Course Name: Industrial Wastewater Treatment

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Week – 06

Lecture 26: Treatment and disposal of sludge

Welcome you all. Today I am going to deliver my lecture 1 of module 06, which is basically on the treatment and disposal of sludge. So, under this we will be covering basic introduction on the sludge, their sources and the characteristics of the sludge, then how to estimate the sludge volume, quantity of sludge, then also determination of sludge age and then we will be also having some numerical which will describe the basic concepts on characterization and estimation of sludge, determination of sludge volume index, determination of sludge volume. So, all these concepts we are going to learn in the coming slide.

So, before this let us talk about the sludge, what are the sludge? Basically, the settled solids which are generated from various treatment process like physical, chemical and biological treatment process, they are called as sludge. Basically it contains around 1 to 4% of the solid and rest is water and if we see the characteristic it varies depending upon the sources of its generation like it may be organic, it may be inorganic sludge, it may be chemical sludge, it may be biological sludge, it may be digestive sludge depending upon the sources of its generation the characteristic varies and then finally the determination of quantity and quality of sludge is basically very important when we design its treatment and disposal facility.

So let us describe about the sources of the sludge. There are different types of sludge like which is generated from primary settling tank, which is generated from secondary settling tank after the chemical treatment and then there are also the secondary settling tanks which are designed after the biological treatment system to settle out the biomass. So depending upon its source if we see from primary settling tanks we will have a mixed type of sludge mostly inorganic in nature but it may also contain some organic fraction into that and the tank which is designed after the chemical treatment here the type of sludge that will be totally chemical sludge which is basically the precipitates generated during chemical precipitation process, coagulation, flocculation process and then we also deal with the secondary settling tank which is designed after the biological treatment unit and this contains mostly the biological or the organic nature of sludge.

And then here depending upon the origin of the sludge how they differ in terms of their characteristics. So, if we see the primary sludge this is basically generated from primary sedimentation tank and usually its color is gray and slimy, while in terms of odor if we see it has very offensive odor and can easily be digested. Whereas if we talk about the chemical sludge this is generated mostly from chemical precipitation process, coagulation, flocculation process and its color may vary from black to white it also has objectionable odor and it decomposes very slowly. While the secondary sludge which is generated from the secondary settling tank after the activated sludge process that is basically in the form of flocculent the color if we see it is brownish color and it doesn't have any offensive order and this type of sludge can be readily digested.

Then if we see the sludge which is generated from the secondary settling tank after the trickling filter this is again brownish in the color, mostly flocculent in nature and they contain more of worms or bacteria or biomass and this type of sludge becomes offensive very quickly and can undergo decomposition. And if we see there are also the sludge treatment system there are various types of digester, aerobic digesters and then there are anaerobic digesters and from these units also there are the sludge generated which is mostly stabilized sludge and we call it as a digested sludge and its color if we see this is from brown to black and it does not have any offensive odor and the most importantly this type of sludge can easily be dried can be dewatered. So this is all about the different types of characteristics of the sludge which is generated from different sources and these characteristics are very important in terms of designing the sludge treatment facilities.

Then let us talk about sludge characterization the very important parameter in the sludge characterization that is the moisture content or the water content basically this if we see that can be determined by using this formula $w(\%) = \frac{W_w}{W_{sl}} X100$, where W is the water content or moisture content in percentage and here if we see this is the ratio of $\frac{W_w}{W_{sl}} X100$ where W_w basically this is the weight of the water and this W_{sl} is basically the weight of the sludge. So, the ratio of the two multiplied by 100 it will give the percentage moisture content. And if we see the water in the sludge may exist mostly in following four form that is like the free water, free water means the water which is attached on the sludge solid and that can be separated by simple gravitational settling and this constitute to around 70-75% of its total volume. And then there is another type of water which is interstitial water which is trapped within the floc structure within the interconnected void, the cavities which are formed within the biomass and they travel along with the flocs or perhaps water entrapped within a cell, so this type of water basically that comes under interstitial water and it is about 20% of the total volume. And then we see Vicinal water which is held on the particle surface by virtue of its molecular structure. So this type of water it is it accounts mostly 2% percent of the total volume and then there is another type of water which we say that is water of hydration is basically the chemically bound water to the particle and which can be released only by thermochemical destruction of the sludge and it constitute around 2.5% of the total sludge volume.

