Biological Process Design for Wastewater Treatment
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Lecture 33
Sludge management - III

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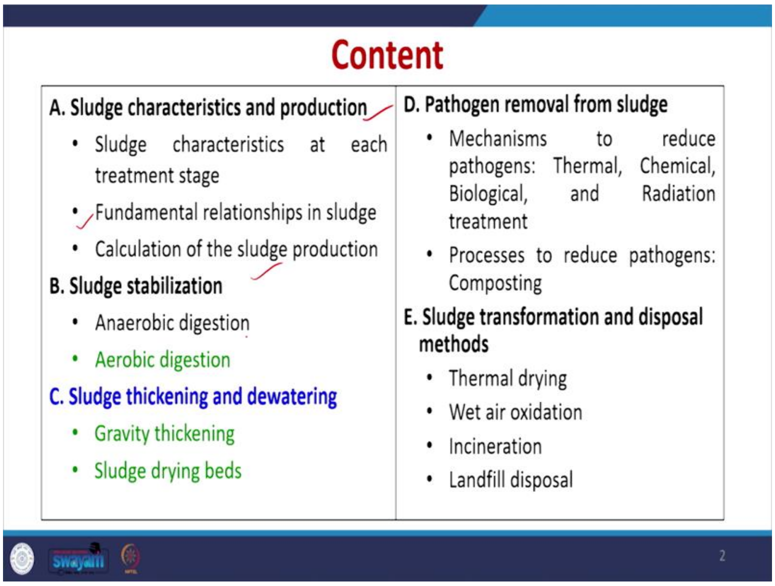

Welcome everyone, in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So in the last few lectures we started studying regarding the sludge management. So already we have studied the two sections, roughly the sludge characteristics and further production. So we have studied the sludge characteristics that each treatment stage then the fundamental relations in sludge in the previous lectures we studied regarding the calculation of sludge production and we started studying regarding the sludge stabilization including anaerobic or aerobic digestion.

So today we will continue with the anaerobic and aerobic digestion will perform some calculations on that and then we will further study the sludge thickening and dewatering. So in particular the gravity thickening will try to study today.

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Table. Design parameters for conventional aerobic sludge digesters

Item	Parameter	Value
Hydraulic detention time (d) 20 °C	Excess activated sludge	10– 15
	Extended aeration	12–18
	Excess activated sludge + primary sludge	15–20
Organic loading rate (kgVS/m ^{3}·d)	–	1.6–4.8
Oxygen demand (kgO$_2$ /kgVS destroyed)	Endogenous respiration	~2.3
	BOD in primary sludge	1.6–1.9
Energy for keeping solids in suspension	Mechanical aerators (W/m^3)	20–40
	Diffused air (L/m^3·min)	20–40
DO in digester (mg/L)	–	1–2

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

So now the design in the previous lectures we studied regarding anaerobic and aerobic processes. So we studied regarding the design parameters for anaerobic process, today we will study the design parameters which are used for conventional aerobic sludge digesters. So we have different parameters items and parameters and also the range of values.

So hydraulic detention time which may continue like for excess activated sludge, whether it is coming from excess activator sludge, or extended aeration, or excess activated sludge plus primary sludge. So depending upon that the parameter values may range from 10 to 15, 12 to 18, another 15 to 20 days. So this is the tentative detention time that we have to use in the design of conventional aerobic sludge digesters.

Also the organic loading may be in the range of 1.6 to 4.8 kgVS per meter cube per day. So we have to see that this is in the range. Then the oxygen demand that will be incurred is roughly kg oxygen per kgVS destroyed depending upon the loading and also depending whether endogenous respiration will take place or BOD in the primary sludge. So depending upon that these are the oxygen demand that will incur. So roughly we can take 2 to 2.5, it will be the oxygen demand in terms of kg oxygen per kgVS destroyed.

Now energy for keeping the solids in suspension that means for keeping them in the CSTR mode the mechanical aerators or diffuse aeration process may be used. So if we are using mechanical aerator.

So we have to use 20 to 40 watt per meter cube of the power, then if diffuse aeration is being used. So we have to use 20 to 40 liters per meter cube per minute then only we can will be able to keep the solid in the suspension mode. And also we have to see in the digester the dissolved oxidation should always be in the range of 1 to 2 or more than that. So this is the minimum DO that will be required in the digester.

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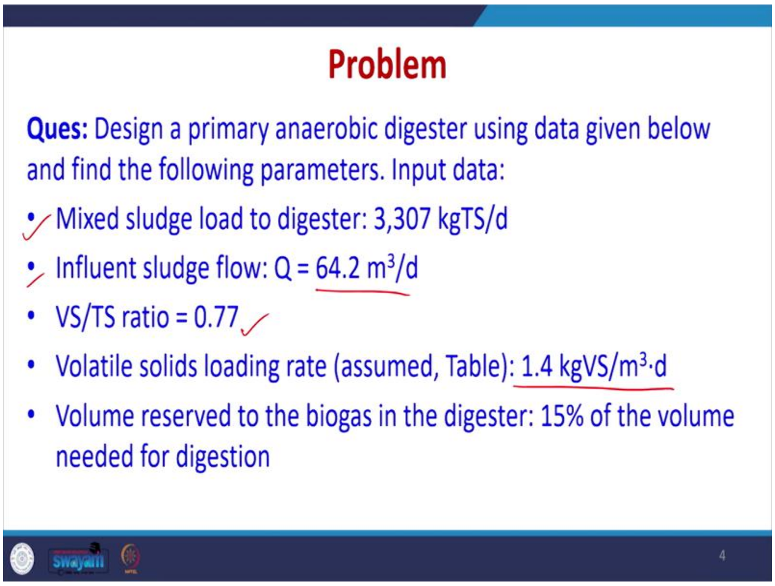

So now let us try to solve a problem we have already studied the design parameters for anaerobic digesters in the previous class. So let us try to design a primary anaerobic digester using the data given below and the following parameters. So the input data is mixed sludge load to the digester is like 3307 kgTS per day, the influent sludge flow is around 64.2 meter cube per day, the VS to TS ratio is roughly 0.7, and the volatile suspended loading rate assuming the table which was given earlier in the previous lecture is 1.4 kgVS per day, and volume reserved to the biogas.

