Water and Wastewater Engineering

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Anaerobic Process (Continued)
UASB Reactor
Lecture minus 28

As we were discussing about anaerobic treatment we have seen the difference between anaerobic treatment and aerobic treatment and the different biochemical pathways involved in the anaerobic degradation. We have also seen the entire contusive environmental conditions for the better performance of anaerobic processors. We have seen the different types of bacteria involved in the process and the role of each bacteria and the nature of each bacteria.

Today we will discuss about all the conventional and modified reactors available which is using anaerobic technology for the treatment of wastewater. So coming to the conventional anaerobic treatment system or classical anaerobic treatment system we have the septic tank which was there from the 19th century itself. It was invented by Cameron in England. He was the first person to use this septic tank. The septic tank is nothing but a tank which allows the settlement of suspended solids in wastewater.

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The settling time is so large that means it gives time of 5 to 10 days so during this period whatever suspended solid is present in the wastewater will be settling down and at that time it will not be having any oxygen supply. So what will happen in the sludge settled in the bottom of the tank is it will be under anaerobic conditions. At this condition anaerobic bacteria will be provided and the solids will be undergoing anaerobic degradation. So after research what will happen is the organic matter present in the system will be getting reduced and biogas will be produced. The biogas will be coming from the bottom of the system to the top. Therefore, because of this biomass movement some of the solids maybe getting floated, this is a disadvantage of the septic tank.

I will show the picture of a septic tank. This is the one.

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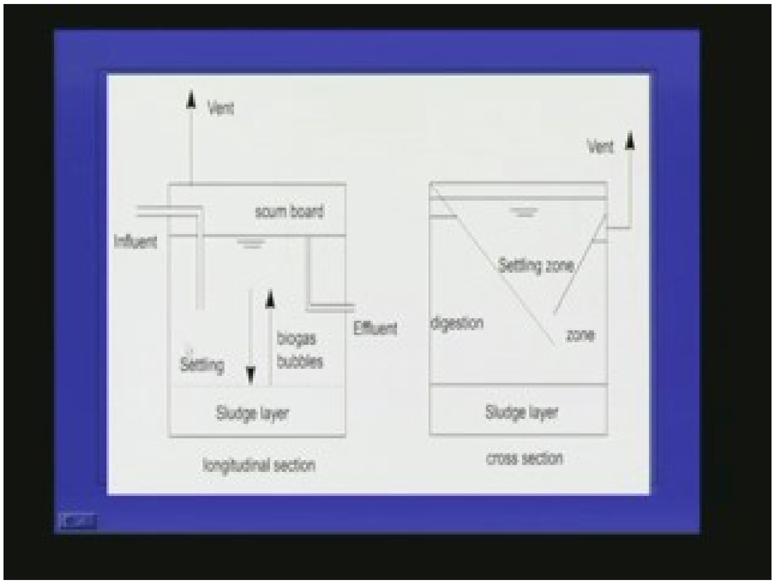

This is the reactor or any closed container and it is not open to the atmosphere only one pipe is there and the influent is coming like this (Refer Slide Time: 3:12) and enough detention time is provided so that all the organic matter in the suspended form will be settling down. Yu will be getting a sludge layer here, the sludge layer will be having so much of organic matter and the oxygen availability is almost nil so the entire system will be under anaerobic condition.

So, after the result what will happen is this sludge undergoes anaerobic decomposition and biogas will be produced as a byproduct. This biogas will be coming in this direction the upward direction and settling will be taking place in the downward direction due to this biogas movement. There will be some trouble. So as a result some particles whatever has already settled may come up and it will float in the surface of the septic tank, that is one of the disadvantages of this septic tank. And whatever scum or oil is present in the influent will be definitely coming up to the bottom of the tank.

So usually in the septic tank there will be scum board which provides the system to enter in the effluent channel so the scum will be retained here and whatever treated effluent is there will be coming out through this one so what is happening in system is the organic content of the wastewater will be decreasing drastically because the influent will be having lot of suspended solids. All the suspended solids will be getting removed from the system and the effluent will be having only the soluble COD whatever is coming out along with the effluent. A part of the soluble COD also will be getting removed in the septic tank. This was the conversional anaerobic system which was used in the 19^{th} century in the first anaerobic reactor which was being used in the well.

The emuff corn this is another anaerobic unit which is conventionally used. This is a modification of septic tank. I have already told that in septic tank because of the bio gas movement the solids can float so in septic emuff corn or emuff tank it is impossible because here we can see that here this arrangement separates the digestion zone and settling zone and gas or the biogas produced due to the anaerobic digestion is not coming or not entering in the settling zone. The biogas will be stored in the digestion zone only so there will not be any turbulence created in the system so what will happen is, you will be getting relatively clear effluent in the emuff tank.

This (Refer Slide Time: 5:50) is the vent through which the biogas is removed from the system and all the digestion will be taking place here and this is the sludge layer and this entire portion will be acting as the settling zone and the effluent will be collected from here. thus, you will be getting a much more clarified effluent from the emuff tank compared to the septic tank. And if you see the history we can see that the first biggest public health system or environmental or wastewater treatment system employed was in Chicago in 1935 they have used this emuff tank in series the treatment capacity of the system was 1.8 mm per day.

The first treatment system in the history of environmental engineering was made up of this emuff corn then or emuff tanks. So what is the problem, why this anaerobic technology is not coming into existence or is it not becoming popular even now, we will see the reason in detail after a while.

The conversional anaerobic system is the anaerobic lagoons. We have discussed this in detail when we were discussing about ponds and lagoons. In anaerobic lagoons what is happening is we can go for high organic loading and the waste will be staying there for a long time so what will happen is because of the high organic loading rate whatever air that is entering or whatever oxygen that is entering from the atmosphere will not be enough for maintaining an aerobic condition in the system so the entire pond will be in anaerobic condition. Thus, because of the anaerobic bacteria degradation will be taking place and a portion of the COD will be getting removed from the system.

If you talk about the efficiency of these anaerobic ponds if you give sufficiently long detention time like 5 to 10 days then you will be getting an efficiency of 50 to 70%. Or we can find out the efficiency using this empirical formula; 1 minus 2.5 by (HRT) raised to 0.050 here where HRT is the Hydraulic Retention Time in days. This is the expression derived from many field experiences or they have studied many field anaerobic ponds and they have evaluated the performance and from that performance they reach this imperial equation.

We can see that the HRT is in the range of 5 to 10 days so the volume of the reactor required will be very very high. That is one of the reasons why anaerobic process did not become popular for domestic wastewater treatment. Though anaerobic treatment was the first one to come into existence in 1935 as a treatment process but after that aerobic system took over anaerobic process because aerobic system we can achieve very high efficiency say 90 to 95% within few hours. Usually we give 8 to 10 hours HRT in the aeration time. So, compared to this one anaerobic system requests lot more time so naturally if the volume of the treatment system will be very very high, if we can reduce the detention time definitely the treatment system will become more attractive. The reason is, we have seen that anaerobic process is having many advantages over aerobic process.

A few other energy requirement is very very less because in aerobic system we have to aerate the wastewater, we have to supply oxygen externally to meet the oxygen requirement. But in anaerobic process oxygen is not required at all because the substrate will be acting as the electron known donor as well as electron acceptor. Another reason is the sludge production anaerobic process. We have seen that the organic matter whatever is used for the anabolic purpose or for anabolism or when cell synthesis is very less, less than 10% whereas in aerobic process it is around 40 to 60%. So definitely the sludge produced in anaerobic process is much, much less compared to aerobic process so sludge handling is not a problem at all.

Moreover the sludge whatever is generated in anaerobic process is almost mineralized so we don’t have to go for any further treatment we can directly put it into sludge drying beds. So anaerobic process is having many advantages over aerobic process but the most important disadvantage is this one; it takes large detention time to get high efficiency. So if we can overcome this one anaerobic process will definitely become popular. Therefore to avoid that one or to make anaerobic process more popular and people who were working in this area for a long time came up with the idea of high rate processes.

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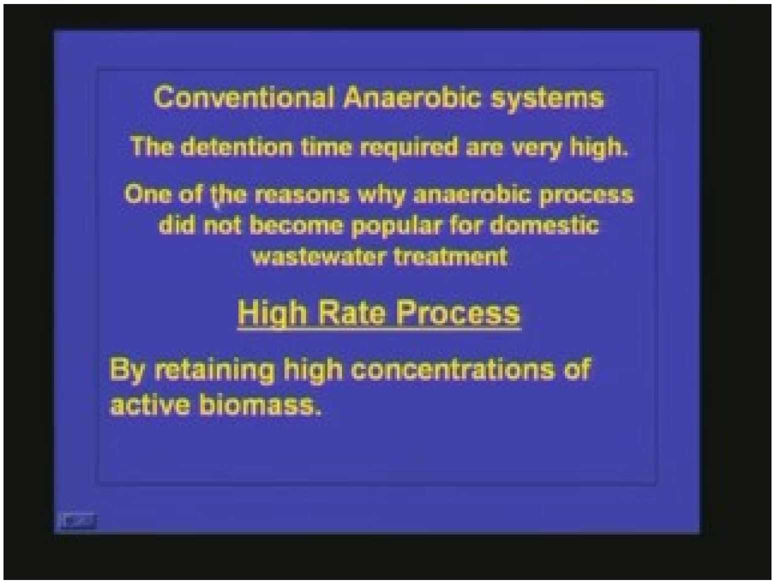

In high rate processes what is happening is the system is able to retain high concentrations of active biomass. That means the microbial concentration in the system will be very very high. We have seen that the regeneration time or the reproduction time of this anaerobic bacteria especially the methanogens the methane produced in bacteria is very very high. If the regeneration time or reproduction time is very high naturally the biomass concentration will be very less. So if you are allowing the biomass whatever is generated in the system to go out what will happen is the system will not be having enough biomass so naturally the treatment efficiency will be coming down. So if you can clearly divide the hydraulic retention time and biological sludge retention time then the system can hold lot of biomass inside.

