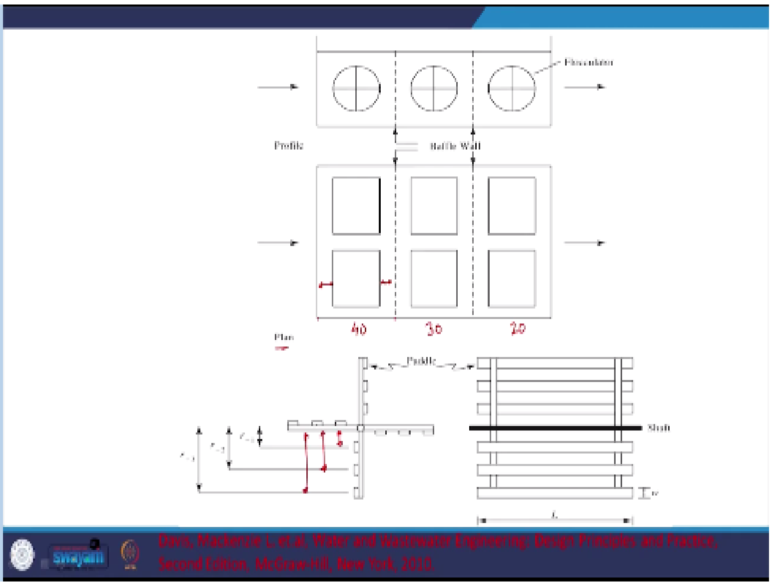
So, we are going to look at the paddle flocculator design. But this will take some time. And I already looked at all the or consumed all the time I wanted to for this session. But let us just look at the question once. We want to design a paddle flocculator. And how do we do that? Or what do we need? We need the basic dimensions, the paddle configuration, how much power is required for that paddle, the rotational speed for the following and the rotational speed for the following parameters. What is given? Q is given.

And they already gave us the theta. So, from that, , I can calculate the volume And they do not want only one compartment; they want 3 compartments, . And water temperature is given for that the dynamic viscosity is given and coefficient of drag is also given. This depends on length to width, . So, this is what we have.

(Refer Slide Time: 26:21)



(Refer Slide Time: 26:22)



So, what are we designing before? This is what we are designed. So, what is coming in through here? This is the top view the plant. So, here G is 40 or what it is 50. Well, what is the G? G is 40, 30 and 20. So, 40 relatively more mixing, lesser mixing and much lesser intensity and that is how it is going out. And here in the side view, this is what it looks like, .

So, I want to be able to get the dimensions. And this clearances, the depth , and also, I have to look at the spacing but spacing, we already know that it is at 1/3 along the arm that is what we have, I need the width and the length of these arms. So, this is what we are going to design. But for that what are my going to use, I know that theta equal to V/ Q, I can calculate V, I can calculate the level of mixing required.

I know that it is 40 per second to the power that is required volume, which I already have and the dynamic viscosity which I already have. So, I already have the power. Power I can use and put it up here and plug it in here, . This is the power. And once I get the power, I will have this. I already have coefficient of drag. I have rho and then area I will get that.V p too, I will be able to calculate and then design accordingly.

So, these are the primary equations, we are going to use. But, this I will continue in the next session. Thank you.