Biological Process Design for Wastewater Treatment
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Lecture 27
UASB and Biotower

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, today we will continue with the UASB reactor that we started studying in the previous lecture. So, as we know UASB director is termed as up-flow anaerobic sludge blanket reactor.

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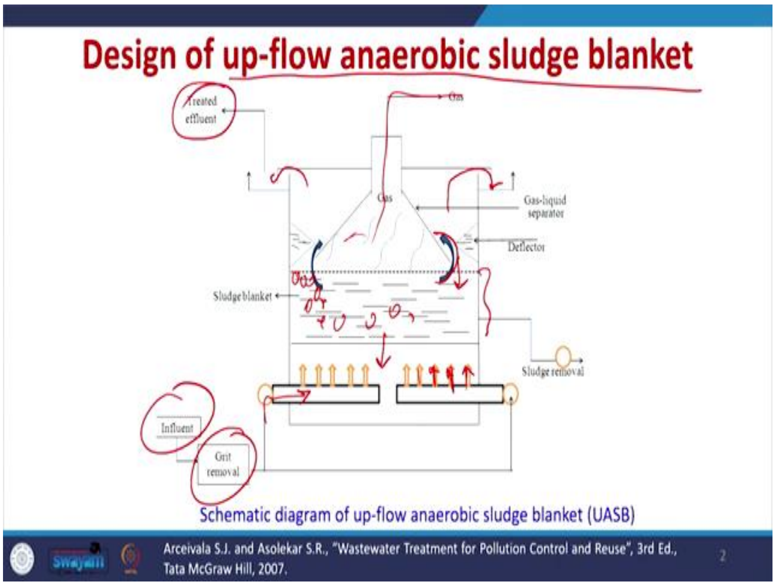

So, this today we are going to learn the design of the up-flow anaerobic sludge blanket reactor and solve one problem, in addition to that we will also study regarding the biotowers which is another type of anaerobic treatment system.

So, already in the previous class we studied that in the anaerobic sludge blanket reactor the influent is coming and after certain amount of grit removal and other things the influent goes into this system where it is uniformly distributed and we have certain flow velocity of this waste water, so that all the sludge which is generated it remains in the sludge blanket, only the those sludge particles which are heavier and whose size have increased beyond the design limit, they will go down and come further they can be removed from the sludge bed.

Now, after treatment we have the biogas which is generated the gas is collected and the water goes up, but because of the deflector the solid is goes down, some amount of solid which is smaller in size may go up otherwise it will be going down and in this zone the sludge or the organic molecules are converted into methane and CO_2 etc., So, the digestion anaerobic digestions happens in the sludge blanket wastewater after treatment goes into the weir and it is further collected and the treatment may be required. So, this is the working of the up-flow anaerobic sludge blanket reactor.

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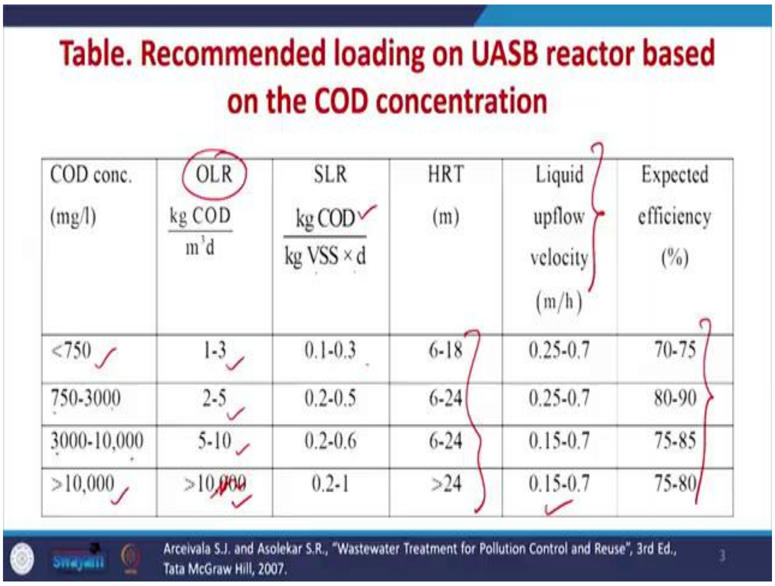

Table. Recommended loading on UASB reactor based on the COD concentration

COD conc. (mg/l)	OLR $\frac{kg\,COD}{m^3 d}$	SLR $\frac{kg\,COD}{kg\,VSS \times d}$	HRT (m)	Liquid upflow velocity (m/h)	Expected efficiency (%)
<750	1-3	0.1-0.3	6-18	0.25-0.7	70-75
750-3000	2-5	0.2-0.5	6-24	0.25-0.7	80-90
3000-10,000	5-10	0.2-0.6	6-24	0.15-0.7	75-85
>10,000	>10,000	0.2-1	>24	0.15-0.7	75-80

Arceivala S.J. and Asolekar S.R., "Wastewater Treatment for Pollution Control and Reuse", 3rd Ed., Tata McGraw Hill, 2007.

Now, there are certain recommended loadings on the UASB reactor based upon the COD consultation. So, if the COD concentration is less than 750 milligram per liter or between 750 to 3000,3000 to 10,000 more than 10,000, so depending upon that the organic loading rate is recommended, so it is recommended in the range of 1 to 3, 2 to 5, 5 to 10 greater than 10, so like this it may be recommended.

Similarly, the sludge loading rate which is defined as the kg COD divided by kg VSS per day, so this is also recommended in certain range. HRT depending upon the COD concentration is in the range of 6 to 24 or more than 24 also, so the hydraulic retention time. The liquid up-flow velocity which is one of the most critical parameters, it varies in the range of 0.25 to in fact it varies in the range of 0.15 to 0.7.

Similarly, expected efficiency is depending upon these are given and we can also that means after achieving this much efficiency we have still to go for further COD removal, so that we can meet the desired quantity of effluent which may be 30 milligram per liter of BOD or 100 milligram per liter of COD. So, depending upon the standards we may have to go for further treatment after the USB reactor.