Once the biomass concentration inside the system is very very high naturally the treatment efficiency will be high because in any biological system as I have already told many times the workers are microorganisms. So if you can increase the number of workers definitely the treatment efficiency will be more. That is the very principle of these high rate processors.

Now we will see the mechanism of sludge retention in high rate anaerobic systems. The sludge can be retained basically in two different ways. One is systems based on immobilization of the sludge and another one is systems based on liquid solids separation with the return of the separated solids to the reactor.

When we talk about the systems based on immobilization of sludge the reactors which are working under this principle are up flow and down flow anaerobic filter, sludge bed reactors such as granular bed expanded or fluidized reactors. In this case what is happening is some inert material is there either it is sand or plastic media or any synthetic media and on that the biomass will be growing so naturally the medium will be having high density so it will not be going out of the system along with the liquid. So whatever the biomass generated in the system will be staying inside the system so definitely we will be increasing the biomass concentration.

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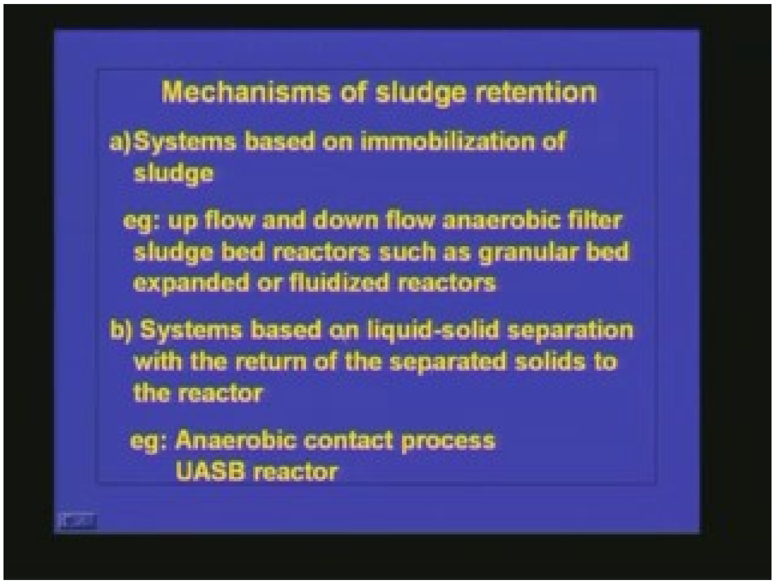

In the second system what we are doing is this is a form of modified activated sludge process. So in activated sludge process what we are doing the aeration time we have lot of microorganisms so we are allowing the microorganisms to settle in the secondary sedimentation tank and we want to maintain a high concentration of biomass in the aeration time. So what we do is we allow a portion of the settled biomass present in the secondary sedimentation tank to come to the aeration tank so naturally the biomass concentration in the aeration time increases.

A similar system works in anaerobic process also and there we provide some arrangement which can easily separate the solid and liquid from the effluent and the solids will be coming back to the system. This arrangement can be provided either within the system or as a separate unit. So depending upon that one we can see different types of reactors. We will see the reactors whatever is commonly used or the reactor which is working on this high rate principle.

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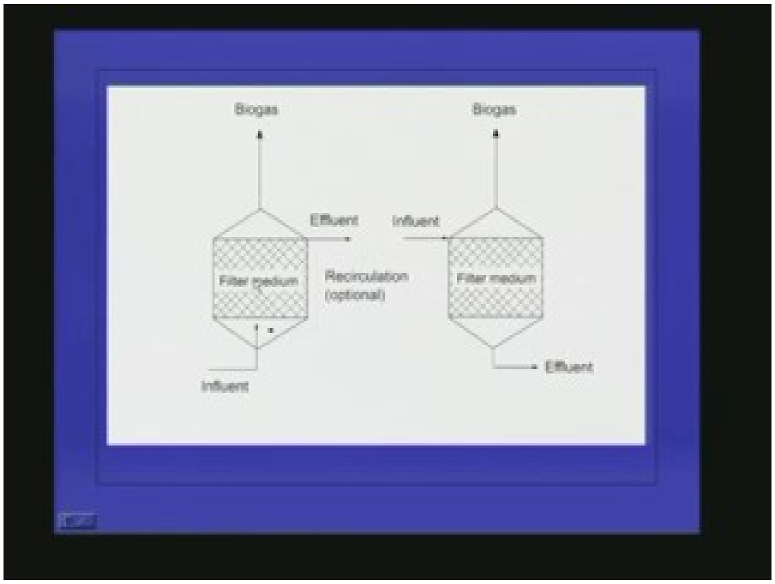

These are the anaerobic filters, this one is up flow anaerobic filter (Refer Slide Time: 14:36) and this one is down flow anaerobic filter. Here what is happening is we can see this dash line this is the filter media this can be any inert material on which microorganisms can grow fast. So the influent will be going like this and active biomass will be growing in this filter media just like our trickling filter or rotating biological contactors. The biomass will be growing in this filter media but the only thing is the entire system is in anaerobic condition because nothing is open to the atmosphere so now entry of air will be there in the system so influent will be going like this and the organic matter whatever is present in the influent will be coming in contact with the biomass in the filter and the biomass will be utilizing the organic matter and some more new cells will be generated and the remaining part will be converted to carbon dioxide and methane and the biogas is collected here (Refer Slide Time: 15:40).

These anaerobic filters are commonly used in industrial wastewater treatment where the organic loading is very very high. This system can take lot of organic loading in the range of 10 to 20 kilogram per meter cube that is the organic loading rate and one of the problems which is usually faced in this type of filters is clogging because with respect to time what will happen is the biomass concentration or biomass thickness in the filter will be very high and that will be slowly decreasing the porosity of the medium and filter clogging can take place.

Another reason for clogging is this influent will be having lot of suspended solids.
Those suspended solids will be coming and settling down here in the bottom portion of the filter so that can also clog the filter and afterwards there may not be sufficient flow and lot of head loss will be there and so on. Sometimes if the influent flow rate is not sufficient what usually is done is, re-circulate a portion of the effluent treated effluent here so that it will get enough velocity for the flow.

Now coming to the down flow fixed bed anaerobic filter here the influent is coming from the top of the filter and the effluent is collected from the bottom of the filter and here we can have the biogas collection system and this is the filter media and on which the biomass will be growing. The advantage of this system is the influent is coming like this and biodegradation is taking place as a result the biogas methane and carbon dioxide will be produced. The gas will be going in the upper direction and influent will be coming in the downward direction so because of that one a proper contact between the wastewater and the microbial system will be taking place because lot of turbulence will be created in the system so short circuiting, clogging etc can be minimized if you go for a down flow fixed bed anaerobic filter. These two are examples of high rate anaerobic reactors.

Now we will see another type of high rate reactor.

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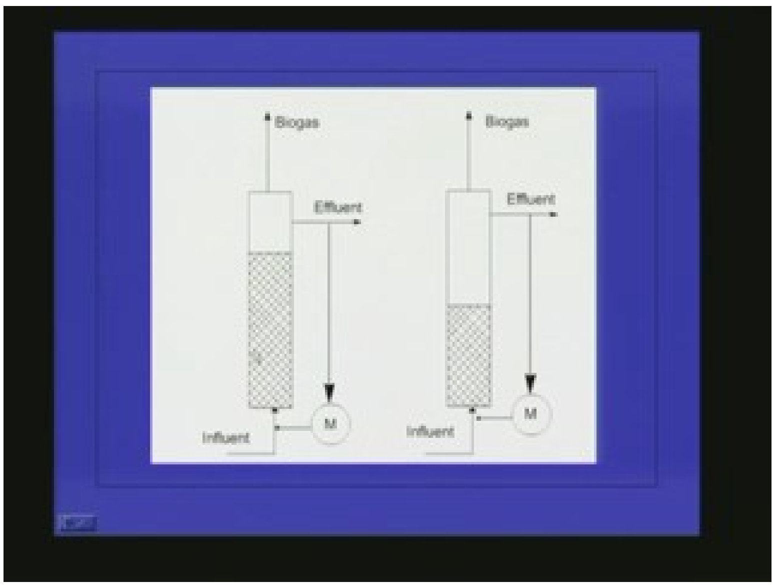

This is the example of fluidized bed reactor. Here what happens is we use sand, corn or any plastic media on which the microorganisms can grow as the supporting material so in the reactor we will be putting the supporting material and with respect to time the microorganism whatever is present in the system will be getting attached to the inert material or the support material whatever we have provided here. The support material will be having high concentration of microorganism and the influent will be coming from the up flow direction. So, from here it will be entering and it will be going in this direction and influent flow velocity will be very very high so that the medium will be in the fluidized form that means one particle will not be in contact with the other particle but everything will be in a fluidized form so as a result of this fluidization there will be very good contact between the microorganisms as well as the organic matter whatever is present in the wastewater so the treatment efficiency will be very very high.