Then let us discuss about the volume-weight relationship, so here if we see the total solid which are present in the sludge that is basically the $TS = FS + VS$, where this *TS* represent the total solids, *FS* represent the fixed solid, whereas *VS* represent the volatile or organic solids. And then another parameter which is used for characterization of sludge that is the specific gravity of the total solids which is represented by these two equations. So if this equation if we see that is the $\frac{W_{ts}}{S_{ts}\rho_w} = \frac{W_{fs}}{S_{fs}\rho_w} + \frac{W_{vs}}{S_{vs}\rho_w}$. So here if we see ρ_w is common both on right hand side and left-hand side in the denominator so it can be cancelled and the new equation we can use that is $\frac{W_{ts}}{S_{ts}} = \frac{W_{fs}}{S_{fs}} + \frac{W_{vs}}{S_{vs}}$. So, these relationship we can use for determination of sludge volume, sludge quantity.

And then another parameter which we say that is specific gravity of entire sludge so earlier we have seen specific gravity of the solids now we are talking about the specific gravity of the sludge entire sludge volume. So this is basically the $\frac{W_{sl}}{S_{sl}} = \frac{W_s}{S_s} + \frac{W_w}{S_w}$. So this relations are most commonly used and then the volume of the sludge if we see that can be computed using this formula $V_{sl} = \frac{W_s}{\rho_w \times S_{sl} \times P_s}$, where this V_{sl} represents the volume of the sludge which is equal to W_s, W_s basically this is the weight of the solids and this divided by ρ_w which is the density of the water and S_{sl} which is basically the specific gravity of the sludge and then this P_s represent that is the percentage of solids in the sludge. So using this equation we can find out the volume of the sludge.

Then there is one more parameter which defines basically the volume of the sludge per unit weight of the solid which is called as the sludge volume index and this is defined as the volume in millimeter occupied by 1 gram of activated sludge settled out in 1 liter of Imhoff cone for 30 minutes. So this is the standard procedure we adopt to determine the SVI and this is equal to $SVI = \frac{V \times 1000}{MLSS}$, where V is the volume of the sludge settled in the Imhoff cone and this MLSS is the mixed liquor suspended solids concentration in mg/L and this 1000 is the conversion factor to find out the SVI in terms of mL/g. So, this basically parameter is used to define the settleability or bulking of sludge and also to find out the recirculation ratio required for activated sludge process.

And then based on this SVI we can also classify the type of the sludge if we see mostly this SVI is inversely proportional to the settling velocity, so settling velocity is more in case of SVI is less. So, less SVI represent more settleable sludge and vice versa and here if we see depending upon its SVI value like if SVI is <50, so it is like a pin clog potential type of sludge which can easily be settled out which has good settling velocity and whereas if the sludge volume index is varies from 50-100, this has a moderate settleability and we can say good sludge. But if the value of SVI increases further goes to 100-150, so it is basically the filamentous growth and filamentous type of sludge, which does not easily get settled out and then if it is 150-200 then the bulking of the sludge takes place during high hydraulic loading rate and if this is 200-300, so this is bulking of sludge and in case >300 there will be severe bulking of sludge problem in the system.

And then another parameter which is called as the fuel value of the sludge. So biological such mostly contains high quantity of organics which have the potential to generate the heat energy when they are burnt. So the amount of heat energy which can be produced by burning of 1 kg of sludge that is basically called as the fuel value of sludge and this value varies from 10,000-20,000 kJ/kg of sludge.

And then there is another parameter the sludge is sludge age basically the amount of the time in days that the solids or the bacteria or the sludge remains there in the tank, so this is called as the sludge age and this is also termed as the mean cell residence time or solid retention time and this parameter is used to determine the recirculation ratio of the activated sludge in the aeration tank to maintain proper F by M ratio and this can be determined by this formula this is equal to the $Sludge\ age = \frac{suspended\ solids\ in\ the\ aeration\ basin}{Suspended\ solids\ entering\ or\ outgoing\ the\ aeration\ basin}$.

So then we will be looking upon few examples which will illustrate the application of these formulas in order to determine the sludge volume and the quantity of the sludge and the sludge age sludge volume indexes so all these parameters what we have learned previously so those will be used in these examples. So here if we see this example what it says determine the specific gravity and volume of 600 kg of secondary sludge if on the analysis it was found that 10% of the sludge contain 30% of the fixed solid having a specific gravity 2.5 and rest 65% of the volatile solids with a specific gravity equal to 1.0. So, in this example what we have to determine the specific gravity and the volume of the sludge so how we can determine the specific gravity of the sludge and volume of the sludge so that we will be illustrating in the next slides.

