Water Supply Engineering
Prof. Manoj Kumar Tiwari
School of Water Resources
Indian Institute of Technology, Kharagpur

Lecture-29
Coagulation and Flocculation: Selection and Application

Hi everyone and welcome back, so we will continue our discussion on Coagulation and Flocculation process what we what we started in the last lecture. We did talk about the basic concepts of Coagulation and Flocculation and in this particular class we will be discussing about the process selection and application.

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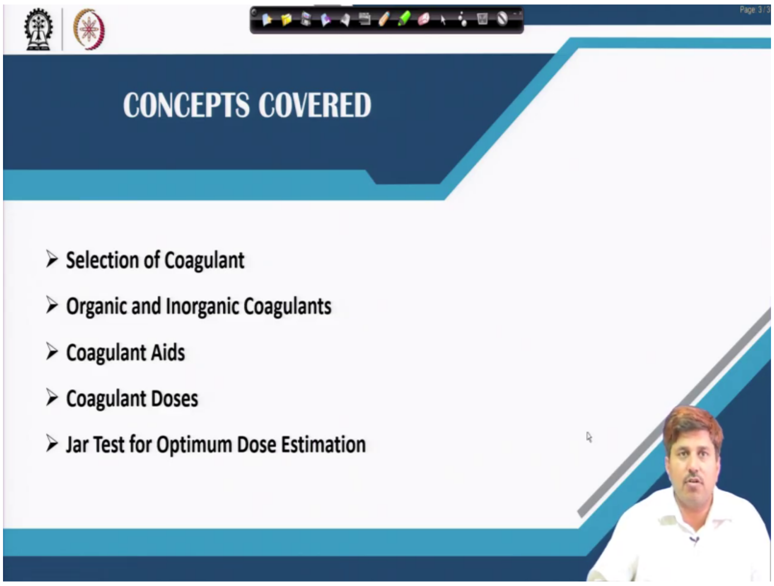

CONCEPTS COVERED

- Selection of Coagulant
- Organic and Inorganic Coagulants
- Coagulant Aids
- Coagulant Doses
- Jar Test for Optimum Dose Estimation

How basically the process is applied and how we select the Coagulant, so practically what we will be discussing is the selection of carbonate and what are the variety of coagulation available the various organic and inorganic coagulants available in the market and their basic characteristics. Then we will be talking about the coagulant ads as well what they are and what roles they might play in the coagulation process.

And we will discuss the doses estimation for the carbonate how much dose must be provided and what impacts it may lead to the different systems what are the criteria's that should be followed. And we will also talk how experimentally we optimize the coagulant dose through Jar test.

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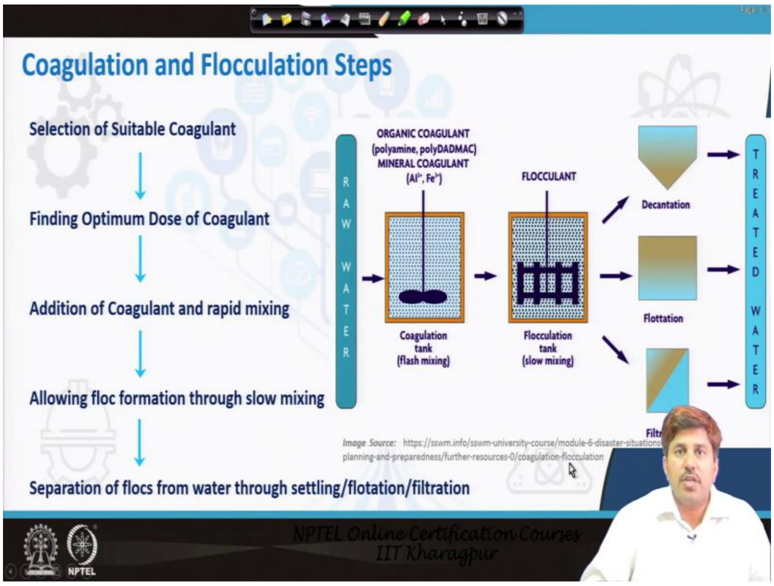

Coagulation and Flocculation Steps

Selection of Suitable Coagulant

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Finding Optimum Dose of Coagulant

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Addition of Coagulant and rapid mixing

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Allowing floc formation through slow mixing

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Separation of flocs from water through settling/flotation/filtration

Image Source: https://sswm.info/sswm-university-course/module-6-disaster-situations planning-and-preparedness/further-resources-0/coagulation-flocculation

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So, to begin with as we have been discussing coagulation and flocculation process, so essentially the process of coagulation and flocculation involves several steps we must need to select a suitable coagulant and then we must need to find the optimum dose of that Coagulant of course in addition we need to find the optimum operating conditions as well. And then we add that coagulant and do it in a in a flash mixture.

So, we do rapid mixing in a flash mixture generally here what we mean is that we add the coagulant whether organic coagulant or inorganic coagulant. We add that and rapidly mix that so that we can form a homogeneous solution of the coagulant. Then we do this slow mixing and allow the floc formation so that is done in a flocculation basin or flocculation zone of a clariflocculator typically.

So, we will do flocculation in this system here and after that so this is what basically coagulation and flocculation is all about and after that we go for separation of floc's from the water which could be done through filtration or through basically decanting the water. That means we go for a settling basis where the solids are settled and water is decanted from the top or we go for floatation process where solids float from the water solids float from the top.

And water remains in the tank or we just simply filter where solids are retained and water passes through the filter. But this process is in fact not a part of coagulation flocculation this is essentially a filtration process or removal process. The coagulation flocculation part is this; what will be basically discussing these particular steps.

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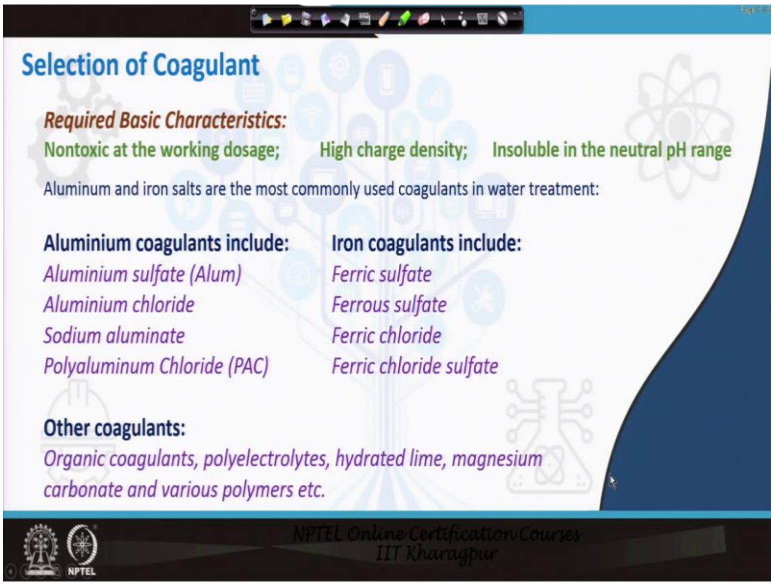

Selection of Coagulant

Required Basic Characteristics:
Nontoxic at the working dosage; High charge density; Insoluble in the neutral pH range

Aluminum and iron salts are the most commonly used coagulants in water treatment:

Aluminium coagulants include:	Iron coagulants include:
Aluminium sulfate (Alum)	*Ferric sulfate*
Aluminium chloride	*Ferrous sulfate*
Sodium aluminate	*Ferric chloride*
Polyaluminum Chloride (PAC)	*Ferric chloride sulfate*

Other coagulants:
Organic coagulants, polyelectrolytes, hydrated lime, magnesium carbonate and various polymers etc.