Whatever biogas is produced will be going from here and we can collect the treated effluent from here because the microbial growth is attached here and the effluent will be relatively clear because not much microorganisms will be coming out along with the effluent. And in this system the recirculation of effluent is most of the time a mass. The reason is influent may not be having enough velocity to fluidize the bed depending upon the bed material because if it is sand particle you know the specific gravity is very very high so we need a very high upflow velocity to fluidize the material.

Most of the time we re-circulate the treated effluent to give the enough upward velocity here. Now, coming to the expanded bed reactor this is an example of expanded bed reactor. Here (Refer Slide Time: 20:13) all the particles will not be in the expanded form, all the particles will not be in the fluidized form. Here the upward velocity will be relatively low compared to the fluidized system. So, if the bed will be expanding up to 30% of the initial height say initial height was only up to here and after the influent passage it will be expanding up to here. So how can we distinguish the fluidized reactor and an expanded bed reactor? There is no clear cut distinction between these two. But if you see that if the expansion is less than 30% of the original bed height then we call it as an expanded bed reactor and if the expansion is more than 30% we call it as a fluidized bed reactor.

The advantage of expanded bed reactor compared to the fluid fluidized bed reactor is that the recirculation is less compared to the expanded fluidized bed reactor because here we want to expand it only to 30% so the velocity will be less compared to this reactor. So the pumping cost can be reduced in expanded bed reactor compared to fluidized bed reactor but efficiency wise expanded bed reactor efficiency will be lower than fluidized bed reactor because here you will be getting more contact with the biomass and the organic matter in the wastewater.

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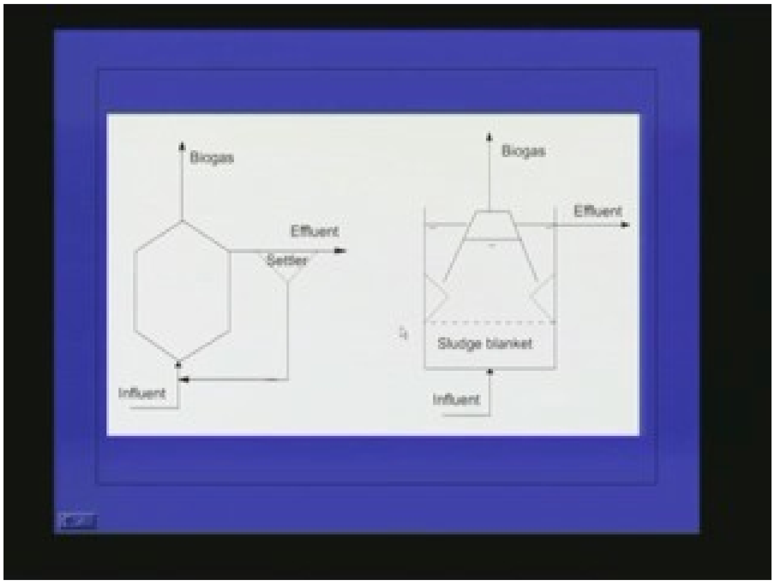

Now we will see another type of system. Whatever we have discussed so far namely the anaerobic filters, fluidized and expanded bed reactors are working on immobilized reactor system. that means some inert material we are providing on that the microorganisms are getting attached so these two reactors whatever we have seen now the anaerobic filter, down flow, fixed bed anaerobic reactor, expanded bed reactor and fluidized bed reactor all these for are coming under immobilized reactor because the bacteria are growing on some support medium the support medium can be some natural material or synthetic material. If you use synthetic material especially the plastic like substances then what will happen is the specific gravity of the particle is low so the velocity required to fluidize them or expand the bed will be less so pumping cost can be reduced drastically.

Now we will come to the systems which use the solid liquid separation process and after that one the sludge will be recycling to the system so that way we can increase the biomass concentration in the system. This is the example of an anaerobic contact process.

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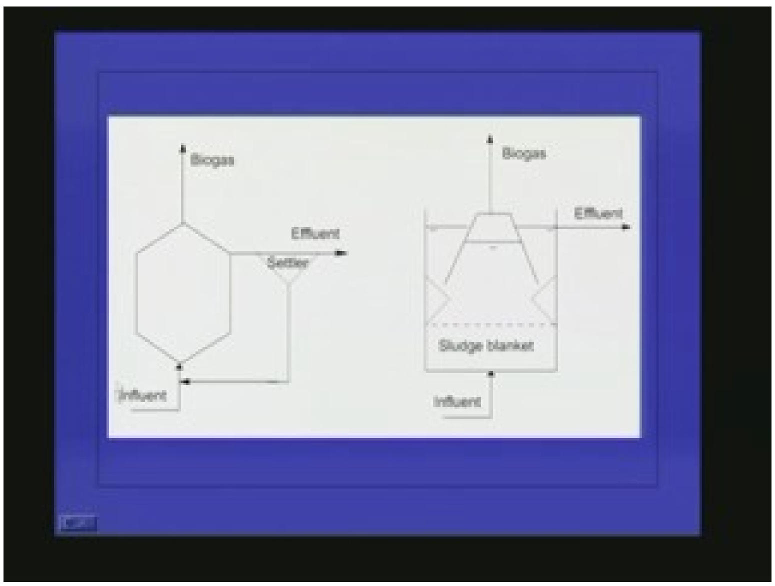

This is the anaerobic chamber, the influent is coming here (Refer Slide Time: 23:05) and this is the digestion zone so anaerobic reactions will be taking place as a result the biogas will be produced and we will be getting the effluent through this one. Because of this biogas production the entire reactor will be getting mixed up thoroughly and if the mixing is not proper we can provide the mixing externally also. So definitely whatever biomass concentration is inside the system the same concentration will be coming out along with the effluent.

So here we are collecting the effluent and allow it to settle. So this is the settler or a sedimentation tank so here all the biomass whatever is coming along with the effluent will be getting settled and all the biomass will be recycled to the system along with the influent. Therefore, the biomass concentration in the system will be very very high so we can reduce the hydraulic retention time considerably. This is known as anaerobic contact process. Here the anaerobic digestion and the settler or the sedimentation tank is separate units. The modified form of this anaerobic contact process is the UASB reactor. This is the schematic of the UASB reactor (Refer Slide Time: 24:25) the influent is coming here and we will be having anaerobic bacteria here and the effluent will be going upward and we will be collecting it from here. but in the reactor itself some provisions are provided so a portion of the reactor itself will be acting as a settling zone or a sedimentation zone so with respect to time the biomass concentration in the reactor will be very very high so we can have a very high efficiency or we will get a high treatment efficiency within a short contact period.

So what happens here see we can see some projections here or deflecting beams here and we have some arrangement here also, the treated water will be coming here and afterwards we can see that this portion is getting expanded so this portion will be acting as a settling chamber or sedimentation tank and this portion will be acting as a reactor or digestion zone. This is a modified form of emuff tanks that we have seen initially and the treated effluent will be collected from here and biogas will be collected from here. Here we are not providing any external units for the biomass settling but the system itself will be providing the settlement of the biomass or the system will not allow any biomass to escape along with the effluent.

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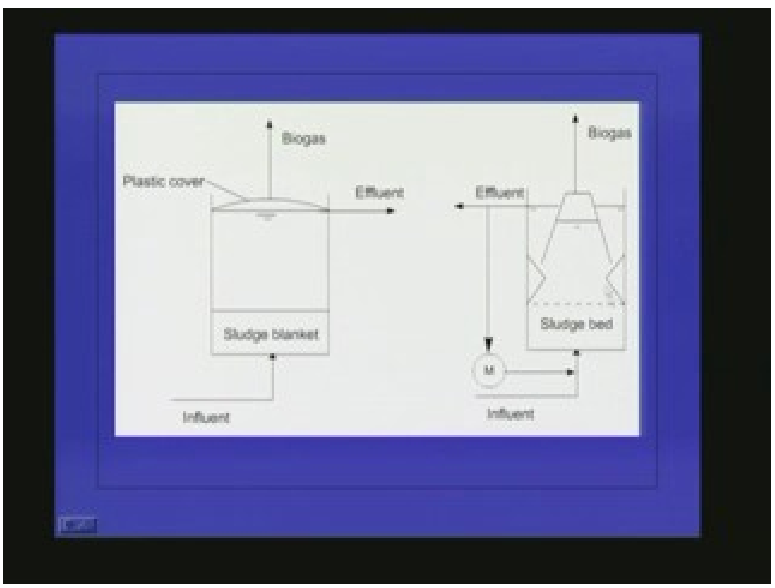

This is another type of reactor so there is no separate GLSS that means Gas Liquid Solid Separator. this is the plastic cover (Refer Slide Time: 26:05) the influent is coming sludge blanket it is here, the velocity is adjusted in such a way that by the time the water reaches here or the treated water reaches here all the biomass whatever is present in the system will be coming back to the sludge blanket, by this way the biomass concentration in the system will be increased.

This is another modification. Here (Refer Slide Time: 26:28) instead of flocculent sludge we use the annular sludge so what we can do is since the sludge is in the granular form the settling velocity will be very very high so we can use or we can treat a high organic waste or we can reduce the detention time considerably in such reactors. This is known as an EGSB reactor that means Expanded Granular Sludge Bed reactor. All these reactors are coming under high rate reactors. Now we will see the efficiencies of each reactor in detail.