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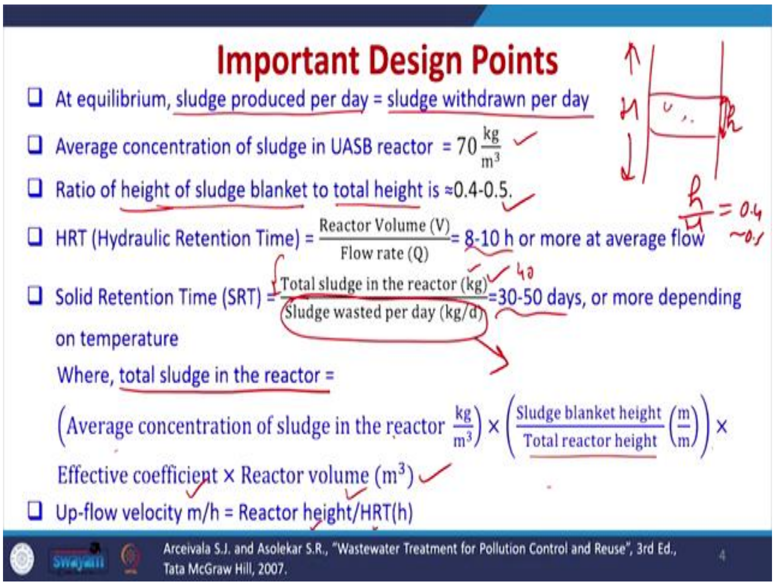

Now, some of the important design considerations are that at the equilibrium the sludge produced per day will be equal to sludge withdrawn per day. So, this we have to see that the sludge removal mechanism have to be there and whatever is the sludge produced per day that much amount of sludge has to be withdrawn per day.

The average concentration of the sludge in the UASB reactor is may vary, but it may be in the range of like 70 kilogram per meter cube. Ratio of height of the sludge blanket to total height, so that meant if the reactor is this and this is capital H and the height of sludge blanket this is a small h, so this h, h divided by H it is in the range of 0.4 to 0.5, so this is there.

The hydraulic retention time which is like reactor volume to flow rate, so it may be 8 to 10 hours it may vary also but it can be taken. The sludge retention time also may be between 30 to 50 days or more depending upon the temperature.

Now, for some cases we will have to calculate the total sludge in the reactor at any time, so how it can be calculated, it can be calculated during designing whatever average concentration of sludge in the reactor we are taking like here it is given 70, so average concentration in the sludge into sludge blanket height, so this small h divided by total reactor height into effective coefficient within the sludge blanket what is the effective coefficient and the reactor volume. So, through this we can calculate the total sludge in the reactor for obtaining the sludge retention type.

So, whatever sludge reactor this tension time, we will have to calculate that how much sludge has to be removed per day, so for doing this since we are taking suppose we take 40, so we have to calculate the total sludge in the reactor and divided by 40 this will be the sludge wasted per day.

But for calculating the slash wasted per day we will have to find out the total sludge in the reactor. So, we can use this formula for calculating the total sludge in the reactor. Also up-flow velocity which is critical parameter can be calculated by reactor height divided by the HRT whatever HRT we are going to take, so this is there.

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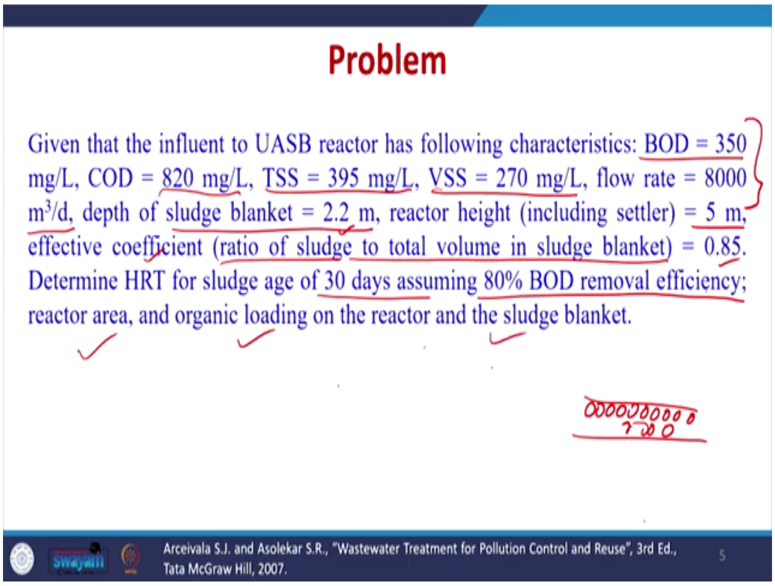

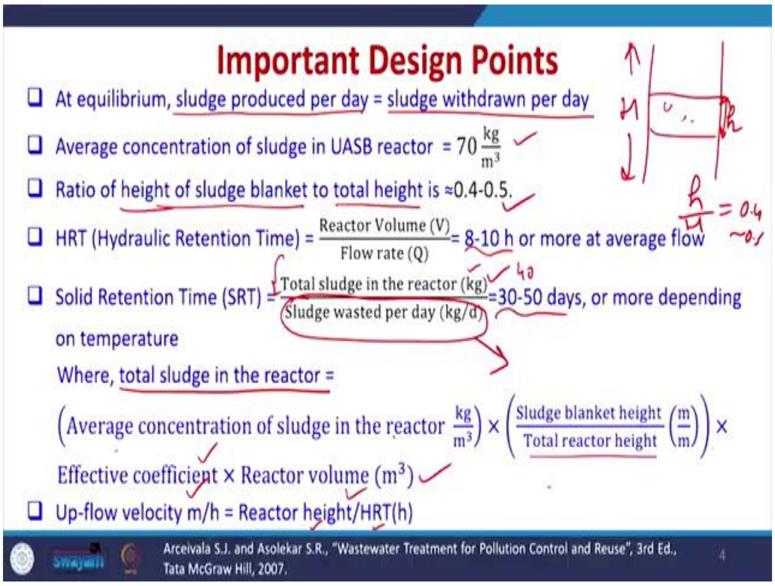

Now, let us solve a problem to understand some of these design parameters and how they are taken care of. So, in this question it is given that, given that the influent to the UASB reactor has following characteristics, it has a body of 350 milligram per liter, COD of 820 milligram per liter, TSS of 395, VSS is 270 milligram per liter, the flow rate is 8000 meter cube per day. And we are also assuming the depth of sludge blanket is 2.2 meter, so this is there.

So, the first are the influent characteristic, then we are assuming something with respect to UASB reactor also. So, we are assuming that the reactor height including the settler zone is 5 meter, the height of the sludge blanket we want to keep around 2.2 meter that means roughly 0.4, so this is the idea.

Now, effective coefficient which was here also given the effective coefficient that means the ratio of sludge to total volume in the sludge blanket. So, if it is the sludge blanket, so actually the sludge how much volume of this is occupied by the sludge. So, this effective coefficient is 0.85 that means within the sludge blanket zone the sludge occupy 85 percent of the total volume.

Now, determine HRT for sludge age of 30 days assuming that 80 percent BOD removal efficiency we have to target. So, we have to find out the HRT, we have to find out the reactor area, organic loading on the reactor and the sludge blanket. So, all these calculations we had to perform we are assuming that we want to remove 80 percent of the BOD removal efficiency, so we have to determine the HRT also. We have assumed for few of the thing that reactor height we are going to keep as 5 meter the effective coefficient is 0.85 and the depth of the sludge blanket is 2.2 meter.