So here if we see it is given that 10% of the sludge has 10% solid and 90% water, it means the sludge has 10% total solids and rest 90% is water. So using this data we can find out the specific gravity of the total solids using this formula which is $\frac{W_{ts}}{S_{ts}} = \frac{W_{fs}}{S_{fs}} + \frac{W_{vs}}{S_{vs}}$, if we see this all is given and if we consider the W_{ts}= 1.0 kg in the sludge, so our W_{fs} = 35% of this total weight which is 1 kg so let's it is 0.35 kg and it has a specific gravity of 2.5. Similarly, the W_{vs} = 65%, so 65% of 1 kg that will become 0.65 kg and its specific gravity will be 1. And if we use this equation the above equation put these values. So from this if we see the $\frac{1.0}{S_{ts}} = \frac{0.35}{2.5} + \frac{0.65}{1.0}$ and from putting this value we can find out the specific gravity of the total solid which comes out to be 1.266.

So now using this specific gravity of the total solids we can further find out the specific gravity of the sludge using this formula $\frac{W_{sl}}{S_{sl}} = \frac{W_s}{S_s} + \frac{W_w}{S_w}$, so here if we see the weight of the sludge already we have assumed this is 1 kg and if we see it says 10% of the sludge means 10% will be the solids and rest will be the water will be 90%. So of 1 kg 10% that will be 0.1 kg and of 90% of 1 kg that will be 0.9 kg and their specific gravity is this. So now putting this value in this in the above equation we can find out the specific gravity of the sludge by that will be equal to 1.02.

So once we have determined the specific gravity of the sludge then we can find out the volume of the sludge using this formula $V_{sl} = \frac{W_s}{\rho_w \times S_{sl} \times P_s}$. So, in this volume of the sludge we have to determine. The weight of the sludge is given, ρ_w is known the specific gravity of the sludge also we have determined and then the percentage of the solid which is given as 10% already given. So, by 10% means this is 0.1 and ρ_w we know that is 1000 kg/m^3 and we have a total weight of 600 kg. So by putting this value $\frac{600 \times 0.1}{1000 \times 1.02 \times 0.1}$ and then this is the percentage of the solid 10% so by putting this value we will get the volume of the sludge. So now we have determined both the volume of the sludge as well as the specific gravity of the sludge. So this is how we can use these equations to determine the volume and specific gravity of the sludge.

So let us take this example again to see how this par formula we can use for determination of sludge volume before and after the digestion which is required for design of a digester. So let us do an exercise. So here if we see the problem this is the raw sludge and there is a digested sludge and here if we see the characteristic of raw sludge which is total solid percentage that is 4% in the raw sludge whereas it is 10% in the digested sludge volatile solid if we see that is 60% in the raw sludge whereas in the digested sludge this is around 70%. Similarly, the specific gravity if we see this is 1.02 in case of raw sludge, whereas in case of digested sludge this value is 1.04. And if we see around 500 kg of solids which are there in the raw sludge. So, for this we have to find out the volume of sludge before and after, it means the volume of the raw sludge and the sludge which is produced after the sludge digestion process and then also we have to find out how much percentage volume will be reduced after the digestion. So, this is a numerical problem for which we have to carry out number of estimations.

So, first of all let us find out the volume of raw sludge so here to find out the volume of raw sludge we have to use again this equation which is the weight volume relationship equation for converting the weight of the sludge into volume. So this is $V_{sl(r)} = \frac{W_s}{\rho_w \times S_{sl} \times P_s}$. So here if we put the value that is given weight of the total solid which is 500 kg already given and if we put that density of water which is 1000 kg/m^3 and the specific gravity of the raw sludge which is given equal to 1.02 and similarly if we see that is percentage of the solid which is given as 4%, so this is 0.04. By substituting this value, we can convert this total weight of the solids in terms of volume so this is the first answer what we require that is the volume of the sludge before digestion which is equal to 12.25 m^3. Now again then we have to calculate the volume of the digested sludge after the sludge digestion process so we have to calculate the total weight of the digested solids. So, first of all let us calculate the fixed solids so basically the fixed solids in the raw sludge that will be equal to the fixed solids in the digested sludge so this and $TS = FS + VS$, so if we see fixed solids in the raw sludge because it contains 60% of the volatile solids, so $100 - 60$ this will be 40% of the total solids that will be fixed solids. So here 40% of the total weight of the solid if we calculate, so this will come around 200 kg that will be the weight of the fixed solids present in the digested sludge.

