Biological Process Design for Wastewater Treatment
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Lecture 18
Treatment of Water and Wastewater-II

Welcome everyone in this NPTEL online certification course on biological process design for wastewater treatment. So today we will be continuing with the treatment of water and wastewater that we studied in the previous lecture. In the previous lecture, we studied that there are treatment methods, which vary depending upon the characteristic of water and the source of the water. So, the source of water, if it is river or lake or any other reservoir, so, depending upon that the water treatment strategy for producing or getting the drinking water may be different also it may be entirely different for treatment of water which is taken from groundwater.

So, similarly, the water which is discharged from industry or from municipal wastewater that has to be treated differently as compared to that for drinking purposes. And there are various steps which are involved in the treatment of water which is discharged from municipal or from industry and those steps involve primary secondary and tertiary treatment. In the primary treatment, there are cleaning steps, which try to remove the bigger particles in the first step.

After that, there are steps which involve flow equalization, aeration and further flocculation or coagulation and flocculation steps. Now, the flow equalization and aeration are the first step, also remember that aeration may be used along with the flow equalization itself and aeration is also used during biological treatment of water. So, aeration is important during biological process design for wastewater treatment. So, today we are going to learn a little bit about flow equalization and aeration.

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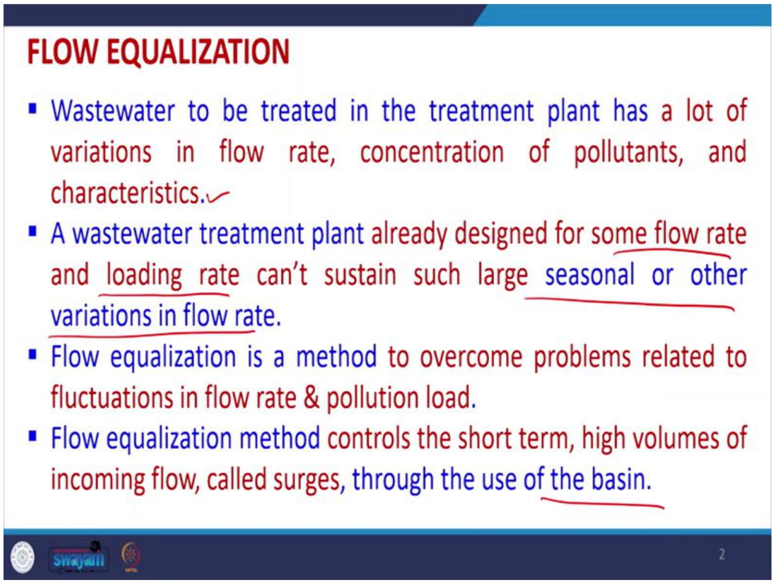

Flow equalization, first we will be studying this the wastewater is to be treated in the treatment plant and it is possible that a lot of variation with respect to water flow rate concentration of pollutant and overall characteristic of water which is going into the treatment plant may be there. Now, any wastewater treatment plant is designed for some particular flow rate and for some particular loading and if the variation is too much from these conditions, the wastewater treatment plant may not operate at optimum efficiencies.

Thus, a wastewater treatment plant is already designed for particular flow rate and loading and it cannot sustain large seasonal or other variations in the flow rate. To avoid this, what we do is that we to try to equalize the flow rate and characteristics and this can be done in the flow equalization basin. So, flow equalization actually work on the problems related to fluctuation in flow rate and the pollution load. And this controls the short-term high volumes of incoming flow called surges through the use of different types of basins. So, there may be some basin which can actually help in equalizing the flow rate as well as the loading.

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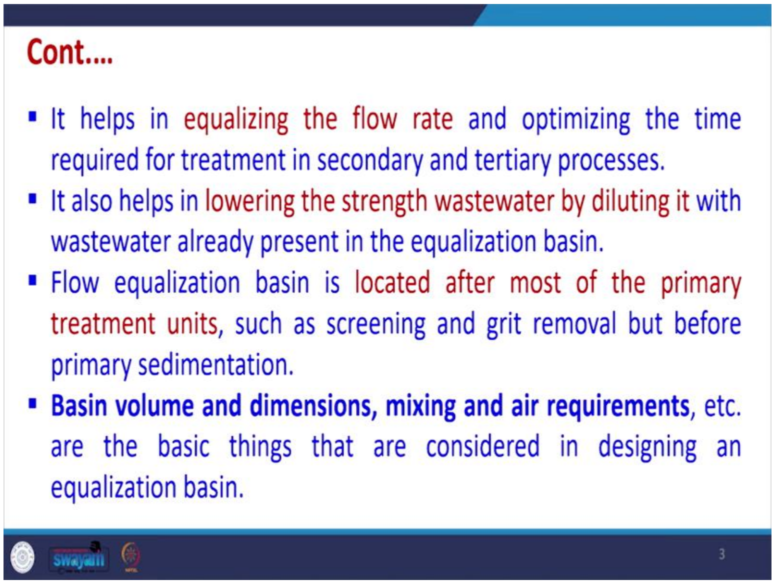

Overall flow equalization helps in equalizing the flow rate and optimizing the time required for treatment in secondary and tertiary processes. It also helps in lowering the strength of wastewater by diluting it wastewater which is already present in the equalization basin. The flow equalization basin is generally located after most of the primary treatment units, such as screening, grit removal, but before the primary sedimentation or coagulation and flocculation units. Basin volumes and dimension, the mixing and air requirement etcetera are the basic things that are considered in designing an equalization basin.

