Water Quality Management Practices
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Lecture – 45

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Dhar Bhowmick. I am from the Department of Agriculture and Food Engineering of Indian Institute of Technology Kharagpur. So, in this lecture we will be discussing about the design of anaerobic reactor like specifically USB reactor. So, in continuation with our earlier discussion, we will be continuing with the design, we will solve one design problem by our self and we will be able to do that by the end of this lecture and it will give us a very good idea our concept will be much more clearer in designing how to design an anaerobic reactor specifically USB reactor, ok. So, after we finish with this lecture I hope you will be feeling much more accomplished and you will be like you know you will you should go through it at least another two one or two times to get an idea about how we have done it and just write it down in your notebook.

So, it will be giving you a very good amount of expertise in this particular field and you will be able to do it this kind of USB reactor design by yourself. We will be majorly doing the this numerical in this lecture. So, please write it down each and every expressions when you will be we will be discussing and this numbers and all please write it down. So, it will be easier for you to actually understand it when we will go through it every time we cannot repeat it we cannot come to this slide.

So, we will I will try my best, but please write it down and in your notebook parallelly. So, it will be easier for us, ok. So, the design it is asked to design a USB reactor for treatment of sewage having an average effluent influent flow of 3000 meter cube per day. So, Q average is given as 3000 meter cube per day please write it down. The maximum hourly influent flow is 5400 meter cube per day or 225 meter cube per hour that is the maximum value, ok.

The maximum hourly or maximum hourly maximum influent flow is also given to you as 5400 meter cube per day. Average influent COD S0 is 600 milligram per liter please write it down 600 milligram per liter is the influent COD and what is the influent BOD? It is 350 milligram per liter, ok. The least temperature of the sewage reaches at 20 degree Celsius 23 degree Celsius average of the coldest month and the sludge yield coefficient Y is to be considered as 0.12 kg of total suspended solid per kg of COD removed. Y is 0.

12 kg of TSS per kg of COD removed. The solid yield coefficient in terms of COD that is why OBS can be considered as 0.17 kg of COD in sludge per kg of COD removed, ok. So, you know the Y observed also Y observed value is also known to us 0.17 and anyway sludge yield efficient Y is different that value is also known to us 0.

12. Expected concentration of the discharge sludge is around 4 percentage and the consider the sludge density lambda is point 1.1020 kg per meter cube, ok. First thing that we need to design we need to find out is the influent COD load L0, ok. L0 the influent COD load can be easily calculated by the inflow rate I mean like the flow rate. So, inflow flow rate is like 3000 meter cube per day in average multiplied by the total COD load.

What is the total influent COD load? It is 600 milligram per liter or 600 gram per meter cube or 0.6 kg per meter cube, isn't it? You can easily convert it by like this. Now, 0.6 kg per meter cube multiplied by 3000 will give you the value of 1800 kg of COD per day that is the average load of COD that your system will in system will you know experience. Now, we need to find out the volume.

Say we will take a we adopt a hydraulic retention time of 8 hour, ok. If we take an adapt we adopt an hydraulic retention of this assumption write it down this assumption is first assumption is hydraulic retention time of 8 hour theta value is 8. So, what will be the volume of your reactor? The flow rate multiplied by the hydraulic retention time flow rate is 3000 meter cube per day or 125 meter cube per hour multiplied by 8, ok. So, it comes as 1000 meter cube we can adopt a reactor module of 2. So, each reactor volume will be 500 meter cube, ok.

Now, although there is no limitation to the volume of the reactor it is recommended that the reactor volume shall not exceed the 1500 meter cube due to the construction and the operational limitations particularly in respect to the influent distribution on the bottom as well as the GLS separator complications the design of the GLS separator. In this case small system for the treatment of domestic sewage we adopt modular reactors which present some advantages. In this particular case normally we will we can take 500 meter cube we just divide this into 2 module and we can have we can take 2 reactor of 500 meter cube. Now, if it is 500 meter cube is the volume of each reactor if we can adapt height of the reactor is 4.