So, generally we keep 15 percent roughly in the average of 15 percent of the total volume, which is reserved for biogas in the digester is roughly 15 percent. So we are keeping the same.

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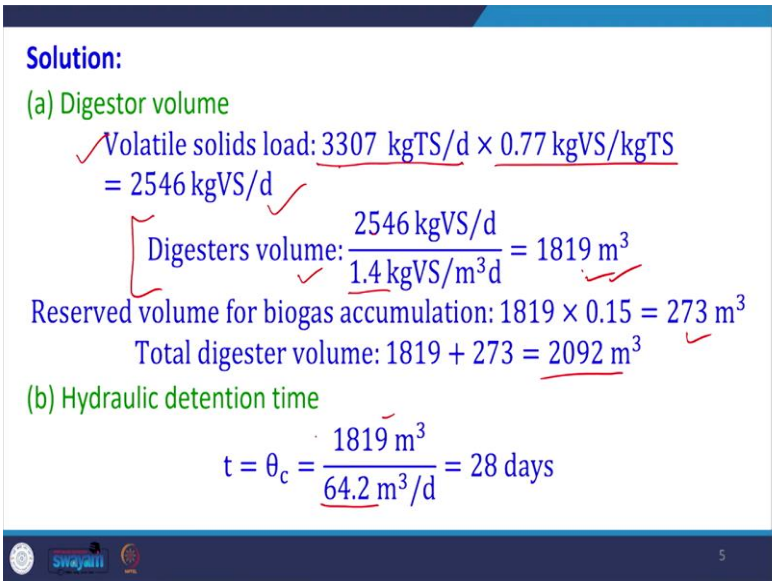

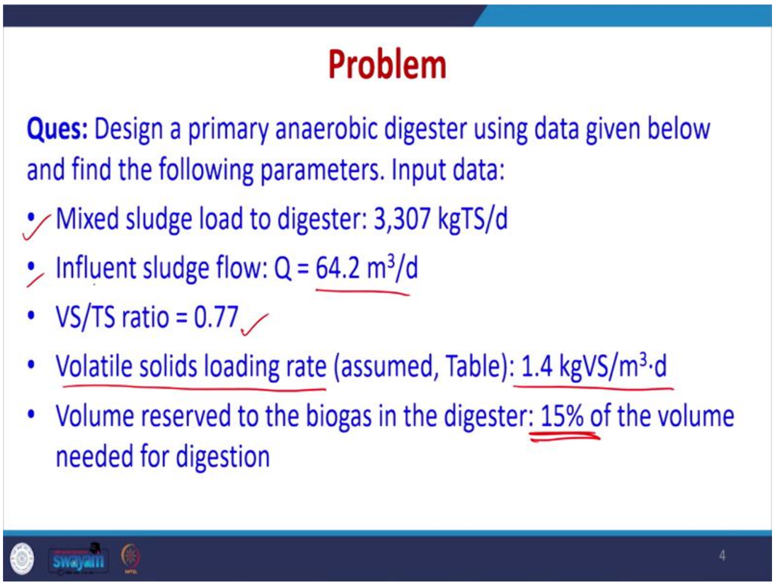

(a) Digester volume

Volatile solids load: $3307\ \text{kgTS/d} \times 0.77\ \text{kgVS/kgTS} = 2546\ \text{kgVS/d}$

Digesters volume: $\frac{2546\ \text{kgVS/d}}{1.4\ \text{kgVS/m}^3\text{d}} = 1819\ \text{m}^3$

Reserved volume for biogas accumulation: $1819 \times 0.15 = 273\ \text{m}^3$

Total digester volume: $1819 + 273 = 2092\ \text{m}^3$

Hydraulic detention time

(b) Hydraulic detention time

$$t = \theta_c = \frac{1819\ \text{m}^3}{64.2\ \text{m}^3/\text{d}} = 28\ \text{days}$$

Now let us start solving the problem. So what will be the digester volume that has to be taken care? First we calculate the total volatile solids load. So remember this was the influent that kgTS per day and within this the VS content was only 0.77, so this is the volatile solids load. Now the digester volume remember, we have roughly taken that will be volatile solids loading rate we are going to take 1.4 kgVS per meter cube per day. So that means the digester volume will be this divided by 1.4. So it is coming out 1819 meter cube.

Now since we are assuming that 15 percent will be taken for this. So out of this the 15 percent is this. So roughly we have 2092 meter cube will be the digester volume. Now the hydraulic detention time is 1819 meter cube is the digester volume which is actually being used for digestion is only this. So the detention time because 64.2 meter cube per day is the influent sludge flow. So based upon this V this is V and this is Q. So V by Q, it is coming out 28 days. So this is there.

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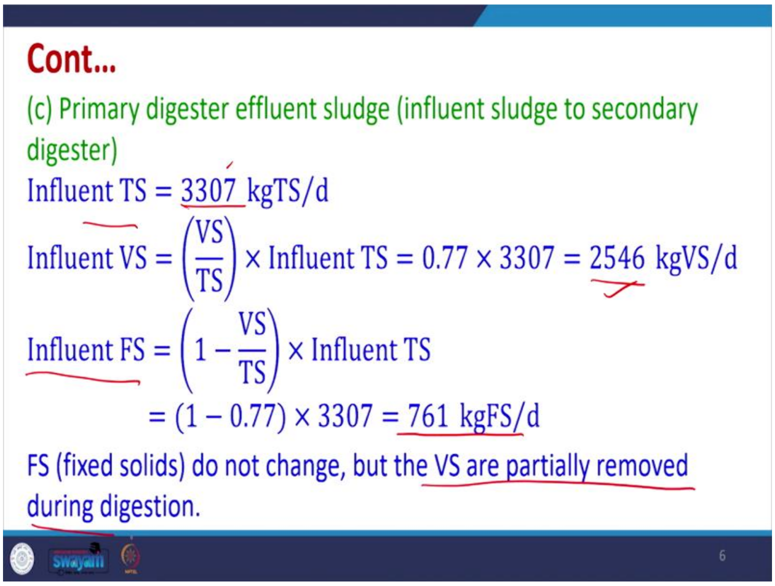