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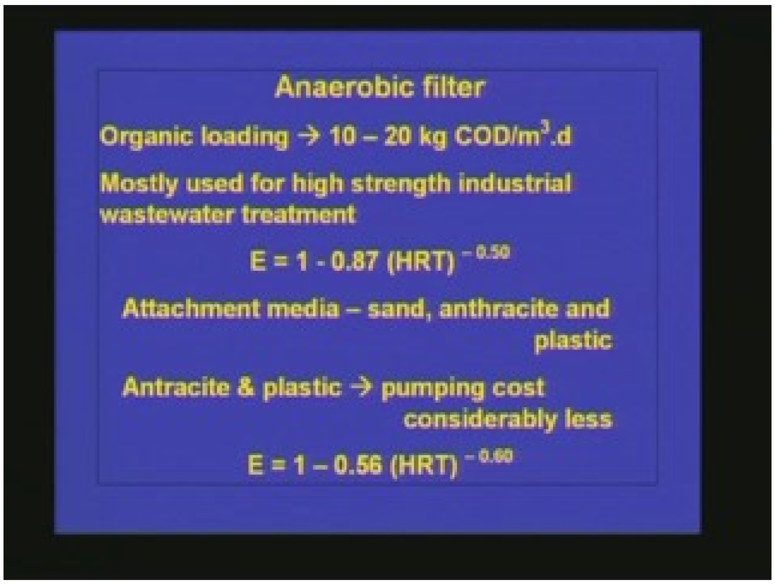

As I have already explained in the anaerobic filter we can go for very high organic loading that means in the range of 10 to 20 kilograms COD per meter cube per day and it is mostly used for high strength industrial wastewater treatment. We can derive the equations for efficiency using kinetic approach. But there are empirical expressions available if you want to find out the efficiency of the system.

The efficiency of this anaerobic filter can be found out using this imperial formula; E is equal to 1 minus 0.87 (HRT) raised to minus 0.50. Here HRT should be in hours. We have seen that in anaerobic lagoons that the efficiency is given by an empirical formula where the HRT was given as in days. But in anaerobic filter this HRT is given in terms of hours.

Now, coming to the expanded or fluidized reactor I have already mentioned that attachment media is usually sand, anthracite and plastic and usually anthracite and plastic are preferred nowadays, the reason is the pumping cost can be reduced considerably.

If you want to find out the efficiency of an expanded bed or a fluidized bed reactor we can use this empirical formula; E is equal to 1 minus 0.56 (HRT) raised to minus 0.60.

As we have seen up flow anaerobic sludge blanket reactor was developed by Lettinga in 1970s. This is the most commonly used high rate reactor for municipal wastewater treatment. Even in India we have many UASB plants at present which is used for the treatment of domestic and industrial wastewater together. For example, in Kanpur initially they have set a 5 MLD treatment plant for the treatment of domestic wastewater and by seeing that it is a success they have put up and the treatment plant which is having a capacity of 36 MLD which is using domestic sewage as well as the wastewater from the tannery industries. This is used for the treatment of municipal as well as industrial wastewater.

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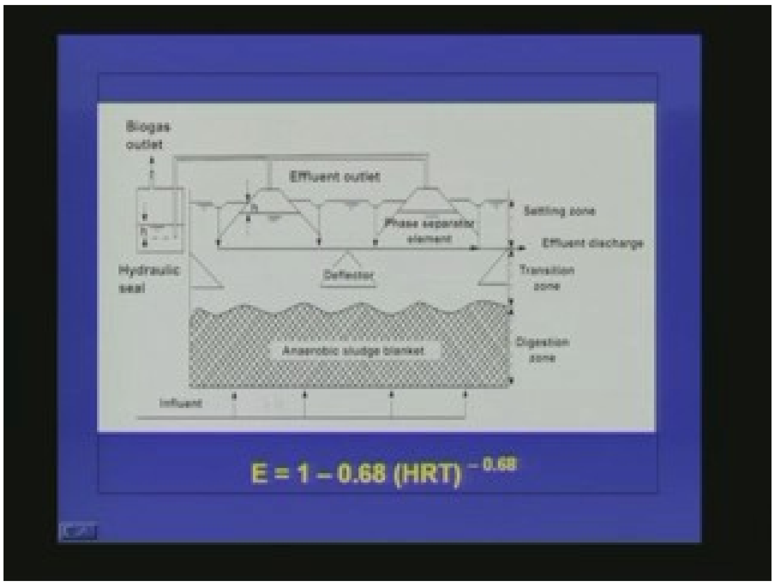

This is the example of an up flow anaerobic sludge blanket reactor because this is the one which is most commonly used. We will see in detail what is happening in a UASB reactor. In UASB reactor the influent will be coming from the bottom of the reactor and we can see that this is the influent distribution types. It will be entering in the reactor at different ports and you will be having an anaerobic sludge blanket that means a thick flocculent sludge blanket will be available in the reactor. So the wastewater will be coming here and it will be entering in the anaerobic sludge blanket through the influent distribution pipes.

Hence, the wastewater will be passing through this anaerobic sludge blanket so definitely this anaerobic sludge blanket is nothing but active microorganism. Hence, these active microorganisms will be coming in contact with the organic matter present in the wastewater so as a result biodegradation will be taking place and more and more new cells will be generated and as a byproduct carbon dioxide and methane gas will be produced.

Therefore, everything will be moving together that means gas, liquid as well as the solids will be moving in the upward direction like this (Refer Slide Time: 30:50) so this is the digestion zone of the reactor and afterwards we see a transition zone here and here this is nothing but a deflector beam and we have another arrangement like this.

Thus, all these things together are known as GLSS that means Gas Liquid Solids Separation system. I have already mentioned that here all the three components the liquid, the biomass as well as the biogas will be coming up in this direction and we want to separate all the components separately that means we want to have liquids separately, we want to have solids separately and we want to have gas separately so that is what is taking place in this zone. Therefore, the biosolids or the microorganisms will be in the flocculent form and the biogas whatever is produced will also be sticking to the microbial flocs. So as such the density of the floc will be less so everything will be rising up along with the liquid because this liquid will be having an up low velocity. So, with the same velocity or almost the same velocity everything will be rising up.

Once it comes here (Refer Slide Time: 32:11) if it hits here then the gas whatever is present in the microbial flocs will be getting separated from the floc. So once the gas bubble gets separated from the floc in the apparent specific gravity or apparent density of the microbial that floc will be increasing so definitely the settling velocity will be increasing so the microbial mass will be going out like this and whatever is the gas bubbles released will be getting collected here.

As we see some portion of the liquid and some microorganism or some flocs which is not yet removed from the system will be coming out through this portion. As we can see here the cross sectional area of this portion is very very less compared to this portion so what will happen to the velocity of the liquid coming out through this portion?
The velocity will be gradually decreasing as the costal area is increasing. Because of the velocity gradient and due to the settling velocity the microbial flocs will be getting settled here and only clearly it will be going up.

As we can see here this is an inclined plane because of the self weight so whatever sludge is collected here will be coming back to the system and the entire sludge will be getting collected here. Therefore, we are getting clear effluent from this portion and all the microbial mass whatever has escaped through this portion also we will be coming back to the digestion zone and we will be getting the biogas through this portion. This system along with the deflector and phase separator element is able to separate the gas, the liquid and the solids and retain a high microbial concentration in the system. This is a typical UASB reactor and it is having three zones; one is the settling zone, another one is the digestion zone and third one is the transition zone.

If we want to see the efficiency of the system here also we can use some empirical formula to get the efficiency of the system. The empirical formula usually used in E is equal to 1 minus 0.68 (HRT) raised to minus 0.68. Here also the HRT is in hours. So if we want to compare the performance of all these high rate reactors whatever we have discussed so far we can see that this is the retention time, it is given in hours and this is the COD removal efficiency and this is the fluidized or expanded bed reactor.

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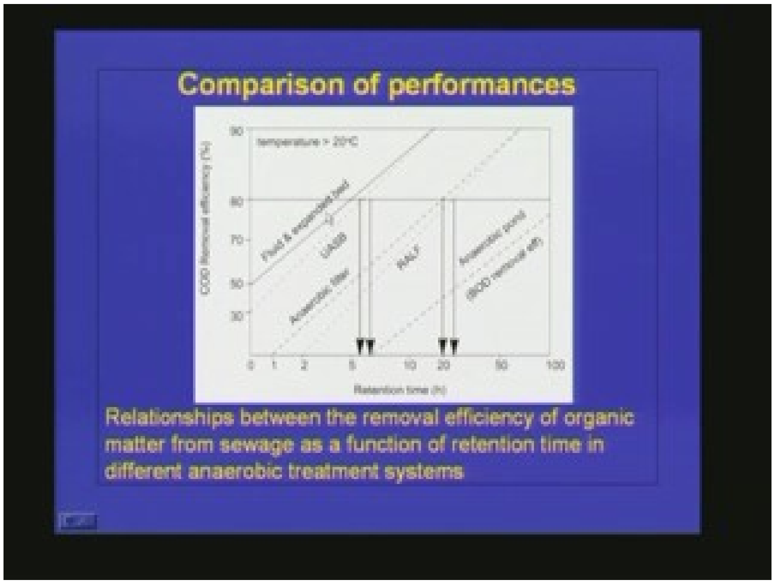

So we can see that even at very low retention time the fluidized bed reactor is able to provide a high efficiency for a temperature greater than twenty degree centigrade because temperature is very very important in anaerobic process and as the temperature decreases the efficiency reduces drastically. this is the performance of a UASB reactor (Refer Slide Time: 35:26) up to five hours, six hours retention time the efficiency is relatively lower compared to fluidized or expanded bed reactors. But for high retention time say ten hours the efficiency of fluidized and expanded bed reactors and UASB reactors are almost the sam.