Now let us find out how much volatile solids that will remain there in the after the digestion. So, first of all we have to find out how much initial volatile solids they are present how much they are destroyed so here in the problem if we see that is given which is 70% of the volatile solids they are destroyed in the digestion process, so here if we see that is remaining 30% that will be there in the sludge after the digestion so we have to find out 30% of the total volatile solids. So volatile solids again it is 60% of the total solids, so 60% of the total solids will give here $VS = 0.30 \times (0.60 \times 500)$,we can get and this gives us a value of 90 kg. So this 90 kg of volatile solids that will remain there in the digested sludge. So total solids after the digestion that will be equal to fixed solids plus undestroyed volatile solids. So here this if we take $200\,kg + 90\,kg$ which is basically the volume of the volatile solids. So the total together we get 290 kg of the total solids, which will be generated during this digestion process and now this is in terms of weight now if we want to see its volume so again we have to use this weight and volumetrical relationship which is equal to the $V_{sl(d)} = \frac{290\ (kg)}{1000\ (kg/m^3) \times 1.04 \times 0.10}$, after putting this value we get the total volume of the sludge that after digestion that is reduced which is equal to 2.8 m^3.

So now if we see how much volume is reduced, $\%\, reduction\ in\ sludge\ volume = \frac{(volume\ of\ raw\ sludge) - (volume\ of\ digested\ sludge)}{(volume\ of\ raw\ sludge)} \times 100$, if we use this relation so we get this how much percentage of the sludge volume is reduced. So if we put the value like volume of raw sludge which is 12.25 and this 2.8 is the volume of the digested sludge divided by volume of raw sludge into 100 so this comes around 76.5%. So this reveals that the digestion process significantly reduces the sludge volume and this is around 76.5%.

In the next examples if we see we will try to learn how we can find out the sludge volume index and the sludge. So here the problem if we see the lab results for a wastewater treatment are given below and the volume of the aeration tank that is given 0.4 million gallon (MG) and rest of the parameter like MLSS is given mixed liquor Volatile content is given 76% and the volume of settled sludge after 30 minutes that is given as 190 ml/L and similarly the primary effluent that contains suspended solid which is equal to 100 mg/L and similarly its BOD is also given and the flow of the sludge is also given which is 2.1 MGD. So using these parameters we have to determine what is the sludge volume index and what is its age in the aeration tank.

So this is let's first determine the sludge volume index. So, we know $SVI,\ ml/g = \frac{settled\ sludge\ volume\ (ml/L) \times 1000\ mg/g}{MLSS\ (mg/L)}$, so it will give us the this value already is given 190 ml/L and MLSS value that is 1600 mg/L multiplied by 1000, so this is to convert the milligram into gram and by computation we will find out this sludge by volume index equal to 119 ml/g.

And then similarly for determination of this sludge age we have to determine first the total solids present in the basin so which will be equal to $Solids\ in\ the\ basin\ =\ Aeration\ basin\ volume\ (MG) \times MLSS\ (mg/L) \times 8.34\ (lb/G)$ that is the conversion factor for calculating the solids in terms of pound. So this aeration basin volume is given equal to 0.4 MG and million is converted into gallon by multiplying by 10^6, so this is in gallon and this is the MLSS concentration which is given as 1600 mg/L. So this is the conversion factor which will directly calculate the total solid in the basin in terms of pound and that value comes equal to 5338 lb and once this total solids present in the basin is known and we know how much solids are entering so this we can determine by multiplying the flow with the suspended solid concentration and its multiplying factor to convert into pound per day so here this is $2.1\ \times 100\ \times\ 8.34.$ So here we will get equal to 1751 lb/day.

And substituting these two values in this equation we can find out the sludge age. So, this is $\frac{5338\ lb}{1751\ lb/day}$, so by dividing this we will get the total amount of time the sludge remains in the tank so that is around 3.05 day.

These are the references we have used where the number of numerical based on sludge treatment system, sludge characterization, sludge digester designs. So, you can refer these references.

So, thank you all.