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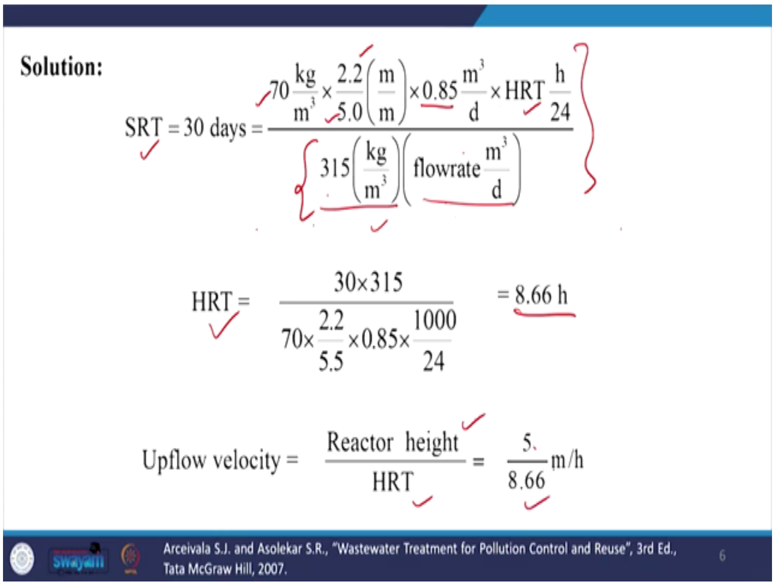

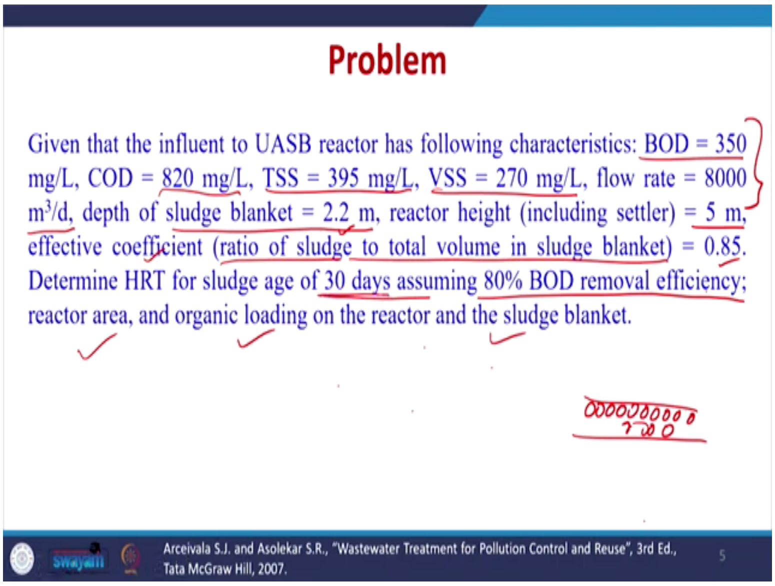

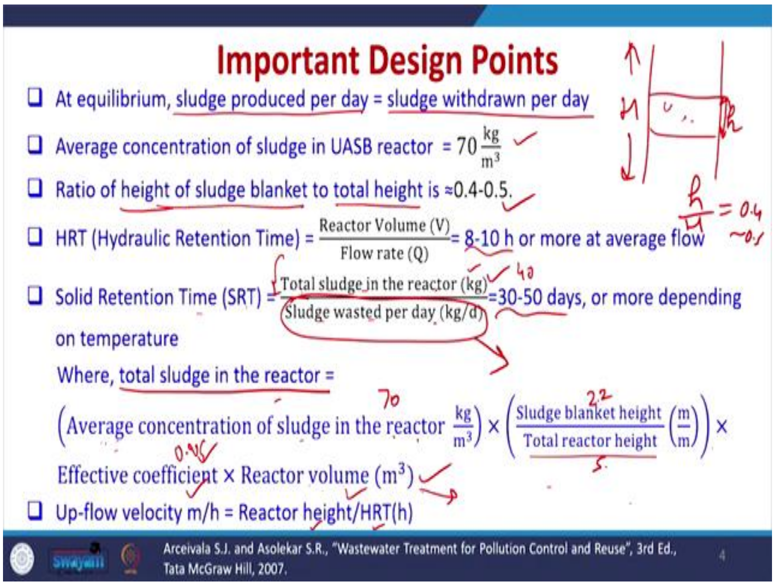

SRT:

$$\text{SRT} = 30 \text{ days} = \frac{70\frac{\text{kg}}{\text{m}^3}\times\frac{2.2}{5.0}\left(\frac{\text{m}}{\text{m}}\right)\times 0.85\frac{\text{m}^3}{\text{d}}\times \text{HRT}\frac{\text{h}}{24}}{315\left(\frac{\text{kg}}{\text{m}^3}\right)\left(\text{flowrate}\frac{\text{m}^3}{\text{d}}\right)}$$

HRT=

$$\frac{30\times 315}{70\times\frac{2.2}{5.5}\times 0.85\times\frac{1000}{24}}$$

HRT= 8.66 h

$$\text{Up flow velocity} = \frac{\text{Reactor height}}{\text{HRT}} = \frac{5}{8.66}\text{ m/h}$$

Now, to let us calculate the SRT first, so SRT has been given to be 30 days, so this is already given. Now, the formula for SRT is like this SRT is equal to we define the formula that solid retention time is equal to total sludge in the reactor divided by sludge wasted per day. So, we are going to use this formula.

Now, sludge wasted per day is 315 kg per meter cube into the flow rate, so the overall formula can be calculated first we have to calculate the total sludge in the reactor to total sludge in the reactor is average concentration of sludge in the reactor which is 70, the sludge blanket height which is given here in this case is 2.2, the total reactor height is 5 meter this is 0.85 and that reactor volume we can calculate. So, this is what has been done here.

So, you can see 70 is this, 2.2 meter is the height, 5 meter is the reactor height, 0.85 is the total effective coefficient. Now, in place of reactor volume we are taking the HRT into concentration, so HRT divided by flow rate, so if we can replace reactor volume we can actually write in place of reactor volume as HRT into flow rate.

So, we can always like this, so this becomes HRT and also the sludge wasted per day is 315 milligram per liter it comes from the fact that the only certain amount of TSS and can be removed, so from that calculation we can roughly calculate that how much sludge will be wasted per day. So, this will be the 315 data is coming from that.

So, if we know this the sludge wasted per day, so from the flow rate etcetera we can calculate the in place of reactor volume we have replaced the HRT into flow rate and from that the volume that this data is coming. So, if we perform this calculation we can roughly calculate the HRT to be 8.66 hour. Now, the up-flow velocity will be reactor height divided by HRT which is 5 divided by 8.66 meter per hour. So, we can calculate that.

