Biological Process Design for Wastewater Treatment

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Lecture 32

Sludge Management – II

Welcome everyone in this NPTEL online certification course and Biological Process Design for Wastewater Treatment. So, today we will continue with the previous lecture the sludge management. So, in the previous lecture we understood that there are different sections with respect to sludge management. And we started discussing regarding the sludge characteristics and production and we tentatively calculated the sludge characteristic at each treatment stage. So, today we will try to focus on understanding this fundamental relationship in sludge and further calculation of the total sludge which is produced.

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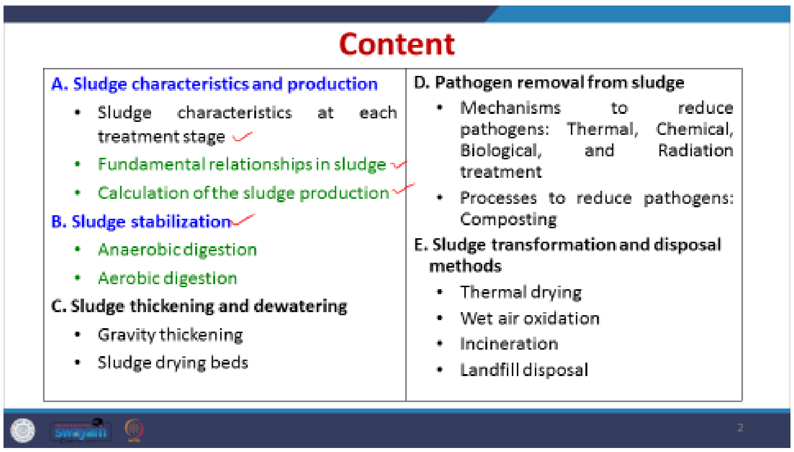

So, we can roughly do that and also we will start section on the sludge stabilization trying to learn what is anaerobic sludge stabilization and what is aerobic sludge stabilization. So, we will do that other sections we will try to do that in the later lectures.

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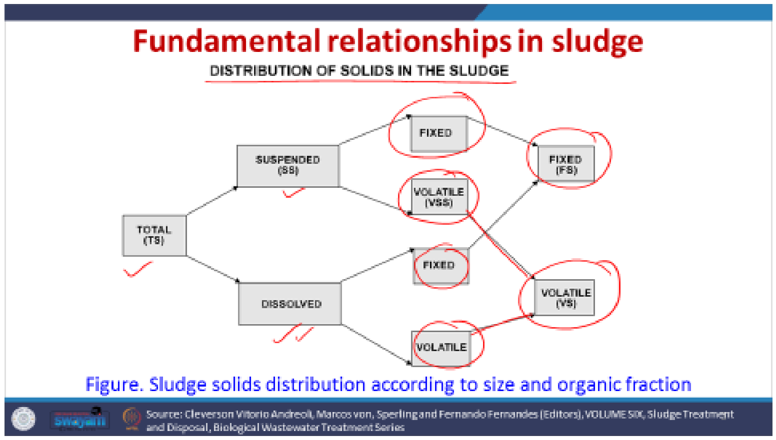

So, the fundamental relation in the sludge. So, distribution of various types of solids which may be defined in the sludge is given here in this figure. So, we have the total solid which is produced. So, total solid can further be subdivided into whether it is suspended or dissolved. So, already we have some lectures related to that. So, this suspended and dissolved solid both some of them may be VSS. So, this is volatile suspended solid and some of them is fixed that means it will not easily evaporate when we heat it.

So, this is there. So, volatile section can go off very easily if it is heated. So, similarly for dissolved solid we have fixed content and we have volatile content. So, all the volatile content whether it is suspended or it is dissolved that can be considered as volatile solids and similarly we have fixed solids. So, this is the total the distribution of various types of solid in the sludge.

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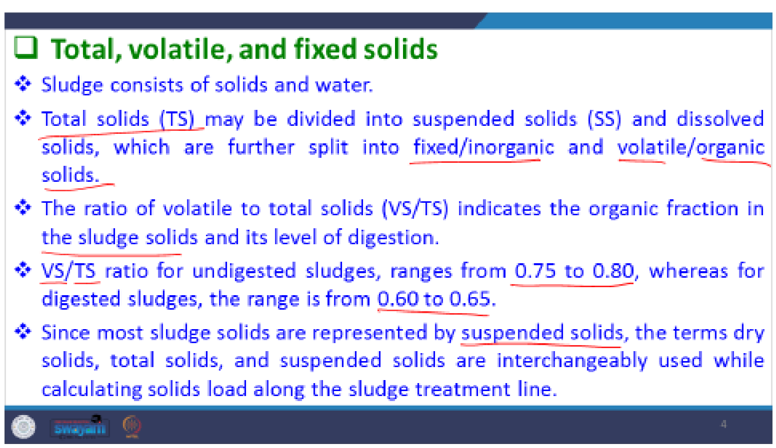

Now, let us further understand them. The sludge consists of both solids and water. So, that is for sure the total solids may be divided into suspended solid and dissolved solid which are further split into fixed or inorganic solid or volatile which is organic solids. The ratio of volatile to total solid indicates that the organic fraction in the sludge solid is more and its level of digestion. So, both factors are given if volatile solids content is more that means that the organic content in the solid is more and whereas, if it is less that means inorganic content is more.

Now, if the V s to T s ratio that means volatile solid to total solid ratio for undigested sludge ranges from 0.75 to 0.80 whereas, for digested sludge it may be from 0.6 to 0.65 it decreases when the digestion happens.