5 meter. So, you will get the area of the each module what is the area 500 meter cube is the total volume and what is the height of the each reactor 4.5 divided. So, if you divide it you will get the area of the each module which is 111.1 meter square. So, if you take a rectangular reactor say 7.

45 meter of width and 15 meter of height length please write it down you draw it even like draw it 7.45 meter of width and 15 meter of length. So, if you multiply 15 into 7.45 it will become 111.

88 square meter. Now, in the calculations while we are designing we are designing always taking some assumptions and all and at the end we come up with this value 11 111.1, but when actually when we design this value may differ right. So, now, the actual area is different. So, based on this actual area now we have to verify the existing assumptions. So, now, the actual area is 111.

8. So, what will be the total area corrected area which is 2 into 111.8 which is 223.6 square meter. So, what will be the corrected volume the height is 4.

5 that is 6. So, 4.5 into 223.6 that is 1006 meter cube instead of 1000 now it will become 1000 meter cube 1006 meter cube. Now, corrected hydraulic retention time 1006 meter cube divided by 125 meter cube per hour it will come somewhere around 8 hour only ok. So, initially when we when we calculate the other values if you see if you remember we take the volume as 1000 meter cube, but in the case the corrected volume will come as 1006 meter cube ok. The HRT becomes the same, but the area will also change it becomes 111.

8 ok. Now, verification for the hydraulic loading rate actual volume average flow will not change 3000 meter cube per day divided by the volume. Now the average now revised volume of this both summation of this both the module is 1006. So, Q by V is now 2.98 meter cube per meter square meter per meter cube per day that is the volumetric loading rate that you are experiencing. What is the volumetric organic loading rate which is the average flow which is 3000 meter cube per day multiplied by 0.

6 kg of COD per meter cube divided by 1006 meter cube which is 1.79 kg of COD per meter cube per day both the values are well within the limit. Also considering the sludge bed occupies the half of the reactor. So, total reactor volume is each of them is how much total volume is 1006 each of them 503 meter cube you know each of the reactor which have which is having a volume of 503 meter cube. So, if 50 percent of the this individual USB reactor there are 2 reactor each of them will having 503 meter cube.

So, if you divided by 2 it will give you the volume of the sludge bed which is the 251.5 meter cube with a sludge concentration of say 20 gram of VSS per day that is a standard we have to maintain. So, if it is a 20 gram of VSS per liter is maintaining that much of VSS concentration is we are maintaining inside the inside the sludge bed. So, how will you get the sludge loading rate? What is the sludge loading rate here? What is the influence sludge here? Influent parameter here major the organic loading rate that we are that organic that we are supplying organic matter that we are supplying that is 3000 meter cube per day multiplied by 0.

6 kg of COD per meter cube. If you divided by 251.5 that is the area of the sludge bed volume of the sludge bed multiplied by the sludge concentration that is 20 gram of VSS per day. So, you will get the sludge loading rate as 0.36 kg of COD per kg of VSS per day. So, in order to keep the SLR this under control this reactor should be operated under full flow conditions with sludge bed volume of 50 to 60 percent of the total reactor.

In this particular case we have taken 50 percentage 50 percentage of the reactor volume is covered with sludge bed ok. So, so it is we so what will be the height of the sludge bed? What is the total height here? 4.5 meter. So, sludge bed height is 2.

25 meter very good. So, this is how we will start designing we will start designing the rest of the part. Now, in verification for the airflow velocity what is the airflow velocity here? Aflow velocity means you have the average flow divided by the area what is the average flow here? 125 meter cube per hour what is the area here? What is the corrected area? The corrected total area is 223.6 meter cube meter square meter for both the reactor 223.6 and what is the total flow? It is 125 meter cube per hour. So, that or 3000 meter cube per day.

So, 125 meter cube per hour divided by 223.6 you will get the airflow velocity of 0.56 meter per hour. So, now, this is equal another way of doing it you remember we did it another way of calculating the offload velocity is height by HRT height is 4.