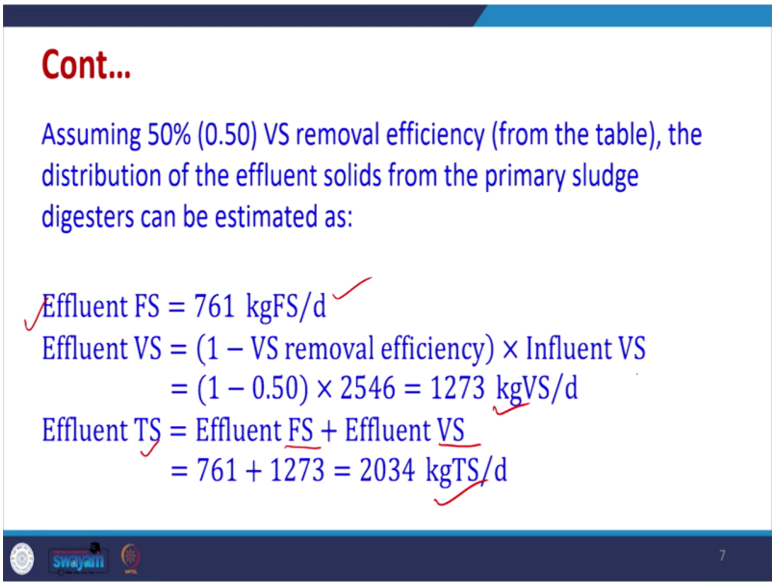
(c) Primary digester effluent sludge (influent sludge to secondary digester)

$$\text{Influent TS} = 3307 \ \text{kgTS/d}$$

$$\text{Influent VS} = \left(\frac{\text{VS}}{\text{TS}}\right) \times \text{Influent TS}$$
$$= 0.77 \times 3307 = 2546 \ \text{kgVS/d}$$

$$\text{Influent FS} = \left(1 - \frac{\text{VS}}{\text{TS}}\right) \times \text{Influent TS}$$

$$= (1 - 0.77) \times 3307$$
$$= 761 \ \text{kgFS/d}$$



$$\text{Effluent FS} = 761\ \text{kgFS/d}$$

$$\text{Effluent VS} = (1 - \text{VS removal efficiency}) \times \text{Influent VS}$$

$$= (1 - 0.50) \times 2546 = 1273\ \text{kgVS/d}$$

$$\text{Effluent TS} = \text{Effluent FS} + \text{Effluent VS}$$

$$= 761 + 1273 = 2034\ \text{kgTS/d}$$

Now the primary digester effluent sludge, influent sludge to the secondary digester that will be there. So influent TS is this, 3307. Now the influent VS is 0.7 of that, so this is the, now the influent FS that means the fixed solid which will be there is we have to subtract this fraction out of this. So this fraction is coming out 761. So nothing will happen to the fixed solids, it will not change but the volatile solids will be primarily removed during the digestion.

So if you are assuming 50 percent of the volatile solid removal efficiency, the distribution of effluent solid from the this that register can be estimated as the effluent FS will be same as earlier the effluent VS will be 1 minus the removal efficiency into influent VS, so this is this. The total effluent TS, the effluent total solid will be effluent fixed solid and effluent volatile solid. So if you add together the 2034 kg of total solid will still be discharged after digestion. So this is there.

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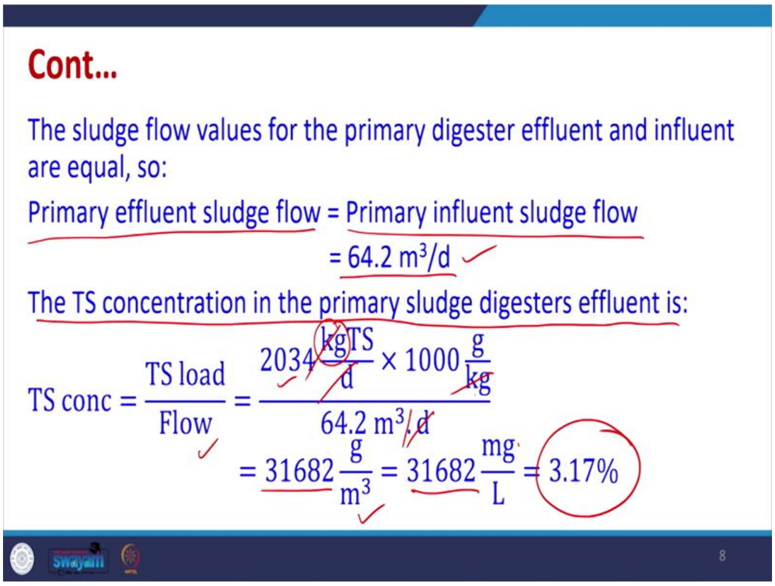

The sludge flow values for the primary digester effluent and influent are equal, so:

Primary effluent sludge flow = Primary influent sludge flow

= 64.2 m^3/d

The TS concentration in the primary sludge digesters effluent is:

$$\text{TS conc} = \frac{\text{TS load}}{\text{Flow}} = \frac{2034\,\frac{\text{kgTS}}{\text{d}} \times 1000\,\frac{\text{g}}{\text{kg}}}{64.2\ \text{m}^3.\text{d}}$$

$$= 31682\,\frac{\text{g}}{\text{m}^3} = 31682\,\frac{\text{mg}}{\text{L}} = 3.17\%$$

The sludge flow values for the primary digester effluent and influent are equal, so the primary effluent sludge flow will be primary influent sludge flow. So it will be 64.2 meter cube per day. The TS concentration in this sludge digester is, the TS load divided by flow. The flow is already known because the concentration is less, so we are roughly assuming the flow to be same. So the flow is same. So this is 2034 into because we have to convert this into gram.

So this is gram per kg, so kg kg goes off, so we have gram here, and then we have per day per day going off, so we have 31682 gram per meter cube which is the amount of solid produced per meter cube or in milligram per liter it will remain the same. So we have 3.1 percent is the total solid concentration in the digester effluent.

