**Biological process design for wastewater treatment**
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Lecture 24
Trickling Filter

Welcome everyone to this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, today we are going to learn regarding another of biological unit operation or treatment system which is used for wastewater treatment and this system is called trickling filter. Remember in the last few lectures, we started studying that treatment of wastewater using various methods and we studied the system have activated sludge process and sequential batch reactors in the last two lectures.

Now, in both the conditions activated sludge or activated biomass was there which was suspended inside the reactor. The wastewater goes into the reactor and then the reaction happens between the organic matter present in the wastewater and activated biomass which is suspended inside the reactor. Since both the operations were aeration or aerobic operation. So, aeration was done and also mixing was compulsory so, as to maintain a proper contact between the organic substrate and the active biomass.

So, this system the activated sludge system or SBR systems, in both the cases the activated biomass was in the suspension form inside the reactor and then aerobic system was there where air or oxygen was supplied to the reactor. Now, there is a fundamental difference with respect to suspension of active biomass in place of trickling filter heal the active biomass is not suspended, it is attached to growth on some media.

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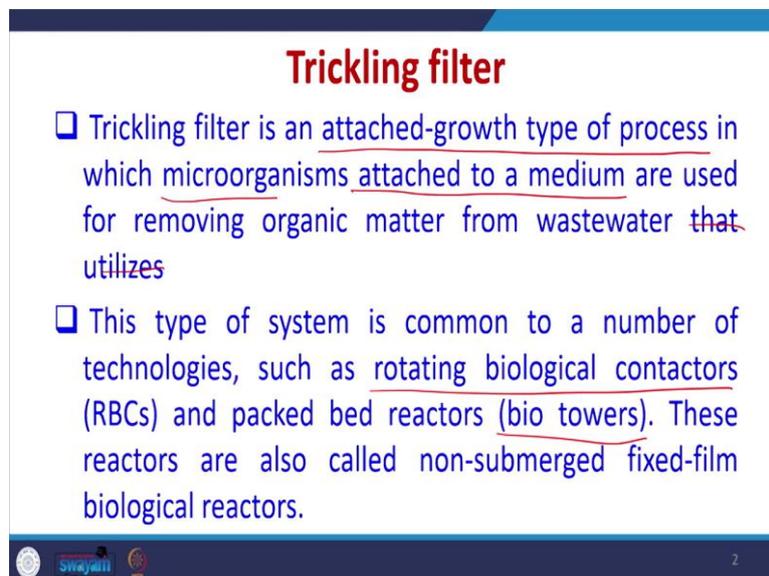
Trickling filter

❑ Trickling filter is an attached-growth type of process in which microorganisms attached to a medium are used for removing organic matter from wastewater that utilizes

❑ This type of system is common to a number of technologies, such as rotating biological contactors (RBCs) and packed bed reactors (bio towers). These reactors are also called non-submerged fixed-film biological reactors.

So, trickling filter is an attached growth type of process that means, it is not suspension type of process it is attached-growth type of process in which microorganisms attached to a medium this medium may be different are used for removing organic matter from wastewater. So, these microorganisms utilize which are grown they utilize this biomass to convert this into CO_2, H_2O, certainly the biomass will also grow.

So, this type of system is common to a number of technologies such as rotating biological contactors that we will be studying, then packed bed reactors are biodiverse these reactors are also called non submersible fixed film by logical reactors. So, trickling filter is attached-growth system which is important now, the microorganism since they are attached-growth on some packing or some materials, so, this packing is very important.
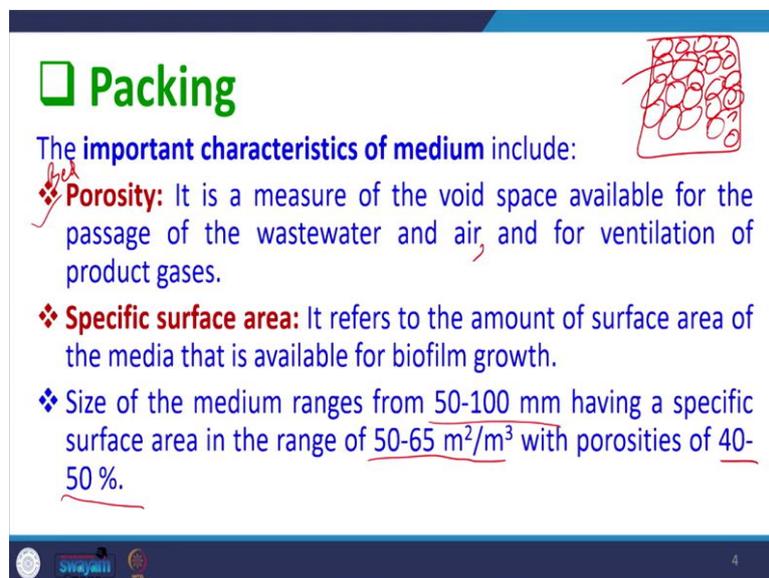
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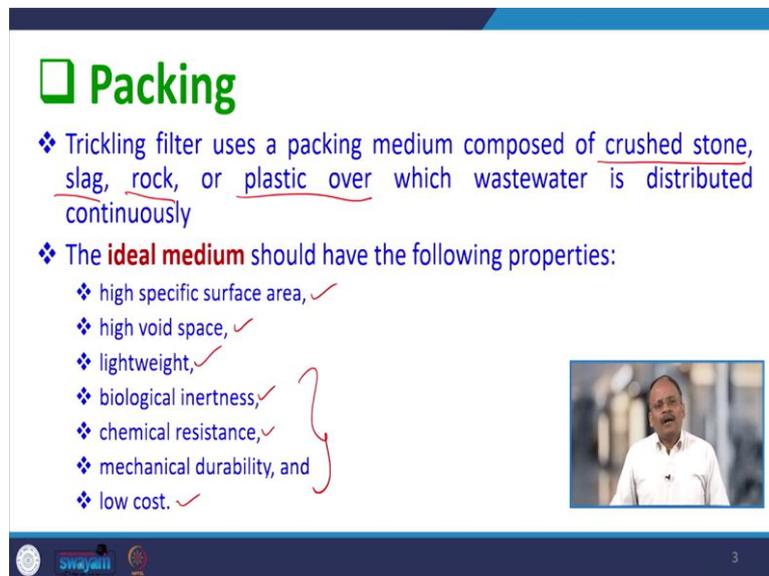
So, trickling filter uses different types of packing medium which may be composed of crushed stone, slag rock, plastic, etc., where which the wastewater is distributed continuously the ideal medium should have the following property. So, the packing material can have it is desirable to have following property it should have very high surface area.