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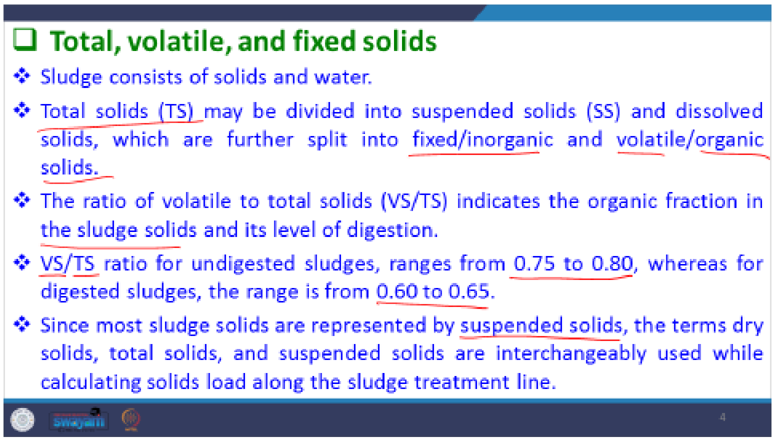

Since most sludge solids are represented by suspended solids the term dry solid, total solid, suspended solids are interchangeably used while calculating solid loads along the sludge treatment line. So, most of the data which is reported is based upon suspended solid. So, the dissolved solids content many times is missed and it means that dry solids, total solids, suspended solids they are used very interchangeably.

Now, the density and specific gravity of sludge remember in the previous lecture we had performed some calculation and in that we had roughly used 1.05 the specific gravity of sludge.

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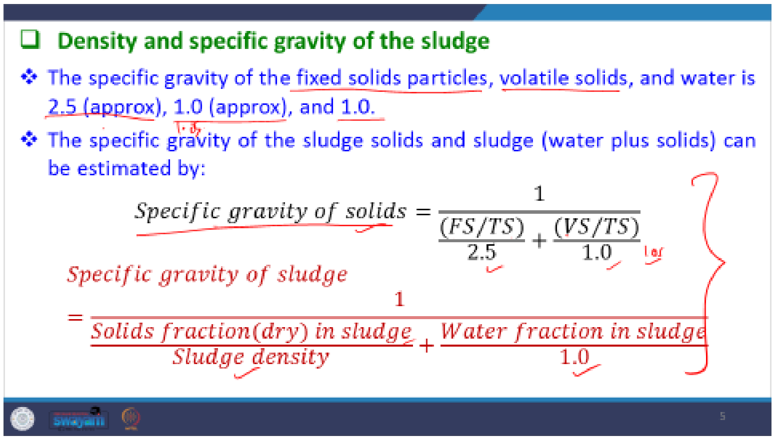

The specific gravity of the sludge solids and sludge (water plus solids) can be estimated by:

$$Specific\ gravity\ of\ solids = \frac{1}{\frac{(FS/TS)}{2.5} + \frac{(VS/TS)}{1.0}}$$

$$Specific\ gravity\ of\ sludge$$

$$= \frac{1}{\frac{Solids\ fraction(dry)\ in\ sludge}{Sludge\ density} + \frac{Water\ fraction\ in\ sludge}{1.0}}$$

So, how do we calculate that? The specific gravity of fixed solid particles volatile solids and water is approximately taken as this. So, for fixed solid particles it is 2.5 for volatile solids approximately 1.0 we may take 1. 1, 1.05 etcetera and for water we already know it is 1. So, if we can take like in the previous 1.05 like this. Now, the specific gravity of the sludge solid and with sludge that means water plus solid can be estimated using this equation. So, we have 1 divided by the ratio of fixed solid to TS.

So, that will be 2.5. So, this is and then the VS to TS we are assuming to be 1. So, we can take 1 or we can take 1.05 like here. So, then we can find out the specific gravity of the solids. Now, specific gravity of sludge has to be further calculated. So, what we do is that whatever is the specific gravity of solids. So, solid fraction that means dry fraction in the sludge will be calculated and it will be divided by the sludge density or specific gravity of solids here and then the water fraction in the sludge divided by 1. So, using both formulas we can tentatively calculate the specific gravity of sludge in the any sludge we can calculate.

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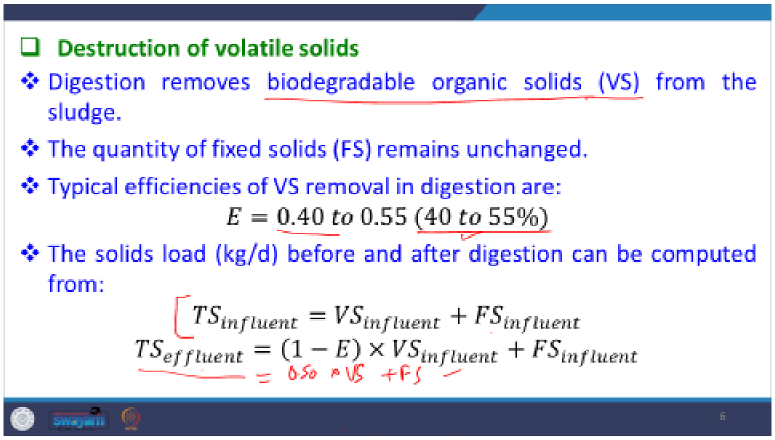

Typical efficiencies of VS removal in digestion are:

$E = 0.40\ to\ 0.55\ (40\ to\ 55\%)$

The solids load (kg/d) before and after digestion can be computed from:

$$TS_{influent} = VS_{influent} + FS_{influent}$$

$$TS_{effluent} = (1 - E) \times VS_{influent} + FS_{influent}$$

Now, how do the volatile solids their destruction happens during various stages. So, digestion removes the biodegradable organic solids that means the volatile solids from the sludge. So, the quantity of fixed solids remains unchanged. So, it will not change only volatile solid will change during the digestion process. The typical efficiencies of volatile solids removal during the digestion are like 40 to 55 percent is the total volatile solid which gets removed during the digestion.