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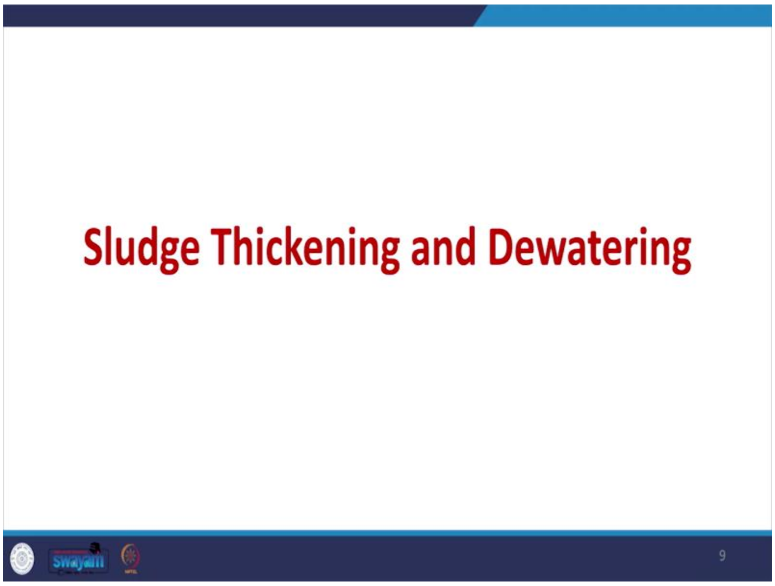

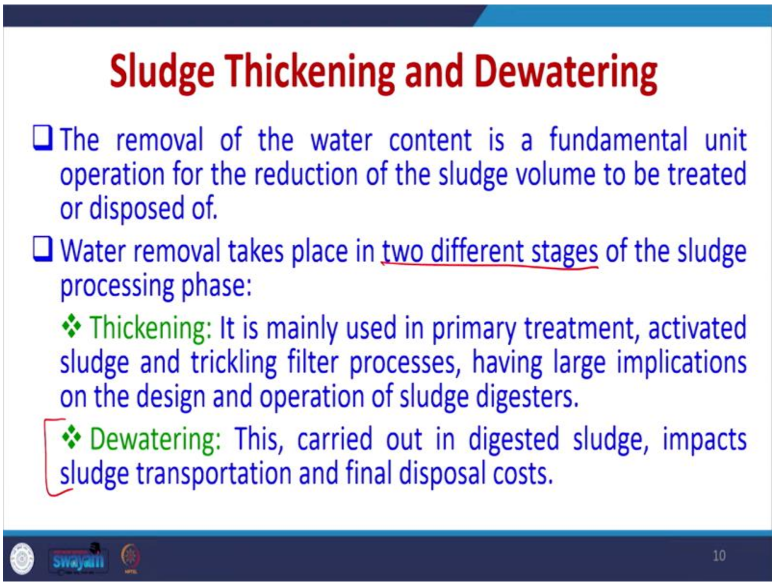

So we will further study the sludge thickening and dewatering today. So this will continue. So this is the third section that we are going to start within this sludge management section today. So sludge thickening and dewatering the sludge thickening and dewatering is very essential because we have to remove the water content. So that the sludge can be easily be transported and its volume reduction takes place and if required we can have the treatment or further convergence taking place.

So the removal of water content is a fundamental unit operation for reduction of sludge volume to be treated or to be disposed of. The water removal takes place in two different stages of the sludge processing phase, one is thickening another is dewatering. So thickening it is mainly used in the primary treatment like for activated sludge taking filter processes have very large implications on design and operations of the sludge digester. So wherever that treatment time is very less in the primary treatment unit, the sludge contains lot of water sludge has to be thickened.

Also dewatering is carried out in digested sludge and it impacts less transportation and final disposable cost because we are reducing the volume. So if we are disposing the disposable cost becomes very less. So thickening and dewatering are very important for sludge management.

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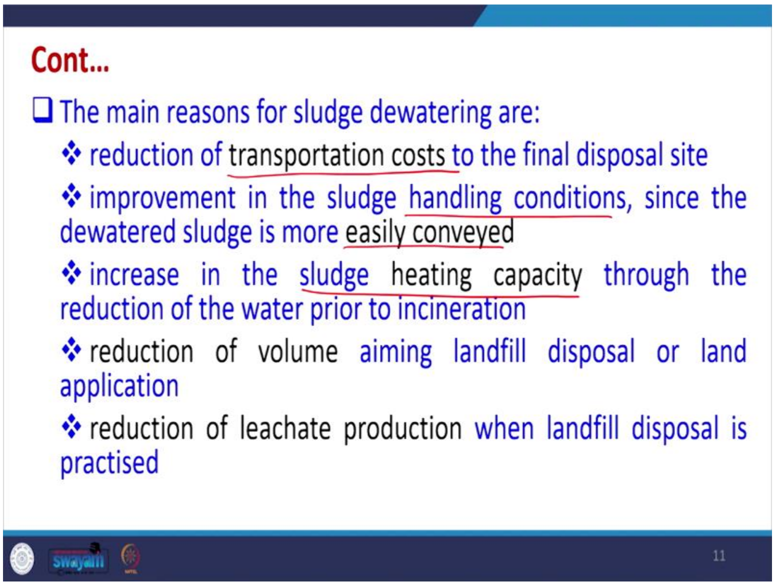

Now the main reason for sludge dewatering are reduction of transportation cost to the final disposal site if you are going for that. Then Improvement in the sludge handling condition since the dewatered sludge is more easily conveyed. So we can handle that sludge very well. Increase in the sludge heating capacity through the reduction of the water prior to incineration. So the sludge heating capacity will increase if water is getting reduced. So if we are taking the sludge for incineration that the heating capacity is increased. So we can use the sludge for incineration.

Reduction of volume aiming at landfill disposal or landfill application. So if volume reduction takes place. So the same area landfill can be used for longer time. Then also reduction in the leachate production when the landfill disposal is practiced. So if already water has been reduced, so that amount of leachate that will be produced when the land filling will be done will be lesser. These are the essential benefits of doing the sludge watering. So that is why sludge dewatering is one of the essential steps in the sludge management itself.