So, this is one of the most essential requirement and this is required so, as to maintain a proper flow of water which is going towards the bottom and also the proper flow of air which may depending upon the temperature and conditions which may go up or down it should have high void space for flow rate of water and air then it should be lightweight, biologically inert. So, it should not react with the microorganism themselves. It should be inert on which the microorganism should grow.

It should be chemically resistance that means, if based wastewater is containing any amount of organic substance or other that organic substance should not be able to chemically degrade the medium itself. Otherwise, the medium collapse et cetera may happen. So, this chemical resistance and mechanical durability are one of the essential requirements of the medium and certainly it should be low cost.

So, all these lightweight biological inertness, chemical resistance, and mechanical durability are the essential requirement of medium and they should have high surface area and high wide space along with lowest cost possible. So, we can have different parameters, the important characteristics of medium include the porosity.

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It is a measure of wide space available for the passage of wastewater and air and for ventilation of product gases. So, if porosity is not good, in fact, the efficiency will go down because the flow rate of water we cannot sustain the flow rate of air we cannot sustain and thus the efficiency will certainly go down.

So, the most important characteristic it should be highly porous then is specific surface area it refers to the amount of surface area of the medium that is available for biofilm growth. If the surface the porosity is there if during the packing, but if we do not have the bed porosity is good enough, but we do not have the surface area then the biological film the amount of biological film which will grow will be less than that, which is the actual treatment of wastewater will also become less specific surface area, which is like meters square per meter cube of the material is very important for film growth as well as further treatment efficiency which is desirable.

The size of the medium may range from 50 to 100 millimeter having a specific surface area and the range of 50 to 65 meters square per meter cube of the bed with porosity of 40 to 50 percent. Remember the bed porosity here porosity means the bed porosity means this bed is there, and then we have packing if it is there, so, all the packing is filled. So, what is the space between these two what are these spaces which are there. So, the bed porosity should be 40 to 50 percent along with the specific surface area have the packing material to be there around 50 to 65. If it is more it is better. So, this is there.

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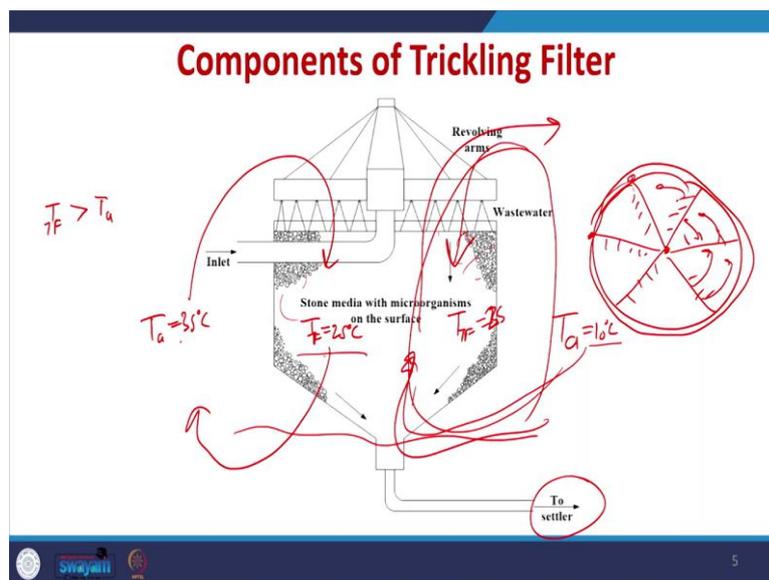
Now, what are the components of the trickling filter which is given here? So, actually, this is we can see this is stone with microorganisms on the surface. So, this stone or we can say the packing media will be this is the main trickling filter, the packing area this will be totally filled, then this inlet water will be coming and it will be distributed. So, if we can say like this on the top view, so, we can have a this is the main revolving point. So, we can have different arms which will be there.