So, now when we go for a correlation flocculation process the first question that we face is what we are going to add. So, what coagulant we are going to select? Now whatever coagulant we are going to select it needs to fulfil some basic criteria so the basic characteristic that a coagulant must have is it should be non-toxic at a working doses. We do not want to add a toxic chemical to water because the water is going to be used for household purpose. So, we do not want any toxic in the even if it is not going to say for household purpose even if it is a going to go for some commercial purpose or any other purpose we do not want any toxic substance to add in the water.

So the one of the basic or very basic criteria is that the power length that we are choosing should be non-toxic then it should have a high charge density which is helpful in coagulation process and it should be insoluble in natural pH ranges because eventually after adding the coagulant we want that to be removed from the water. So, it should remain in the solid phase so that it can remove through settling simple settling process or filtration process.

We do not want to add a substance which gets dissolved in the water completely and then the removal of the coagulant itself becomes a major challenge later on. So, these are the some of the key criteria which a coagulant should be following. Now most commonly in water treatment facilities and particularly the municipal water treatment facilities the aluminium and iron salts are used as a coagulant. The common aluminium salts that are used are alum then could be aluminium chloride alum which is basically aluminium sulphate would be used aluminium chloride, sodium aluminate or poly aluminium chloride PAC which is becoming more popular.

Alum is by far the most popular coagulant in fact. Similarly we have variety of option in the iron based coagulants which are the ferric sulphate ferrous sulphate ferric chloride ferric chloride sulphate. So, these are some of the iron based coagulant there are other options also available there are a series of organic coagulants even polyelectrolytes and these kinds of chemicals can also be used as a coagulant though they are used as a coagulant adds also sometime.

Then there are hydrated lines there are magnesium carbonate and various other polymers particularly the organic polymers are used as a coagulant.

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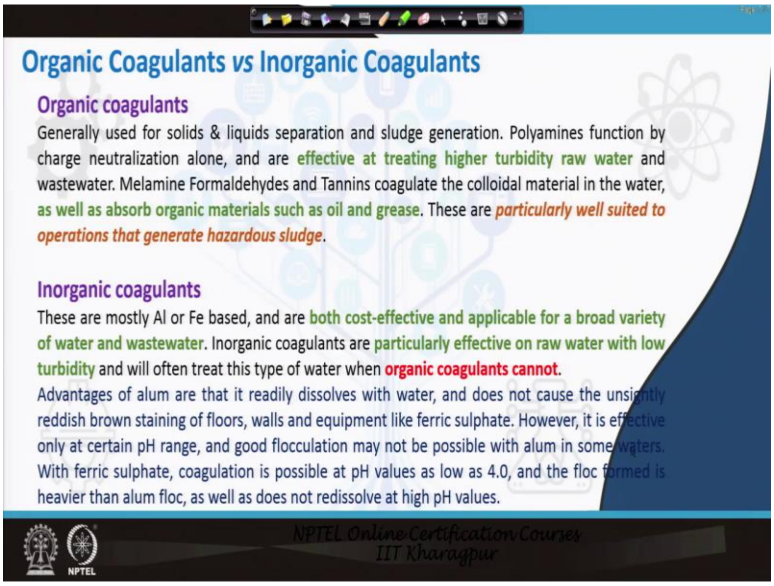

Organic Coagulants *vs* Inorganic Coagulants

Organic coagulants

Generally used for solids & liquids separation and sludge generation. Polyamines function by charge neutralization alone, and are effective at treating higher turbidity raw water and wastewater. Melamine Formaldehydes and Tannins coagulate the colloidal material in the water, as well as absorb organic materials such as oil and grease. These are *particularly well suited to operations that generate hazardous sludge*.

Inorganic coagulants

These are mostly Al or Fe based, and are both cost-effective and applicable for a broad variety of water and wastewater. Inorganic coagulants are particularly effective on raw water with low turbidity and will often treat this type of water when **organic coagulants cannot**.

Advantages of alum are that it readily dissolves with water, and does not cause the unsightly reddish brown staining of floors, walls and equipment like ferric sulphate. However, it is effective only at certain pH range, and good flocculation may not be possible with alum in some waters. With ferric sulphate, coagulation is possible at pH values as low as 4.0, and the floc formed is heavier than alum floc, as well as does not redissolve at high pH values.

So, overall we have to make a choice between organic and inorganic coagulants both have their own advantages and disadvantages. The organic coagulant the major advantage is they are very effective at treating higher turbidity raw water. So, when you have the very high turbidity to begin with that means the colloidal concentrations or suspended material concentrations is high then these kind of coagulant can very well treat that water.

These are generally like polyamide kind of substances which works on charge neutralization mostly there are then melamine formaldehyde and which contains populate which basically instead of coagulation they can also absorb all organic materials such as oil and grease if they are present in the water. They are particularly well-suited for kind of systems which is having higher turbidity. But if the turbidity of water is low to begin with these coagulants are not going to be very effective there.

So that is the limitation of organic coagulant they are they are good in treating high turbidity waters but their performance is not that great when treating low turbidity water that is where the inorganic coagulants come into the picture they are more cost-effective generally. So, they like the iron and alum salts are not that pricey so we can get them in a relatively cheaper cost they are available easily and they are applicable for a broad variety of water and waste waters.

They are particularly effective on treating raw water with low turbidity when the turbidity is low then also these kind these kind of systems can lead substantially good performance. The advantage of alum is that it particularly kind of not causes the reddish brown staining of the floors which iron coagulant does like ferric sulphate but the disadvantage side that it is only effective at certain pH ranges it works over generally pH 4 to 8 range pH 5 or 5.5 to 8 range and we do not get a good flocculation with alum in some waters.

Whereas with ferric sulphate the correlation is possible over a much wider pH range it can work as low as pH 4 and floc is formed are generally heavier than alum because iron is a heavier metal than alum. So, the floc's that are formed are heavy and they do not re-dissolved in water even at higher pH values and the settling characteristic is also better.

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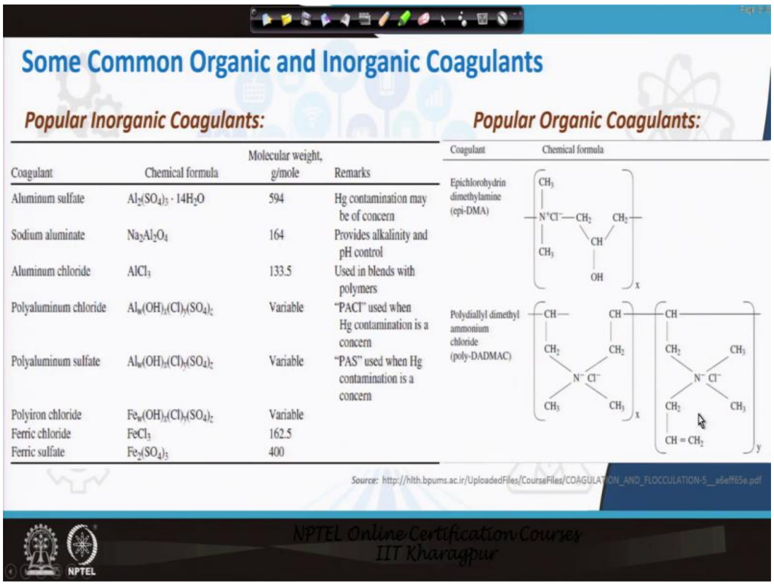