Thus, the solid load kg per day before and after digestion can be calculated. So, like total solid in the effluent will be the volatile solid in the effluent plus fixed solid in the influent. Now, after treatment after digestion the total solid after digestion or in the effluent it will be 1 minus efficiency. Suppose, whatever is the fraction. So, it will be suppose we are taking 0.5. So, this will be 0.5 into volatile solid in the influent plus fixed solid will remain as such. So, this way we can calculate the solid load before and after digestion.

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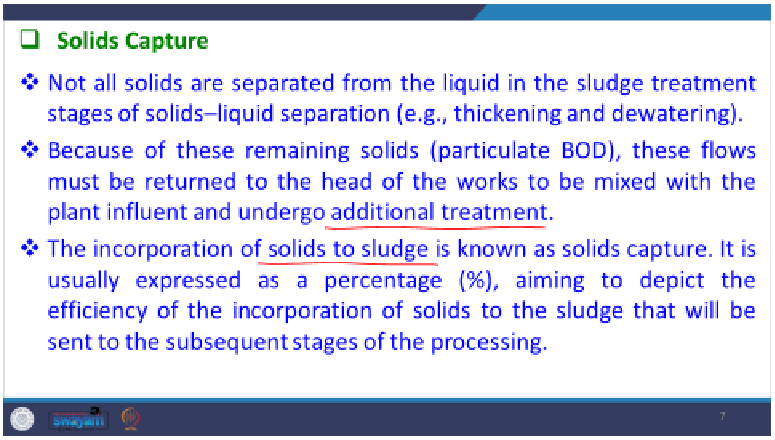

So, this is then there is solids capture not all solids are separated from the liquid in the sludge treatment stages of solid liquid separation like thickening dewatering. Because of these remaining solids the which can be considered as particulate BOD these flows must be returned to the head of the works to be mixed with the plant influent and further go additional treatment. Because this liquid will incur BOD and we cannot discharge that liquid.

So, we have to recycle it back the incorporation of solids to the sludge is known as solid capture and it is usually expressed as the percentage aiming to depict the efficiency of incorporation of solids to the sludge that will be sent to the subsequent stages for processing.

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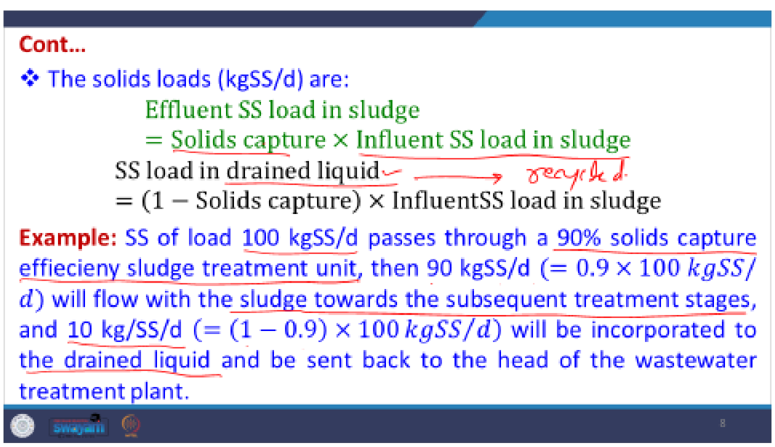

The solids loads (kgSS/d) are:

$$\text{Effluent SS load in sludge} = \text{Solids capture} \times \text{Influent SS load in sludge}$$

$$\text{SS load in drained liquid} = (1 - \text{Solids capture}) \times \text{InfluentSS load in sludge}$$

The solid load kg SS per day is the effluent SS in the sludge is equal to solid capture into influent SS load in the sludge. So, SS load in the drain liquid will be whatever we do not capture. So, that will go into the drain liquid and that drain liquid has to be recycled back.

So, this is there now the example is like here. So, if suppose the suspended solids of load 100 kg SS per day passes through a 90 percent solid capture efficiency sludge treatment unit. So, that means we have 90 kg SS will flow to the sludge towards the subsequent treatment stages. Because we are assuming that only 90 percent solids capture takes place and 10 kg SS per day that means which has been calculated by 1 minus 0.9 into 100 kg will be incorporated in the drain liquid and this has to be recycled back to the whole treatment plant for that re-treatment itself. This has to be taken care we cannot discharge any drain liquid anywhere which contains some amount of BOD.

