Water and Waste Water Treatment

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Lecture - 37
Rapid Mixing

Hello everyone, welcome back to the latest lecture session. In the last couple of sessions, we were discussing rather in detail if I may say so, coagulation and relevant aspects and we looked at lessening or decreasing the electrical double layer thickness by various ways and one of the ways was charged utilisation and inter particle bridging and the other one based on the type of coagulant, you are adding was sweep coagulation.

So, in that context, we looked at inter particle bridging, I think there was a pretty good figured that we looked at. So, in general, you will also or you can add polymers that can lead to formation or lead to this kind of inter particle bridging. Let us take this through.

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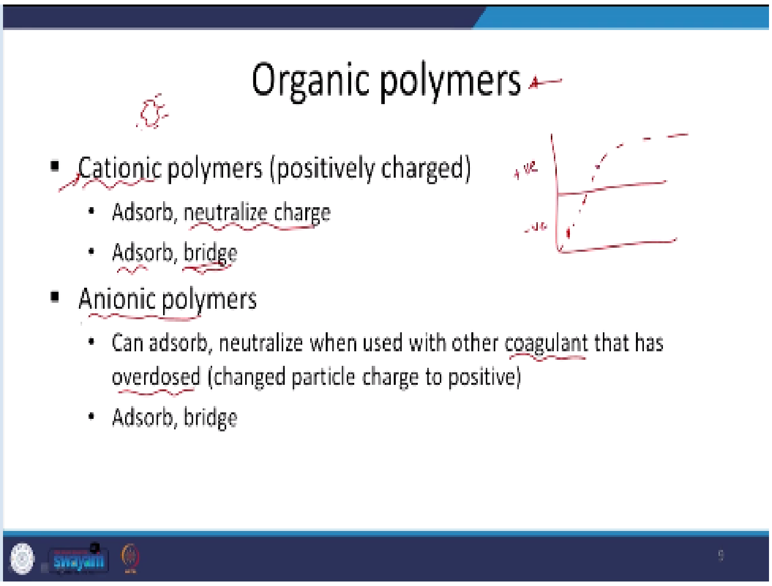

Organic polymers

- Cationic polymers (positively charged)
  - Adsorb, neutralize charge
  - Adsorb, bridge
- Anionic polymers
  - Can adsorb, neutralize when used with other coagulant that has overdosed (changed particle charge to positive)
  - Adsorb, bridge

So, you have organic polymers that can be added. Organic polymers , there are 2 kinds based on the type of polymers, so, cationic, we know that the colloid is negatively charged. So, if you add a cationic polymer, cation meaning positively charged, what can it do? It can either neutralise after adsorption or also it can form a bridge. So, first it is going to adsorb and then neutralise, depending on the charge and it can also form a bridge with respect to or with the other particle.

So, you will have both neutralisation and inter particle bridging, you can also have anionic polymers, there are also non-ionic polymers where the primary purpose is to act as what we say, a bridging agent if I may say so, or to promote inter particle bridging. Here, we are looking at anionic polymers. So, when can we use them? When we say that the other coagulant let us cationic polymer or any other cationic itself has been overdosed.

You saw that with respect electrophoretic mobility and such; if you overdose it, this is the picture. So, somewhere here is the sweep spot. And if you overdose it, then you have to bring down the charge, then anionic polymer and such or you can also add them just for bridging purposes, . So, that is the aspect that we need to discuss here.

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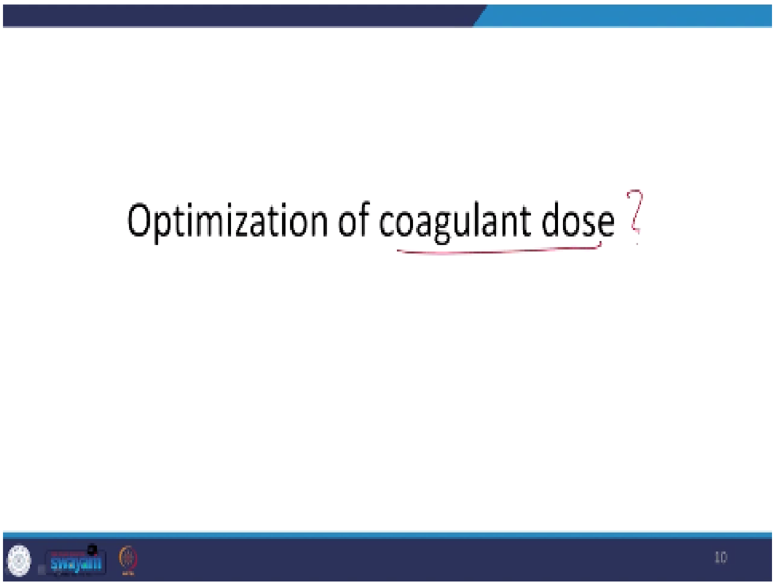

Optimization of coagulant dose ?

So, how do I know what is the dose to be added ? For example, with respect to ferric hydroxide or aluminium hydroxide, we saw the relevant graphs and we saw that in order at different regions as in different pH, different aluminium, different ferric iron concentrations, different types of iron or aluminium will predominate. So, how do I know in my, , scenario which one do I want or , which concentration do I want?

Whether I primarily want to go with sweep coagulation or will charge neutralisation also play a role or such. Here, it will depend on various factors, one NOM and other specious. So, analysing what is there and such is remarkably difficult or not difficult, time consuming and costly, that is the major aspect. So, we are going to conduct a simple test.

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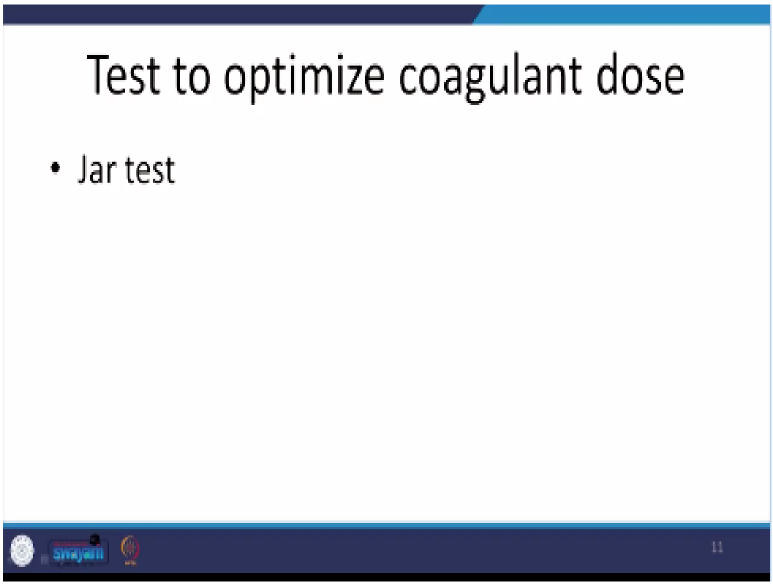

Test to optimize coagulant dose

- Jar test

How am I going to optimise the coagulant dose? So, we conducted test, which is called a jar test, . how we will go about it.

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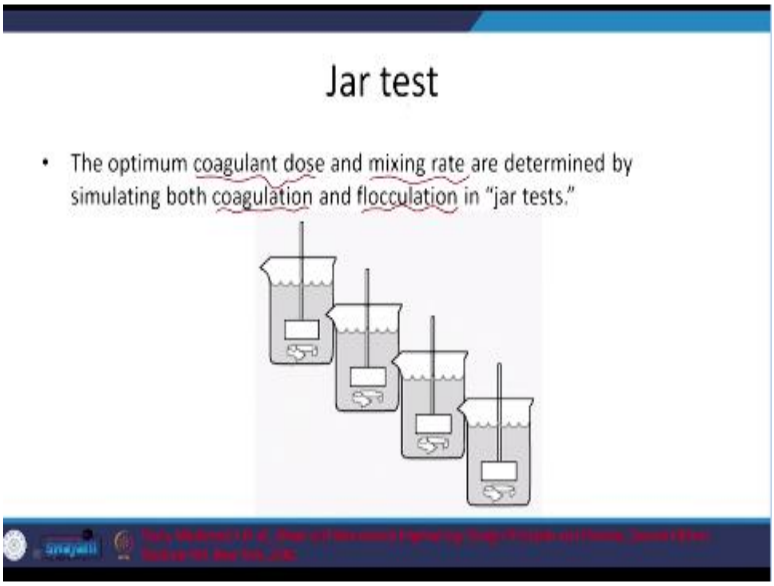

Jar test

- The optimum coagulant dose and mixing rate are determined by simulating both coagulation and flocculation in "jar tests."