So, wastewater will be coming and from each of the arm this distribution of water will happen and these arms, actually, they themselves are revolving continuously. So, that means, they are moving on a certain all around the perimeter certain system is maintained so, that the arms are here, there are wheels and these wheels are continuously moving across each of the arms.

So, continuous distribution of water is taking place and then the water is going inside this packing media and during the percolation over the stones or the packing media the treatment happens and ultimately the treated water is obtained here. Now, depending upon the

temperature conditions which are prevailing, the air will also either go down or go up. So, this will depend upon the temperature inside this trickling filter and what is the temperature at the ambient condition.

So, sometimes the air may be forced to go in or out then they will maybe condition with draft index is there because of the draft natural flow of air will be there. So, this will depend upon the ambient condition and the actual trickling filter water conditions. So, if suppose in one other condition we are making here the T_F inside the tickling filter suppose that the temperature T_F is greater than T_a.

So, that means, here the temperature is suppose around 35 degrees centigrade or 25 degrees centigrade but outside it is 10 degrees centigrade. So, that means we have colder air outside. So, under this condition the air will go inside it will get warmed and it will go up. So, this is because with warming it will become less and denser. So, the moment will become like this under this condition, but in another condition suppose outside temperature is 35 degrees centigrade, but inside again it is suppose inside the trickling filter is just 25 degrees centigrade, now, this is warmer and this is cooler.

So, under this condition the natural draft will be like this the air will go in it will become heavier and again go out because the temperature here is less. So, this is the natural draft. So, then maybe natural draft trickling fitter or we may also have the conditions we have may force air to go inside and come out. So, these are the essential components of that tickling filter.

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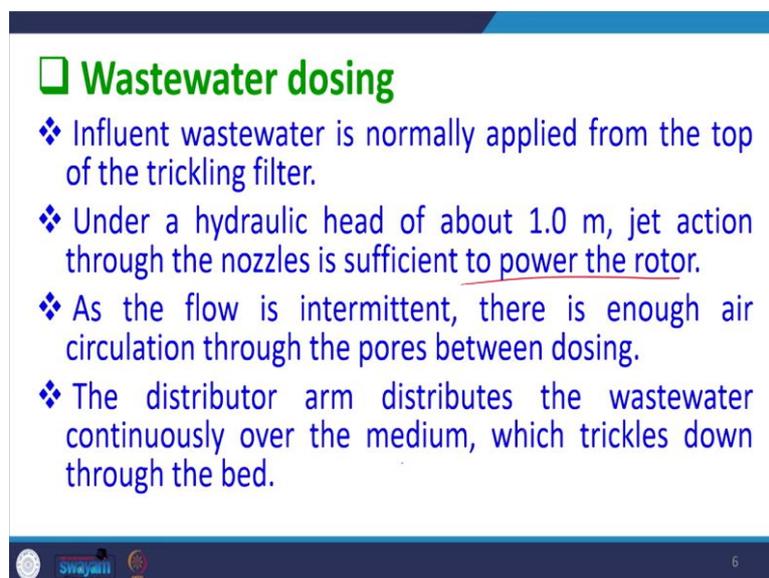
❑ **Wastewater dosing**
- ❖ Influent wastewater is normally applied from the top of the trickling filter.
- ❖ Under a hydraulic head of about 1.0 m, jet action through the nozzles is sufficient to power the rotor.
- ❖ As the flow is intermittent, there is enough air circulation through the pores between dosing.
- ❖ The distributor arm distributes the wastewater continuously over the medium, which trickles down through the bed.

Now, going further, what is the wastewater dosing? So, the influent wastewater is normally applied from the top of the tickling filter. So, under a hydraulic head of about 1 meter. Jet action through the nozzles is sufficient to power the rotor. So, there is a rotor under which the movement is taking place as the flow is intermittent there is enough air circulation through the pores between the dosing. The distributor arms distribute the waste water continuously over the medium which trickles down through the bed. So, this is how the wastewater dosing takes place.