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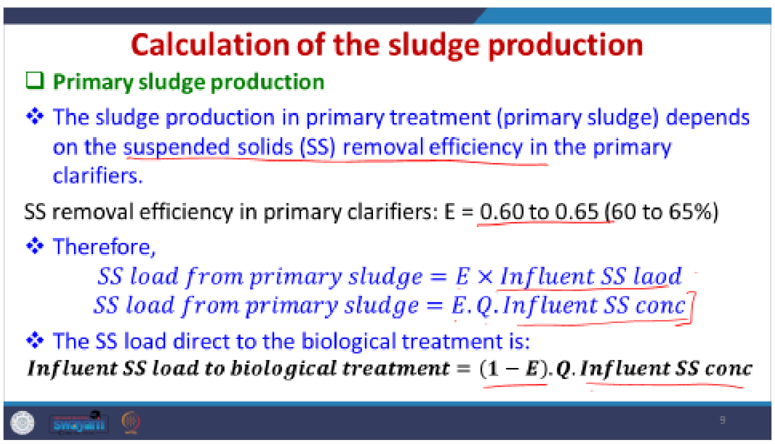


$$SS\ load\ from\ primary\ sludge = E \times Influent\ SS\ laod$$

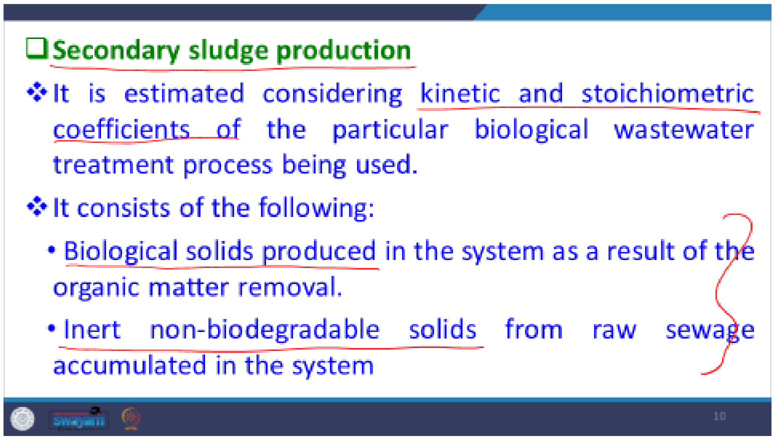
$$SS\ load\ from\ primary\ sludge = E.Q.Influent\ SS\ conc$$

The SS load direct to the biological treatment is:

$$Influent\ SS\ load\ to\ biological\ treatment = (1 - E).Q.Influent\ SS\ conc$$

Now let us do some calculations with respect to sludge production. So, we have primary sludge production let us calculate. The sludge production in the primary treatment that during the initial stages depends upon the suspended solids removal efficiency in the primary clarifiers. So, the SS removal efficiency in the primary clarifier varies in the range of 60 to 65 percent. So, therefore, SS load from primary sludge will be E whatever is the efficiency into influent SS load.

Then SS from the primary sludge will be efficiency whatever is the efficiency into Q into influent SS. So, we are trying to just calculate in terms of concentration. So, the SS load direct to the biological treatment will be whatever has not been captured. So, 1 minus E into Q into influent SS concentration. So, this is very straight forward we can perform calculation like this. (Refer Slide Time: 10:45)



Then estimated considering kinetic and stoichiometric coefficients of particular biological treatment process we give. So, we can tentatively calculate the secondary sludge production also whatever data or earlier lectures we had studied regarding the kinetic and stoichiometric coefficient of the biological wastewater treatment whether it is aerobic anaerobic or different other classifications were there. So, it will depend upon that. So, the secondary sludge will consist of the biological solids produced in the system as a result of organic matter removal. So, since organic matter removal is taking place some amount of bio solids will be produced and that we have to take care.

Then also inert non-biodegradable solids from raw sewage will be getting accumulated in the system and that will also be produced in the secondary sludge. So, this also has to be taken care of.

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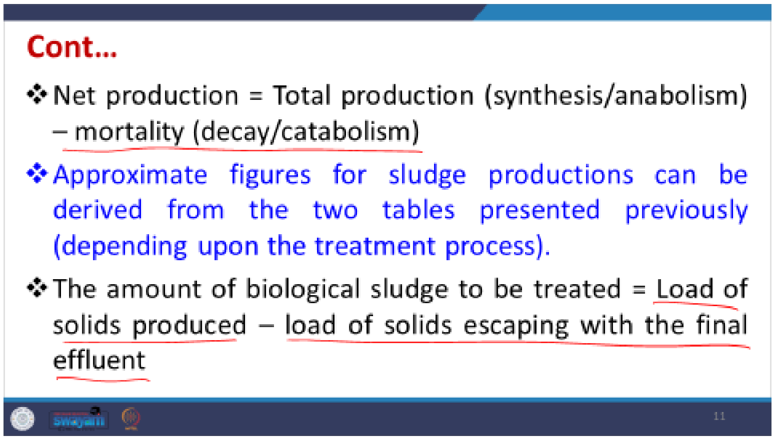

The net production will be or total production whatever via these two methods and then there is a endogenous respiration or catabolism happening or decay. So, that mortality among themselves the biomass that has to be subtracted. So, approximate figures for sludge productions can be derived using the tables which have been presented in the previous lecture.

And the amount of biological sludge to be treated will be load of the solids produced minus load of the solid escaping with the final effluent that we have studied just two slides earlier. So, that has to be considered.