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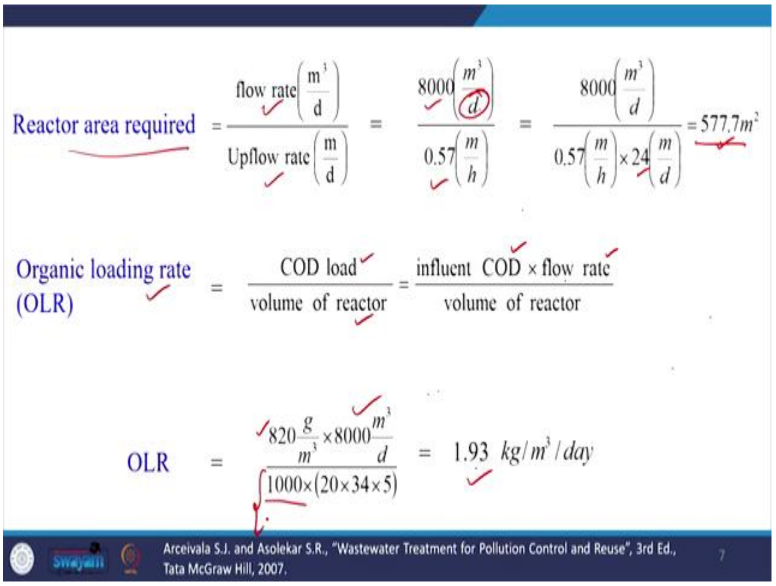

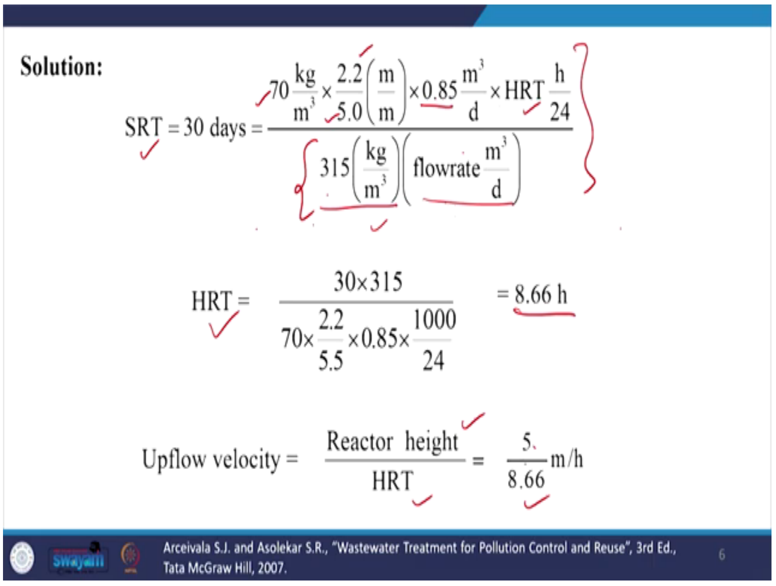

Reactor area required:

$$= \frac{\text{flow rate}\left(\frac{\text{m}^3}{\text{d}}\right)}{\text{Upflow rate}\left(\frac{\text{m}}{\text{d}}\right)}$$

$$\frac{8000\left(\frac{m^3}{d}\right)}{0.57\left(\frac{m}{h}\right)\times 24\left(\frac{m}{d}\right)} = 577.7m^2$$

$$\frac{8000\left(\frac{m^3}{d}\right)}{0.57\left(\frac{m}{h}\right)}$$

Organic loading rate (OLR):

$$\frac{\text{COD load}}{\text{volume of reactor}} = \frac{\text{influent COD} \times \text{flow rate}}{\text{volume of reactor}}$$

$$\frac{820\frac{g}{m^3} \times 8000\frac{m^3}{d}}{1000 \times (20 \times 34 \times 5)}$$

1.93 kg/m^3/day

The reactor area required will be flow rate divided by the up-flow rate, now we can see here the flow rate is 8000 meter cube per day, the up-flow velocity is 5 divided by 8.66. So, it is roughly 0.57, so 0.57 is the up-flow rate. So, if we divide by this, so this comes out to be in place of per day we are calculating per hour, so we have to change this unit, so that is why 24 has been multiplied here, so the overall area comes out to be 577 meter square which is the required reactor area.

Now, if the area is known, volume is known, then we can calculate the organic loading rate. So, organic loading rate is COD load divided by volume of reactor. So, COD load is influent COD into flow rate, so the influence weight is 820 gram per meter cube and the flow rate is 8000 and volume of the reactor is 1000 into from the dimensions also we can take directly this also, so if we can divide by the height into this area that will also give the idea that what is the reactor volume and then we can get 1.93 kg per meter cube per day. So, this is the total reactor OLR which is required.

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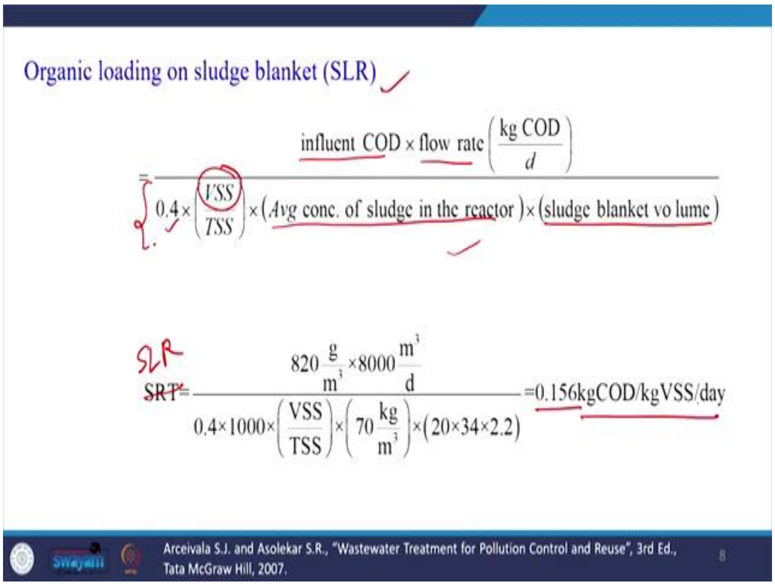