This is the performance of anaerobic filter (Refer Slide Time: 35:50) and this is the efficiency of anaerobic pond. And compared to all these things the efficiency of anaerobic pond is much less because here we don’t have any mechanism by which we can maintain the microbial concentration in the system. Or in anaerobic pond the hydraulic retention time and BSRT or not clearly distinguish or we are not providing very high BSRT compared to hydraulic retention time in anaerobic pond that’s why the efficiency or the COD removal efficiency of this anaerobic pond is much lower compared to all these high rate reactors. So the more microorganisms we can retain in the system the more will be the efficiency.

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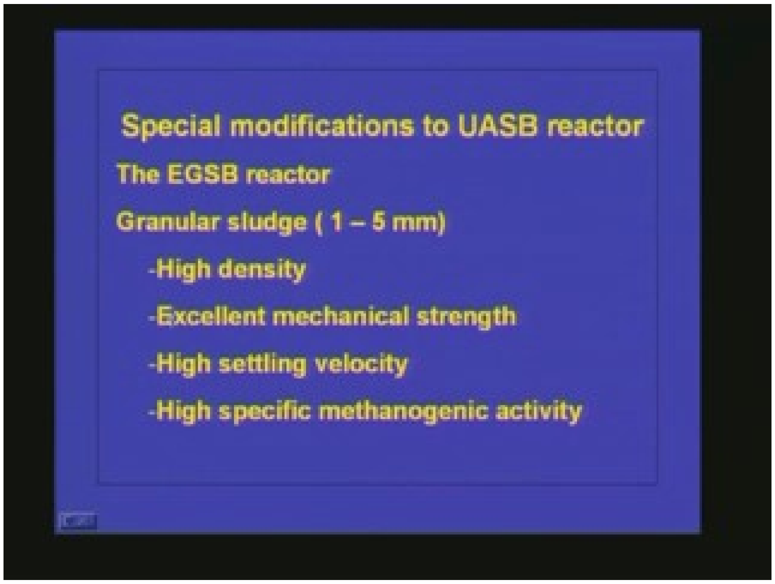

We have seen that in UASB or up flow anaerobic sludge blanket reactor the reactor is most commonly used for the domestic wastewater treatment in tropical countries. There the sludge is in flocculent form. So when the sludge is in flocculent for its settling velocity is very low. So if you give a high up flow velocity of the influent or the wastewater the sludge will be rising up and since up flow velocity is very large compared to the settling velocity of the sludge the sludge will be escaping though you provide a proper settling chamber inside the system. We may not be able to capture all the microbial cells whatever is escaping from the system and it will be difficult to maintain a high concentration of biomass in the system. So in UASB reactors or whenever we use flocculent sludge the up flow velocity is limited. We can go maximum of 1 m per hour. That means if you provide more than that the settling velocity of the sludge will be very very less compared to the up flow velocity and it will be washing away from the system.

Hence, in order to avoid this problem, as it is limited up flow velocity, if you want to give high organic loading rate or high volume metric loading rate we have to have a provision for changing the up flow velocity. So as a modification of this UASB reactor nowadays EGSB reactors are in use.

EGSB reactor, what we are using is the flocculent sludge, we are using granular sludge, without the help of any in inert material the sludge themselves will be forming a granular of 3 to 5 mm and definitely the granular will be having a very high settling velocity compared to the flocculent sludge. So because of this high settling velocity we can use a high up low velocity or even if the wastewater enters the system with high up low velocity the sludge will be remaining in the system. That is the modification of UASB reactor, it is known as EGSB reactor known as Granular Sludge Bed Reactor and another one is up low anaerobic sludge blanket, it is a sludge blanket here it is a granular sludge bed reactor.

As I have already mentioned the granular sludge diameter varies from 1 to 5 mm and it is having high density and it is having excellent mechanical strength, high settling velocity and high specific methanogenic activity. The sludge or the granule will be having different types of microorganisms staying together so definitely the gas liquid contact will be very high so it always shows a high specific methanogenic activity.

There are some disadvantages for this system.

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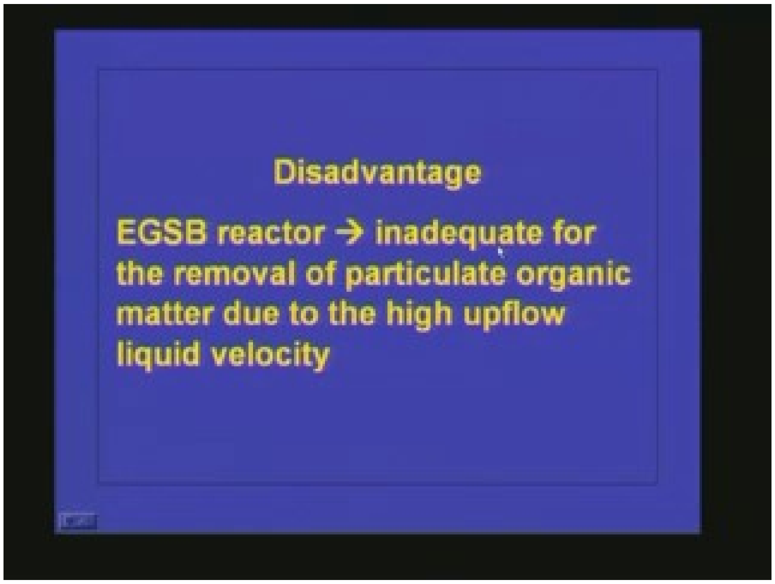

EGSB reactor: Inadequate for the removal of particulate organic matter due to the high up flow liquid velocity. This EGSB reactor is very very good for the treatment of wastewater having dissolved organic matter. But if suspended organic matter is there the treatment efficiency will not be very very high. The reason is the organic matter whatever is present in the wastewater will be having a very low density. The density will be in the range of 1.01 to 1.05. Therefore if you have a very high up flow velocity the wastewater whatever we are giving to the system will be going along with the liquid so it will not be having enough contact with microorganism whatever is present in the system so the suspended solids will not be getting removed from the system or the suspended solids will not be biodegrading in the system because it will be washing away.

As we know that, if the suspended particles are present in the system first hydrolysis has to be taken place then only the organic matter will be available for the microorganism. As in suspended form it will not be able to penetrate through the cells of the microorganism. Unless it enters in the cells of the microorganism microbial cells will not be able to metabolize them and convert them into biogas. That is a major disadvantage of EGSB reactor.

Now we will see another modification that is two stage anaerobic digestion.

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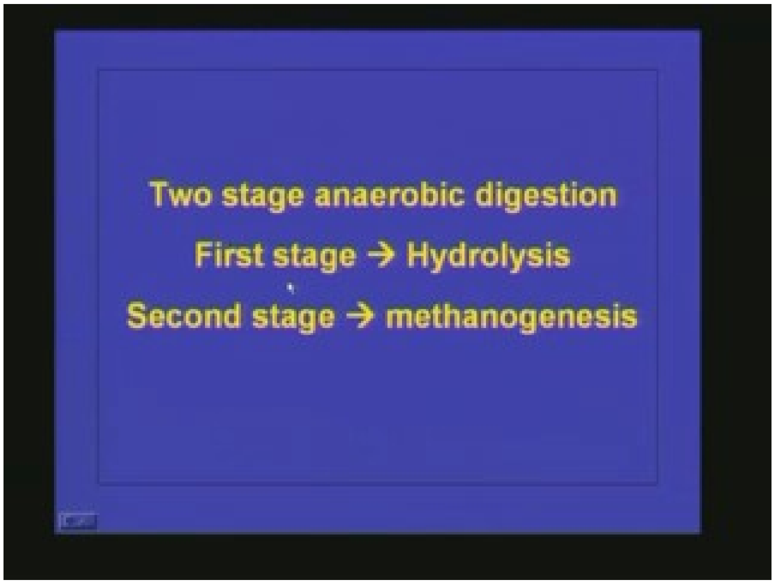

As we have already discussed if suspended solids are there EGSB reactor will not be able to do a good job. So if we can separate the hydraulic system and the methanogenic system the reactor volume can be reduce considerably. So in two stage anaerobic digestion what is happening is the first stage is used for hydrolysis and the second stage is used for methanogenesis. So, in the first stage all the first suspended matter will be hydrolyzed and getting converted to soluble acids. The PH of the system will be coming down because most of the time the hydrolysis process is very fast and the reproduction time of this acid formed as or hydrolytic and acid forming microorganisms are less compared to the methanogens, the sludge production also will be high so the activity will be more. Hence, we have to give only a low hydraulic retention time. Once the hydrolysis is taking place here the hydrolyzed portion can go to a second stage where the methanogenesis will take place.