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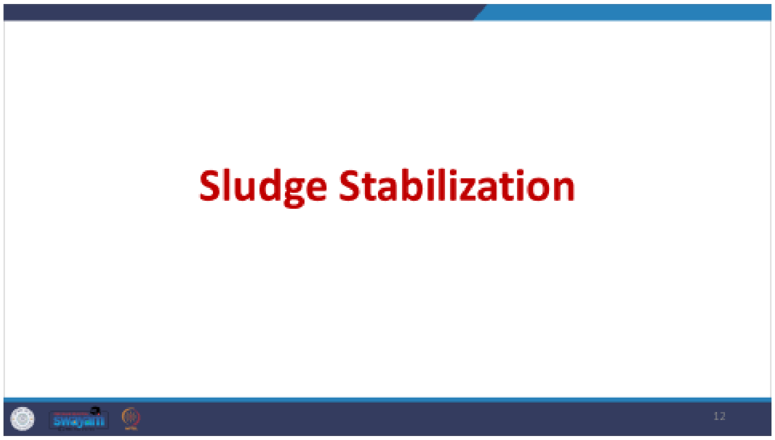

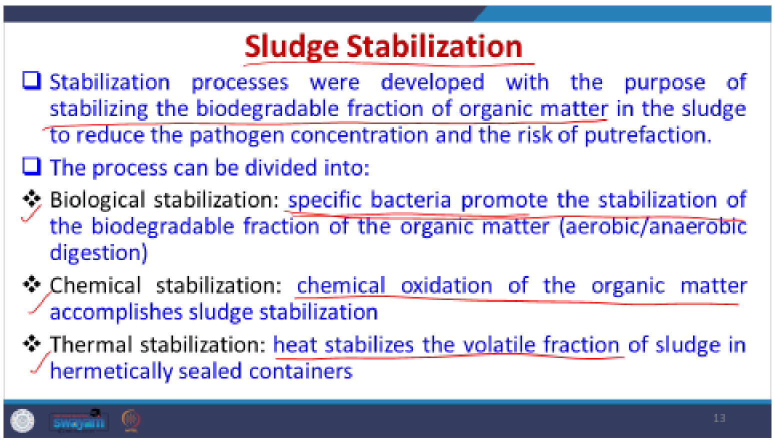

So, now we will go and try to understand the second step which is called as sludge stabilization. So, will be this is the B section.

So, that will be now we will continue. So, sludge stabilization processes were developed with the purpose to stabilize the biodegradable fraction of the organic matter in the sludge and to reduce the pathogenic concentration and the risk of putrefaction. So, what we wish is that the volatile suspended solids or the organic fraction can be reduce them or can we use it for some other purpose can we convert it like this. So, this is very important and right now in India lot of focus is related to this. So, can we convert the volatiles suspended into some gaseous form which can be used. So, lot of studies large scale planning is being done.

So, the sludge stabilization process can be divided into biological stabilization, chemical stabilization and thermal stabilization. So, biological stabilization refers to specific bacteria that promote the stabilization of the biodegradable fraction of the organic matter. So, there could be aerobic anaerobic digestion. So, that will be studying later. So, we can use some bacteria for stabilizing the and through that process we can convert some gas etcetera also.

So, this is possible. Then chemical stabilization that that means, we perform some chemical oxidation of the organic matter. So, this process is also being studied and here we use some chemicals to oxidize the volatile suspended solid or organic matter. Then we have thermal stabilization where heat is used for stabilizing the volatile fraction in the sludge and this process is also possible.

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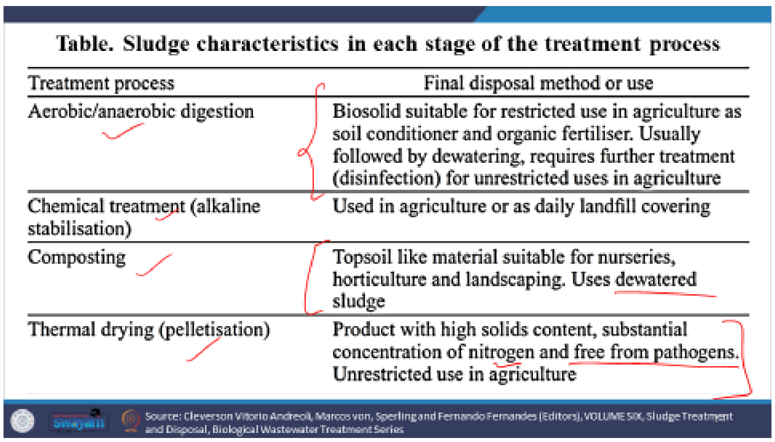

Table. Sludge characteristics in each stage of the treatment process

Treatment process	Final disposal method or use
Aerobic/anaerobic digestion	Biosolid suitable for restricted use in agriculture as soil conditioner and organic fertiliser. Usually followed by dewatering, requires further treatment (disinfection) for unrestricted uses in agriculture
Chemical treatment (alkaline stabilisation)	Used in agriculture or as daily landfill covering
Composting	Topsoil like material suitable for nurseries, horticulture and landscaping. Uses dewatered sludge
Thermal drying (pelletisation)	Product with high solids content, substantial concentration of nitrogen and free from pathogens. Unrestricted use in agriculture

Source: Cleverson Vitorio Andreoli, Marcos von Sperling and Fernando Fernandes (Editors), VOLUME SIX, Sludge Treatment and Disposal, Biological Wastewater Treatment Series

Now the sludge characteristics which will be obtained in each state of the thermal or this digestion process. So, we have aerobic or anaerobic digestion, we have chemical treatment, some chemical oxidation we can have composting, thermal drying etcetera.

So, the final disposal methods are used will depend upon the what type of processes we are using. So, bio solids produced via this will be suitable for restricted use in agriculture as soil conditioner or organic fertilizer. Usually it is followed like we have other steps like dewatering requiring further treatment like disinfection for unrestricted use in the agriculture. Then via alkaline stabilization can be used in the agriculture or it can be used for dale or dill. Landfill covering, then via composting the top soil like material is suitable for nurseries, horticulture, landscaping and many times we have to dewater the sludge also before uses.