Some Common Organic and Inorganic Coagulants

Popular Inorganic Coagulants:

Coagulant	Chemical formula	Molecular weight, g/mole	Remarks
Aluminum sulfate	$Al_2(SO_4)_3 \cdot 14H_2O$	594	Hg contamination may be of concern
Sodium aluminate	$Na_2Al_2O_4$	164	Provides alkalinity and pH control
Aluminum chloride	$AlCl_3$	133.5	Used in blends with polymers
Polyaluminum chloride	$Al_w(OH)_x(Cl)_y(SO_4)_z$	Variable	"PACl" used when Hg contamination is a concern
Polyaluminum sulfate	$Al_w(OH)_x(Cl)_y(SO_4)_z$	Variable	"PAS" used when Hg contamination is a concern
Polyiron chloride	$Fe_w(OH)_x(Cl)_y(SO_4)_z$	Variable	
Ferric chloride	$FeCl_3$	162.5	
Ferric sulfate	$Fe_2(SO_4)_3$	400	

Popular Organic Coagulants:

Coagulant	Chemical formula
Epichlorohydrin dimethylamine (epi-DMA)	
Polydiallyl dimethyl ammonium chloride (poly-DADMAC)	

Source: http://hlth.bpums.ac.ir/UploadedFiles/CourseFiles/COAGULATION_AND_FLOCCULATION-5__a6eff65e.pdf

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So, these are some of the like competitive advantages disadvantages. If we see the common organic and inorganic coagulants so like we have as you say that aluminium sulphate which is also known as alum. These are hydrated alum this we may have may not have at all or we may have a 14H2O or H2O variety of forms are available then sodium aluminate aluminium chloride poly aluminium chloride which are PAC's then poly aluminium sulphate PAS. Then poly iron chloride ferric chloride ferrous sulphate. So, these are their molecular weights these are their chemical formula and some specific remark.

Like the PAC polynomial or it is used when the HD contamination is a concern then really it can be more helpful in that cases. The some of the popular organic coagulants are like DMA DA DMAC. So, these kind of structures or polymers may be used as a organic pollutant organic coagulants.

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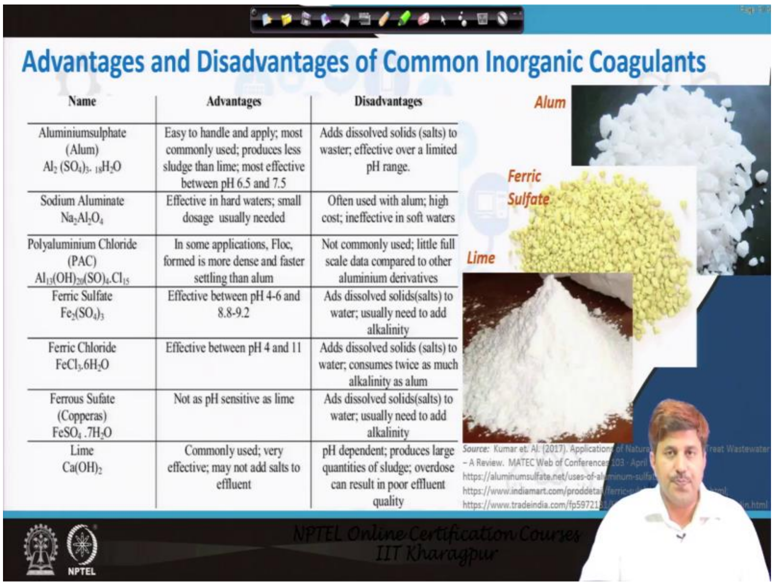

Advantages and Disadvantages of Common Inorganic Coagulants

Name	Advantages	Disadvantages
Aluminiumsulphate (Alum) $Al_2 (SO_4)_3 . {}_{18}H_2O$	Easy to handle and apply; most commonly used; produces less sludge than lime; most effective between pH 6.5 and 7.5	Adds dissolved solids (salts) to waster; effective over a limited pH range.
Sodium Aluminate $Na_2Al_2O_4$	Effective in hard waters; small dosage usually needed	Often used with alum; high cost; ineffective in soft waters
Polyaluminium Chloride (PAC) $Al_{13}(OH)_{20}(SO)_4.Cl_{15}$	In some applications, Floc, formed is more dense and faster settling than alum	Not commonly used; little full scale data compared to other aluminium derivatives
Ferric Sulfate $Fe_2(SO_4)_3$	Effective between pH 4-6 and 8.8-9.2	Ads dissolved solids(salts) to water; usually need to add alkalinity
Ferric Chloride $FeCl_3.6H_2O$	Effective between pH 4 and 11	Adds dissolved solids (salts) to water; consumes twice as much alkalinity as alum
Ferrous Sufate (Copperas) $FeSO_4 .7H_2O$	Not as pH sensitive as lime	Ads dissolved solids(salts) to water; usually need to add alkalinity
Lime $Ca(OH)_2$	Commonly used; very effective; may not add salts to effluent	pH dependent; produces large quantities of sludge; overdose can result in poor effluent quality

Source: Kumar et. Al. (2017). Applications of Natura Treat Wastewater – A Review. MATEC Web of Conferences 103 · April
https://aluminumsulfate.net/uses-of-al
https://www.indiamart.com/proddetai
https://www.tradeindia.com/fp59721

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If we see the like inorganic coagulant which are more popularly more commonly used in water treatment so their comparative advantages and disadvantages like we discussed in fact these the alum which is easy to handle and apply most commonly used it produces less sludge than lime. And most effective in a range pH 6.5 to 7.5 whereas ferric chloride is very effective in pH between 4 to 11.

Lime is generally used for pH control but can also be used as a coagulant at time for pH control it is very commonly used and it is very effective in that sense the reaction is also pH dependent it produced very large quantity of sludge. So, these are like example of lime these this is the ferric sulphate granules this is the alum. And these are generally all of these are in various forms so like we may get in the crystal forms or granule forms we may get in the powder form we may get in the liquid forms.

And each form has its own advantages and disadvantages liquid is easier to apply because it is in a liquid and with the known concentration. So, when we are going to add in a water we can compute how much volume is to be added and precisely we can add solids are that way like needs more manual contact in loading uploading then mixing producing adding into the water. So, that would require more manual contact which is which can be avoided with the liquids.

Some other like sodium aluminate and PAC these kind of things may have their own some advantages and disadvantages. PAC is used in some application floc that are formed in more dense and faster the amount of PAC required is also lower when we compare it with the other coagulant available like other common element iron coagulant available.