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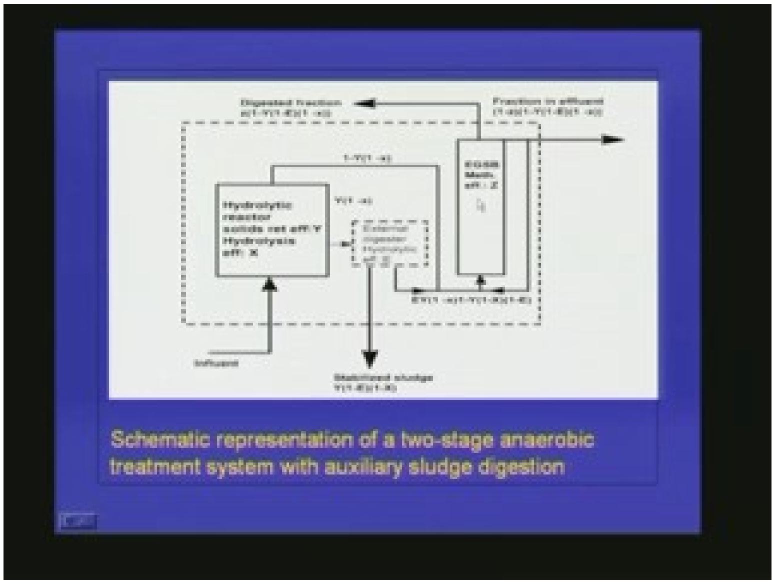

This is a schematic of a two stage reactor. The influent is coming here, this is the hydrolytic reactor (Refer Slide time: 42:30) and whatever soluble organic matter that comes out after hydrolysis is coming here and it will go to the methanogenic reactor. For methanogenic reactor here we can use EGSB reactor because we have seen that EGSB reactors are very very efficient to treat wastewater having high dissolved organic matter. So here in hydrolytic reactor all the suspended particles are getting converted to dissolved organic matter and that is going to the EGSB reactor and we will be getting the digested fraction here and we get the effluent here (Refer Slide Time: 43:15).

Now we will see the design criteria for UASB reactor because this is the one which is most commonly used in domestic wastewater treatment so we will see the design as much of UASB reactor in detail.

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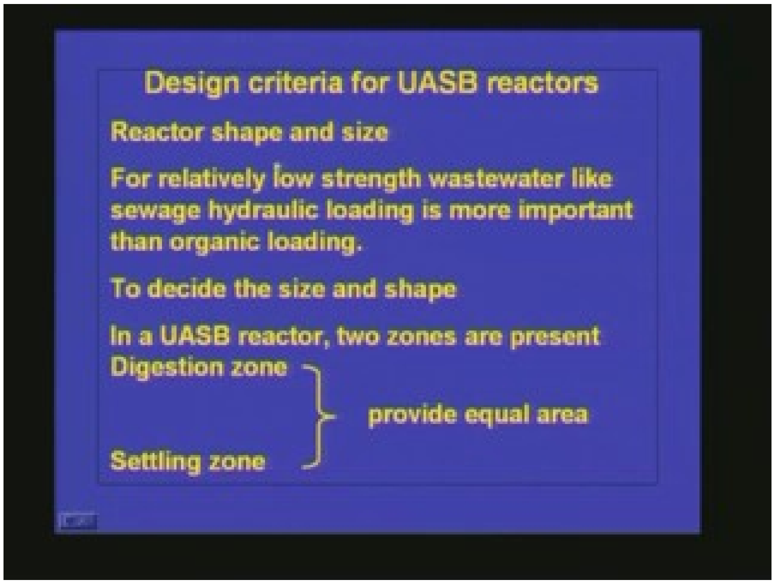

First we will see the reactor shape and size. For relatively low strength wastewater like sewage hydraulic loading is more important than organic loading. Whenever we talk about the design of UASB reactor to low strength wastewater like sewage the hydraulic loading is more important than the organic loading because this organic loading will not be the rate limiting step, the hydraulic loading will be the one because if you provide a large hydraulic loading corresponding to the required organic loading then you will be ending up with a high up low velocity so if the up flow velocity is more than one meter per hour the sludge flying ahead whatever is present in the reactor will be rising up and it will be washing out from the reactor so that will be drastically reducing the efficiency of the system. That is why I told hydraulic loading is more important for low strength wastewater compared to organic loading.

Now if you want to decide the size and shape of the UASB reactor it is having basically two important zones, we have to say three zones. One is the digestion zone, another one is the settling zone and there is a transition zone also. So if you take the digestion zone and settling zone as the important thing it is advisable to provide equal area for both. That means 50% of the reactor will be used as the digestion zone and the remaining 50% will be used as the settling zone.

Hydraulic loading rate: 6 hours of HRT is sufficient in tropical and sub tropical conditions to achieve satisfactory removal efficiency. But if the temperature is low if it is in the range of 10 to 12 degree centigrade we have to provide an HRT of 12 to 14 hours to achieve the same efficiency. We have seen that for every ten degree rise or fall in temperature the efficiency will be decreasing drastically because in tropical countries the temperature will be always above 25 degree centigrade so that is the optimum temperature for anaerobic process which is 35 plus or minus 2 degree centigrade. So at optimum temperature the hydraulic retention time required for achieving the desired efficiency is only 6 hours.

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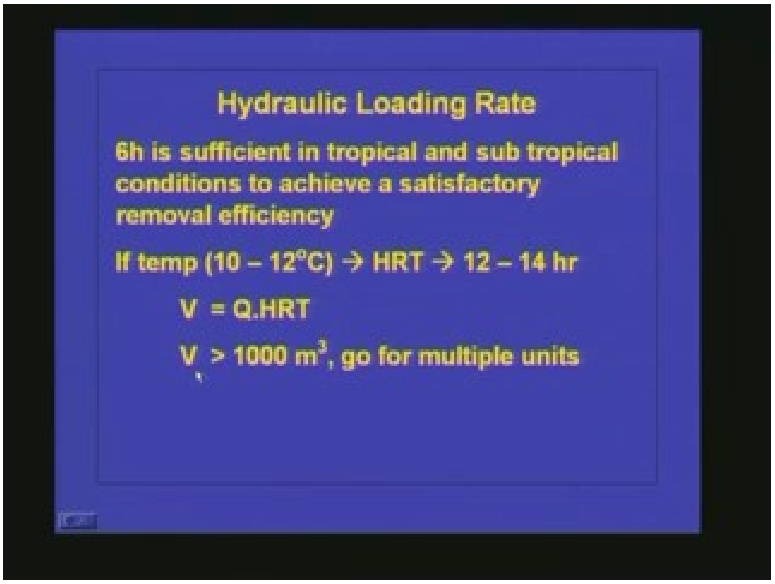

But if the temperature is less then we have to provide a high hydraulic retention time. And if we want to find the volume of the reactor, we know the flow rate of the wastewater Q and if we multiply the flow rate with a hydraulic retention time we will be getting the reactor volume. This is the commonly practiced rule (Refer Slide Time: 46:20), if volume is greater than thousand meter cube go for multiple units and if the volume is less than thousand we can go for a single unit.

Now, coming to the height of the reactor, we have seen how to find out the volume, the volume is decided based upon the hydraulic retention time and the flow rate of the wastewater. Now we want to see what is the height we can provide. The liquid up flow velocity decides the height. We have seen that this is the limiting height profile UASB reactor and we can find out the vi. Here vi is nothing but the liquid up flow velocity that is equal to Qi by area of cross section Qi is the influent flow rate and A is the cross sectional area so Q is the volume of the reactor by hydraulic retention time so that will give you Q value because v volume is nothing but Q into HRT so volume by HRT will give you Q so Q by A gives us the velocity.

So, if you use like this we can see that the up flow velocity is nothing but H by HRT, the area of this one and this one will be getting canceled and we will be getting up flow velocity which is nothing but H by the hydraulic retention time. We also know that this up flow velocity should not exceed one meter per hour in UASB reactor because the flocculent sludge will be having a very less settling velocity. So, if the settling velocity is less than the up flow velocity the sludge washout will be taking place, so this is the limit usually provided. So, for an HRT of six hours the height should not exceed 6 m so the maximum height for the digestion zone in a UASB reactor you can provide is 6 m.

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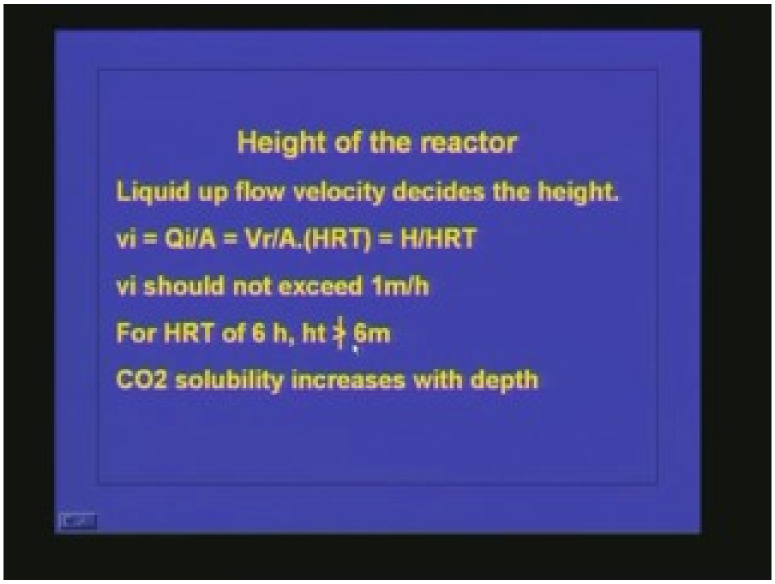

One more reason is there, if you give more height the hydrostatic pressure the reactor will be more so naturally the CO_2 solubility increases with depth. So if CO_2 solubility increases once CO_2 gets dissolved in the water we will be getting carbonic acid and these carbonic acids will be reducing the system PH. Thus, in these aspects also it is not advisable to go for a very high reactor.

Now coming to the shape we can provide rectangular as well as circular. If you go for a rectangular reactor it is having less structural stability but a circular reactor is having high structural stability but construction is difficult.