Then thermal drying product with high solid content is obtained substantial concentration of nitrogen and it will be free from pathogens and it can be used in the agriculture. So, depending what type of sludge treatment or sludge digestion we are using the uses will vary.

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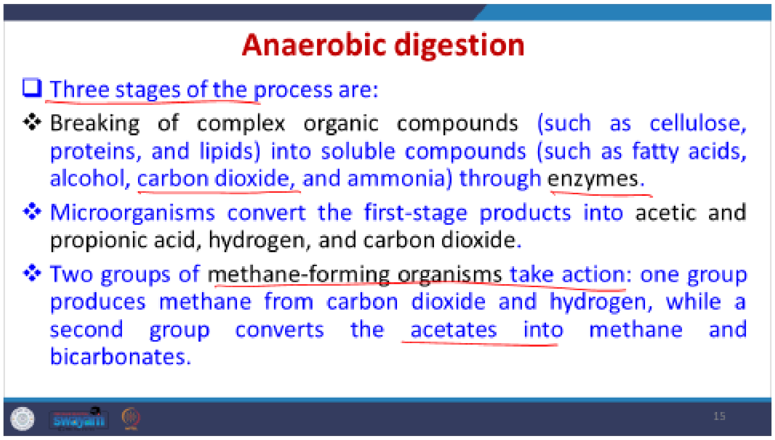

Now, we will try to concentrate on the biological digestion and within that we are going to study the anaerobic digestion first. So, anaerobic already we have studied the anaerobic treatment of wastewater. So, now we are going to understand the anaerobic digestion of sludge.

So, within the anaerobic digestion of sludge there are three stages. So, first stage is breaking of complex organic compounds and these organic compounds which are broken are like cellulose, proteins, lipids etcetera and these compounds are broken into soluble compounds which may be fatty acids, alcohol, carbon dioxide, ammonia etcetera and this is done via enzymes. Now, microorganisms convert the first stage products into acetic acid, propanoic acid, hydrogen, carbon dioxide and within this the two groups of methane forming organisms that take action include one group which produces methane from carbon dioxide and hydrogen while a second group further converts the acetates into methane and bicarbonate. So, one group is working on this carbon dioxide and hydrogen whereas, other group is working on the acetates to convert them into methane and bicarbonates. So, this is done.

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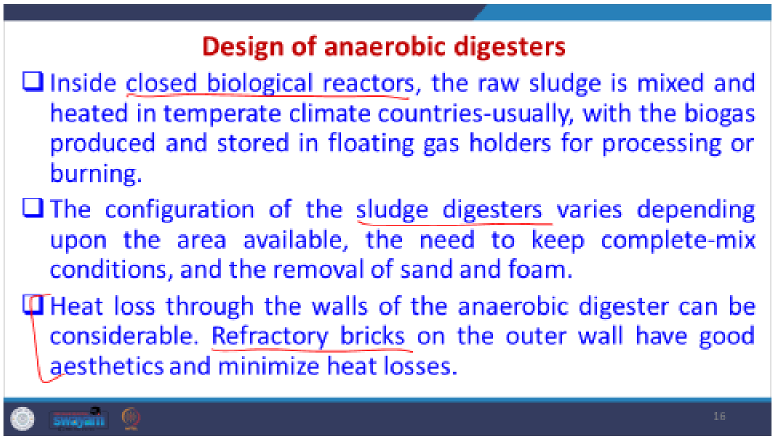

Now, the designs of anaerobic digesters we have lot of anaerobic digesters for which people are working will not go very detail, but some idea is given here and this is the area where lot of work is required because we have lot of sludge which is produced in the waste water treatment plant. So, that sludge if we can perform anaerobic digestion we can produce lot of methane etcetera or hydrogen also. So, we can use that gas. So, that is why lot of focus is nowadays here is on the design of anaerobic digesters and so as to convert maximum possible to methane and hydrogen. So, now, the these are basically closed biological reactors thus raw sludge is mixed and heated in temperature climate countries usually with the biogas produced itself and which is stored in the floating gas holders for processing and burning.

The configuration of the sludge digester may vary depending upon the area available. The need to keep completely mixed conditions or otherwise and the removal of sand and foam etcetera. Also the heat loss through the walls of anaerobic digester can be considerable. So, we may have to use refractory bricks on the outer wall to have good aesthetics as well as minimize the heat loss. We will reuse the biogas produced for maintaining the temperature because certain amount of temperature is the requirement for treatment of such sludge’s in the anaerobic system.

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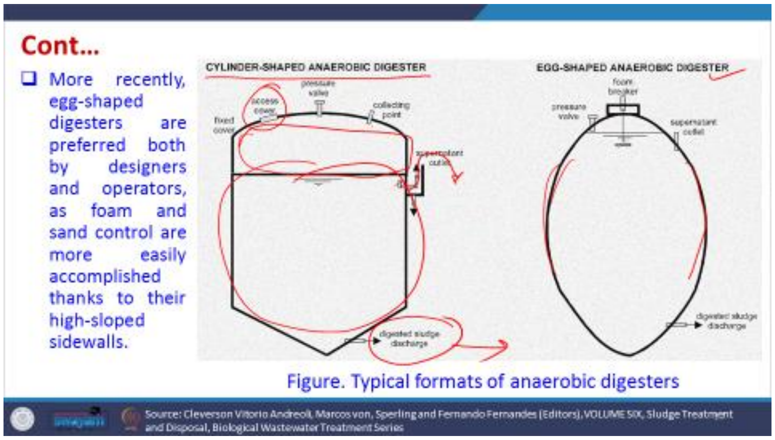

Now, more recently the egg-shaped so you can see the tentative cylinder shaped anaerobic digester. So, we have this section in which that digestion taking place at the top we have like pressure valve because in this section the gas will get accumulated. So, we have pressure valve we have sub collection points access cover also and this is from where the super net and the water will come out. So, we have to take care further for this and the digested sludge will be discharged from this section. In place of this now the egg-shaped anaerobic digesters are also coming into picture.