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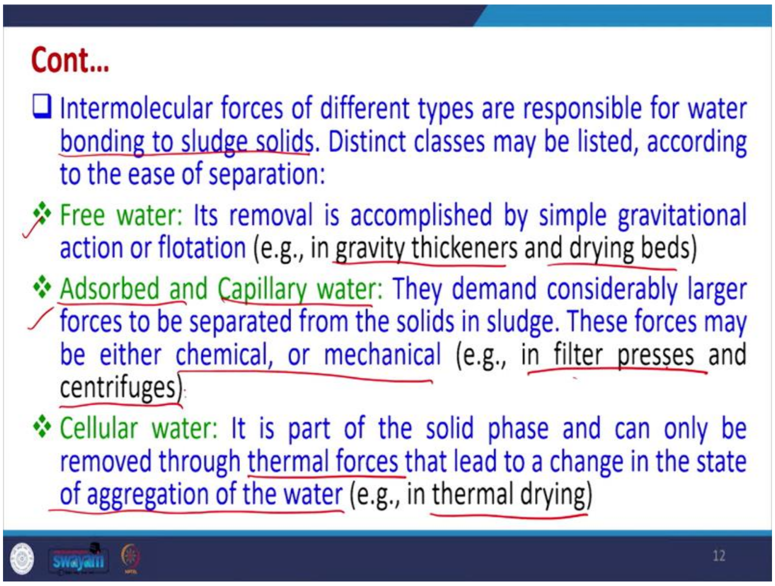

Now the intermolecular forces of different types are responsible for water bonding to sludge solids. So different classes may be listed. So there are different types of waters which get bond to the sludge and these different waters have to be reduced. So the easiest is free water, it is removal is incomplete by simple gravitational action or flotation. So gravity thickener or drying bed etcetera can be used to remove the free water.

Now adsorbed and capillary water, water will ultimately may be adsorbed and it will may form the capillary water. So this type of water they demand larger forces to be separated from solids in sludge. And these forces may either be chemical or mechanical. So if you have to remove this type of water the capillary water or adsorb water, then we have to use the filter process or centrifuges, then only we can remove this type of water, otherwise we cannot remove such type of water.

Then the cellular water, it is a part of solid phase and can only be removed through thermal forces that lead to change in the state of aggregation of the water. So for this we have to use thermal drying. So depending upon what type of water is present in the sludge we use different types of methods for removing water, it may be gravity thickener or drying bed which will remove the free water, it may be filter press or centrifuges which will not only remove free water they will remove the adsorbed and capillary water also. Then we can use thermal drying also, it will remove the cellular water also.

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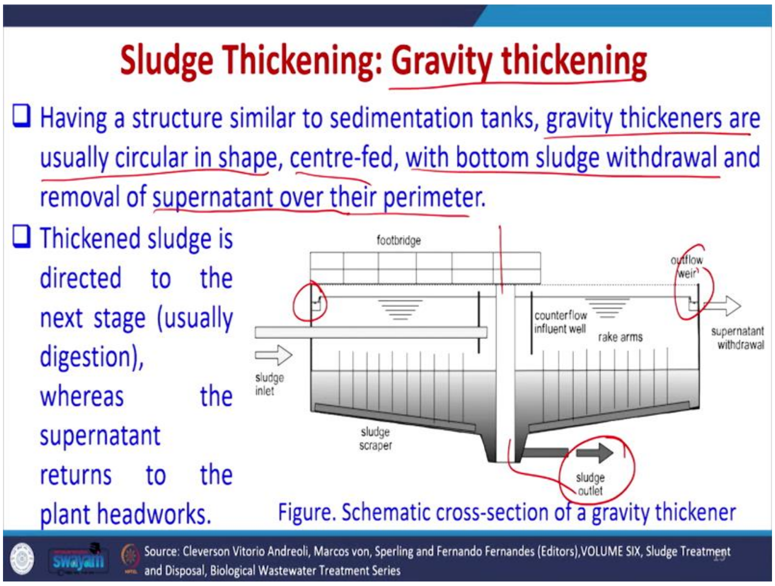

Now let us study sludge thickening via gravity thickening. So we will try to because this is the process which is followed a lot in the wastewater treatment plant in particular where sludge management is happening. So let us study gravity thickening. So it is having a structure similar to sedimentation tank. So gravity thickener are usually circular in shape, they are centre-fed. So there will be centre-fed with bottom sludge withdrawal, from the bottom the sludge withdrawal is taking place and removal of supernatant over their perimeter.

So from here you can see and this will be circular from every place this, the water will be removed from the perimeter. So these are the characteristics which are very similar to the sedimentation tank. Now thickened sludge is directed to the next stage usually a digestion unit whereas the supernatant is returned for the further treatment if required or it may be taken somewhere else.

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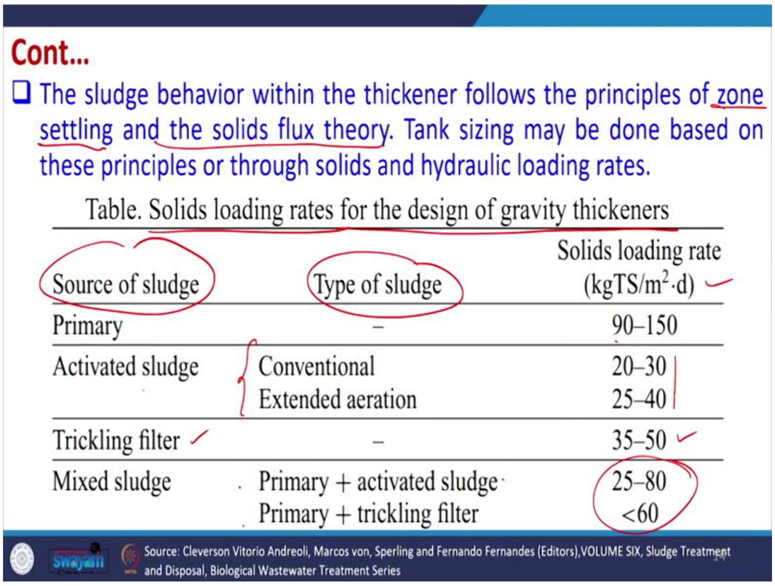

The sludge behavior within the thickener follows the principle of zone settling. So remember this is different as compared to the settling which happens in after maybe activated sludge process. So this is zone settling and here we have to apply the solids flux theory. So you can refer to the, my lectures in another course on Physico-Chemical Treatment of Wastewater, where this zone settling is explained in detail.