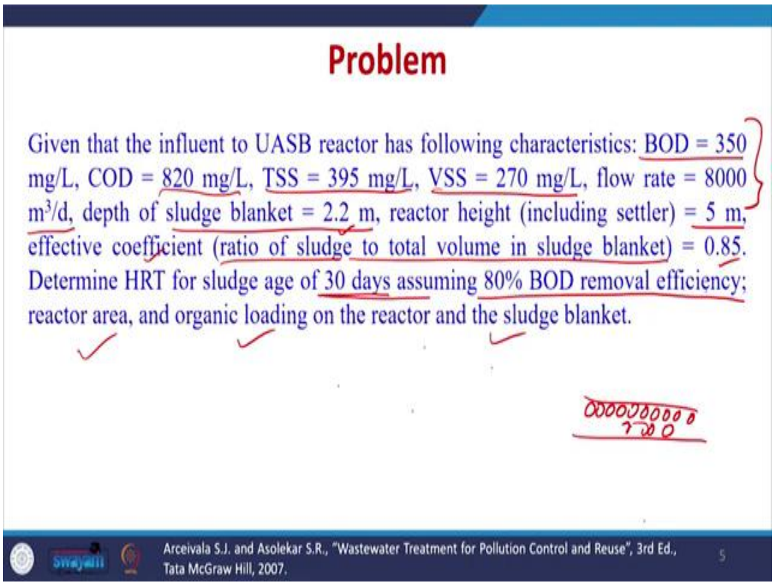

Organic loading on sludge blanket (SLR):

$$= \frac{\text{influent COD} \times \text{flow rate}\left(\dfrac{\text{kg COD}}{d}\right)}{0.4 \times \left(\dfrac{VSS}{TSS}\right) \times \left(Avg\ \text{conc.of sludge in the reactor}\right) \times \left(\text{sludge blanket volume}\right)}$$

$$\text{SRT}=\frac{820\dfrac{\text{g}}{\text{m}^3}\times 8000\dfrac{\text{m}^3}{\text{d}}}{0.4\times 1000\times\left(\dfrac{\text{VSS}}{\text{TSS}}\right)\times\left(70\dfrac{\text{kg}}{\text{m}^3}\right)\times\left(20\times 34\times 2.2\right)}=0.156\text{kgCOD/kgVSS/day}$$

Now, we have to calculate the organic loading on the sludge blanket, so we can calculate that via this formula the influence COD into flow rate divided by what is the average concentration of sludge in the reactor with respect to sludge blanket volume. So, from this we are taking and since only 0.4 is the total volume which has been occupied by the sludge blanket. So, from this idea we are calculating.

Also, we are assuming that only VSS fraction of the total TSS will be removed, so that is why we are taking here these were values and if we put all the values and take into consideration the different units which are there. So, we can easily solve the SLR and the sludge blanket, so this will be coming out to be 0.156, this is SLR the sludge blanket the organic loading on sludge blanket, so it will be coming out 0.156 kg COD per kg VSS per day. So, because we want to calculate in this case, so it we have to take convert this.

Now, we can find out that how much amount of different parameters have been calculated and we can cross check with the earlier table whether these parameters fall into this category otherwise we will have to change the parameters and again calculate back, so this is how we go ahead.

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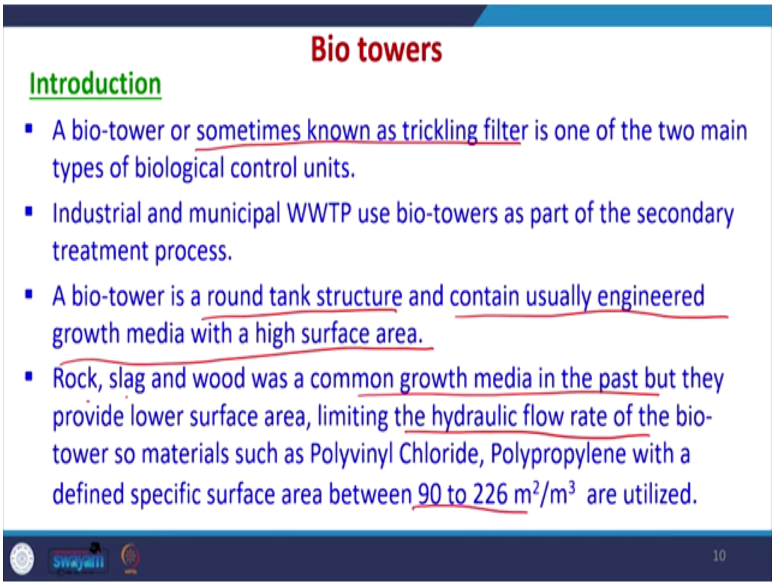

Now, we will be studying regarding bio towers, so bio towers is another type of anaerobic sludge treatment system and this can be used for anaerobic treatment, it is similar to tickling filter and but it the operations are carried out in anaerobic condition. So, a bio tower sometimes known as trickling filter is one of the two types of biological control units industrial and municipal wastewater use bio towers as a part of secondary treatment units.

A bio tower is a round tank structure and contains usually engineered growth media with high surface area. So, we can have packing which have very high surface area these packing's may be rocks, slag, wood are the common growth media in the past but they provide lower surface area.

So, now these are used then the hydraulic flow rate is will be limited, so in place of that now the packing's are made of polyvinyl chloride, polypropylene etcetera which have very high surface area in the range of 90 to 226 meters square per meter cube and they are utilized in the bio towers for treatment.

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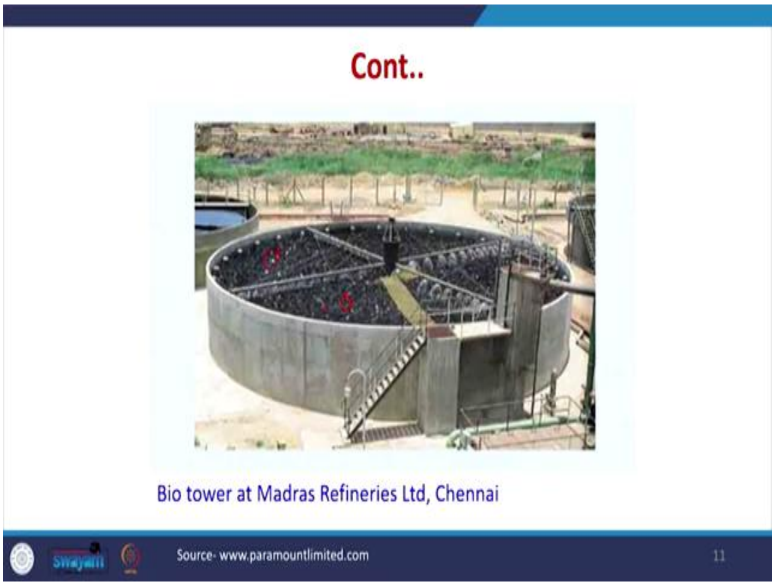

So, you can see here the bio tower one of the bio tower which is filled with the packing material and where the treatment will happen.