So, it is simple. I am going to take the sample and here, what are the aspects of interest, we remember that pH plays a role because depending on the pH, you can have the precipitation occurring or you can have different charge out there. So, you can vary 2 primary variables. One is the charge not charge, charge indirectly by the pH and also the coagulant though. So, these are the 2 aspects you will check while conducting these jar tests in the lab.

So, you will take the actual water and conduct the test . What are we trying to do? We are trying to simulate initially coagulation and then flocculation, . So, let us go for. Here, we are looking at 2 aspects, coagulant dose and even mixing rate, but primarily for the jar test, we are looking at a coagulant dose, mixing rate and such, will also depend upon the kind of mixer or impeller or such, you are using in your particular system and the dimensions of your system and such. So, coagulant dose primarily.

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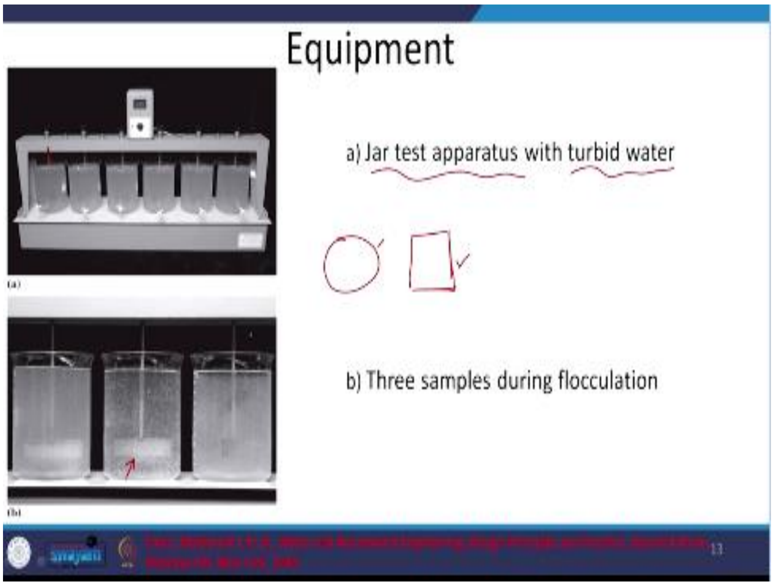

Equipment

a) Jar test apparatus with turbid water

b) Three samples during flocculation

So, this is what it looks like most UG labs would have had it. What do we have? We have this mixer, that is dipped into this solution. Here, you can see a clearer picture out here. It is a blade out here. So, whatever are you going to do? We are going to take the operators with the water or the sample that you want to conduct the test upon. So, 3 samples or 6 depends on the kind of test, .

So, , one thing is here, people took the circular beakers, if I look at the plan view, this is the thing. But for greater turbulence, if you takes square or rectangle once that is better, but in general, these are difficult to maintain, easier to maintain. So, that is why people use the circular ones that is something to keep in mind. So, you can see the flocs being formed and maybe later settling out. So, different stages of coagulation and flocculation.

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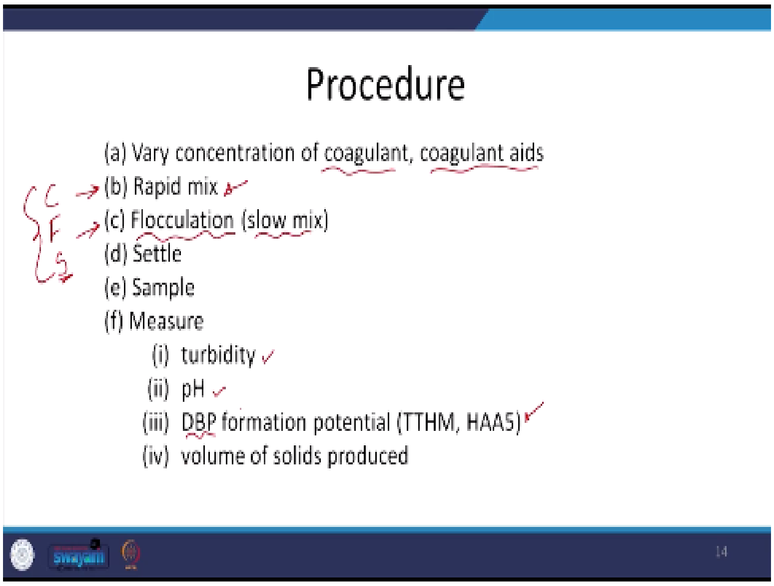

Procedure

(a) Vary concentration of coagulant, coagulant aids

(b) Rapid mix

(c) Flocculation (slow mix)

(d) Settle

(e) Sample

(f) Measure

- (i) turbidity ✓
- (ii) pH ✓
- (iii) DBP formation potential (TTHM, HAA5) ✓
- (iv) volume of solids produced

So, what is the procedure? Obviously, I want to, , test a range of doses with the different kinds of coagulants. So, then what do I need to do? I need to form what we say, coagulation. For this, I am going to mix it as in create considerable turbulence. So, that the coagulant mixes well with my solution and will either adsorb and then neutralise the charge or precipitate.

, we will look at that later or have some inter particle bridging but , that is only initially. If you mix it too high, that inter particle bridging will be affected. So, rapid mix for a small amount of time, so, that you have good mixing and then you will go to slow mix. Why you want to promote flocculation? If you continue with rapid mixing, the flocs are going to either shear or you will have, we looked at the issues with respect to the polymer , binding itself with the same particle and such.

So, we will have to look at slow mixing. Initially, we want coagulation occurring here and then during slow mixing, flocculation. So, then we are going to let it settle down. What am I trying to do? Coagulation and flocculation and then settling or sedimentation, this is what I am trying to simulate in the lab. So, then I will test the sample for turbidity and also pH because after addition of alum or some of the other coagulation, that the pH will decrease.

You want to see whether that pH decrease is acceptable or not. So, thus, you will measure pH. Turbidity is our primary aspect or concern, as in we are trying to measure how much suspended solids we were able to settle down. So, obviously I will measure turbidity. In India, we do not do this. But if we are able to remove some natural organic matter, which will affect the DBP formation potential that also you can measure and volume of solids, how much volume of solids or such is produced.

Why? Because in the actual treatment plant, you will have sludge being settled down. And that sludge, you will have to take care of it . So, you want to be able to calculate that. So, optimal coagulant dose.

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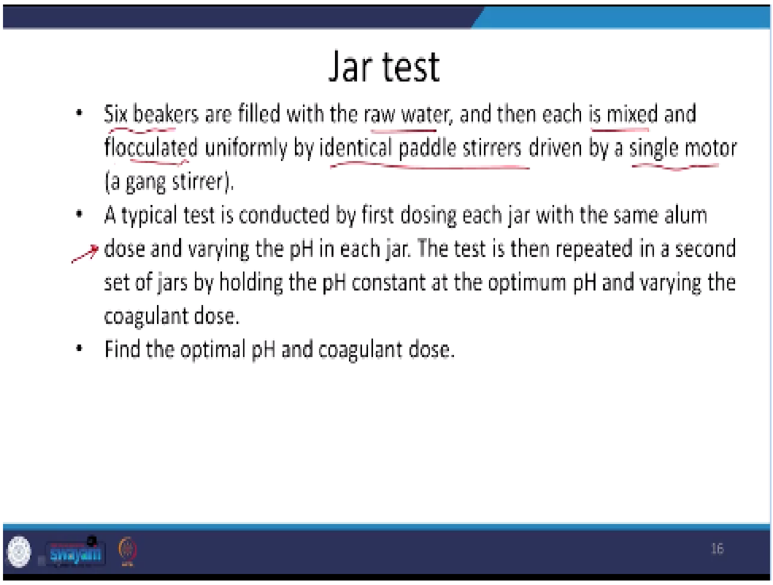

Jar test

- Six beakers are filled with the raw water, and then each is mixed and flocculated uniformly by identical paddle stirrers driven by a single motor (a gang stirrer).
- A typical test is conducted by first dosing each jar with the same alum dose and varying the pH in each jar. The test is then repeated in a second set of jars by holding the pH constant at the optimum pH and varying the coagulant dose.
- Find the optimal pH and coagulant dose.