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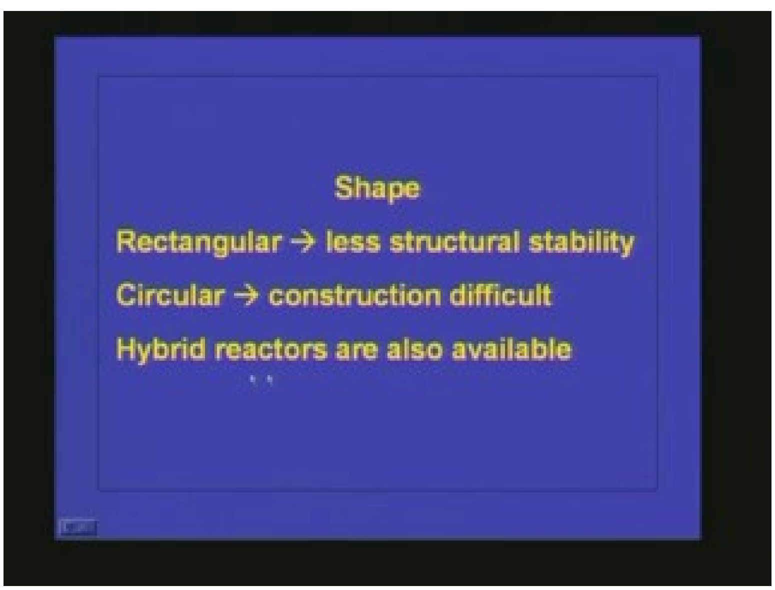

Nowadays people are going for even hybrid reactors. That means the bottom portion is circular or the top portion is rectangular and vice versa the bottom portion is rectangular and the top portion is circular. So these are the geometrical shapes of UASB reactor.

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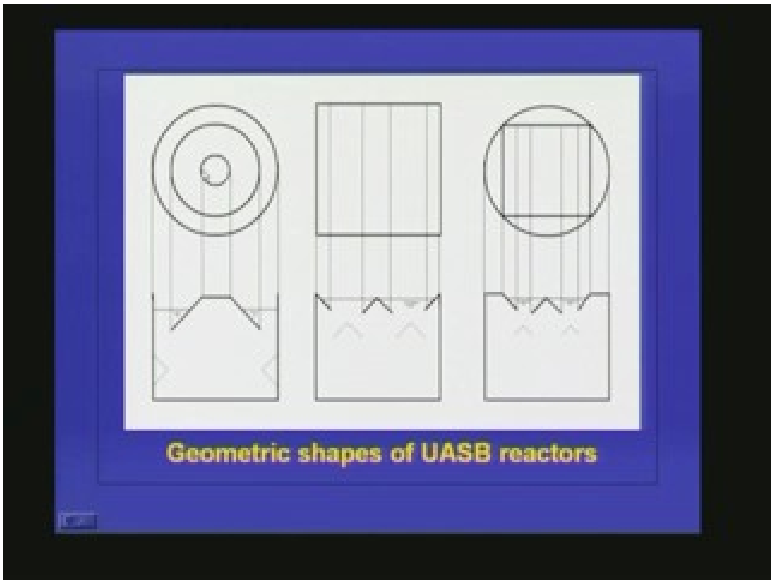

This is a circular reactor. This is the rector zone and settling zone and this is the gas collection system (Refer Slide Time: 49:25) and this shows a rectangular reactor and this is a hybrid one that means the bottom portion is circular and the top settler portion is rectangular.

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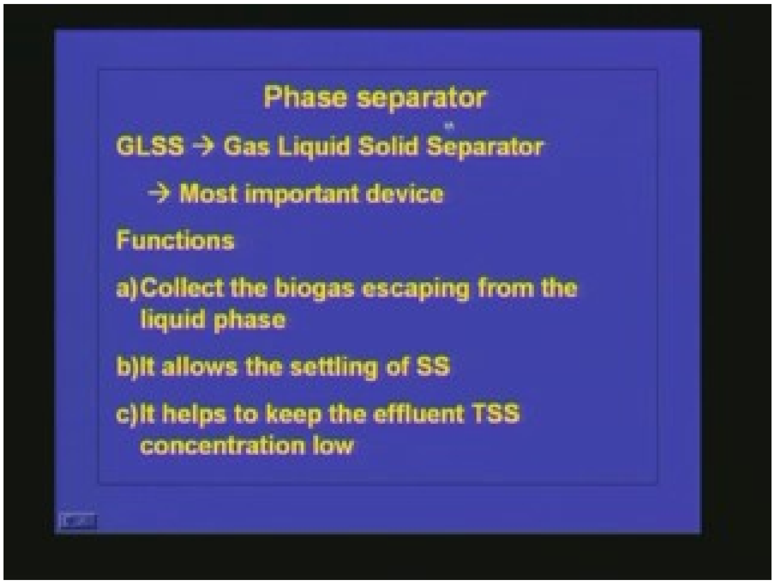

Now we will see how to go around for the design of phase separator. This is the most important component of a UASB reactor the gas, liquids, solids separator. Its functions are it collects the biogas escaping from the liquid phase which is the gas separation and second one is it allows the settling of suspended solids. It also helps to keep the effluent total suspended solids concentration low and the last one is it creates a space above the separator for the sludge bed to accommodate expansion due to high temperature and high hydraulic loading.

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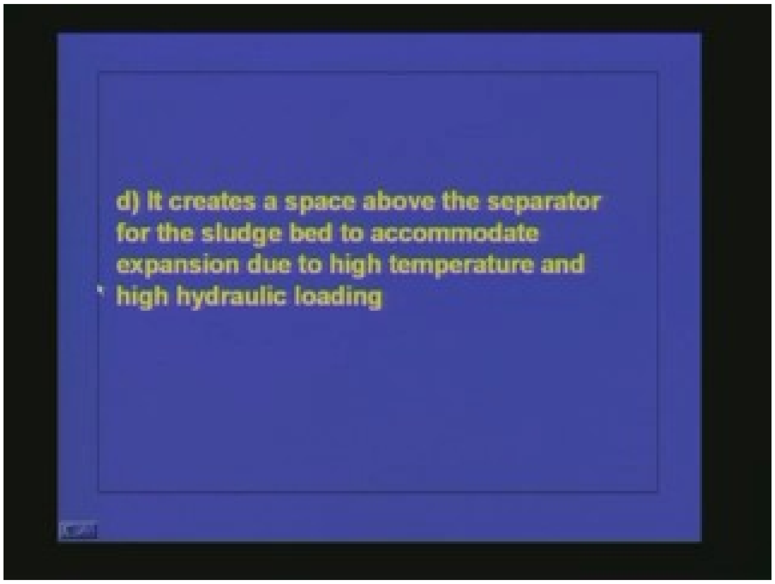

So whatever excess loading comes to the system the reactor will be able to take care of it because it is having a huge area above the solid liquid separator.

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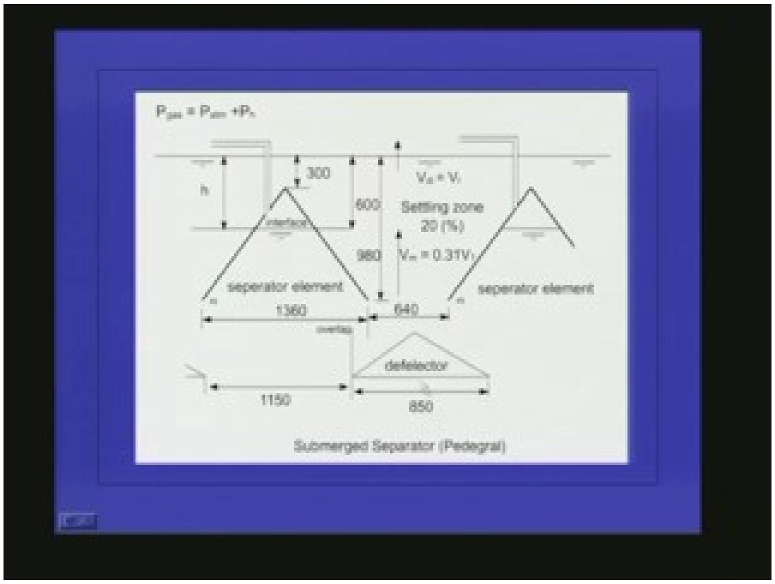

How to design a solid liquid separator?
This is the detail of a solid liquid separator. We can see that here a deflector beam is there and here the separator element is there and this is the interface between the biogas and the liquid and this is the settler (Refer Slide Time: 50:55).

We can give the usual dimensions like the deflector beam around 850 mm and here this portion is 640 mm and this is the separator element it can have a width of 1360 and this portion is 1150. Or in other words the overlapping between the deflector beam and the separator element should be at least 100 mm that means at least 10cm overlap should be there. Now what happens is the wastewater solids as well as the gas will be coming here and here there is a reduction in the cross sectional area and this separator element is placed at angle of 45 degree so here the water will be entering here at a velocity Vm and this Vm is almost equal to 0.31 of V1 that means up flow velocity.

We can see that the cross sectional area is keeping on increasing as we go up so here the Vdi will be equal to Vi. So what is happening is here we will be having a high velocity and it will be gradually decreasing so a velocity gradient is available so flocculation can occur and this will be acting as a sedimentation zone also so all the biomass will be getting settled here. Here this is having an angle of inclination of 45 because of the self weight of the sludge whatever is settled here so everything will be coming back to the reactor.