The tank sizing may be done based upon these principles or through solids and hydraulic loading rates. So there are different solids loading rate for the design of gravity thickener and depending upon the source of sludge, type of sludge. So depending upon that the solid loading rate may vary. So if the source of sludge is primary which can take up to 90 to 150 kg of TS per meter square per day, whether if it is from activated sludge, whether it is activated sludge, whether it is conventional or with extended aeration, then the values may change.

Then for trickling filter we have some values and similarly mixed sludge. So whether primary plus activated or primary plastic trickling filter. So we can have some solids loading rate which is in kgTS per meters curve per day that will be taken in the gravity thickener.

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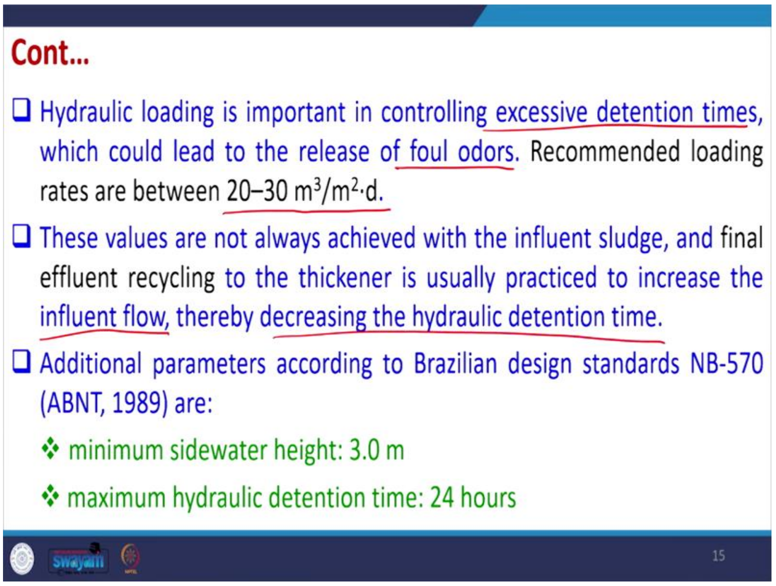

The hydraulic loading is important in controlling the excess detention times which could lead to release of foul odors. So this is very important thing because wherever the sludge dewatering thickening digestion etcetera may occur. So the foul odor may come and it may cause problem to the whole management team because the people who are living are passing through the surrounding areas will report for that. So we have to take care of the foul odor and the recommended loading rates are 20 to 30 meter cube per meter square per day for the hydraulic loading in case of gravity thickening.

These values are not always achieved with the influent sludge, and final effluent recycling to the thickener is usually practiced to increase the influent flow and thereby decreasing the hydraulic detention time. So additional parameters according to Brazilian design standards are like minimum side water height, maximum hydraulic detention time. So these are the design standards which are there. So let us solve a problem with respect to design of a gravity thickening unit.

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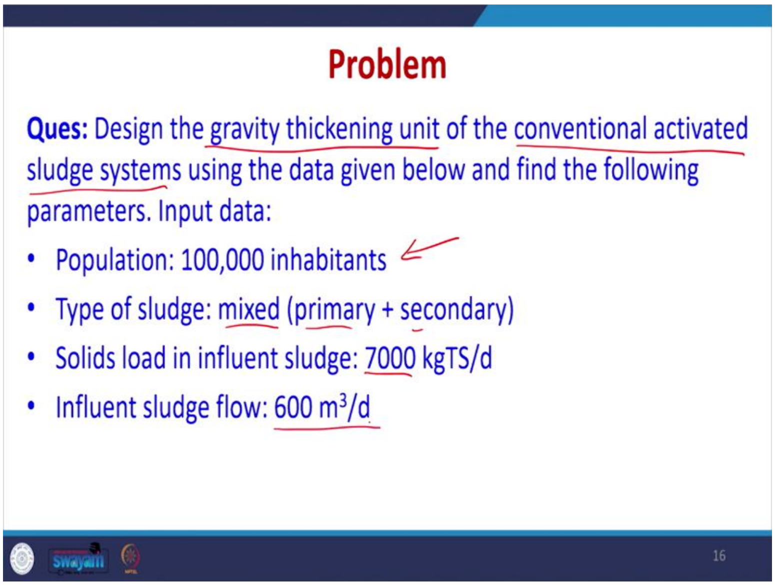

So we have to design a gravity thickening unit of conventional activated sludge system using the data which is given below. So already we have taken some data. So here the population of inhabitant is 100,000 inhabitants, the type of sludge which is being treated is mixed which is primary and secondly both are there. The solid load in the influent Ledges 7000 kgTS per day and the influent sludge flow rate is 600 meter cube per day. So we have to design a gravity thickening unit.