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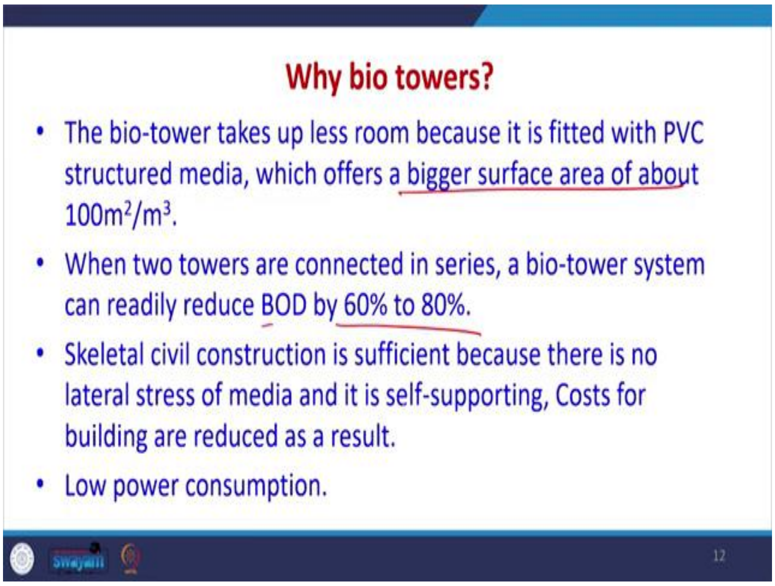

So, bio towers take up less room because it is fitted with PVC packing material and which offers a bigger surface area of more than 100 meters per meter cube. When the two towers are connected in series a bio tower system can readily reduce the BOD by 60 to 80 percent. So, this is possible. Skeletal civil construction is sufficient because there is no lateral stress of media and it is self-supporting.

So, there is no stress or no loading on the walls because of the packing. Cost for building are reduced, because of that and also it requires lower power consumption, because only water has to be distributed at the top.

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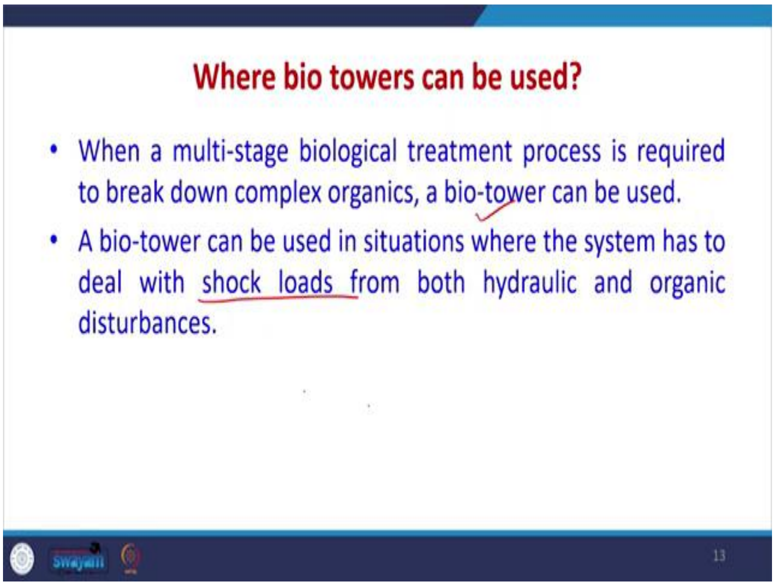

When a multi-stage biological treatment process is required to break down complex organic a bio tower can be used, a bio tower can be used in situations where the system has to deal with shock loads also, so this is possible that in terms of both hydraulic and organic disturbances also. So, bio tower is a better technique which can take care of these shock loads.

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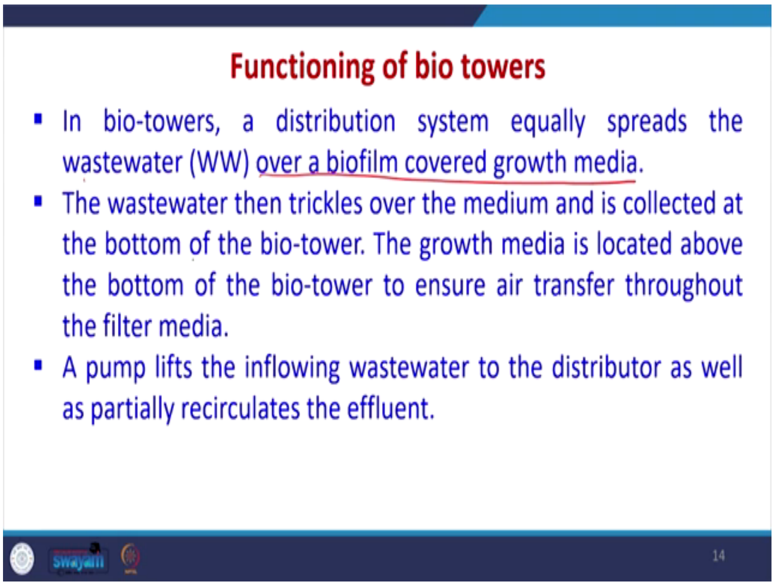

Now, the biotower functions? In bio tower distribution system equally spreads the wastewater or a biofilm covered on the growth media which may be of any of the new type of material where the surface area is high.

The wastewater then trickles over the medium and is collected at the bottom of the bio tower the growth media is located above the bottom of the bio tower to ensure air transferred throughout the filter media if required and the pump leaves the inflow wastewater to the distributor as well as partially recirculates the effluent.

Now, this type of system may work both ways anaerobic or aerobic, so depending upon the requirements we may use the bio tower, we may use the bio tower similar to tickling filter, we may use the bio tower as purely anaerobic treatment systems also.

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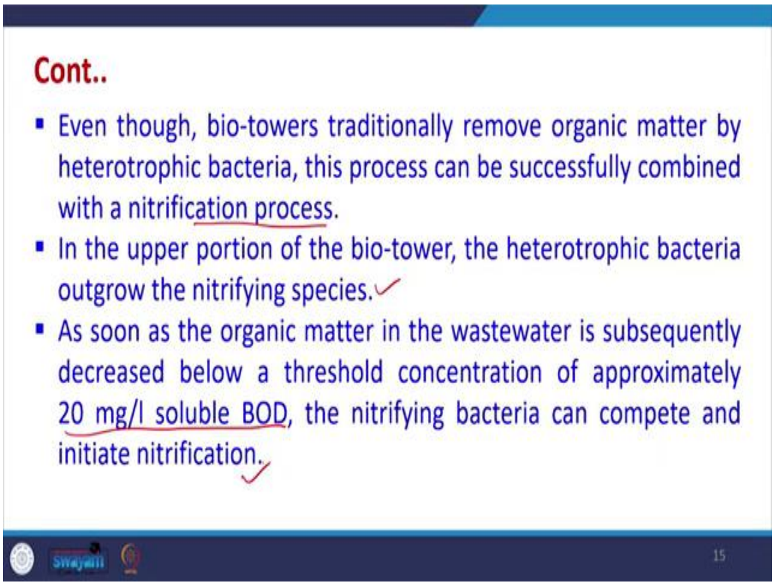

Even though bio towers traditionally remove organic matter by heterotrophic bacteria, this process can be successfully combined with the nitrification process. In the upper portion of the bio Tower the heterotrophic bacteria outgrow the nitrifying species.