And here, the aspect is that it is not always the minimum, it is obviously balanced between practical aspects such as the costs and the final turbidity that you want to achieve . We are not looking at the ideal case scenario. So, that is one aspect to keep in mind. So, what do we have? Typically 6 beakers with the sample and then we are going to have rapid mixing and then flocculation and with slow mixing. Yes.

And the kind of mixers are going to be the same throughout we looked at the picture earlier identical paddle stirrers and in general by a single motor, . So, what do we do? In the first test, I am going to either change the pH or the dose. Typically, I will keep the pH constant and vary the dose. So, that is what we see. So, depending on it, people will go about it the other way.

But typically, if we look at the effect, it is always better to keep the pH constant and then look at the dose, but , different ways to go about it. So, then I am going to find the optimal pH and the coagulant dose. So, first, people are looking at the pH and then using that optimum pH to find the optimum coagulant dose. So, how we can go about it.

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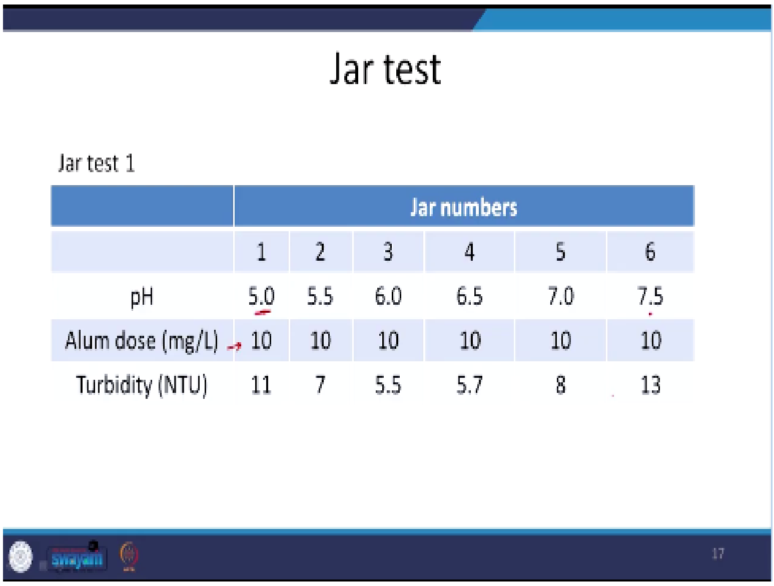

Jar test

Jar test 1

	Jar numbers					
	1	2	3	4	5	6
pH	5.0	5.5	6.0	6.5	7.0	7.5
Alum dose (mg/L)	10	10	10	10	10	10
Turbidity (NTU)	11	7	5.5	5.7	8	13

So, we have a jar test. Here, we have the 6 samples and pH was varied from 5 to 7.5 and the alum dose was fixed at 10 milligram per litre. Obviously trial and error, initially do as an, I am not obviously going to go to 2 acidic or 2 basic pH, it will depend upon my objectives too at the end of the day and the costs of neutralising this. , I am not going to use (09:19), even if the turbidity is vast, I am not going to use that or probably might not.

Why? Because to neutralise, it bring up the pH to 7, I need to add a NaOH or such concentration, not concentration, costs are involved. So, these are the aspects to be mindful of. And then alum dose is kept constant. And then we are measuring the turbidity. You see that the turbidity well decreases and then increases here. So, here it is , mix of, what is this, optimum charge utilisation and sweep coagulation.

Maybe depending on the type of alum but here it is just alum, maybe less of inter particle bridging, .

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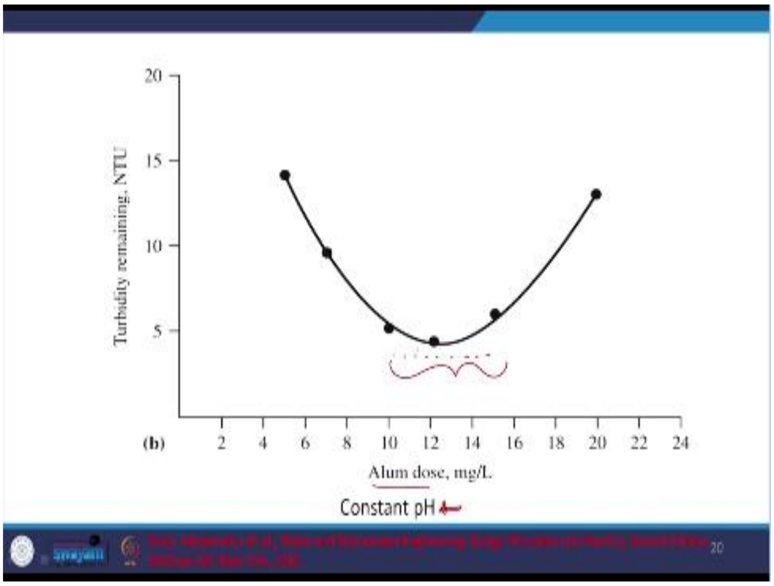

Constant pH

So, what do we see? We see the effect of pH. And so, you can choose either 6.5 or 6. And I think based on the data, we will choose 6. So, based on the data, we are choosing pH value of 6, and then you are going to choose that pH 6 and keep that constant across all your samples. Now, you will conduct the test at this pH across 6 samples. And now, you are going to vary the alum dose 5, 7, 10 , .

, trial and error is obviously involved. And then I will get the residual turbidity. This is the turbidity of the solution that is remaining. And here, we have the effect of alum dose at constant pH. So, that is what you see out here. And then we see that this is the profile from here, you can choose the relevant concentration. But in general, because the range is considerable, what people will do is they will conduct a test with the values chosen in this range, .

So, that you can get the accurate concentration, you do not want to put in too much alum. To be able to capture the most optimum one, you will typically conduct the test.

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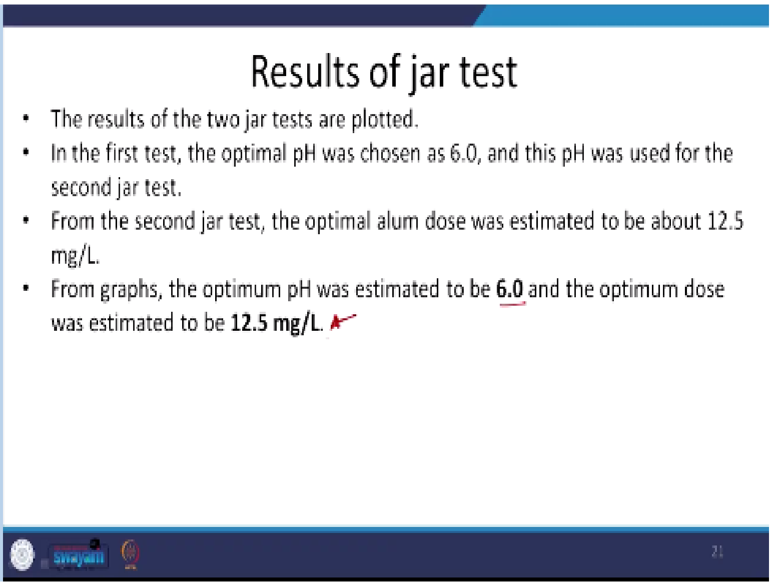

Results of jar test

- The results of the two jar tests are plotted.
- In the first test, the optimal pH was chosen as 6.0, and this pH was used for the second jar test.
- From the second jar test, the optimal alum dose was estimated to be about 12.5 mg/L.
- From graphs, the optimum pH was estimated to be **6.0** and the optimum dose was estimated to be **12.5 mg/L**.