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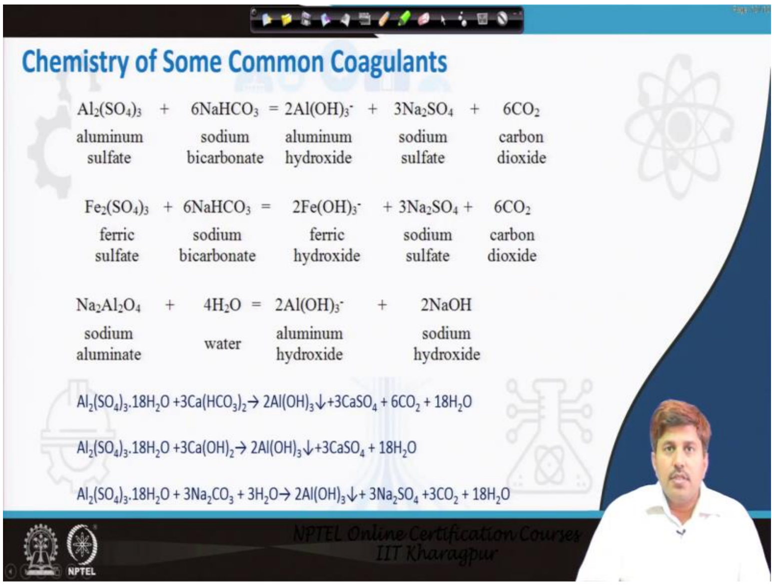

Chemistry of Some Common Coagulants

$$\underset{\text{aluminum sulfate}}{Al_2(SO_4)_3} + \underset{\text{sodium bicarbonate}}{6NaHCO_3} = \underset{\text{aluminum hydroxide}}{2Al(OH)_3^-} + \underset{\text{sodium sulfate}}{3Na_2SO_4} + \underset{\text{carbon dioxide}}{6CO_2}$$

$$\underset{\text{ferric sulfate}}{Fe_2(SO_4)_3} + \underset{\text{sodium bicarbonate}}{6NaHCO_3} = \underset{\text{ferric hydroxide}}{2Fe(OH)_3^-} + \underset{\text{sodium sulfate}}{3Na_2SO_4} + \underset{\text{carbon dioxide}}{6CO_2}$$

$$\underset{\text{sodium aluminate}}{Na_2Al_2O_4} + \underset{\text{water}}{4H_2O} = \underset{\text{aluminum hydroxide}}{2Al(OH)_3^-} + \underset{\text{sodium hydroxide}}{2NaOH}$$

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + 6CO_2 + 18H_2O$$

$$Al_2(SO_4)_3.18H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + 18H_2O$$

$$Al_2(SO_4)_3.18H_2O + 3Na_2CO_3 + 3H_2O \rightarrow 2Al(OH)_3\downarrow + 3Na_2SO_4 + 3CO_2 + 18H_2O$$

This is the common chemistry of some of the coagulants. So, what happens when we add say certain coagulant like for say we are adding alum aluminium sulphate, so it will react with the alternately present in the water. So, we have say sodium bicarbonate present in the water it will react with that and form the aluminium hydroxide which will actually form precipitate and settle and then in addition it will form the sodium sulphate and carbon dioxide.

And if it is a hydrated say alum like this is Al2SO4 3 is whole size 18 H2O, so hydrated alum this also they can react with the various forms of eternity like calcium bicarbonate with lime with sodium bicarbonate as in here and it eventually will produce the aluminium hydroxide which will form precipitate and that way practically we get these like these precipitate form and they further help in the flocculation process.

They provide precursor and then particularly with the sweep floc formation they are very helpful. These kinds of precipitates form. We may see like similar reactions from ferric sulphate or sodium aluminate kind of this thing they all like ferric sulphate will also act with the alternately will form ferric hydroxide. So, iron salts will form ferric hydroxide aluminium salts will typically form aluminium hydroxide.

And these are all precipitates so they will get removed from the system easily. Now the one of the interesting thing to note here in this that in order for these substances these coagulants that we are adding in water in order for them to form precipitate because of course the charge neutralization or the double-layer suppression part they will do. They are going to increase the electrolyte concentration in the solution and particularly iron and LMR so far used because of their higher electro positive potential.

So, they are going to neutralize the electrolyte they are going to kind of increase the electrolyte levels and as a result they will do that charge neutralization part double layer suppression part which helps in bridging the existing collide but they themselves must be removed from the system so that is done through formation of hydra's hydroxides. So, either alum or either aluminium or iron hydroxides are formed. For them to react in water for forming their hydroxide they need alkalinity in the water.

So there must be alternative present in the water a requirement of alkalinity would be there when basically we are going to going to go for a coagulation flocculation process and in some cases with low alkalinity water and when enough alkalinity is not present and we are adding a coagulant we may need additional alkalinity and generally in that cases lime used as a source of alkalinity. So, we may additionally add lime or alkalinity in water at times so that the coagulants that we are adding should be should later on be neutralized and should be basically forming precipitate.

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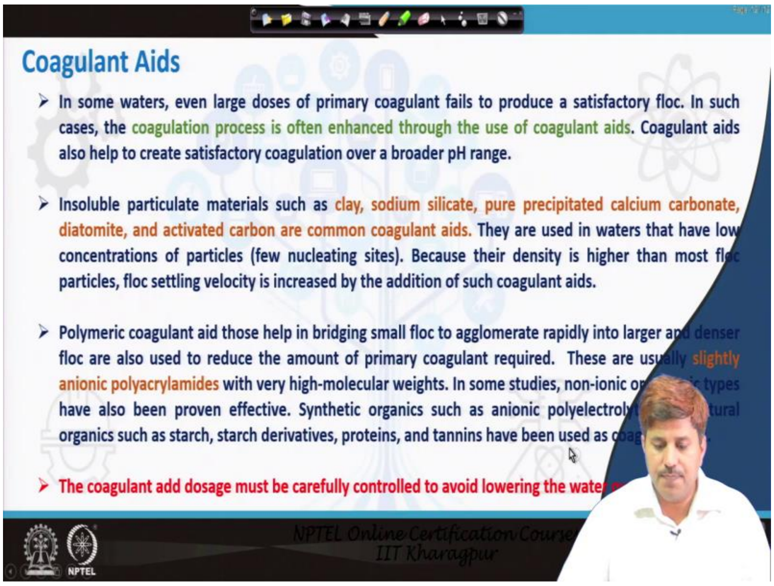

Coagulant Aids

- In some waters, even large doses of primary coagulant fails to produce a satisfactory floc. In such cases, the coagulation process is often enhanced through the use of coagulant aids. Coagulant aids also help to create satisfactory coagulation over a broader pH range.
- Insoluble particulate materials such as clay, sodium silicate, pure precipitated calcium carbonate, diatomite, and activated carbon are common coagulant aids. They are used in waters that have low concentrations of particles (few nucleating sites). Because their density is higher than most floc particles, floc settling velocity is increased by the addition of such coagulant aids.
- Polymeric coagulant aid those help in bridging small floc to agglomerate rapidly into larger and denser floc are also used to reduce the amount of primary coagulant required. These are usually slightly anionic polyacrylamides with very high-molecular weights. In some studies, non-ionic o types have also been proven effective. Synthetic organics such as anionic polyelectrolyt tural organics such as starch, starch derivatives, proteins, and tannins have been used as coag
- The coagulant add dosage must be carefully controlled to avoid lowering the water

So, the label of alkalinity control of the level of alkalinity is also very essential in the coagulation flocculation process. Now that is about when we add a coagulant simply but many times what happens in basically in quite a few waters even if we add huge amount of coagulant it fails to produce the sufficient or satisfactory level of removal of the colloids. So, the flux will not be forming that great.

Now what to do in such cases in such cases we may go for adding an additional compound which is normally refer as coagulant add. So, what happens we add coagulant add we use the coagulant add and this eventually helps in creating the satisfactory level of coagulation over a much broader pH range. Now the coagulant add generally are of 2 types we may go for the insoluble particulate matters such as clay, sodium silicate or sometimes precipated calcium carbonate.