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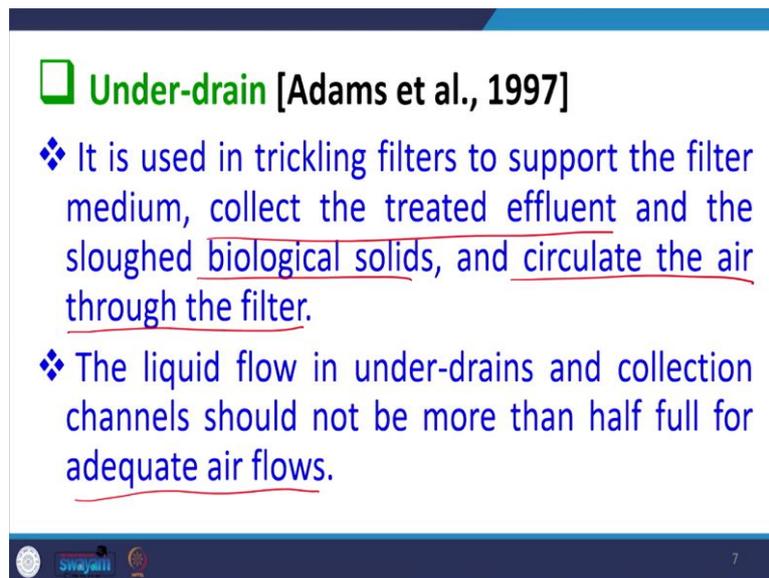
□ Under-drain [Adams et al., 1997]

❖ It is used in trickling filters to support the filter medium, collect the treated effluent and the sloughed biological solids, and circulate the air through the filter.

❖ The liquid flow in under-drains and collection channels should not be more than half full for adequate air flows.

Under drain, there are under drains in in the tickling filter. These under drains are used in the tickling filter to support the filter medium above them, then collect the treated effluent, they will collect the treated effluent after the treatment and collect the sloughed biological solids also, because the biological solids which will continuously grow on the medium.

So, after a certain time depending upon the flow rate, these sloughed biological solid away and they go into the under drain. So, this is done also these under drains help in the circulation of the air through the filter depending upon the conditions prevailing, so there may be updraft, downdraft.

So, depending upon the draft condition which are prevailing, the liquid flow in the under drains and collection channels should not be more than half full for adequate airflow. So, these under drains are designed in such conditions that the wastewater flow inside the under drain should never be more than half of the under drain. So, it should always be less than under less than half so that the air flows can be maintained otherwise, the efficiencies of operation will go down.

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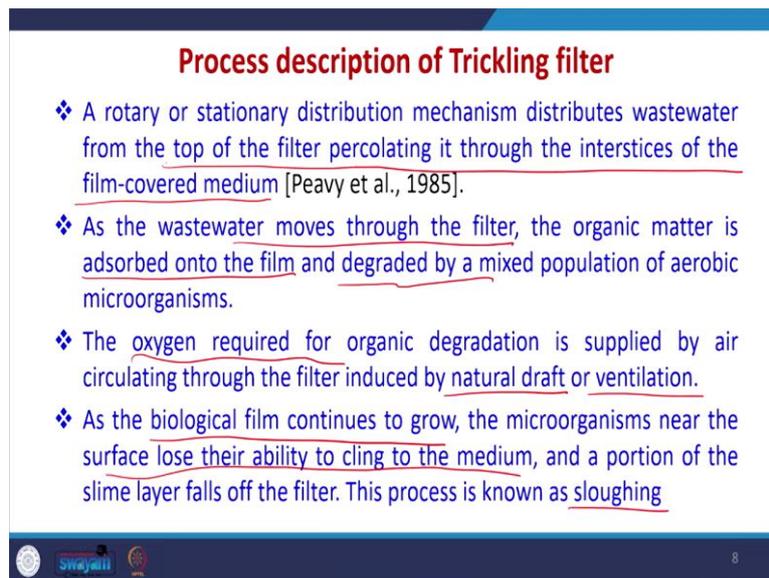
Process description of the trickling filter. A rotary or a stationary distribution mechanism distributes the wastewater from the top of the filter, percolating it through the entire spaces or spaces of the film covered medium. So we have a stationary or a rotary distribution mechanism is generally there which distributes the wastewater from the top of the filter over the medium as the wastewater moves through the filter, the organic matter is adsorbed on the film and degradation happens by him makes the population of aerobic microorganism.

So, there is a film which is covering the medium or the wastewater flows above that the organic matter is adsorbed biodegrade by the population of the aerobic microorganism. For that they require oxygen, the oxygen required for organic degradation is supplied by air circulating through the filter induced by the natural draft or ventilation.

It may be possible that we may have natural draft as I explained, so oxygen will be required as the biological films continue to grow because of the utilization of the organic matter as substrate, the microorganisms near the surface lose their ability to cling to the medium and a portion of the slime layer falls off the filter. So it happens naturally. And this process is called sloughing.

The sloughed solids are picked up by the under drain systems and transported to a clarifier for removal from the wastewater. So these all these microorganisms are removed from the wastewater by these secondary clarifier. The microorganisms used in the tickling filter, the microorganism used are mainly facultative bacteria that decompose the organic matter in the wastewater along with the aerobic and anaerobic bacteria.

So, it includes like Achromobacter, Flavobacterium, Pseudomonas, alcaligenes and it says that depending upon the requirement the microbes are maybe different in the lower reaches of the filter nitrifying bacteria usually present this is there. So, we have a there is one difference is that that means, we have a clarifier also for the removal of wastewater from this system, remember there is a fundamental difference in terms of clarifier as compared to activated sludge process and trickling filter.