So, we looked at this looks like pH 7, we already looked at that. And people were choosing 12.5. But , as I mentioned, in general, you will conduct a test , . And depending on your objective, sometimes you can even choose this after you choose this particular coagulant dose, you can conduct the effect on the pH as in there is a better pH, .

But , it obviously is slightly time consuming. It is not a lot, though; it is pretty fast, because we are only talking about a few seconds, but for settling maybe a few minutes. So, it is not very time consuming. But , in general, if you repeat it, it is going to be an issue. So, there is some trial and error involved. And depending on how accurately you want to capture the effect of pH, you can repeat it for pH but that is rarely done.

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Rapid mix design

So, rapid mix design. When I say rapid mix design, what is it? I am concerned with at least at our level. So, I want to promote mixing. How will I promote mixing? I want to create turbulence, turbulence meaning if , no water is flowing in this direction, let me put it down on the paper here. So, water is flowing in this direction and everything or if it is laminar flow, everything going at the same velocity or such. And then there is little to no mixing here.

But if I have different velocities or such, yes and different directions and such, I will have Eddies being formed and then mixing of layers and such. So, I want to create this differential velocities or velocity gradients. So, if the water itself does not have sufficient gradient or turbulence, what will I do? I will create that. So, for example, think of it in your home, what do we do? We turn on the fan. Similarly, you can have different types of mixers or impellers here (13:06).

So, here, there are 2 aspects, I am a bit, it is a bit sultry and I want to turn on the fan until I feel comfortable. So, 2 aspects, either I increase the fan speed to the highest possible and feel comfortable in a relatively shorter amount of time or maybe at lesser intensity for a longer period of time. But , it is not a straightforward analogy, but what I wanted to point out was the level or mixing intensity and the time or the duration for which you are going to mix both play a role.

Obviously, here we are limited by the kind of energy we want to impart. If you give too less energy or such at this point during coagulation, the system will not mix well. But , what are we concerned with intensity of mixing and how long will you mix it?

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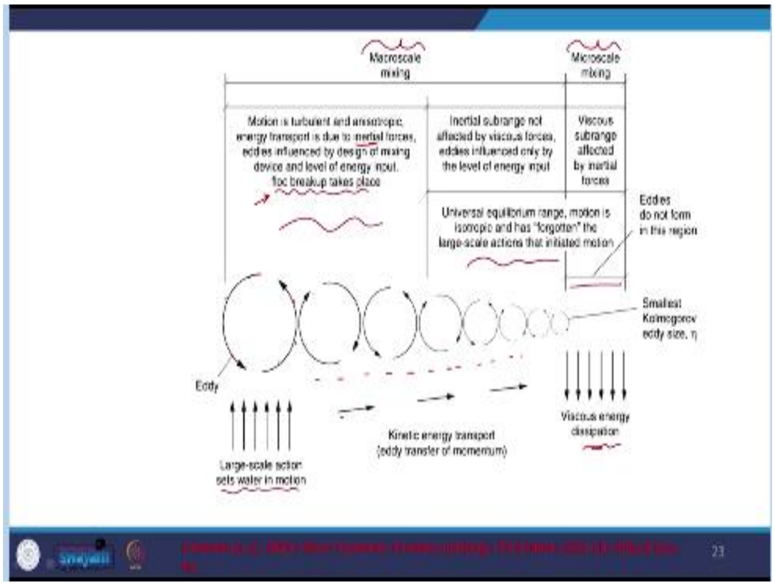

So, how is it that energy is transferred from the largest scale to the smallest scale, ? Let me look at this figure that is present in kritendent et al (14:08) at all. So, here I am going to start my motor. So, large scale action sets water in motion from my impellers or fans in the water. So, I am going to form a Eddies and this Eddies lead to transport of the energy from one Eddy to the other and to smaller and smaller Eddies .

And here, we see that there are 2 aspects, macro scale and micro scale. We will come back to this earlier but please do understand this figure. Here, motion is turbulent, energy transport is due to inertial forces as in some water is still others are in motion So, you have inertial forces. And Eddie's influence the design of mixing device and level of energy input. Floc will break up.

So, obviously, here at this level, floc will break up. And then inertial sub-range is not affected by the viscous forces, at least influenced only by the level of energy input. And then we come to the smaller scale where Eddies do not form. And here, it is viscous energy dissipation, . So, , Eddy's transfer of energy, , so, that is one aspect to keep in mind.

Yes, initially, the large scale motion is relevant. And later that large scale motion is not that relevant . Yes, so, Eddies in one region and no Eddies, but , micro scale mixing, which is important for smaller particle and macro scale for the bigger particle.

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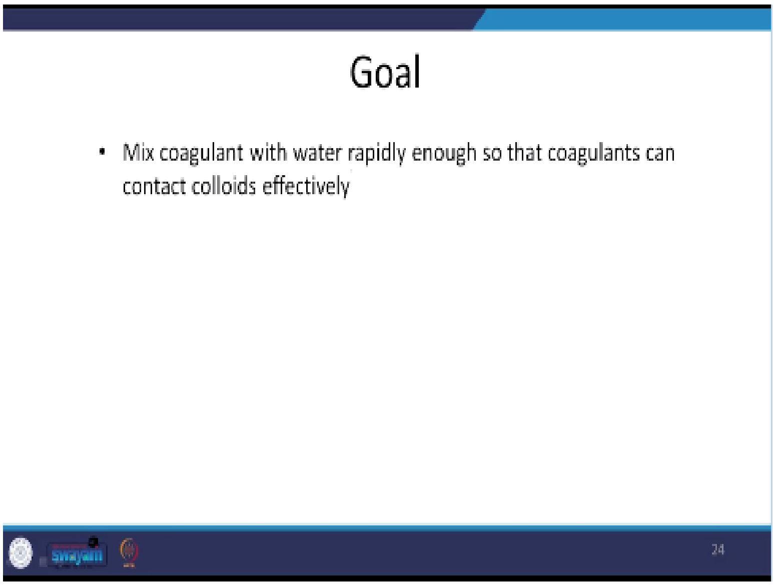

Goal

- Mix coagulant with water rapidly enough so that coagulants can contact colloids effectively

So, what is the goal? I want to quickly mix them. So, that the coagulants can destabilise the colloids effectively, .

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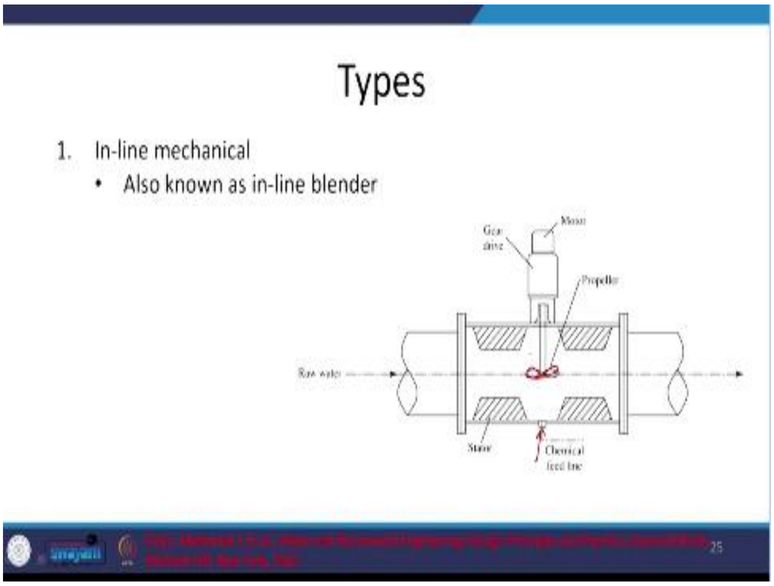

Types

1. In-line mechanical
   - Also known as in-line blender

So, we have different types. So, what do we have? One is the in-line blender. That is what you see in-line mechanical blenders or also known as in-line blender. So, you have water coming in and going out, you can add a chemical feed, chemical is being added from here. And you have this propeller or impeller here . And you are going to have mixing in here.