Then activated carbon might also be used so these are some of the common coagulant adds which may be used in the which may be used in the water in case of when we are planning a coagulation flocculation process. Now they are used in the water which particularly have low concentration of particles because what we are adding clay, clay is also a form of kind of colloid which will add on the colloid concentration in the water.

Sodium silicate is also another form of clay itself, so these are the parts some of the particles which will eventually add the turbidity in the water or we are adding the alkalinity as just we were discussing that we may need alkalinity or we are adding activated carbon which provides large surface area for precipitation of the particles. So, what essentially we are doing we are providing the; we are increase either increasing the turbidity or increasing the alkalinity or kind of providing the additional surface area.

And all these helps in basically increasing the eventually the concentration of particle because the coagulation may not be effective when there are very few nucleating sites. When there are very few colloids when there are very few particles which on which basically the further agglomeration can take place. So, we need chances of interaction and for that we need significant amount of turbidity present in the raw water.

So if that is not there then this kind of coagulant can be very effective and these are all heavier particles so their density is quite high and when basically the floc's form, so the settling velocity of floc's will be increased because of the higher density of these particles higher specific gravity of these particles and even the removal of the floc's formed or agglomerates form will also be enhanced when we add these kind of coagulant adds.

The other type of coagulant adds which may be used sometime this is in fact known as the flocculent instead of just coagulant add. So, the other type of coagulant add can be like an anionic poly acrylamides is kind of substances. So, these are the polymers in fact we add the polymeric coagulant and this which as I told you that this many people refer them as a flocculent as well. So, we can add these flocculants and this helps in bridging small floc's to agglomerate larger and denser floc's.

So, the small floc's that are being formed when we add these kind of bridging elements. So, those smaller floc's are bridged here we are not adding turbidity but we are actually adding flocculent as a form of the coagulant add. So, these are generally the polymeric substances. And if let us say we are using LMR iron kind of salt. So, they are basically because of their nature because of their electro positivity so we generally go for the anionic polyacrylamide which has higher molecular weight of course so that it can settle quickly.

In some time we go for non ionic or even the cationic type of the polymers they also have to been kind of proven helpful or proven quite effective in some studies. We can go for the synthetic organics such as the anionic polyelectrolyte or we can go for the natural organics such as starch or it starch derivatives protein tannin that kind of that kind of substances also may be used as the coagulant add.

Now we must ensure that that those of the coagulant add that we are providing they are carefully controlled and we do not kind of want to have them a negative impact on the water quality. So, we are we tend to add these coagulant adds so that the coagulation process can be more effective and we want that only we do not want that they so some negative impact on the water quality.

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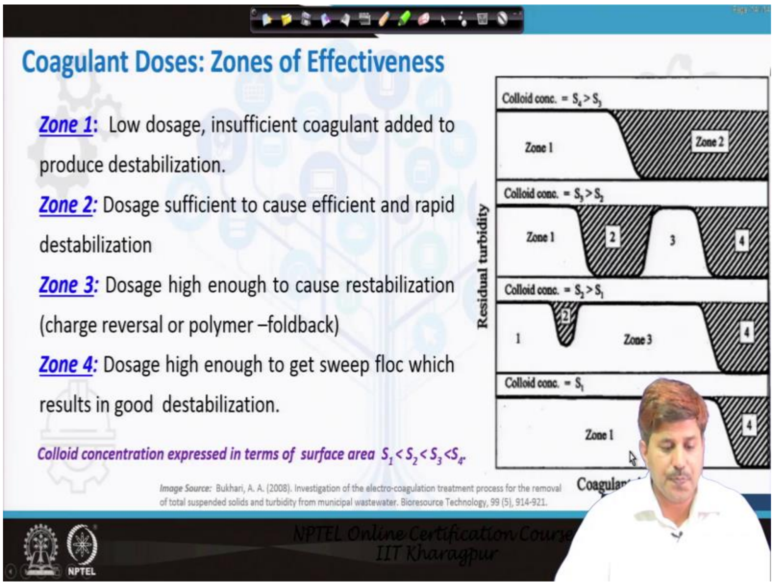

Coagulant Doses: Zones of Effectiveness

Zone 1: Low dosage, insufficient coagulant added to produce destabilization.

Zone 2: Dosage sufficient to cause efficient and rapid destabilization

Zone 3: Dosage high enough to cause restabilization (charge reversal or polymer –foldback)

Zone 4: Dosage high enough to get sweep floc which results in good destabilization.

Colloid concentration expressed in terms of surface area $S_1 < S_2 < S_3 < S_4$.

Image Source: Bukhari, A. A. (2008). Investigation of the electro-coagulation treatment process for the removal of total suspended solids and turbidity from municipal wastewater. Bioresource Technology, 99 (5), 914-921.

So, what typically happens under that like there are 4 different zones of effectiveness if we look at a coagulation flocculation process. So, let us say we are having a system which is having different ranges of the colloid concentrations. So, we have a chloride concentration ranging from S1 which is very low to S4 which is say substantially high colloid concentration and S2 and S3 are intermediate collide concentration.

Colloid concentrations are generally expressed in terms of surface area because we get the measurement of the colloid is in the typically in the form of turbidity. So, how much light they are able to scatter that will depend on how much surface area they are providing in the water for scattering of the light. So, we do the measurement instead of just like gravimetric or in terms of mass what is the total mass of the collide it is far easier to measure in terms of turbidity or in terms of the surface area of the colloids are present in the unit volume of water.

So, let us say there are different collide concentrations and we may have we may see actually 4 different zones when we add these coagulants in the water the different zones indicate different type of activities like in zone one but whichever case you take in zone 1 when we add very low doses when we are adding low doses of the coagulant, so the coagulant is insufficient to produce any sort of destabilization. So, in that case we will not see any sort of flocculation or any sort of removal there as we are in zone 1 and zone 1 as we see initially whenever we are having this is the coagulant doses.

So whenever we are having the low carbon doses we do not see any removal. Removal or coagulation is shown here with the hatch lines. So, we do not see any removal in this case now in the different cases we can see that zone 1 extends to the different labels. Like in case of if you see in case of when we have very low colloid concentration this is all through zone 1 when we have increased colloid concentration we have mostly like we have in the beginning we have zone 1 and then there is some formation of zone 2.

And here there is again formation of zone 2 but after some time and with the higher colloid concentration this is even further shifted. The zone 2 is the doses are sufficient to cause efficient and rapid destabilization. So, the zone 2 that we see here is when the through charge neutralization or through double layer separation the colloids present in the water has been destabilized. So, when they destabilize and any floc formation is taking place that is happening in zone 2.

This is purely due to destabilization means as we add the coagulant they are supposed to destabilize. Now if you see here when the chloride concentration is very low we do not see any zone 2 here that means the destabilization is not practically happening when with very low chloride concentration. Destabilization even if say destabilization might be happening there is no removal. So, there is no flocculation there is no floc formation.

Because even if say the charge neutralization has happened but because the concentration of the colloids are very low if you have say a setup like here and just five particles. So, opportunity of these particles to meet and interact and form floc’s is very small because their density their kind of concentration or their amount is very low in the system. Now in zone in like when we add further when we add further coagulant then we move to the zone 3 which is when the doses are high enough to cause destabilization.

So what happens that there are negatively charged particle we are adding normally the cations so they first like they first destabilize those but there is a possibility if we add too much there is a possibility that the cationic charged particles are increased in the system and as a result what we may see that there is again the particles becomes restabilized now not because of the negative potential but because of repulsion due to the positive potential they are carrying.