What is the difference in the activated sludge process ASP the water is coming, it is going into the secondary clarifier SC I am just writing for simpleness from here the sludge is taken out, some of the sludge is recycled back, and some of the sludge is wasted? So, this is wasted sludge and then this is recycled sludge for maintaining the required amount of MLSS. Now, in the case of trickling filter, which is like here, so, far the case of trickling filter here the wastewater is coming it is treated after that from the under drain it will go into the secondary clarifier.

This is trickling filter. Now, from here waste will be taken out so this wasted sludge is there, but this sludge will not be recycled back, but it is a possibility that the water which is coming out here, treated water, it may be recycled back into the system because the efficiency may not be good enough. So, remember in that trickling filter, we do not recycle the wasted sludge, we recycle the treated water for improving the efficiency.

This is called recirculation of water. But in the case of activities sludge system, we recycle the sludge not the water after treatment that treated water is coming here and it is taken off. So, this is the difference as compared to ASP in that trickling filter.

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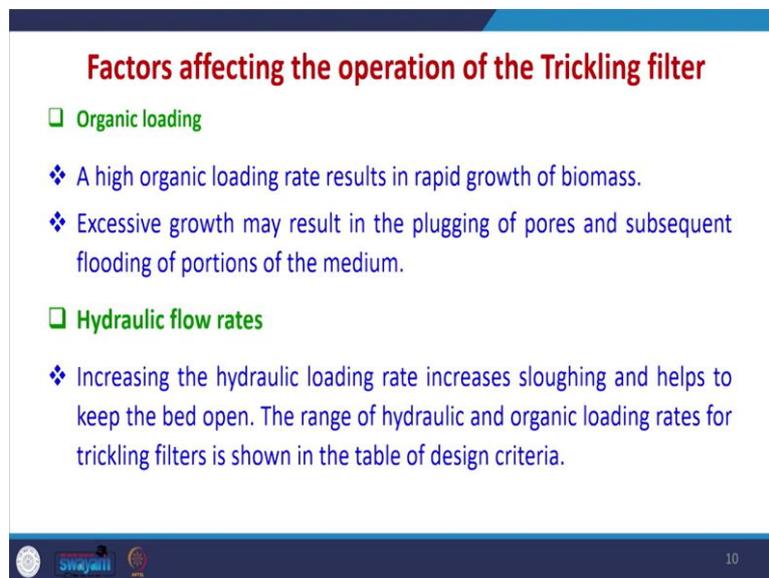
Going further the factors which affect the operation of trickling filter. So, a high organic load results in rapid growth of biomass, the organic load is very high, the rapid growth of biomass will happen an excessive growth of biomass may result in plugging of pores and subsequent flooding a portion of the medium. So it will actually hamper the operation. So there are many consequences may happen. So that is why the organic loading should be properly to be decided.

So many times that is why the recycling is done because treated effluent is there, its organic loading is much lower as compared to the original wastewater. So, we depending upon the requirement, we may actually manipulate the organic loading which is there on the tickling filter, then the hydraulic flow rates, increasing the hydraulic flow rate increases the sloughing and helps to keep the bed open the range of hydraulic and organic loading rates for tickling filters will be shown later on as a design-criteria.

Then the relative temperature of wastewater and ambient air. Already I have discussed this. So, this is very important in case of tickling filter, remember, cooled water absorbs heat from the air and the cold air falls towards the bottom of the filter in a concurrent fashion with the water. So, cool water will absorb heat from the air and the cold water and the cold air will go down along with the water.

So, operation will become concurrent or co current warm water heats the air causing it to rise through the under drain and up through the medium. So, there is condition. This condition will prevail when the wastewater is having a higher temperature are that the temperature inside the trickling filter is higher than the ambient condition. So this is a condition when actually the air will go up through the tickling filter, whereas in this condition that T_W and T_F the temperature inside that trickling filter is less than that in the ambient or for ambient air as the tip pressure differentials of less than 3 to 4 degree relatively little air movement reserves.

So, when suppose the difference becomes very less then at that condition the stagnant conditions prevent good ventilation. So, and under this condition we may have to force the air to go either up or down. So, counter current operations are generally more beneficial, they give better efficiencies as compared to co current operations. So, and when the temperature differentials are very less they may cause problem.

So, that is why we have to select properly under which condition we have to operate the extreme cold may result in icing and destruction of the biofilms. So, that wise trickling filter are not good enough where the extreme cold conditions may prevail.

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Tentative method of ten states of USA [Davis and Cornwell, 2000]:

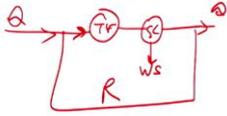The equation is given as follows:

$$E = \frac{(R/Q)+1}{(R/Q)+1.5}$$

Now, there are many design equations which have been developed for uses in the trickling filter design. So, some of these design equations are we have given here and we can use these depending upon what conditions are prevailing for our case. So, first method is called the tentative method of 10 states of the USA and the equation is that E is equal to R by Q plus 1 is equal to R by Q plus 1.5 where Q is the flow rate and R is the recycle flow rate.