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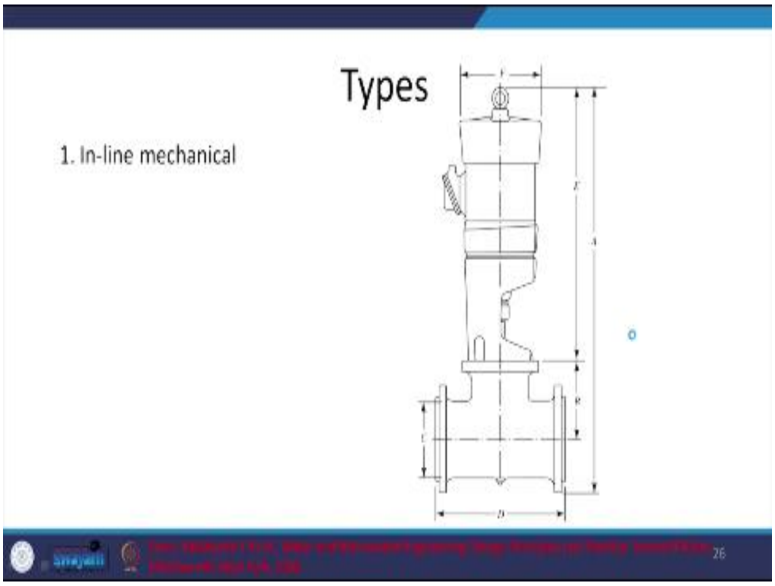

Types

1. In-line mechanical

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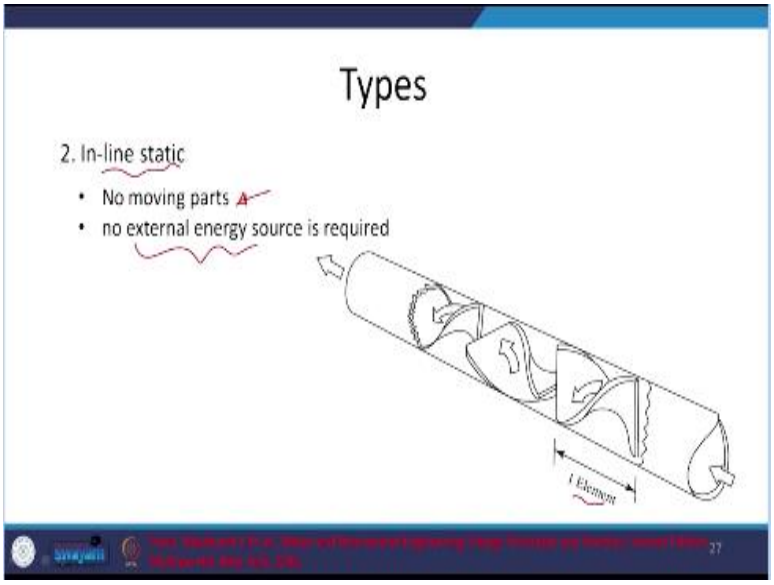

Types

2. In-line static

- No moving parts
- no external energy source is required

And next is in-line mechanical different types. So, will not go into that in detail. Other one is static, no moving parts that is obviously a relevant advantage and thus, no external energy sources require. Looking at the design you can see that the water mix aside, Yes. Different elements, differently sized elements, from a few centimetres to maybe even 100 centimetres, but rarely, that is what industrial zones, industrial types. So, this is static. (()) (16:45) one obviously, as you see was mechanical.

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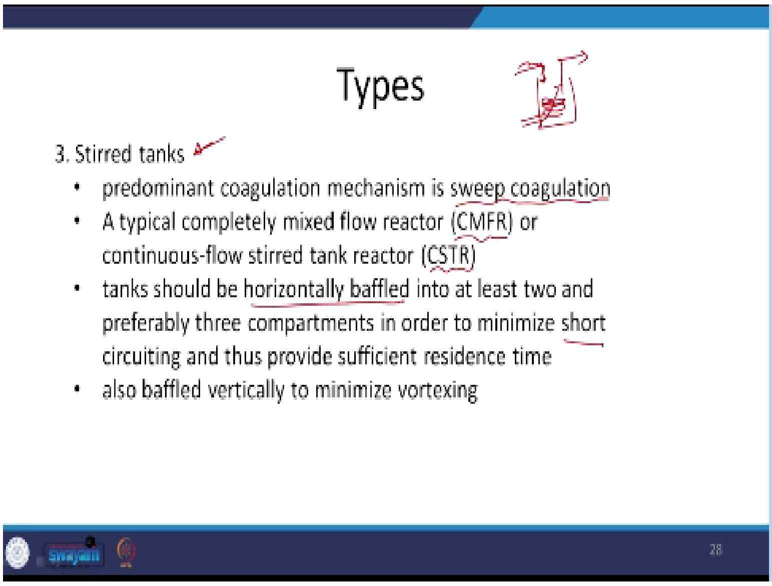

Types

3. Stirred tanks

- predominant coagulation mechanism is sweep coagulation
- A typical completely mixed flow reactor (CMFR) or continuous-flow stirred tank reactor (CSTR)
- tanks should be horizontally baffled into at least two and preferably three compartments in order to minimize short circuiting and thus provide sufficient residence time
- also baffled vertically to minimize vortexing

And we have another one stirred tanks. Well, it depends on the system; depending on the space, if you do not have space, you will go for in-line. If you have space and depending on the level of control on the mixing, maybe you will go for your stirred tanks. So, stirred tanks obviously, so, flow is coming in and flow is going out, what is it? It is a completely mixed flow reactor or a continuously stirred tank reactor.

And in general looks like, we will promote sweep coagulation. And here, we will also have horizontal baffles to minimise short circuiting as in depending on where the water is coming in and where it is going out. You do not want the water to take the shortest path. You want it to be well mixed. So, we want to prevent short circuiting that is why you have these baffles walls, .

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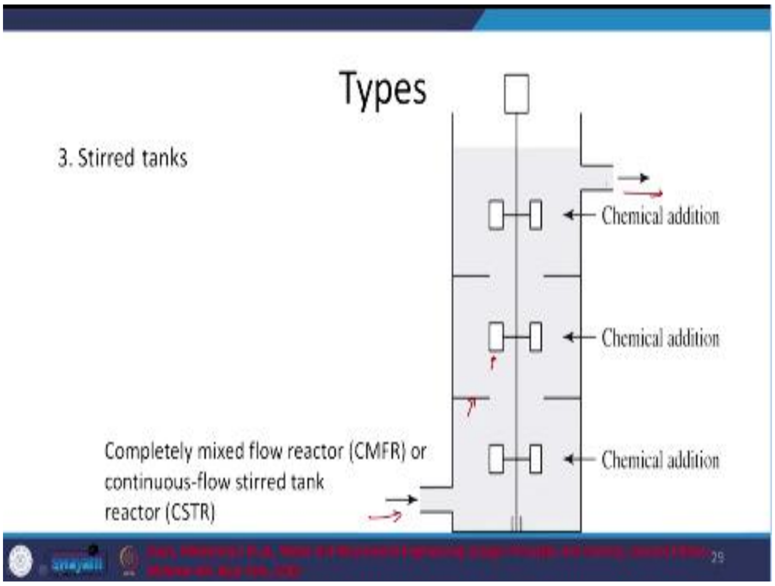

Types

3. Stirred tanks

Completely mixed flow reactor (CMFR) or continuous-flow stirred tank reactor (CSTR)

So, let me see that. Here, you have the baffle walls, you have the mixers. So, chemical addition is taking place at different stages. And the water is coming in here. And it is going out. So, it is completely mixed the system here. So, let us move on.