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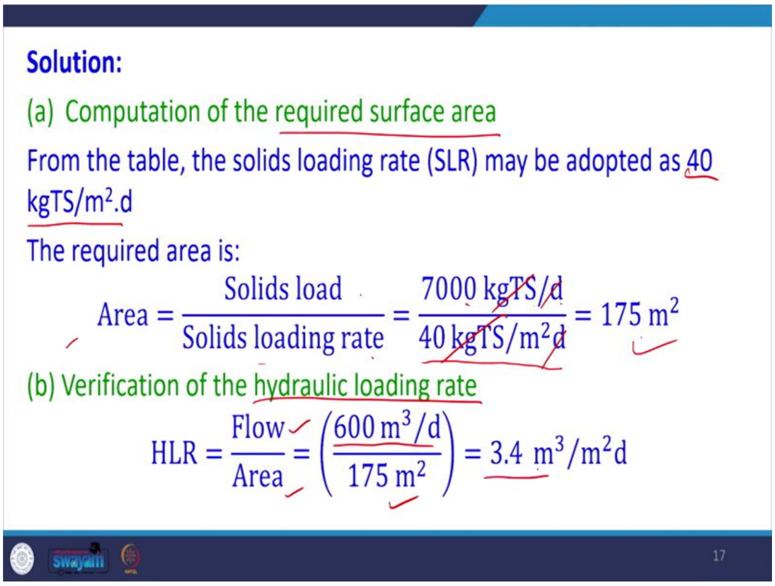
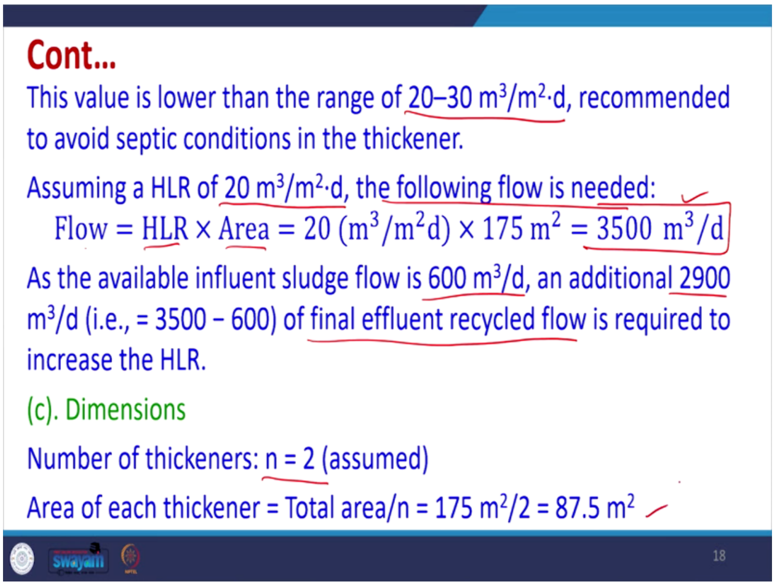


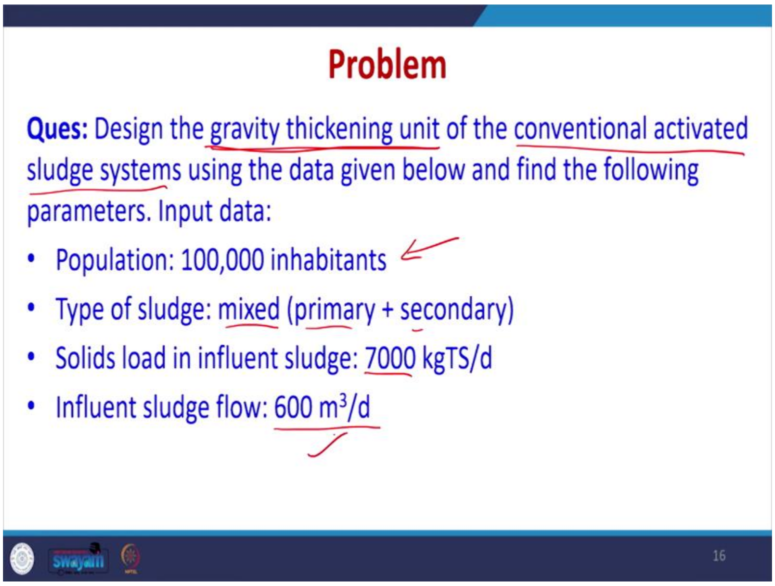
(a) Computation of the required surface area:

$$\text{Area} = \frac{\text{Solids load}}{\text{Solids loading rate}} = \frac{7000\ \text{kgTS/d}}{40\,\text{kgTS/m}^2\text{d}} = 175\ \text{m}^2$$

(b) Verification of the hydraulic loading rate

$$HLR = \frac{Flow}{Area} = \left(\frac{600\,m^3/d}{175\ m^2}\right) = 3.4\ m^3/m^2d$$





$$Flow = HLR \times Area = 20\ (m^3/m^2d) \times 175\ m^2 = 3500\ \ m^3/d$$

So let us calculate the parameters, because designing means we have to calculate the hydraulic loading rate, we have to calculate the required surface area. So first calculate the required surface area. So that for the gravity thickening we can assume, we can take the solids loading rate roughly as 40 kgTS per meter square per day. So if you do that, the required area is solids load divided by solids loading rate. So 7000 kgTS per day divided by

40 kgTS per meter square per day. So kgTS goes off this this goes off. So we have 175 meter square will be the required surface area for this gravity thickener.

Now verification of the hydraulic loading rate whether we are within the limit or not. So we determine the hydraulic loading rate via flow divided by area. So flow is 600 meter cube per day, already it is given in the data, in the previous slide, so this is 600 meter cube per day. Now 175 is the area which is calculated in this section. So if we divide, it is coming out 3.4 meter cube per meter square per day.

So this value is lower than the range of 20 to 30 meter cube per meter square per day. So to avoid shifting conditions in the thickener recalculate that. So we let us calculate on 20 meter cube per meter square per day. If this is the hydraulic loading rate, what will be the flow required? The flow required will be HLR into area. So this is coming out 3500 meter cube per day is the flow rate which is required for gravity thickener.

As the influent flow rate is only 600 meter cube per day additional 2900 meter cube per day of final effluent is recycled flow which is required to increase the HLR. So we have to see. Now if we assume the number of thickener to be two that area of each thickener will be 87.5 meter square. So this is there.

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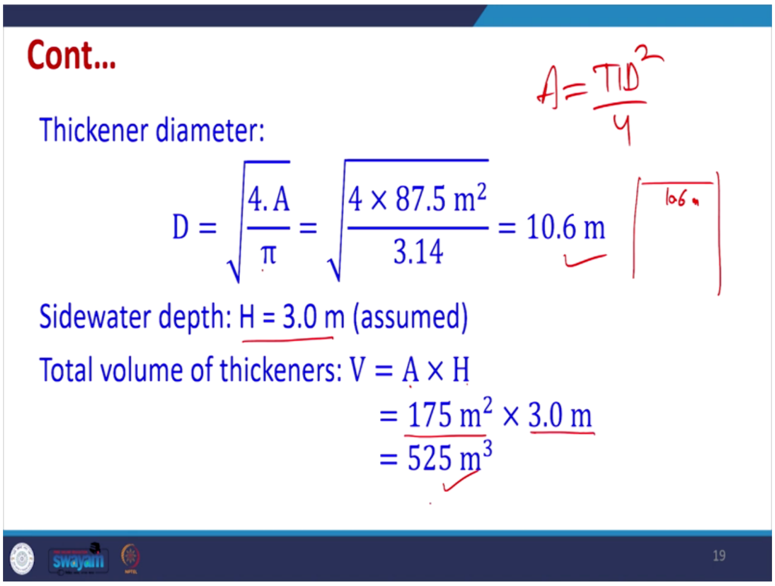