Remember, this is trickling filter T_F, wastewater is coming which is Q, and then we have a secondary clarifier from which the we have wasted sludge, then this is the treated effluent and this treated effluent is recycled back which is R. Remember this is an again the flow rate is Q. So, this is the user flow rate R is the recycle. So, and these equations are good when the raw settled domestic sludge is having BOD less than this and the BOD entering the filter here that means, inside this including the recirculation in is less than that 3 times the BOD expected in the effluent. So, certain conditions are there for each of the design equation.

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Velz equation [Adams et al., 1997]:

The following equation is used for a single-stage system and in the first stage of a two-stage system:

$$S_{e1} = [(S_i + r_1 S_{e1})/(1+r_1)]\exp[(-kDA^n/Q^n)(1.035^{T-20})]$$

The following equation is used for the second stage of a two-stage system:

$$S_{e2} = [(S_e + r_2 S_{e2})/(1+r_2)]\exp[(-kDA^n S_{e1}/Q^n S_i)(1.035^{T-20})]$$

Where, S_e is the effluent BOD from the filter (mg/l), S_i is the influent BOD (mg/l), r is the ratio of recirculated flow to wastewater flow, D is the filter depth (m), A is the filter plan area (m^2), Q is the wastewater flow (m^3/min), T is the wastewater temperature (^{o}C), k and n are empirical coefficients (for municipal wastewaters, k=0.02 and n = 0.5) and subscript i (i=1, 2) represent the stage number.

After tentative method of 10 states we have Velz equation. So, Velz equation is used for two stage trickling filter systems. And in the two stage systems it is possible that we have two trickling filters which are there. So, they may be operated this is one this is second. So, this is possible and after that there may be a secondary clarifier is SC and then there is a recycling. So, this type of system is also possible. So, in the Velz equation can be used. Remember in this equation, so, for a single stage system and for suppose we have two stage system so, far the first stage this equation can be used.

So, Velz equation can be used for single filter also it can be used for two trickling filters in series, two stage system. So, for the first stage or for single stage system, the equation is

given by this here is Se stands for the effluent BOD of the filter. So, what is coming out then rI stands for the Si stands this Si stands for the influent BOD the one which is going into the BOD into the trickling filter.

E stands for effluent, R is the ratio of recirculated flow to the wastewater flow, D is the filter depth, remember D is the filter depth and A is the filter plan area. So, what is the area, this is the d, and this is the area which is there under filter plant. So, this is their T is the wastewater temperature here and it whether it is more than 20 degrees centigrade, it is less than 20 degree centigrade, k and n which is the coefficients which are given here are the empirical constants for municipal wastewater k is taken to be 0.02, n is 0.5 and the subscript this i may be 1 or 2 depending upon the stage numbers.

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NRC equations [Adams et al., 1997]

The following equation is used for a single-stage system and the first stage of a two-stage system

$$1-(S_{e1}/S_i) = 1/[1+0.532(QS_i/V_1F_1)^{0.5}]$$

The following equation is used for the second stage of a two-stage system

$$F_1 = [(1+r_1)/(1+0.1r_1)^2]$$

$$1-(S_{e2}/S_{e1}) = 1/[1+0.532(QS_{e1}/V_2F_2)^{0.5}]$$

$$F_2 = [(1+r_2)/(1+0.1r_2)^2]$$

Where, V is the filter volume (m^3), and F is the recirculation factor.

Then we have NRC question the following equation is used for single stage system and for the first stage of two stage system. So, this is again the nomenclatures are same, there are some fundamental difference which are there with respect to NRC equation or for the equation for 10 states or for Velz equation. So, all the notations are same, but there are significant differences which have been there and because of which these equations have been derived.

Similarly, for the second stage of a two stage system, the following equation can be used in this case there is a term new term which is F. So, F is the recirculation factor. So, how much recirculation is being done? So, F, these F_1 and F_2 are recirculation factor and V is the filter volume. So, in place of depth and area the volume has been used. So, volume will always be equal to depth into area. So, remember this, so, we have in this case the V has been given.

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Eckenfelder equation (Plastic media) [Eckenfelder, 1996]

The Eckenfelder equation used for plastic media is as follows:

$$S_e / S_i = \exp[-KD(QS_a^m / A)^{-n}]$$

Where, K is the observed rate constant for a given filter depth (m/d), S_a is the specific surface area of the filter (m^2/m^3), D is the filter depth (m), Q is the wastewater flow rate (m^3/d), A is the filter plan area (ft^2), and m and n are empirical coefficients.

Then there is another equation which is given by Eckenfelder equation which is used for plastic media. Remember this is use of plastic media. This equation was given and k is the

observed rate constant for a given filter depth Sa is a specific surface area here that specific surface area of the filter has been used and D is the filter depth, Q is the wastewater flow rate, and A is the filter plan area or filter area m and n are empirical constant.

So, remember these are empirical constants and their values may be obtained from the literature. So, Se and Si are the remember here this is the fraction of treatment that happens inside the reactor, k is the observed rate constant for given filter, so this is there.