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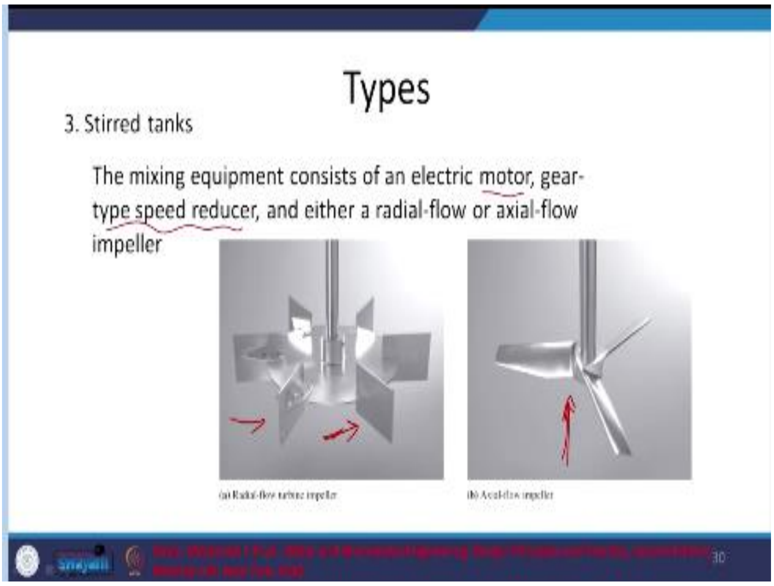

Types

3. Stirred tanks

The mixing equipment consists of an electric motor, gear-type speed reducer, and either a radial-flow or axial-flow impeller

(a) Radial-flow turbine impeller

(b) Axial-flow impeller

, the types of mixers here, . So, mixing equipment consists obviously of a motor and speed reducer or regulator and either radial flow, this is radial flow think of this and this is axial flow depending on the type of flow ; radial flow or axial flow impeller. , why is this relevant and such? Because depending on the relevant area here and the design, you are going to have what we say, shear forces being generated that lead to turbulence and such.

And obviously, the energy that you are putting in through your motor for which you are paying will have to be able to do the job efficiently. So, that is where the design comes into play and we will look at this soon.

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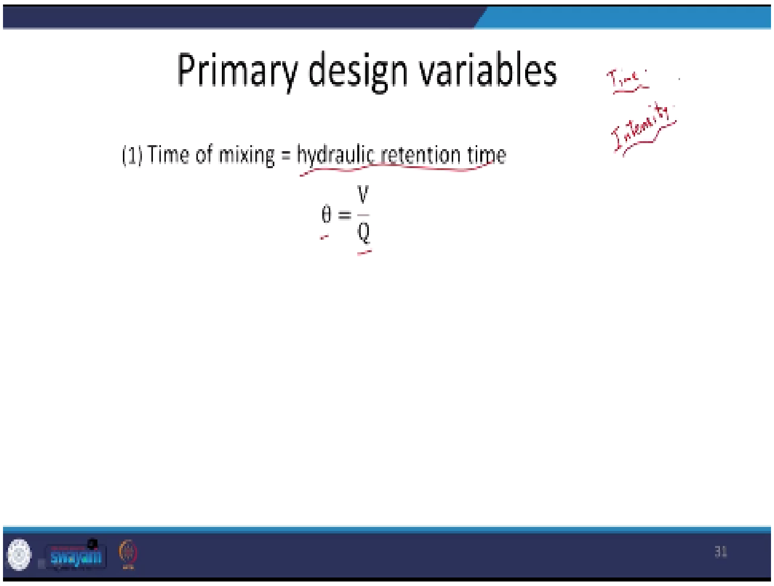

Primary design variables

Time

Intensity

(1) Time of mixing = hydraulic retention time

$$\theta = \frac{V}{Q}$$

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Primary design variables, as I mentioned, one is the how much time am I mixing it for? When I say time, it obviously refers to the time that this water is spending in my system. Time the water is spending in my system and we know that it is called the hydraulic retention time theta equal to V/ Q, you can calculate that pretty simply. And what is the other one? It is about the intensity of mixing.

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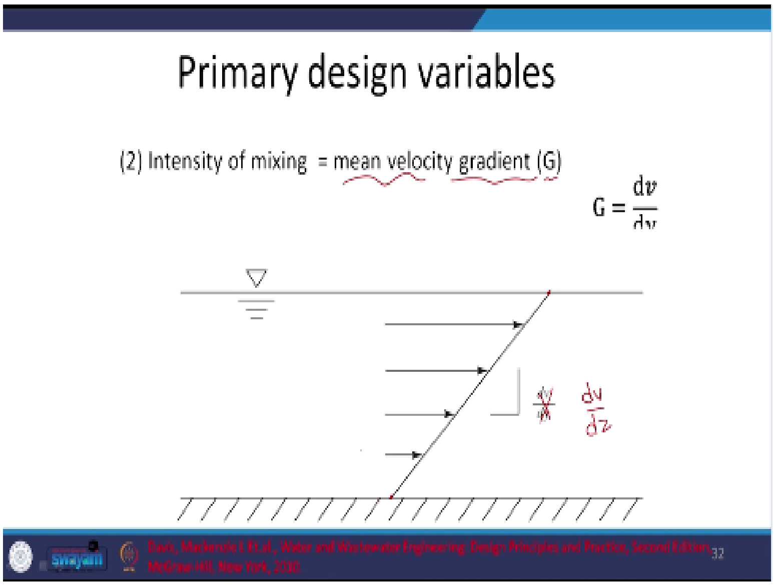

Primary design variables

(2) Intensity of mixing = mean velocity gradient (G)

$$G = \frac{dv}{dy}$$

Davis, Mackenzie L Et.al., Water and Wastewater Engineering: Design Principles and Practice, Second Edition, McGraw-Hill, New York, 2010.

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How will I be able to achieve that? We know that we talked about , different velocities or , you want to have a gradient or difference in velocities at different levels that is when you will promote mixing, . So, that is what we have out here. So, this is the figure here, there is zero flow. And after creating the conditions, I have this velocity gradient.

So, here, I am saying that the velocity gradient is dv/dy or , for the sake of uniformity, in case of other pictures, this is dv/dz. So, this is the mean velocity gradient. What is the gradient in velocity? Here, it is zero and here the velocity is increasing. So, there is a gradient in velocity. What is that? Or what is the variable? It is G and it is called mean velocity gradient.

So, it is in this direction that is what this is Z, . So, that is something to keep in mind. The velocity is zero here. And it is increasing with, , or increasing with z.

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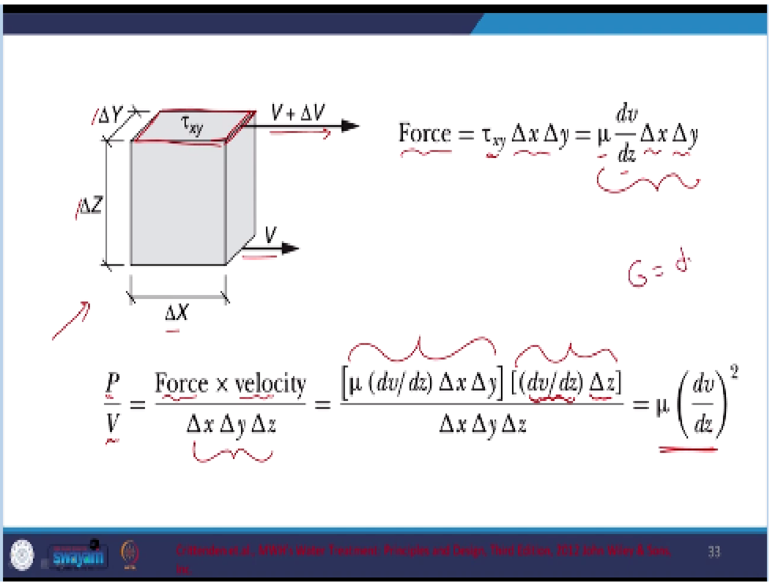

$$\text{Force} = \tau_{xy}\,\Delta x\,\Delta y = \mu \frac{dv}{dz}\,\Delta x\,\Delta y$$

$$\frac{P}{V} = \frac{\text{Force} \times \text{velocity}}{\Delta x\,\Delta y\,\Delta z} = \frac{[\mu\,(dv/dz)\,\Delta x\,\Delta y]\,[(dv/dz)\,\Delta z]}{\Delta x\,\Delta y\,\Delta z} = \mu\left(\frac{dv}{dz}\right)^2$$

Crittenden et al., MWH's Water Treatment: Principles and Design, Third Edition, 2012 John Wiley & Sons, Inc.