So, the egg-shaped digesters are preferred both by designers and operators as foam and sand controls are more easily accomplished in this thank to the highly sloped side walk. So, because this is slope is very high so the sand and foam etcetera can easily be controlled in this egg-shaped anaerobic digesters.

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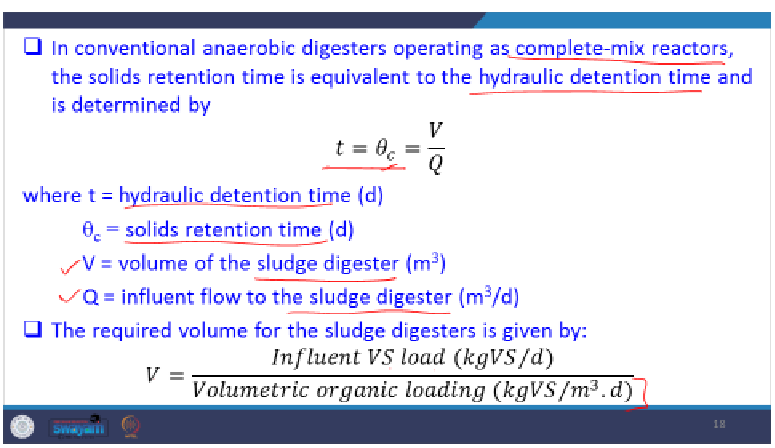

The solids retention time is equivalent to the hydraulic detention time and is determined by

$$t = \theta_c = \frac{V}{Q}$$

where t = hydraulic detention time (d)

θ_c = solids retention time (d)

V = volume of the sludge digester (m^3)

Q = influent flow to the sludge digester (m^3/d)

The required volume for the sludge digesters is given by:

$$V = \frac{Influent\ VS\ load\ (kgVS/d)}{Volumetric\ organic\ loading\ (kgVS/m^3.d)}$$

In conventional anaerobic digesters operating as a complete mix reactor. So, if CSTR approach we are taking the solid retention time is equivalent to the hydraulic retention time itself. If we are assuming complete mix reactor and it can be calculated as t is equal to theta c which is the solid retention time or hydraulic retention time both are taken same and this is equal to V by Q where V is the volume of sludge in the digester and Q is the influence flow to the sludge digester.

So, this is there now the required volume of the sludge digester is given by so we can calculate back influent VS load that means what is the kg of volatile solids which is being introduced per day and volumetric organic loading the kg of volatile solids per meter cube per day. So, what is the concentration of volatile solid in the sludge that is important and through that we can calculate back that what is the volume which will be required of the sludge digester. So, the volume of sludge digester can be calculated.

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Table. Typical design parameters for anaerobic sludge digesters

Parameters	Typical values
Detention time (θ_c) (d)	18–25
Volumetric organic load (kgVS/m^3·d)	0.8–1,6
Total solids volumetric load (kgSS/m^3·d)	1.0–2.0
Influent raw sludge solids concentration (%)	3–8
Volatile solids fraction in raw sludge (%)	70–80
Efficiency in total solids reduction (% TS)	30–35
Efficiency in volatile solids reduction (% VS)	40–55
Gas production (m^3/kgVS destroyed)	0.8–1.1
Calorific value of gas (MJ/m^3)	23.3
Digested sludge production (gTS/inhabitant·day)	38–50
Gas production (L/inhabitant·day)	20–30
Raw sludge heating power (MJ/kgTS)	15–25
Digested sludge heating power (MJ/kgTS)	8–15

Source: Cleverson Vitorio Andreoli, Marcos von, Sperling and Fernando Fernandes (Editors), VOLUME SIX, Sludge Treatment and Disposal, Biological Wastewater Treatment Series

Typical design parameters for anaerobic sludge digesters are given here. You can see the detention time is typically from 18 to 25 days then we have volumetric loading in kg that what should be the loading in the digester.

So, it is 0.8 to 1.6 similarly, total solids in the volumetric load we can calculate it will be 1 to 2. The influent raw sludge solid concentration is 3 to 8 percent that we can take in the digester for further digestion. The volatile solid fraction in the raw sludge will be this. So, we can tentatively calculate we can also calculate back that assuming certain efficiency. So, this is the efficiency we are assuming in the anaerobic sludge digester.

So, efficiency in total solid reduction is approximately 30 to 35 percent till this point it is the that what is the concentration or what are the characteristics of the solids which is coming. Now, if you are assuming that efficiency in the volatile solid reduction is 40 to 55 percent and total solid reduction is 30 to 35 percent. We can tentatively calculate back that what is the gas production that will happen what is the calorific value of gas. So, what will be the uses then that digested sludge production that total sludge that will be produced per inhabitant per day or the total gas which is produced per inhabitant per day in liters can be calculated. Similarly, the raw sludge heating power that will be required and digested sludge heating power is also can be calculated.So, these are the typical design parameters for anaerobic sludge digestion unit that we can calculate and through this we can perform.