5 HRT is 8 right. So, 4.5 by 8 is also 0.56 meter per hour. So, in both the way you can calculate this number this offload velocity. Now, for in case of maximum flow what is the offload velocity? In case of maximum flow is 225 meter cube per hour divided by the same area total area of both the reactor 223.

6 square meter. So, it will come as 1.01 meter per hour. In general, offload velocity should be in the range of 0.5 to 0.7 for average and for preferably less than 1.

5 to 1.5 meter per hour for peak flow. In this case both the case are satisfying our design our design is satisfying both the cases ok. Design of the inlet distribution if you remember after the in the last lecture we discussed about the splitter box right we placed it on the top we have the splitter box feed inlet system is there from there water will reach to this 12 different points and from different points this suppose it will go down like this pipe and it will enter it see the number B it is the it is the inside the reactor it is inside the USB during the construction that picture is shown. This inlet distribution channel inlet distribution channels are there which is like you know like literally leading towards like you know putting the putting its head towards a certain degree of inclination

on the bottom of the reactor where from where the waste water will be introduced ok. You understand the picture you can now picturize the system how it will look like inside the USB reactor also this inlet distribution systems very good. So, now, how many its suppose we know that each of this distribution point has an influence area of 2.

25 square meter. So, what will be the total number of feed inlet tubes that it requires? So, total area is 223 square meter. So, each distribution each point is distribute each feed inlet pipe can influence 2.25 square meter. So, we need 99 number of distributors. So, in this particular in this figure we have used say like 2r number of distributor, but in the design problem we may need 99 number of distributors ok.

We have to design it accordingly because it is for the huge scale high scale reactor. Now, the biogash production we say that biogash production considering the 70 percent COD removal is CODCH COD of for like you know remove because of the present conversion of a methane is the Q into S 0 minus S E minus Y observed into Q into S 0 minus S. So, here Q is how much 3000 meter cube per day, A 0 is given 600 milligram per liter or 0.6 kg per meter cube, 70 percent removal.

So, 600 to 70 percent removal means 7 into 0.7 into 6 0.7 into 600 its 420. So, that means, if you 420 kg of COD per meter cube is removed. So, what will be the final COD? 180 600 minus 480 420.

So, 180 that is 0.180 kg of COD is removed because 70 percent COD removal right points initially 600 now it is become 180 gram of COD per meter cube or 0.180 kg of COD per meter cube ok. You understand the calculation? So, now, 300 3000 meter cube per day into 0.

6 minus 0.18 kg of COD per meter cube minus 0.17 the Y observed value is given in your in the in the numerical itself that it should be taken as 0.17 kg of COD sludge per kg of COD removed multiplied by 3000 meter cube per day multiplied by 0.6 minus 0.

18. The finally, you will get the value as 1045.8 kg of COD per day. Now, if the k T value this temperature with this correction factors from T into k divided by R into 273 plus T where R T is the in the atmospheric pressure in 1 atm k is 64 gram of COD per mole divided by R is the universal gas constant which is 0.08206 atm liter per mole kelvin multiplied by 273 plus T is the 23. It is remember the temperature is the minimum temperature we should consider which is 23 degree Celsius in the average of the colder months cold ones ok.

So, now, k T value is coming as a 2.63 kg of COD per meter cube. So, what will be the volume of the methane that will produce? You can easily get the COD influenced by the methane divided by the COD converted reused by the methane production divided by the k T which is coming as 397 meter cube per day. Please remember this value we normally we do not use this we normally this we take it as a 360 to 400 meter cube per day as a standard value ok. We do not like in this case just for you to understand this concept I have gone through it in more details and I hope you understand the why we take this value 397.

64 meter cube per day. Now, considering the methane content of 65 percentage in the biogas because as I told you it is not only methane, but also carbon dioxide nitrogen nitrogen nitrous oxide hydrogen sulfide there are different other gases can also be present there. So, in that case biogas total volume will be volume of the methane divided by 0.65 total volume will be 611.75 meter cube per day ok. Please remember this value it will be useful later on again this biogas production value.