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Germain/Schultz equations (Plastic media) [Adams et al., 1997]

The Germain/Schultz equations used for plastic media are as follows:

$$S_e / S_i = \exp[-K_{20,i} D_i (Q/A)^{-n}]$$

$$k_{20,2} = k_{20,1} (D_1 / D_2)^x$$

Then, another equation was given by Germain and Schultz, this is similar to the Eckenfelder equation again for plastic media, but with some difference and here there are constants which are encountering for temperature also. So, k_{20}, i is the treatability constant corresponding to a specific filter depth di at 20 degree centigrade, but suppose the filter this specific filter depth changes.

So, under those conditions we can use this equation. So, once we have data for one system, we can use this equation for finding the data for another system and there are n and x are empirical constant, n is usually 0.5, x is 0.5 for rocks and 0.3 for class flow plastic media. So, these are the different many equations are available for trickling filter design. Depending upon the conditions prevailing we can use these equations.

Now, in the end we will be trying to solve the problem before ending this section on trickling filter. And in this case, the problem we have to calculate the value of k_f the constant and influent BOD to the trickling filter for different R by Q ratios, R by Q ratio has been given to be 1.65. So, given that the raw settled BOD after primary settling, it is coming to be 220 milligram per liter.

So, here this value is to remember 220 milligram per liter, the flow rate, the hydraulic loading on this trickling filter is given as 30 meter cube per day per meter square and depth of filter is 1.5 meter, the empirical constant and effluent BOD after secondary settling here it is given that it has to be 30 milligram per liter and this Q is given to be 30 meter cube per day per meter square. So, these conditions are given now, we have to find out what is the actual influent BOD, which is going into the tickling filter and based upon that we can find out other parameters.

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Problem

Calculate the values of k_f and influent BOD (S_o) to trickling filter for R/Q (ratio of recycle flow rate to hydraulic loading) value of 1.65. Given that: raw settled BOD after primary settling (S_a)=220 mg/l; hydraulic loading (Q)=30 m³/(d. m²); depth of filter (D)=1.5 m; n=0.5 and effluent BOD after secondary settling (S)=35 mg/l.
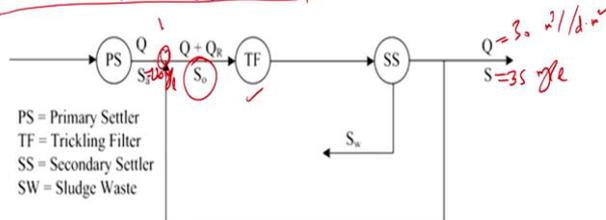
PS = Primary Settler
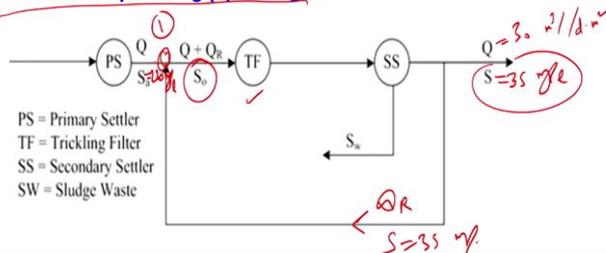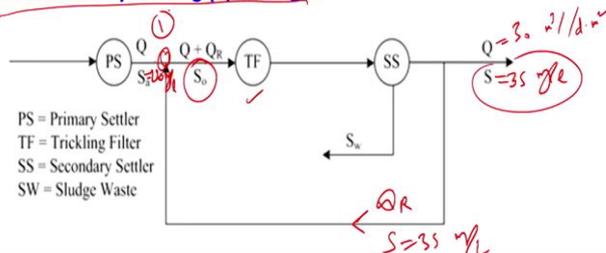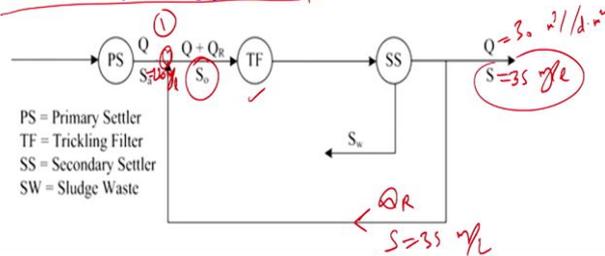TF = Trickling Filter
SS = Secondary Settler
SW = Sludge Waste

Solution

$$QS_a + Q_R S = (Q+Q_R)S_o \qquad ①$$

$$S = \frac{(Q+Q_R)S_o - QS_a}{Q_R} = \frac{(1+(Q_R/Q))S_o - S_a}{(Q_R/Q)} \qquad ②$$

Also,

$$S_o = \frac{QS_a + Q_R S}{Q+Q_R} = \frac{S_a + (Q_R/Q)S}{1+(Q_R/Q)} \qquad ③$$

On putting values in last equation, we get,

$$S_o = \frac{220 + 1.65 \times 35}{1+1.65} = 104.81 \text{ mg/l}$$

Following Equation can be used to detemine the paramaters and others, k_f

$$QS_a + Q_R S = (Q+Q_R)S_o$$

$$S = \frac{(Q+Q_R)S_o - QS_a}{Q_R} = \frac{(1+(Q_R/Q))S_o - S_a}{(Q_R/Q)}$$

$$S_o = \frac{220 + 1.63 \times 35}{1+1.65} = 104.81 \text{ mg/l}$$

So, what we do is that, we put a balance on the system and for doing this remember Q S_a is the flow rate which is going into the at this point. So, at mixing point 1 we are putting a balance at mixing point 1. So, Q S_a is coming from the primary unit Q_R S remember after treatment the S is the concentration and suppose this is the Q_R which is being recycled back and the concentration is S.