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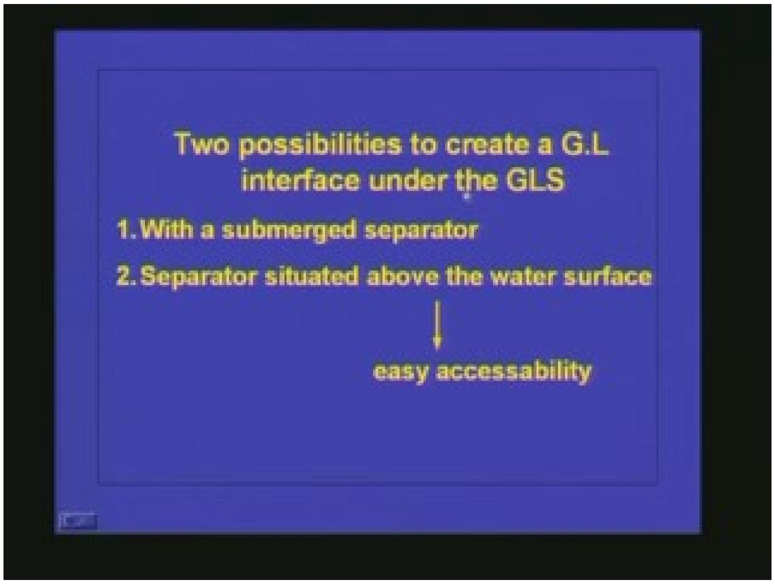

There are two possibilities to create a GL interface. One is with a submerged separator and another one is a separator situated above the water surface. If the separator is situated above the water surface we have easy accessibility. But most of the time we go for submerged separator.

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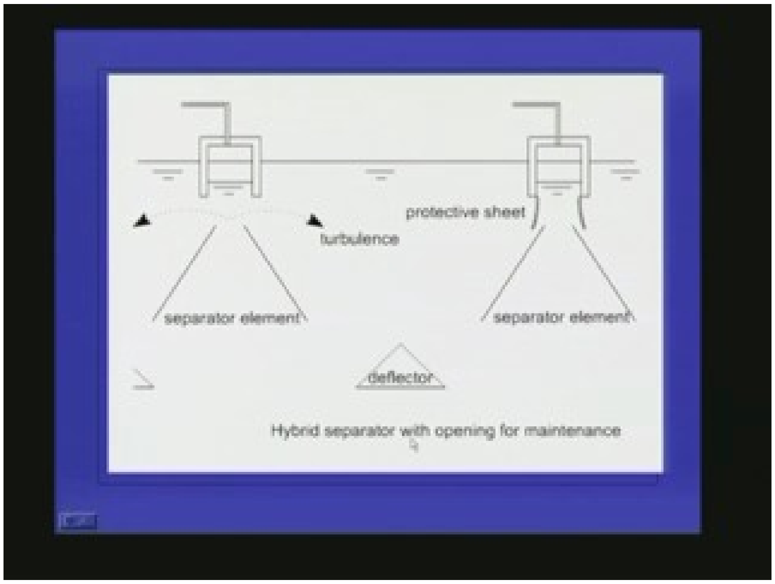

This is a separator with atmospheric pressure because it is exposed to the atmosphere. Here we have easy accessibility and this is a hybrid one and this is a submerged one (Refer Slide Time: 53:12). We will see what all are the advantages of a submerged separator.

- Corrosion of construction material will be high
- The entire reactor area is available for solids settling
- The biogas will be released under an high pressure
- External seal to prevent explosion during flaring

These are the advantages of submerged separator. It is better to have a submerged separator if you can take care of the corrosion.

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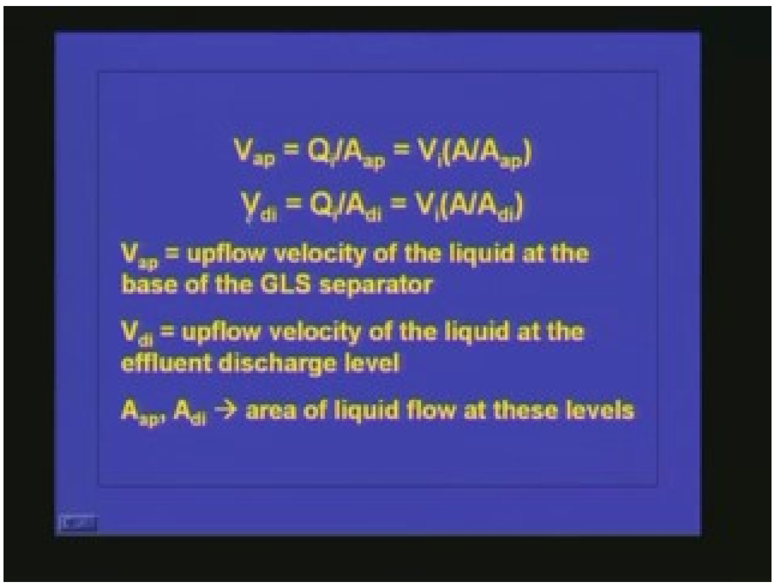

These are the velocities. So if you want to find out the velocities whatever is coming in the aperture and this is the discharge velocity AVp Vap that is nothing but the up flow velocity of the liquid at the base of the GLS separator then we know what is Q and what is the cross sectional area then we can find out that velocity and Vdi which is the up flow velocity of the liquid at the effluent discharge level. That also we can find out if you know the area at the discharge level.

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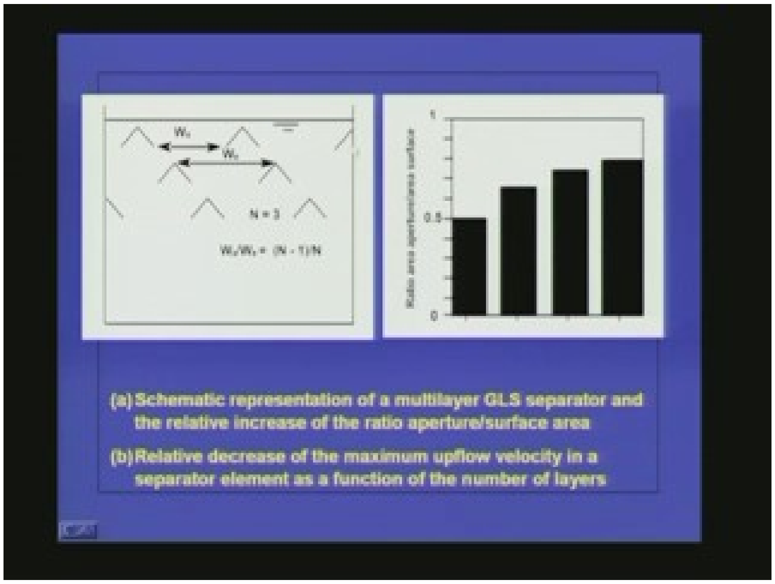

So, instead of providing the GLSS as a single row we can even provide them as different roles so that the efficiency will be much more. So if you want to see the principles of design of a GLSS this one is very very important. This portion we will discuss in detail in the next class because we have to see how the influent arrangement, the effluent arrangement and how to provide the inclination and all other dimensions of a GLSS.

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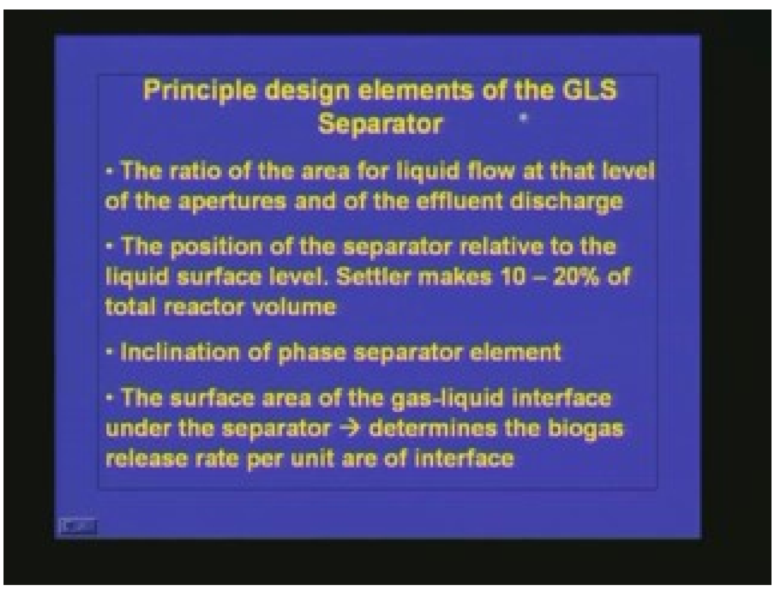

We will summarize what we have seen today. We have seen the entire conventional anaerobic reactors which are used in the earlier days, those were the septic tanks and emuff tanks. These septic tanks and emuff tanks are being used nowadays also especially in rural areas. in this type of conventional systems the biomass retention was very less or we need a very high hydraulic retention time so the efficiency was very very less or the volume of the reactor required was very high so anaerobic technology was not becoming very popular.

Nowadays the hybrid reactors are available which can retain a high biomass concentration in the system. The examples of hybrid rectors which are most commonly used nowadays for the treatment of domestic as well as industrial wastewater are anaerobic filters, down flow, stationary but anaerobic filters, fluidized bed reactors, expanded bed reactors, up flow anaerobic sludge blanket reactors, up flow granular sludge bed reactors and so on. All these reactors are being used commonly nowadays for the treatment of domestic wastewater.