Now, let us design the GLS separator. When we design the GLS separator the maximum liquid velocity at the aperture if you remember in the aperture in the inlet of the settler which you remember in the last class we did it like you know this W a. So, this inlet of this aperture from there the maximum liquid velocity should be 3 meter per hour to reduce the chances of turbulence inside the dome inside this GLS separator. So, area of the opening in the inlet of the settler should be 3000 meter cube per day is the capacity and 3 meter per hour multiplied by 24 3 into 24 that much meter per day. So, area of the inlet of the settler should be at least 40.

56 meter square meter. Now, we have a 2 number of reactor. So, 40.56 divided by 2 20.28 square meter of area you have to provide with this space. So, that in where the water will go to the for the settling for the further like you know in the effluent dinette also in the settler area. So, once it will go to the settler area then it will reach this from the super antenna of that only will come out of the system as a as an effluent.

In this settling zone now suppose the width of the opening of the inlet is 0.3 meter. So, what will be the width of the deflector beam below as 0.5 meter you remember we design it the width of the opening and width of the deflector beam should be at least 0.

2 meter higher than the width of the opening of the inlet settler. So, now, there is this width of this inlet settler we have let me show you one. If you see in this case we get to know about this value 0.3 meter 0.3 meter is the width of the inlet and thus 0.

5 in the bottom if you see deflector is 0.5 because we remember in the equation also in the last year last lecture also we discussed that this deflector width will be 0.2 meter higher than the inlet width. So, now, inlet width is known to us 0.

3 deflector width will be 0.5 very good. So, now, this is clear to us now we also know the total amount of area that for the inlet is given inlet area should be inlet of the settler

should be 20.28. So, total length of the opening that it requires is area is known to us 20.28 and the width of the individual inlet settler is also known to us which is 0.

3. So, total area that is required is 67.6 meter. So, now, we also know the 67.6 meter of length is provided. Now, what is the width of the dome width of the reactor USB reactor you remember 7.

45 by 15 meter is the length. So, 7.45 if you place the dome place the dome in the width wise manner. So, that the individual sorry individual gillier separator you may place it in the width wise manner you know parallel to like you know one after another you know width wise manner. So, you do not have to design 15 meter long I mean like design it you construction complexity will reduce. So, then how what is the number of dome that you require 67.

6 is the total length and individual width is 7.45. So, what will be the total number of dome required that is 9 you 67.6 divided by 7.45 width you will be seeing that you need a you need 9 number of dome. This 9 number of dome now will be we will have to placed in length wise manner ok.

Now, there will be 2.15 meter gap on the wall right. See this figure is not representing the actual there may be a number of domes here only for the 2 domes in this case though for aperture gap of 0.3 meter on the wall side it will be 0.15 meter in one side and 0.

15 meter in the other side right. So, suppose we have a 9 number of dome. So, there will be 8 number of 0.

3 meter gap in between and another 0.5 on the on the both the side 0.5 0.15. So, total 9 number of 0.3 meter will be there. So, what will be the base width of this each dome how you can calculate the base width of each dome because we know the total length total length of the reactor is 15 meter. Now you are placing 9 number of dome on top of it.

So, in between there is this gap 0.3. So, what is the base width of the reactor base width of the dome you will easily calculate total 15 divided by 9 into 0.3 that much of area is spared by this inlet of the settling zone. Now point now 9 into 0.

3. So, we will get the total value divided by 9 number of dome. So, what is the base width of each dome 1.37367 you will get the base width of the each dome as 1.367. In this picture there are only 2 domes placed, but theoretically there should be 9 dome one after another in actual case in this design problem 9 domes are placed one after another and we can easily calculate the base width of each dome by actually designing because we know the total length is 15 meter we know the in between gap is 0.

3 meter. So, 0.3 into 9 number of dome divided by and 15 minus 0.3 into 9 divided by 9. So, we will get the base width of each dome. Now how will you calculate the angle of inclination this theta value what is the height provide a height of say 1.2 meter because we already know that this is the total height of the reactor is 4.5 meter out of them 2.