So, concentration will remain the same 35 milligram per liter. So, we are assuming so, this is getting mix. So, this is Q_R S and after that the flow rate becomes Q plus Q_R and S_0 is the loading on the trickling filter which has to be determined. So, from this we can find out capital S is equal to Q plus Q_R S0 minus Q S_a upon Q_R and if you divide by Q, this equation becomes 1 plus Q_R Q S_0 minus S_a Q_R Q.

So, from here also from the same equation, we can also find this equation. So, any of these equations can be derived from equation one now, if we use this is second and this is third, now, if we can put the values in the equation third and we can find out the value of S0. So, it is given that S_a which is coming is having a BOD of 220 milligram per liter. So, this is 220. Now the recycle ratio is already given that we are going to use 1.65. So Q_R by Q the value in as compared to here it is very high. So Q_R by Q is 1.65 and 35 is the total. So 1 plus this becomes 1.65. So, this is the loading which will happen on that tickling filter 104.81.

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From Eckenfelder equation,

$$\frac{S}{S_o} = \exp\left[-\frac{k_f D}{Q^n}\right]$$

$$\frac{35}{104.81} = \exp\left[-\frac{k_f \times 1.5}{30^{0.5}}\right]$$

$$k_f = 4.004 \text{ m}^{-1/2}\text{d}^{-1/2}$$

Now from the Eckenfelder equation which was given earlier the S by S_0 is equal to exponential minus k_fD Q raise to n. Now, in this case, all the parameters are known to us. So, this is the concentration after treatment, this is the loading concentration on the trickling filter 1.5 is the depth the flow rate is 30 and the trickling filter and 0.5 is the so the value of k_f can be obtained.

There could be opposite things also which could have been asked like in place of k_f we could have asked the depth also k_f has been given, so this is possible. So this way we can design a trickling filters under various conditions. Remember trickling filter is different as compared to activated sludge process or SBR. In that trickling filter the microorganisms are attached growth and media which is essentially required to have a very high surface area.

The bed porosity should be high. We have also it is very important to check the temperature difference with respect to ambient conditions. If the temperature conditions are not good enough, the natural draft will never be there and the flow of air will not be there. So under those conditions, forced flow of air has to be done. So the temperature differential between the wastewater temperature and the air temperature has to be crosschecked always for better operation of this trickling filter.

So, trickling filter is different as compared to activated sludge process. They have some benefits as compared to the treatment deficiencies are not as good as this activated sludge process. But the mode of operation and other things are very simple. If it is to the proper filter media.

So depending upon these requirements also trickling filter cannot be used under those very cold climate conditions. Otherwise, the freezing etc., may happen and the wastewater flow may not happen. So all these things are important during the design of trickling filter. I will continue further with understanding of other reactor systems or other unit operations where attached growth system is there in the next lecture. Thank you very much.

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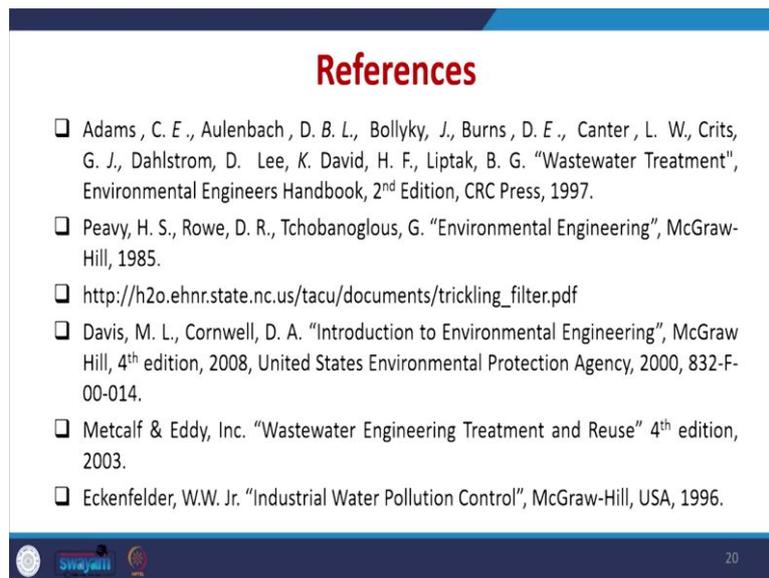
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You can refer to any of these books for better understanding of trickling filter. Thank you very much.