So then there is a possibility that we may have this we may see a zone 3 coming in where again it does not allow particle to bridge in. So, there is no removal even in the zone 3. And then the Zone 4 is when we have very high doses which gets this free floc and that results in a good destabilization. So, when we add further coagulant what we see that there is a like large mass as we discussed in the previous lecture also there will be a large mass of the sludge will be produced because of the coagulant itself like if you are adding LMR iron salts.

So, the ferric hydroxide or aluminium hydroxides they will be in a sufficient mass and because of the sweep floc action they will be actually removing the turbidity or coagulants present in. So, that sweep floc has nothing to do with the stabilization not much to do with the stabilization or destabilization part it is because that has created a substantial mass which is going to settle and in the process it will remove the turbidity or the collides present in which are basically going to come in the path of that settling floc, settling large mass of the floc or settling large mass of the metal hydroxides what we have added.

And then through entrapment or enmeshment these also get in matched in the floc and get removed from the system. So, that is 4th type this will happen only when we have very high coagulant doses and as you can see that the 4th type like depending again depending on what level of the colloid concentration we have if we are working at very low polite concentration as just we are discussing here. So, the possibility of removal through the just destabilization is not possible it is generally removed only through these sweep floc formation when we have a little more collide concentration.

Some destabilization will occur but again it is not good enough to kind of see the floc formation and as a result again the major level is possible to see floc formation only. When we are having significantly substantial concentration of the collide then we will see that it is first forming zone 1 then it is actually getting good removal due to the destabilization itself. However if we add further it will so the restabilization due to the charge reversal and then if we further add it will go to the zone 4 which is actually the sweep floc formation.

If we are beginning with very high colloid concentration the turbidity is very high then we straight away like when we add the sufficient doses we will see we go into the zone 2o and the colloid concentration is so high that all whatever we are adding goes on to the neutralization part and we in fact do not need to go to the sweep floc formation generally that is not seen and even the zone 2 itself.

Because of very high mass of the collides we get large precipitates formed here itself and we can get the removal through the destabilization itself we do not need to go to the sweep floc formation level.

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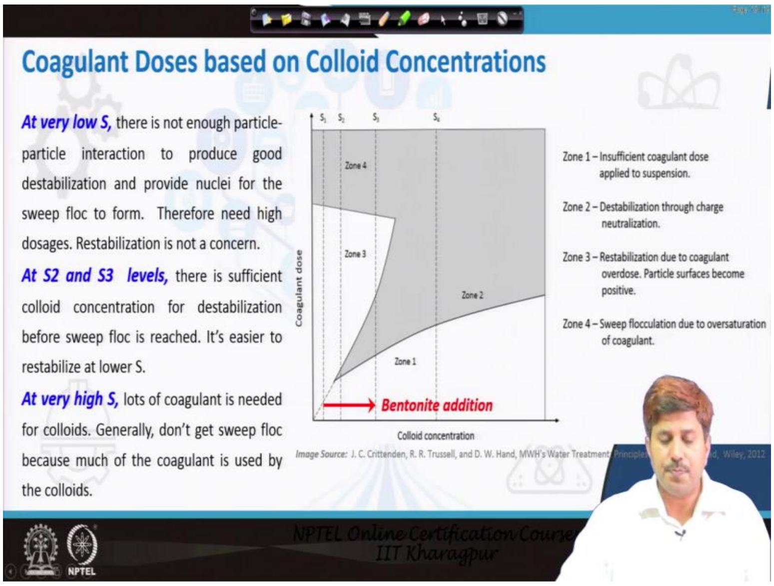

Coagulant Doses based on Colloid Concentrations

At very low S, there is not enough particle-particle interaction to produce good destabilization and provide nuclei for the sweep floc to form. Therefore need high dosages. Restabilization is not a concern.

At S2 and S3 levels, there is sufficient colloid concentration for destabilization before sweep floc is reached. It's easier to restabilize at lower S.

At very high S, lots of coagulant is needed for colloids. Generally, don't get sweep floc because much of the coagulant is used by the colloids.

Zone 1 – Insufficient coagulant dose applied to suspension.

Zone 2 – Destabilization through charge neutralization.

Zone 3 – Restabilization due to coagulant overdose. Particle surfaces become positive.

Zone 4 – Sweep flocculation due to oversaturation of coagulant.

Image Source: J. C. Crittenden, R. R. Trussell, and D. W. Hand, MWH's Water Treatment: Principles d, Wiley, 2012

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So, what typically happens like this is what will happen if we add basically collide concentration and the coagulant doses. So, if we are at very low collide concentrations what we see is the removal is through only zone 4 free floc formation if we are into somewhere into kind of zone 2 then or say S2 then what we see is we may see little of the destabilization process through charge neutralization.

But again it it is not probably sufficient enough so the major removal is again happens in the zone 4 through sweep floc formation with higher chloride concentration in S3 we can actually get removal substantial remover here itself and then we may not need to go there and in when concentration is further higher we get this thing removed in the zone 2 sufficient level of removal in the zone 2. At very high we generally do not get sweet floc because much of the coagulant is used by the colloids.

Whatever coagulant we are adding mostly is getting used by the colloids at level S2 and S3 there is sufficient collide concentration for destabilization before we go for sweep floc formation. But if we are at lower S level it is easier it is rather much easier to restabilized because this is the zone of restabilization over here.

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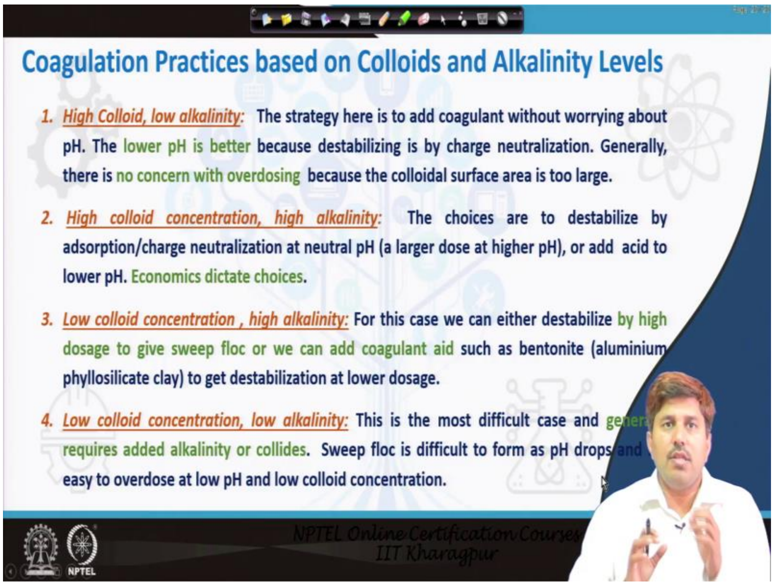

Coagulation Practices based on Colloids and Alkalinity Levels

1. *High Colloid, low alkalinity:* The strategy here is to add coagulant without worrying about pH. The lower pH is better because destabilizing is by charge neutralization. Generally, there is no concern with overdosing because the colloidal surface area is too large.
2. *High colloid concentration, high alkalinity:* The choices are to destabilize by adsorption/charge neutralization at neutral pH (a larger dose at higher pH), or add acid to lower pH. Economics dictate choices.
3. *Low colloid concentration , high alkalinity:* For this case we can either destabilize by high dosage to give sweep floc or we can add coagulant aid such as bentonite (aluminium phyllosilicate clay) to get destabilization at lower dosage.
4. *Low colloid concentration, low alkalinity:* This is the most difficult case and genera requires added alkalinity or collides. Sweep floc is difficult to form as pH drops and easy to overdose at low pH and low colloid concentration.