25 meter is already spent for sludge bed and you can provide say like another 1.2 meter for height of the your GLA separator. So, whatever is left you will be used as a sludge blanket ok we know that it is a sludge blanket reactor right off flow anaerobic sludge blanket reactor. So, there will be off flow anaerobic sludge blanket should be there sludge bed sludge blanket and then GLA separator ok. You try to understand the whole concept ok. So, now what is happening this how will calculate the angle of inclination we know this value we know this 1.

2 is the height of the dome we know the width of the dome is 1.367 we know the top width is 0.3 in this on the top width you see like top width of the dome is 0.3. So, now, you imaginary if you make a imaginary center line from the middle of the top width to the middle of the bottom width ok.

So, it makes a like a it makes like a right angled triangle ok. In this right angled triangle if you calculate the tan theta tan theta is equal to you can easily is the height, height is how much? 1.2 ok. So, height is 1 1.

2 and height is 1.2 what is the base here? What is the base here? Base here is 1.367 divided by 2 1.367 minus 0.3 divided by 2 you understand total width from the bottom total width from the top.

So, 1.367 minus 0.3 which is in the top then you divide it by 2. So, then only you will get the actual the width of the this imaginary triangle. So, this the you know the base you know the length you know the height now. So, if you in now you can easily calculate the angle of inclination by tan inverse 1.

2 height and base is 1.367 minus 0.3 divided by 2 you will get the angle of inclination as 66 degree ok. So, now, you know the degree of inclination also you see you are keep on doing one after another stuff and you are finalizing the construction details of your design ok. Next is the check for the surface overflow rate in the settler. The area which is available on the top of the reactor is 7.45 is the total I mean total area is how much total area is obviously, the total area of the rectangular reactor individual reactor is having a width of 7.

45 multiplied by the 15 meter length if you remember from the beginning we are designing that. Now, what is the area that is available for the settling? Total area minus the area available for the this aperture other than that all the area all the rest of the area is available this aperture aperture width is 0.3 meter. So, 0.3 meter multiplied by 9 number

of 0.3 meter this aperture widths are there multiplied by the it is a width wise right width wise we are placing it with this all this dome.

So, for in like for all this 9 dome 9 into 0.3 into 7.45 that much of area is unutilized for settling purpose. So, total area minus this unutilized area you will get the final area is 91.635 meter square meter which will be used for settling purposes ok. Now, this calculation is normally based on the provision of GLS dome with the MS plate which will have a minimum thickness of 5 millimeter to 10 millimeter including the corrosion protective cover. If the GLS is proposed to be constructed in RCC then the wall thickness of GLS need to be considered in this calculation as well because the wall thickness in case of RCC reinforced concrete cement in this case what happened we the value of this the thickness of the GLS is also considerable right.

So, in that case you have to consider that value as well, but in this calculation we are not considering the any wall thickness anywhere ok. Please remember this things in the real life situation you may have to experience this kind of issues as well ok. Anyway the surface overflow rate so, the area available for the settling is known to us. So, what is the surface overflow rate at average flow of settling compartment of each reactor 3000 meter cube per day is the total flow rate inflow rate divided by 2 number of domes are there 2 number of USB reactors are there divided by 2 into available settling area is 91.

635. Surface overflow rate coming as 16 meter cube per meter square per day. We also can calculate which is also acceptable because it is less than 20 meter cube per meter square per day and we can also calculate the surface overflow rate for peak flow rate this the area value will be same, but the flow rate will change 5400 meter cube per day the peak flow if you remember it is given. So, which is coming as 29.47 meter cube per meter square per day which is also acceptable as it is less than 37 36 meter cube per meter square per day ok. Please remember this acceptable range at least write it down ok. Now the biogas we can check for the gas loading rate the biogas release rate should be under control to overcome possible to overcome the possible scum layer formation, but it should be high enough to quickly release the gas from the sludge not allowing the sludge to be dragged and consequently accumulated on the gas exit pipings ok.

A maximum rate of 3 meter cube of biogas per meter square per hour is recommended ok. So, this value is recommended and we also know that what is the total biogas formation biogas formation is 611.75 meter cube per day that is also known to us total biogas volume ok. Now checking for the further surface overflow rate in the settler this area of the gas water interface inside the dome of each reactor is 9 into 0.