As soon as the organic matter in the wastewater is subsequently decreased below a threshold concentration of approximately 20 milligram per soluble BOD, the nitrifying bacteria can compete and initiate the nitrification. So, we can have the first the removal of carbon content and later on the removal of nitrogen content.

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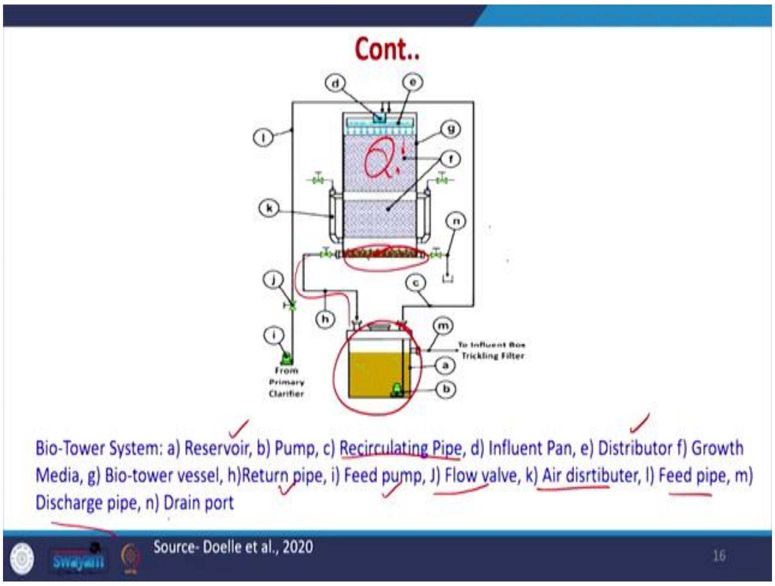

This is a schematic diagram of bio tower system, so it will contain a reservoir which is given here, it will contain pump system for distributing the water into the bio tower, then is recirculating pipe will be there after the treatment if required, then influent pan will be there, then a distributor which will be distributing the water.

Then the growth media which is packed here, then a bio tower vessel is overall, a return pipe may be required depending upon the condition, then a feed pump will be required for and certainly a flow wall has to be there for better distribution and air distributer if required, air distributer if required and a feed pipe and a discharge pipe and the drain port. So, these are the essential features of bio tower.

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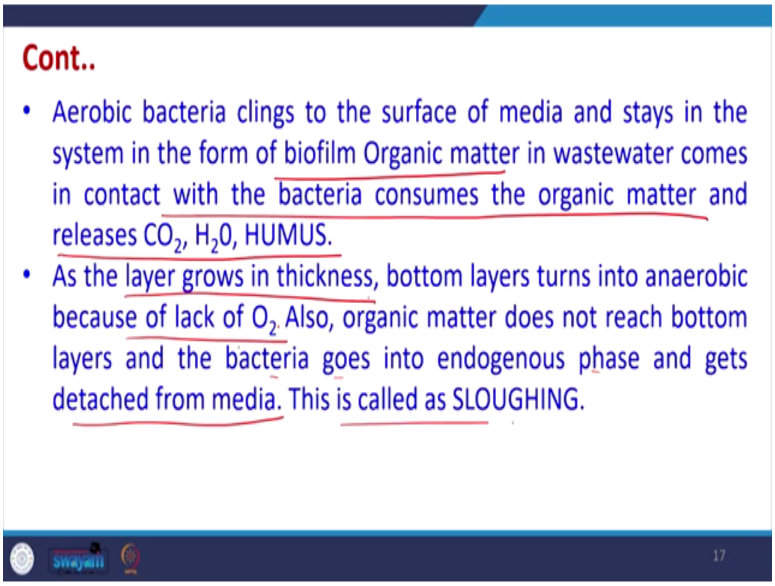

Aerobic bacteria cling if this is aerobic system then aerobic bacteria's will cling to the surface of the media and stay in the system in the form of biofilm organic matter in the wastewater comes in contact with the bacteria consumes the organic matter and releases CO_2, H_2O and HUMUS etc.

In the anaerobic system will be generating different types of methane, CO_2, etcetera and that will be coming out at the top of the tower and eventually collected. So, bio towers are also used in many places as anaerobic system, only thing is that the some performance difference will be there.

As the layer grows in thickness bottom layer returns into anaerobic, because of lack of oxygen. Also, organic matter does not reach bottom layers and the bacteria goes into endogenous phase and get detached from media this is called Sloughing. So, depending up when the aerobic conditions are prevailing, it is possible that the Sloughing will happen by itself and the extra added thickness will be removed.

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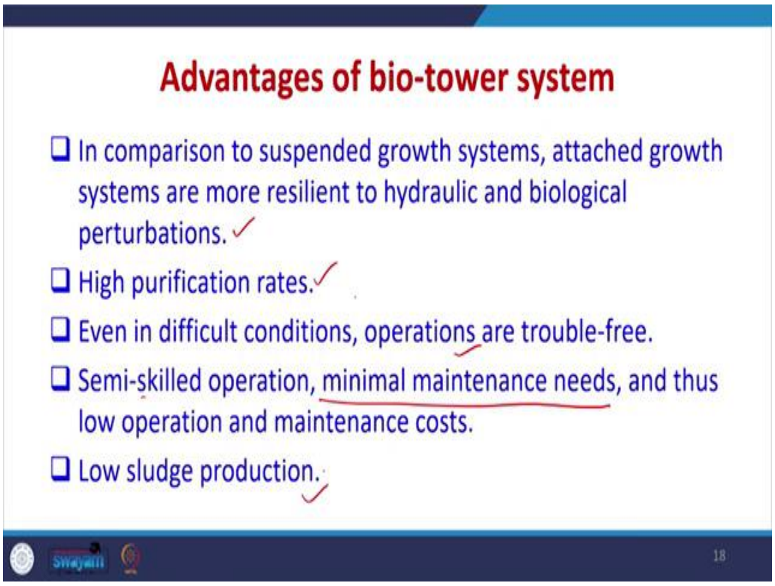

Advantages of bio towers in comparison to suspended growth system the attached growth systems are more resilient to hydraulic and biological perturbations, they have high purification rates, also in the difficult conditions operations are trouble-free.

So, in those conditions where hard conditions are there and it is difficult to operate have so many manpower still the operations can be done and generally the operations are trouble-free, so we do not have to take care of highly skilled operator is not required. A semi-skilled operation with minimal maintenance is only required and thus low operation and maintenance costs happen. Now, the sludge production depending upon the type of system it may be lower as compared to other systems.