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Now so based on all this we can guide on what doses must be selected or what kind of floc coagulation, coagulation flocculation system must be selected. So, if we are at high colloids and low alkalinity levels then we do not need to worry much about the pH though lower pH is better but it should not be very low. So, that it causes the it increases the solubility. So, the destabilization is generally happened by the charge neutralization because the colloid concentration is very high.

Generally there is no concern of overdosing as just we see it does not usually go to the sweep floc formation level because of the colloidal surface area present is substantially large. So, this is an easy case to deal with when we are having a high colloid concentration but and high alkalinity, so then the choices are to be destabilized by the adsorption or charge neutralization at new kind of neutral pH or we add acid to lower the pH.

So because if there is too much of alternative it is ultimately is helpful in the sweep floc formation rather because it will produce the hydroxide if you want to go for the charge neutralization we like we need a lower alkalinity in the system because we do not want the coagulants that we are adding to react with the alternative. We want them to be present in the system in its ionic stage so that they can help in the charge neutralization process or double layer separation process.

So, for that purpose so if you to get them all in zone 2 we need low alkalinity if you want to get more in zone 4 we generally need a substantial amount of alkalinity present in the system. Now here so either we basically destabilize by the charge neutralisation at neutral pH or we add ultimately to lower the pH whatever we are choosing like whichever is the most cost-effective can be chosen, the third case which is low alkyl concentration and high alkalinity.

So for this case again either we destabilize by high doses to give this free floc or we can add a coagulant add such as say bentonite. Now the coagulant adds helps in kind of increasing the coagulant concentrations. So, we may go for 2 things in such cases okay one is that like if we just look at the previous graph over here. So, if our system is say somewhere here what those of coagulant we need is in this range. So, this is basically minimum dose required we need very high dose or if say we are somewhere in this range the dosage needs are very high.

If we add little of the clay bentonite is a form of clay or any kind of stable thing which will yield the turbidity which will increase the turbidity of the system which will increase the colloid concentration in the system. So, if we move from S1 if we say move from S1 to from S1 to S3 then if we move to S3 we can achieve the coagulation at a much lower dose. So, instead of like here what we need is addition of this much of coagulant dose for say.

So we have 2 tries either we add this much of coagulant dose, so say this is the dose of coagulant dc or we instead add only this much of coagulant dose and add this much of the clay. So, this is those of the bentonite clay say db and then this is the say the dose of coagulant. What we are using here, so we need to see which one is the more cost-effective either this like we add little of clay and then gets the coagulation at lower doses or we do not add clay and add high doses for sweep floc formation.

So, we need to basically make a decision based on the cost and these two options we will have like either we give high doses to give the sweep floc or we can add coagulant adds such as say bentonite to get the destabilization at lower doses. And then the last case which is low alkalite concentration and low alkalinity so this is generally the most effective case sorry this is the most difficult case in fact.

And generally requires to alkalinity or collide again like because we are having low collide concentrations so sweep floc formation is difficult and we are having like low alkalinity sweep floc formation is difficult and local or low chloride concentration so the neutralization is difficult. So, we are actually lacking on both the parts. So, either again we add enough alternative so that we go to the sweet flock formation level or we add the clay or those kind of things so that we go for thee we go for the kind of sweet floc formation.

So, or if when we are adding clay we can get the destabilization at lower doses, so either we add enough clay so that the collide concentration increase and we can get it done or we add the alkalinity and then add very high doses of or substantially high doses of coagulants so that sweep floc is formed. So, in any case we have to add something otherwise this is a very difficult case to deal with.

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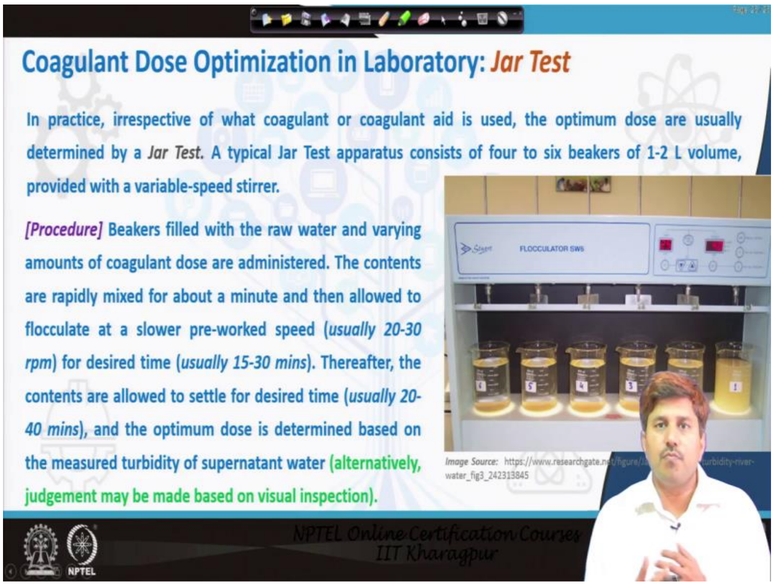

Coagulant Dose Optimization in Laboratory: *Jar Test*

In practice, irrespective of what coagulant or coagulant aid is used, the optimum dose are usually determined by a *Jar Test*. A typical Jar Test apparatus consists of four to six beakers of 1-2 L volume, provided with a variable-speed stirrer.

[Procedure] Beakers filled with the raw water and varying amounts of coagulant dose are administered. The contents are rapidly mixed for about a minute and then allowed to flocculate at a slower pre-worked speed (*usually 20-30 rpm*) for desired time (*usually 15-30 mins*). Thereafter, the contents are allowed to settle for desired time (*usually 20-40 mins*), and the optimum dose is determined based on the measured turbidity of supernatant water (alternatively, judgement may be made based on visual inspection).

Image Source: https://www.researchgate.net/figure/ turbidity-river-water_fig3_242313845

So next is basically this is what we have been discussing is about the how we work out the different doses. But again these are all theoretical concepts that what those we should keep for practical purpose the doses of the coagulant are estimated or rather optimized through a laboratory test which is known as the jar test. So, jar test is a simple laboratory procedure we have an apparatus like this which is known as jar test apparatus.

And this will typically have 6 may have some time 4, 4 to 6 beakers are generally there and each will have a basically stirrer variable speed stirrer so this like we can achieve stirring at variable speed. Now what is done typically we fill all these beakers with raw water and keep one as a control so say this is our control we are not going to add anything to this and then in all other beakers we add variable doses of coagulant.

So let us say here we added 2 milligram per litre here we added 4 milligram per litre, similarly 8 milligram per litre, 12 milligram per litre, 20 milligram per litre that way we can add the different doses. And then after we added the coagulant here we rapidly mix it may be around 100 rpm or 80 rpm for a minute or generally maybe a less than minute. But about a minute we can mix it and then that is when the mixing is done.

So we assume that we added the coagulant and we rapidly mix it so our coagulant is well mixed in the system and then what we do we reduce the speed of these stirrers and we do it at a slower speed usually 20 to 30 rpm range. And for flocculation purpose and that we may go for 15 to 30 minutes of course this is not a strict range some people do it even at a lesser or higher times. So, during this period what we try to achieve is that the contact between the particles.