3 into 7.45 that much of area is there gas water interface in this 20 into 115 9 into 0.3 into 7.45 that is the area of the inlet of the settler. Total biogas production we know that 611.75 divided by 5 divided by 2 for each reactor 305.875 meter cube per day. So, the

biogas loading at the gas water interface of each dome how we can calculate total volume is known to us total volume total flow biogas production is known to us 305.

875 divided by this area of the gas water interface in the each dome 21 115 multiplied by 24. So, the biogas loading at this gas water interface inside the dome is 0.63 meter cube per meter square per hour. This is less than the 3 meter cube per meter square per hour which is now acceptable. Now we can design this thing that is perfectly ok.

Now we can provide the 10 number of effluent collection channel with the width of 0.3 meter and the depth of 0.3 meter and each reactor and providing the 90 degree v notch at point 50 0.15 meter that is 15 centimeter center to center distance as we discussed in the last lecture also. Now the discharge can be collected in each of this effluent collection channel will be total 1500 divided by 1500 meter cube because 1500 meter cube per day is like you know individual reactor is facing that much of flow divided by 10 ok. So, divided by 10 so, you will get total 150 meter cube per day for individual this individual collection channel which is nothing, but 0.

00174 meter cube per second. Having another 50 millimeter drop in the bed of this effluent collection channel of one of the reactor this in this common effluent collection launder if we design and with the slope of say like 1 in 149 meter which is the s using the Manning's equation we can easily calculate the depth that we can provide ok. How we will calculate this depth this d value from this d value of this each channel can be easily estimated ok. So, we know that this value this Q is known to us what is the Q value here 0.00174 meter cube per second which we just calculated.

We also know that it is the area we can easily calculate for area also from here this 0.3 is the width the depth this d value we need to we need to we need to find out multiplied by 1 by N the Manning's equation Manning's formula Manning's equation formula. So, Manning's coefficient is 0.013 multiplied by the hydraulic radians to the power 2 by 3 hydraulic radius means area by weighted perimeter area is 0.

3 into d and the weighted perimeter 2 d in this depth plus the width 0.3 2 d plus 0.3 we know weighted perimeter means the depth and the 2 into depth multiply plus the width.

So, width is 0.3. So, 2 d plus 0.3. So, area by weighted perimeter to the power 2 by 3 plus s the slope is given 1 in 149 to the power 1 by 2. From there you can easily calculate the depth of wastewater of in each channel as 0.016 meter hence a total depth of 0.3 meter is provided as we have provided in this design is perfect we it is it is ok.

If you remember in the first line only we have mentioned that we already provided depth of 0.3 meter, but in this way we can actually calculate and we can actually prove it that based on the open channel hydraulic formula and all open channel hydraulic if you follow this equation in the Manning's formula Manning's equation actually we follow the open channel hydraulic formula. So, this is actually right the design is actually perfect acceptable ok. Using the similar procedure common effluent launder which can be collected from the discharge from this 10 launders for this each like in each of this reactor can be designed for the flow rate of 1500 meter cube per day for each reactor and the dimensions of this common effluent launder shall be finalized subsequently. So, this is how we design an UASB reactor. So, now, I know you if you go through it again at least one more time go through this lecture one more time and parallelly you open the lecture that we have done we you followed in the last one last lecture.

There also you open the picture of the UASB at least it two times you follow this lectures thoroughly I am telling you will be able to design the UASB reactor by yourself you have the capacity to do this by yourself and this is really a very good like job opportunity as well there are people who is who will give you like good amount of money for doing this for their treatment plant in their municipalities and all ok. Perfect. So, I hope it is a very good interaction is you will be able to understand this concept of this UASB design in general and these are the references that you can follow this Willis book is you can follow this Weiners and Professor Ghangrekar from IIT Kharagpur his book is book also you can follow this is there you can get in depth analysis of this UASB reactors and all till then till the next module. Thank you so much. Thank you.