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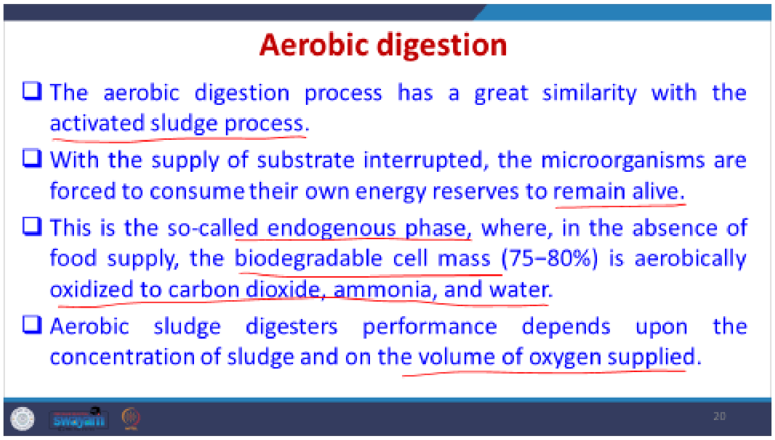

Now, we have aerobic digestion also. The aerobic digestion process has a similarity with the activated sludge process that we have studied earlier. With the supply of substrate interrupted the microorganisms are forced to consume their own energy reserves to remain alive. So, sometimes if the substrate is interrupted somehow the microorganisms start killing themselves.

This is called endogenous phase where the in absence of food supply the biodegradable cell mass is aerobically oxidized to carbon dioxide ammonia and water. Aerobic sludge digesters performance depends upon the concentration of sludge and the volume of oxygen being supplied. This will depend upon these parameters.

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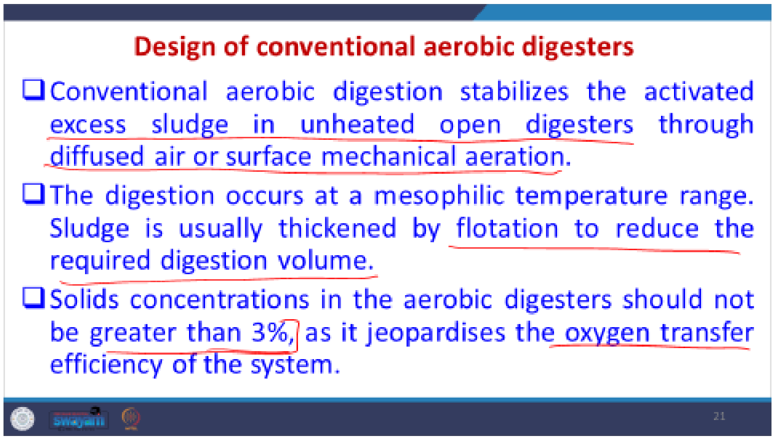

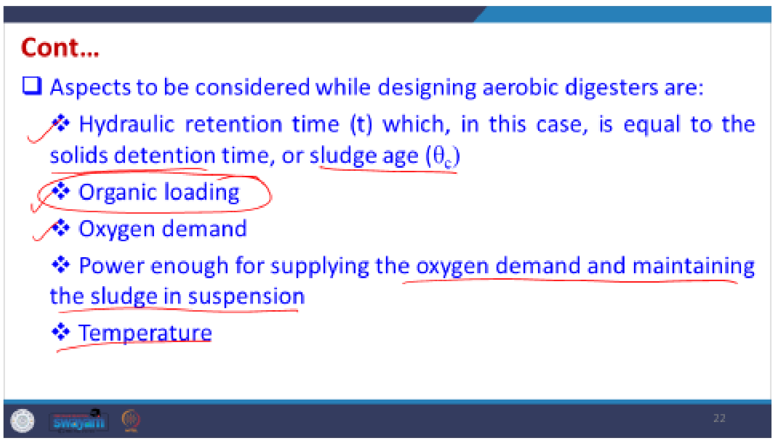

Now, let us consider the design also of conventional aerobic digester little bit. The conventional aerobic digestion stabilizes the activated excess sludge in unheated open digester through diffused air or surface mechanical aeration.

So, we can have a surface aeration or diffused aeration inside the sludge. The digestion occurs at a mesophilic temperature range and the sludge is usually thickened by flotation to reduce the required digestion volume. This is done. Then the solid concentration in the aerobic digester should not be greater than 3 percent. Otherwise, the oxygen transfer efficiency of the system will be reduced and the system will not operate well.

So, we have to take care that more than 3 percent solid concentration should not be there because we are using aerobic digester. So, oxygen transfer is very important parameter and if it is not sufficient, the system will go down. The aspects to be considered while designing aerobic digesters are hydraulic detention time that what should be the hydraulic detention time and is equal to the sludge detention time or sludge age if we are assuming CSTR certainly. Then organic loading which is there, what will be the oxygen demand that is there and we power enough for supplying the oxygen demand and maintaining the sludge in the suspension and the temperature.

The organic loading is very important parameter. If it is very less than really we will go for aerobic digester. Otherwise, if it is high, we should go for anaerobic digester so that we can produce maximum amount of gas etcetera. So, through this now we will end today's lecture. We will continue understanding little bit more about the digestion process anaerobic or aerobic in the next lecture with some examples and problems. So, today we will end this lecture. Thank you very much.