So, how to go about it kritendent (20:11) et al use this. So, you have this particular , section if I may say so. And here the velocity is V about, we know that the velocity is increasing as we are going up. So, V + delta V is out here. So, you are going to have force here, . And that force is, , this is from Newtonian flow, tau xy, this is on this plane, x, y plane. This is x and this y on this plane.

What is the force being applied tau xy into area? And that is going to be equal to this is from Newtonian flow mu dv/ dz. How is the velocity changing? And delta x, delta y, we will look at it in a different way too. But I wanted to present this aspect here. And power, we know its force into velocity, power per volume. So, I want to calculate power per volume, force into velocity volume is delta x, delta y and delta z that is what we have.

Force, we just calculated that here. Force is what we calculated that from here. And what is the velocity, at any particular height? We know that the velocity gradient is dv /dz. And at a particular height delta z, it will depend upon the rate at which the velocity grey or the rate at which the velocity is changing with z. So, velocity is equal to (dv/ dz) x delta z. So, if I simplify this, looks like this is what I will get.

And please note that we said that this G is the mean velocity gradient. So, this is what we have here G, . So, what is a different way to? So, this will give me an idea about the level of mixing.

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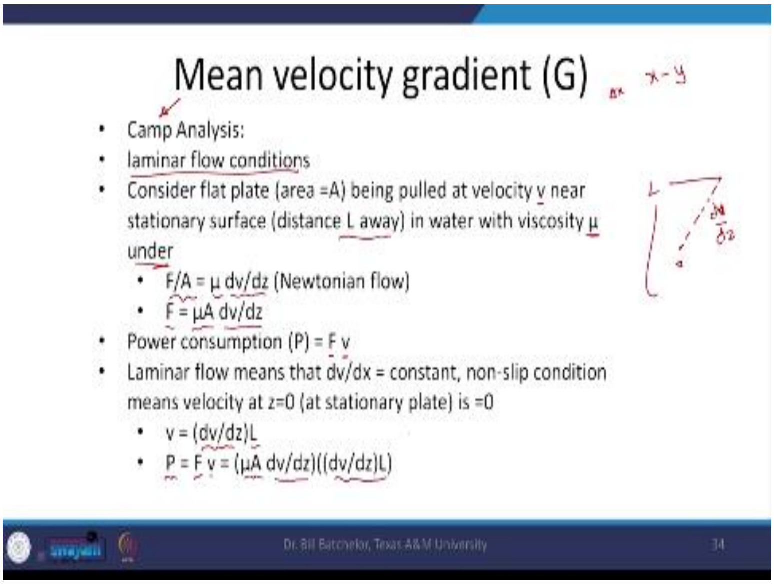

Mean velocity gradient (G)

- Camp Analysis:
- laminar flow conditions
- Consider flat plate (area =A) being pulled at velocity v near stationary surface (distance L away) in water with viscosity μ under
  - $F/A = \mu \, dv/dz$ (Newtonian flow)
  - $F = \mu A \, dv/dz$
- Power consumption (P) = F v
- Laminar flow means that dv/dx = constant, non-slip condition means velocity at z=0 (at stationary plate) is =0
  - $v = (dv/dz)L$
  - $P = F v = (\mu A \, dv/dz)((dv/dz)L)$

So, a different way, , this is from Dr. Bachelor, but the person who looked at it or presented this was Dr. Camp. So, Camp analysis, we are assuming laminar flow conditions. That is what we saw 2 slides before. And we are assuming that the flat area, , which was delta x or in the xy plane earlier, is being pulled at a velocity v, nearest stationary surface and distance L away. This is in the z direction and the viscosity is mu. So, under laminar flow conditions, so, it is under laminar flow conditions. So, what is F/A?

On that particular plate in the x, y plane, so, it is similar to what we have, what is F/ A. Here F/ A, it is mu into dv/dz, similar to what we had earlier. So, F = mu A (dv/dz). I am just presenting the previous information in a relatively better manner, which can be easily understood, . So, earlier A, we took that to be delta x into delta y. That is something to keep in mind. And power consumption, power is force times the velocity, .

And laminar flow, what does that mean? here, we saw that in the 2, what we say, graphs before, velocity at this place is, the location is zero. And it is increasing at what rate dv/ dz. So, velocity at particular height L, will be given by the rate of change of velocity with height into L , or dv/ dz into L. So, from here, I can calculate the power, power equal to F x V, that is equal to mu A (dv/dz) and thus, so, that is going to give me and I can transform this.

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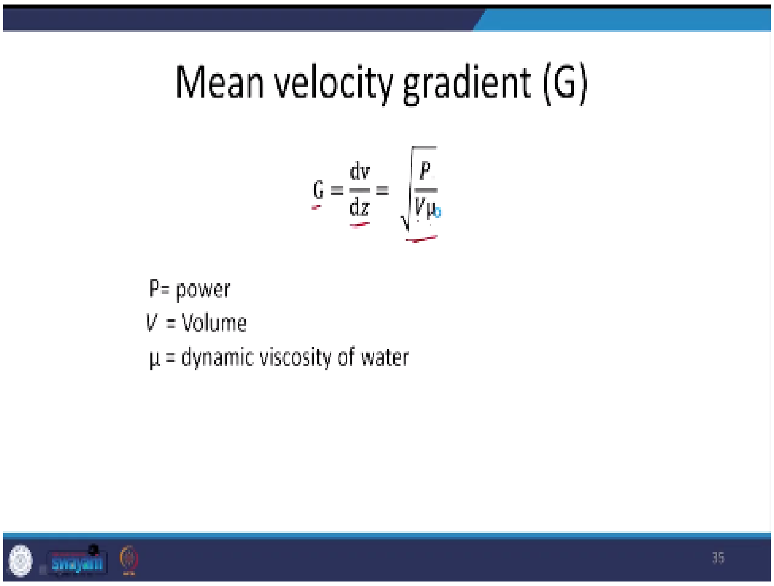

Mean velocity gradient (G)

$$G = \frac{dv}{dz} = \sqrt{\frac{P}{V\mu}}$$

P= power
V = Volume
μ = dynamic viscosity of water

And from here, I will get this G is equal to dv/ dz that is equal to the square root of the power. That is what you are imparting from your pump. V is the volume of that particular section. And mu is the dynamic viscosity of water. So, that is something to keep in mind. And how do I relate this to the different kinds of mixers or impellers out there? We will look at that, .