Thickener diameter:

$$D = \sqrt{\frac{4.A}{\pi}} = \sqrt{\frac{4 \times 87.5\ m^2}{3.14}} = 10.6\ m$$

Side water depth:

H = 3.0 m (assumed)

Total volume of thickeners:

$$V = A \times H$$

$$= 175\ m^2 \times 3.0\ m$$

$$= 525\ m^3$$

Now let us calculate the thickener diameter. So the thickener diameter can be calculated as D is equal to depending upon the area. So it is 87.5, so we are assuming the area is equal to pi D square by 4. So using this formula D is equal to 4 A by pi. So if you assume this is the diameter of the gravity thickener which is coming, it is 10.6 meter which is coming. And now if side water depth, the depth which is there, and this is the diameter which is 10.6 meter now the side water depth you have to calculate.

Now the total volume we are assuming this to be 3 meter. So in this case the total volume of the thickener will be 525 area into H. So area is already 175. So this is 3 meters of 525 meter cube will be the volume that has to be required.

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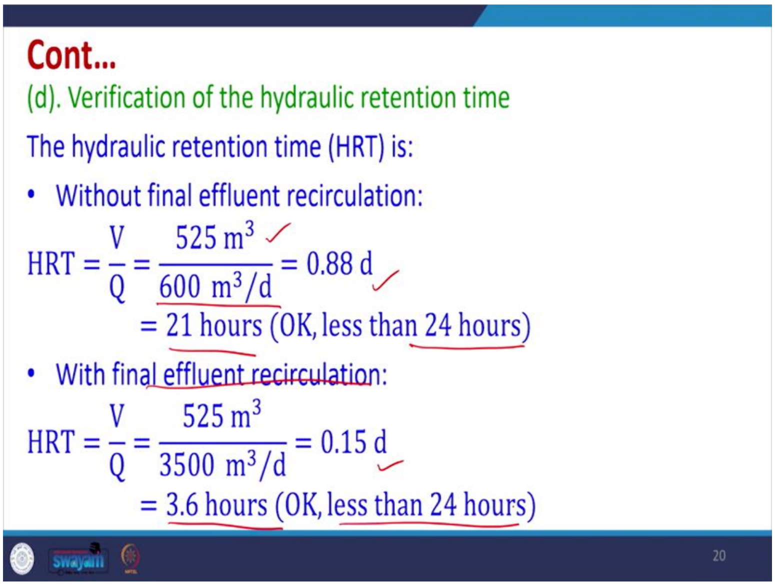


(d). Verification of the hydraulic retention time

The hydraulic retention time (HRT) is:

Without final effluent recirculation:

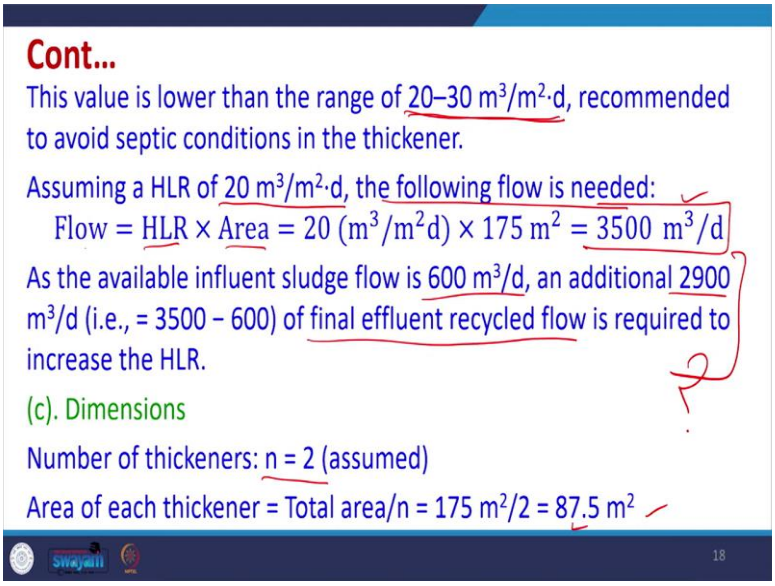
$$HRT = \frac{V}{Q} = \frac{525\ m^3}{600\ m^3/d} = 0.88\ d$$

$$= 21\ \text{hours (OK, less than 24 hours)}$$

With final effluent recirculation:

$$HRT = \frac{V}{Q} = \frac{525\ m^3}{3500\ m^3/d} = 0.15\ d$$

$$= 3.6\ \text{hours (OK, less than 24 hours)}$$



Flow:

$$\text{Flow} = \text{HLR} \times \text{Area} = 20\ (m^3/m^2d) \times 175\ m^2 = 3500\ m^3/d$$

Now let us recalculate the hydraulic retention time. So the hydraulic retention time without the final effluent recirculation is 525 was the volume and Q was the flow rate was 600 meter cube per day. So it is 0.8 day or roughly 21 hours. So it is less than 24 hours. So again if we calculate back with final effluent recirculation, it is coming out 0.15 day which is 3.6 hours. So this is better because we are able to treat more volume. So it is less than 24 hours, so again okay.

So this is the hydraulic retention time. As per this system it feels that this is the only thing that that we have to take care for this that we require additional amount of water which has to be recycled, so as to increase the HLR. Otherwise the hydraulic loading rate is not in the range of 20 to 30 meter cube per meter square. So septic conditions may prevail in the system if you do not recycle enough water. So this is what we have to take care.

So with this today we perform some calculation with respect to design of anaerobic digesters. Then further we studied the thickening importance of thickening and dewatering, we studied regarding the gravity thickener but in the next lectures we will be studying the drying bed, the sludge drying bed, how they work, and will solve problems related to that.

And then will further go ahead understand the how the pathogen removal from the sludge can happen, because this is very important and until unless we perform the pathogens removal, it will be very difficult for many cases to dispose the sludge. So we will study those in the next lecture. So today we will end with this lecture and we will continue further. Thank you.