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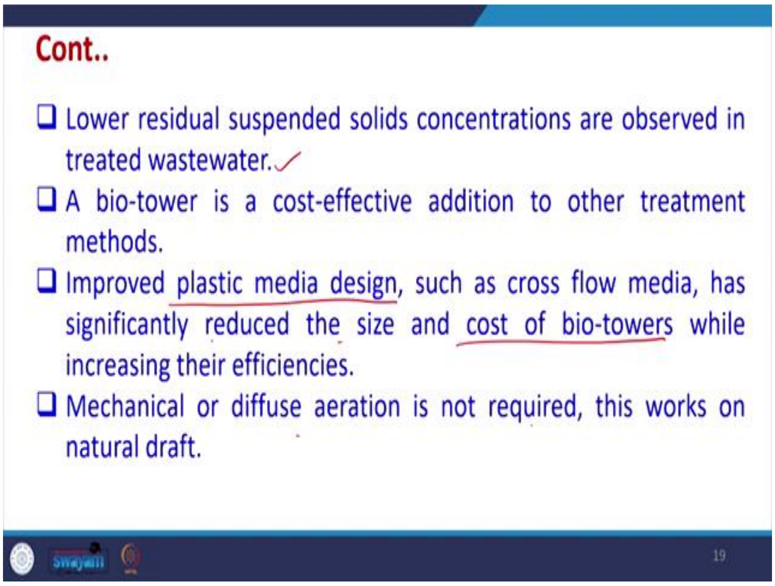

Now, the lower residual suspended solid concentrations are observed in the treated wastewater of such system, because some filtration also happens. A bio tower is cost-effective addition to the other treatment method as compared to other, but it efficiency may vary be depending upon the wastewater characteristics and other parameter.

Improved plastic media design, such as cross flow media has significantly reduced the size and cost of bio towers while increasing their efficiency. Mechanical or diffused aeration is not required for aerobic treatment, such as only natural draft in the similar to that of biological trickling filter may work.

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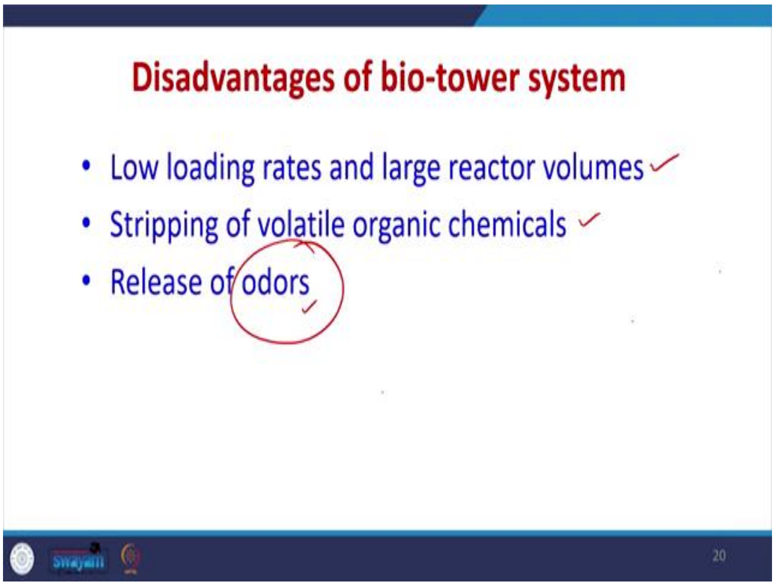

Disadvantages of bio tower system, a low loading rates are there, so that means the reactor volumes may be larger than usual. So, it is possible that we may require a larger reactor volume as compared to the traditional treatment system, so this is possible.

Then stripping of volatile organic chemicals, so because if we are using aerobic system the stripping may happen of the VOCs, so we have to take care of the VOCs in the effluent. So, this is possible, when anaerobic treatment system is there then this problem will not arise because the VOCs will go in the anaerobic treatment system and then they can be taken care of. Depending upon the condition the odor may also be released.

So, it may be if it is anaerobic treatment system very high amount of order formation may happen and people around the bio towers will feel the same. Similarly, for aerobic treatment systems also odor formation happens, now these are the disadvantages of bio tower system.

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Now, these bio tower systems are used in many applications, they can be used for treatment of municipal sewage, they are recommended for treatment of like pharmaceutical industry wastewater, Distillery wastewater, paper mill, paint industry wastewater which contains very high organic loading, then food processing industry, dairy, sugar brewery etc.

So, all those places where the concentration is higher we can go for anaerobic bio towers for methane and CO_2 formation, those places where the concentration is low we can go for an aerobic bio towers and thus perform the treatment.

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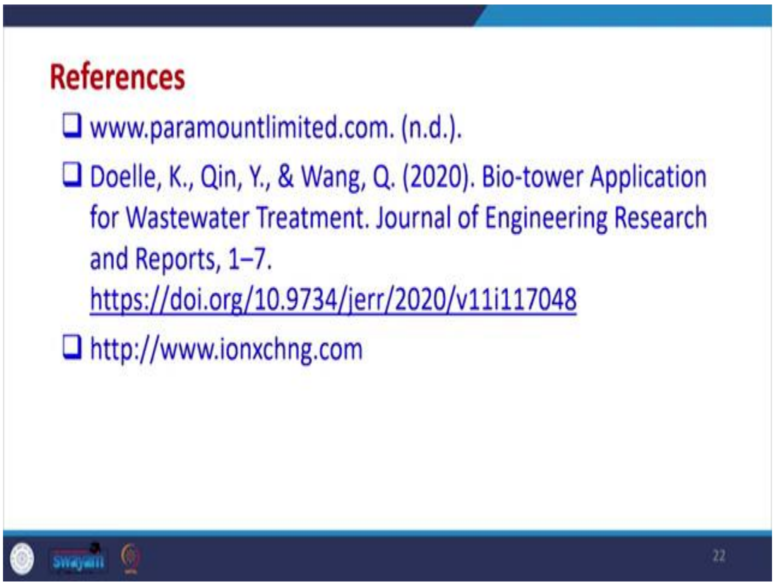

So, we have studied different types of treatment units till now, anaerobic, aerobic etcetera and within aerobic we studied the activated sludge system, tickling filter, sequential batch reactors, etc.

Similarly, we studied rotating biological disc reactor which is one of the aerobic treatment system, after that we studied the UASB reactor which is the common most anaerobic treatment system. We also studied today the bio tower which may be used as aerobic treatment system as an anaerobic treatment system. It is possible to design the attached growth systems in either aerobic means or treatment via anaerobic means.

So, we have studied the common treatment systems till now, in the further classes we will be studying the treatment of wastewaters in a specialized treatment units. So, we will continue in the next few lectures regarding the advanced treatment systems, now which are evolving and will study all those biological advanced treatment systems in the next few lectures. Thank you very much.