So that the flocculation takes place and after the time what we have decided we stop the stirrer. So, the stirrers are completely stopped and we allow the content to settle for a desired time which is usually 20 to 40 minutes. And then the optimum dose we can determine by the major turbidity of the supernatant water. So, once the settling is happen we can measure the turbidity of this if we are not measuring turbidity traditionally like when turbidity measurements were not that easy people use to just make a judgement based on the visual inspection.

So like visually also I can see if I see say this is this is my control 0 dose this is say 2milligram this is say 4 milligram 6 milligram 8 milligram 10 milligram. So, now I can see that this is dirty this is also not good this is also not that good and maybe these 3 looks same. So that means adding more is not going to help. So, I can choose maybe a 6 milligram per litre as a dose. So, some visual interpretation also used to work earlier but now where they we have better facility of measuring the turbidity.

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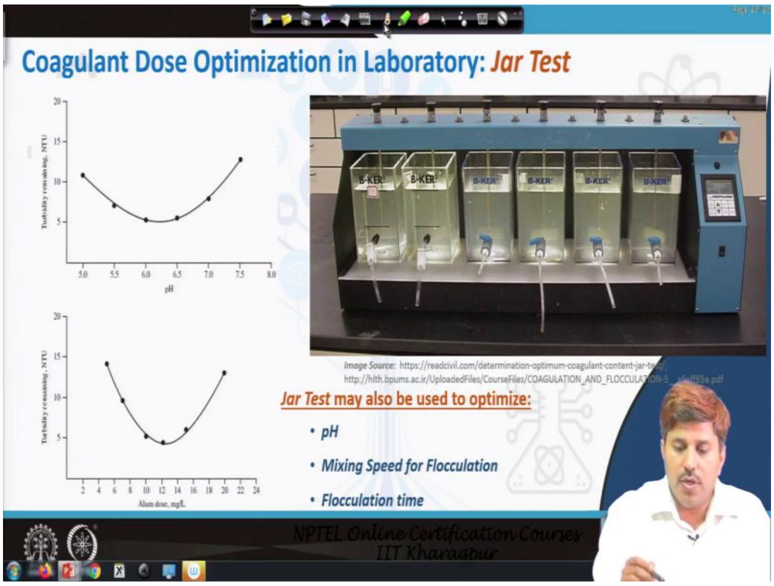

Coagulant Dose Optimization in Laboratory: *Jar Test*

Image Source: https://readcivil.com/determination-optimum-coagulant-content-jar-test/; http://hlth.bpums.ac.ir/UploadedFiles/CourseFiles/COAGULATION_AND_FLOCCULATION-5__a6eff65e.pdf

***Jar Test* may also be used to optimize:**

- *pH*
- *Mixing Speed for Flocculation*
- *Flocculation time*

So what can be done is based on the doses and we may measure the turbidity and plot these, so what we will see that at a particular dose generally what we will see that at a particular dose we are actually getting the minimum turbidity. So, we select this as an optimum dose. Many times we may get a curve like this or many times we may get a curve like this that means it is actually not increasing but it is again constant so what we can choose like from where there is no further decrease that point we can choose.

Similarly the same type of jar test may be used for say optimizing other parameters like pH mixing speed therefore flocculation flocculent time. So, what happens we keep all the parameters constant like in these jars what will sue what we will do we will make one control and in the other very one parameter so for say if you are varying doses then we will ensure that all are at same pH all are at mixed at the same speed all are at allowed to be basically mixed for the same time.

Now similar exercise can be done let us say instead of like what we are here we had we decided that we are going to add say 6 milligram per litre, so we add 6 milligram per litre doses in all and then very pH. So, we are doing one at say 5 pH one at 5.5, 6.5, 7 7.5 and we are doing at variable pH. And then again we plot that which pH is gives in giving you the least turbidity. So, we can select that pH so we can optimize.

Similarly pH we can optimize the mixing speed for flocculation so like some not all but some setups comes with aware we can vary the speed of the different stirrers so let us say one we are mixing at a 15 rpm then 20 rpm 25 rpm. So, it is like or maybe 10, 15 say 10 rpm 15 rpm

25 rpm 30 rpm that way and then again plot with the turbidity which was which one is giving the least.

We can have the different times we can stop let us say we are mixing all at same rpm but then one we stopped after 10 minutes another we stop after 15 minutes this we stop after 20 minutes this we stopped after 25 minutes so that way we can see we can do it at a variable flocculation time and see which one is giving us the best removal. So, like keeping all other parameter constant this kind of setup provides us the opportunity to vary one parameter at a time and optimize that.

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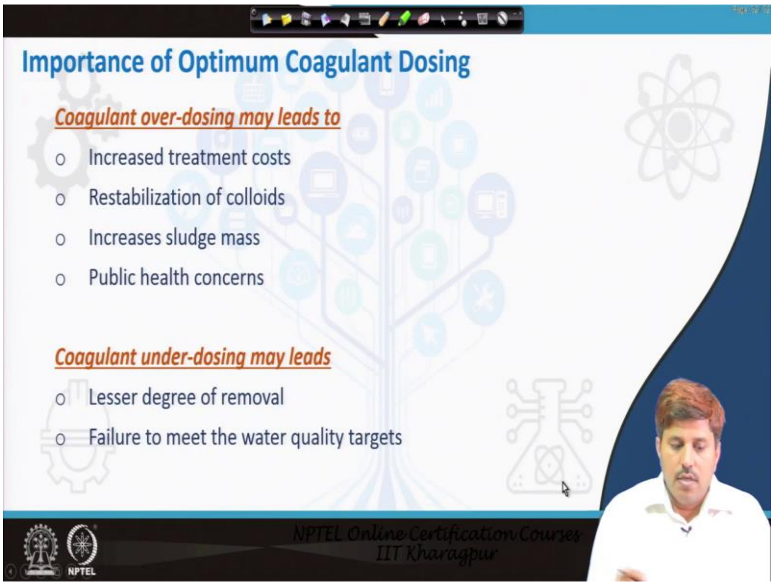

Importance of Optimum Coagulant Dosing

Coagulant over-dosing may leads to

- Increased treatment costs
- Restabilization of colloids
- Increases sludge mass
- Public health concerns

Coagulant under-dosing may leads

- Lesser degree of removal
- Failure to meet the water quality targets

So, that is about the using Jar test you know and getting the optimum doses. The optimum dose estimation is very important because if we are adding more so like if you are going for the overdosing of the coagulant then it increases the treatment cost first because we are adding more compound more chemical it restabilizing the colloids that possibility is again there. It will increase the sludge mass because if you are adding more coagulant it is eventually going to get convert to the sludge.

So the amount of solid waste generated or amount of sludge generated is going to go high and it may have some public health concerns also if it is not adequately removed or recovered back from the system. If we are going for under dosing then the major problem is that we will get lesser degree of removal and as a result we will fail to meet the water quality target. So, we do not want to go this because this is not fulfilling our purpose at the same time we do not want to go overdosing also because that is also creating lot of problems.

So the best solution is that we optimize and choose an optimum dose. So, we choose an optimum dose depending on the system and little play around is possible as we discuss that we may need to add clay or alkalinity at times. So, that we can get a good removal through these processes so we will conclude this lecture here. And in the next class we will be talking about the design and kind of operation and of these coagulation flocculation systems.

How they are operated actually in the field, what are their process controls and how these can be designed. So, we will discuss that in the next class thank you for joining and see you in the next class.