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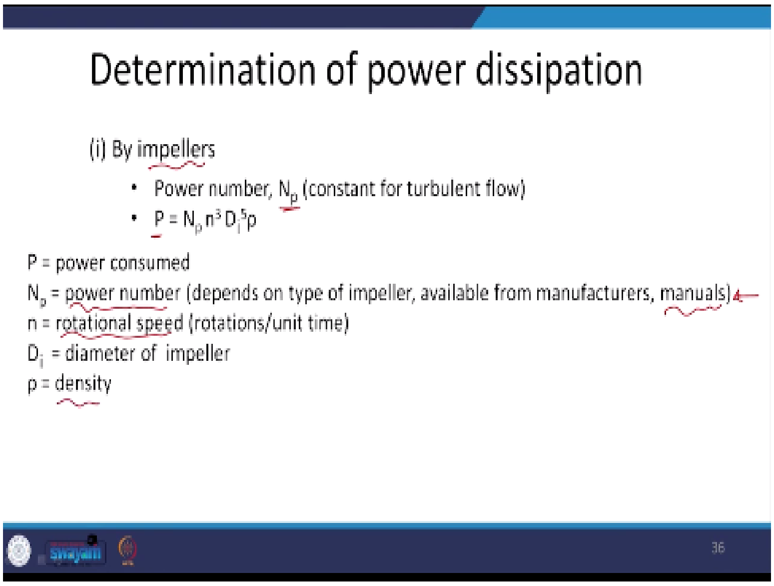

Determination of power dissipation

(i) By impellers

- Power number, N_p (constant for turbulent flow)
- $P = N_p n^3 D_i^5 \rho$

P = power consumed
N_p = power number (depends on type of impeller, available from manufacturers, manuals)
n = rotational speed (rotations/unit time)
D_i = diameter of impeller
ρ = density

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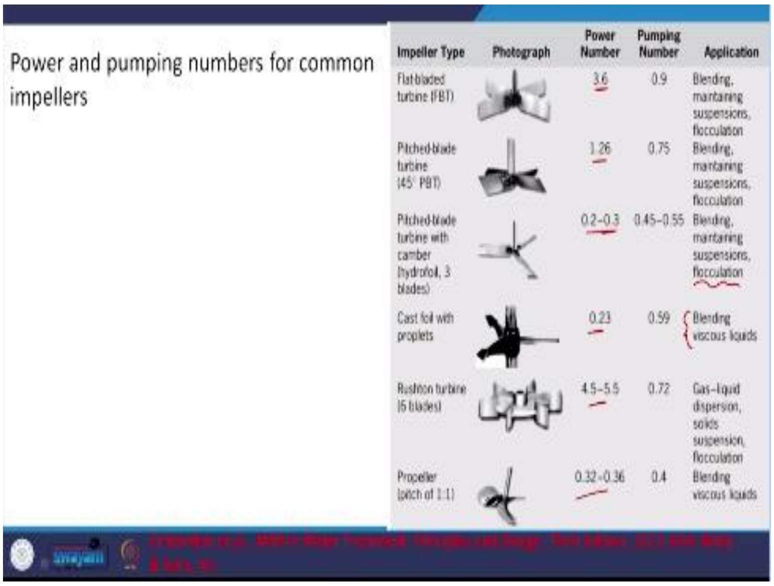

Power and pumping numbers for common impellers

Impeller Type	Photograph	Power Number	Pumping Number	Application
Flat-bladed turbine (FBT)		3.6	0.9	Blending, maintaining suspensions, flocculation
Pitched-blade turbine (45° PBT)		1.26	0.75	Blending, maintaining suspensions, flocculation
Pitched-blade turbine with camber (hydrofoil, 3 blades)		0.2–0.3	0.45–0.55	Blending, maintaining suspensions, flocculation
Cast foil with proplets		0.23	0.59	Blending viscous liquids
Rushton turbine (6 blades)		4.5–5.5	0.72	Gas–liquid dispersion, solids suspension, flocculation
Propeller (pitch of 1:1)		0.32–0.36	0.4	Blending viscous liquids

So, by impellers, I am talking about these different kinds of impellers. Note that , the angle, there are different kinds; for each one, there is a power number. Keep that in mind. And then the application is also given here blending viscous liquids, blending and maintaining suspensions and for flocculation and such, . So, for blending, it can be used for both blending coagulation and flocculation. This is what I am talking about when I say impellers.

So, power number is given. It is a constant for turbulent flow. And the power consumed, , which will depend upon or which can be related to power number. And this we just saw, it is calculated by the relevant manufacturer, it is going to be depend upon the power number, the rotational speed as in how fast is it rotating? You have different impellers. How fast is it rotating?

The diameter, obviously, of the impeller and the density of that particular water, . So, from that you will get the an idea about the power consumption that is required, . And then you can relate it to G and such.

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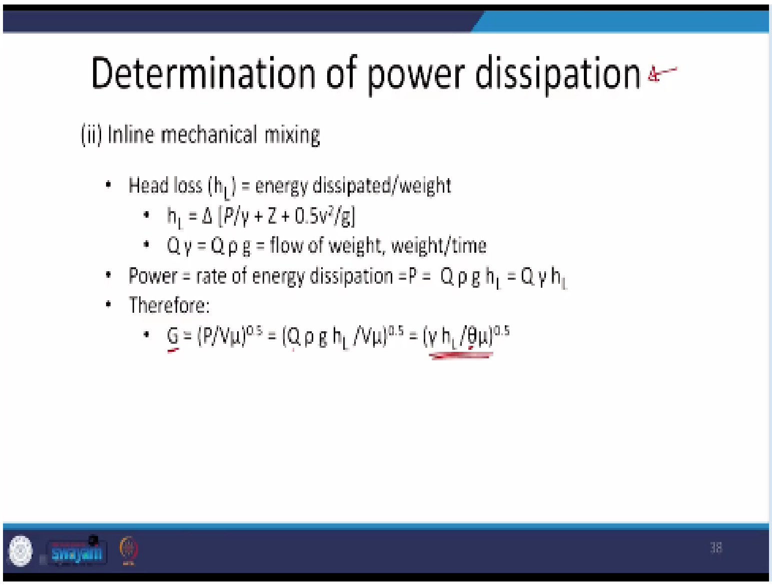

Determination of power dissipation

(ii) Inline mechanical mixing

- Head loss (h_L) = energy dissipated/weight
  - $h_L = \Delta\,[P/\gamma + Z + 0.5v^2/g]$
  - $Q\,\gamma = Q\,\rho\,g$ = flow of weight, weight/time
- Power = rate of energy dissipation = $P = Q\,\rho\,g\,h_L = Q\,\gamma\,h_L$
- Therefore:
  - $G = (P/V\mu)^{0.5} = (Q\,\rho\,g\,h_L/V\mu)^{0.5} = (\gamma\,h_L/\theta\mu)^{0.5}$

So, in-line mechanical mixing. How do I do that? Either with mechanical mixing or even static mixing, how do I get it? How do I relate this power, ? And G, how do I get that information? So, we should understand that in-line, we are going to have a head loss. And head loss is nothing but energy that is lost or dissipated per weight. And we know from Bernoulli's equation, head loss is equal to this.

So, P is pressure here, not power. P here is pressure. Head and $v^2/2g$. And here, I want to remove this weight term. So, how we can do that. Q into mu or , I am going to get Q x rho x g, this is volume per time and mass per volume. So, I will get mass per time or weight per time. Because it is g; it is not mass. It is weight per time that is what I am going to calculate here. And now, energy dissipation.

So, if I want energy dissipation, , how will I get that which is P, this is power, Q, rho g, which is weight per time, weight per time, into energy that is dissipated per weight, which is head loss. So, that is what we have (Q x rho x g) x h_L. So, Q into this particular variable and h L, . So, from this, I will be able to calculate this. And I know that g is equal to $(P/V)^2$ mu and I can get the relationship between g and the relevant aspects out here, .

So, let me just erase this now. From g, the level of mixing based on the relevant head loss and the hydraulic retention time. So, that is something for you to look at, because we know Q/V is equal to or V/Q is equal to theta (ɵ). So, , we are looking at the power dissipation, , I am putting in power and I want to be able to understand how is it being dissipated and how much level of mixing I am going to get.

So, that is what we are trying to understand out here. So, I am out of time, we will continue the next aspects in the next session. But what have we looked at until now, we have looked at different types of mixers and we know that how much time the water spends in the system is of primary importance, which is theta. And we also want to know how much turbulence needed (27:53) or how much mixing is needed.

For that what is the variable we are using, it is called G mean velocity gradient velocity; gradient meaning change in velocity, . So, we were able to also then look at energy dissipation, how is this energy dissipation , relevant to either head loss or G? So, that I can understand and design accordingly. So, with that, I will end today’s session. Thank you.