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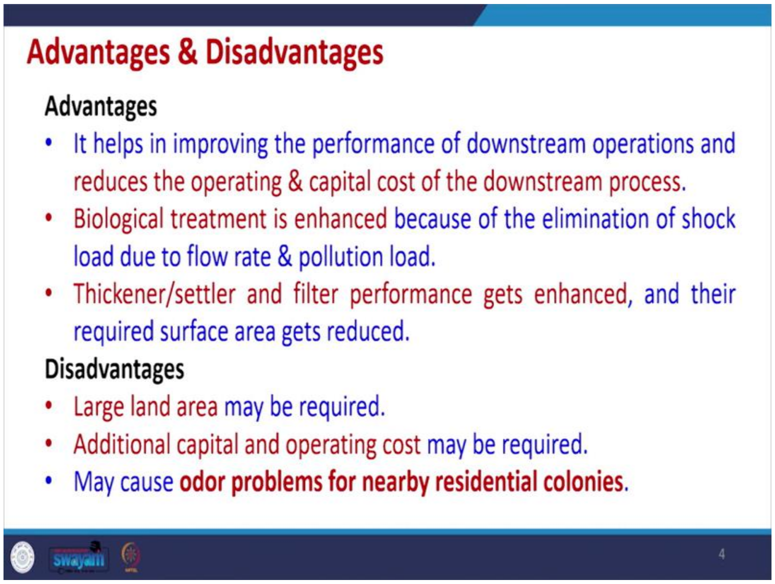

Now, there are certain advantages and disadvantages of using the flow equalization basin. The advantage is that it helps in improving the performance of downstream operations and reduces the operating and capital cost of the downstream processes. Because the flow is being equalized. Biological treatment efficiencies get enhanced because of the elimination of shock load due to flow rate or the pollution load. The thickener oblique settler and filter performance also get enhanced and they are required surface area gets reduced.

Overall the disadvantages include some large land area may be required for flow equalization basin, additional capital and operating costs may be required with respect to pumps etcetera, may cause odor problem for nearby residential colony because water as such is being stored in a basin. So, odor may come out of that basin and it may cause some problem.

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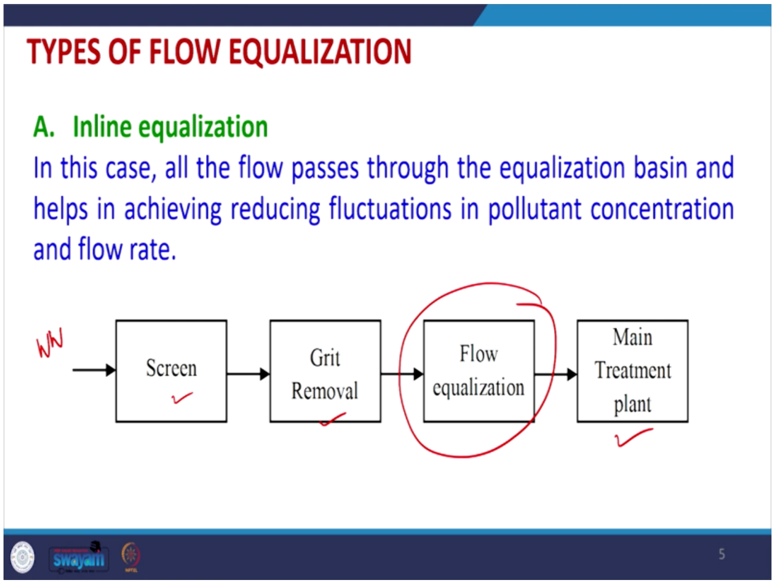

There are two types of Equalizations one is called Inline equalization another is called Offline equalization. So, in the inline equalization, the flow passes through the equalization basin. So, this is the equalization basin and we can see the wastewater which is coming it may be municipal wastewater it may be industrial wastewater, so, it goes through the screen and grit removal after that it passes through the flow equalization basin and to the main treatment plant. So, this is inline equalization.

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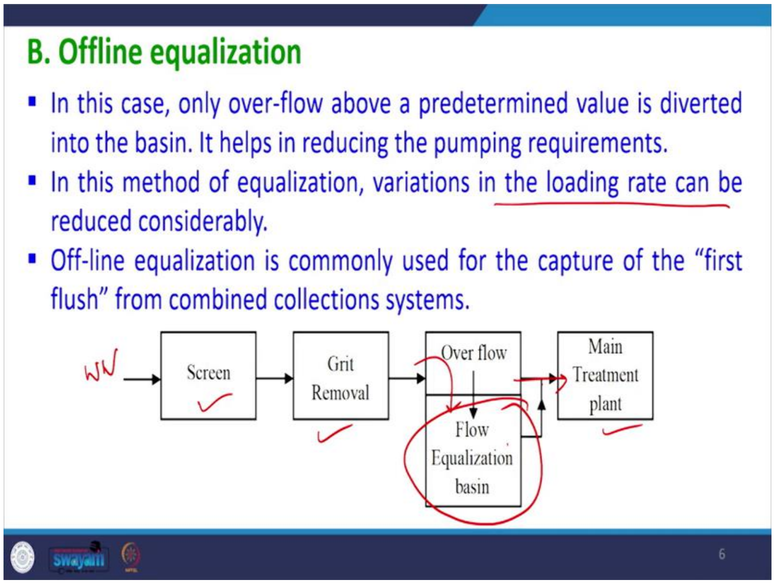

Then offline equalization is also possible in this case only overflow or a predetermined value is diverted into the basin. So, we have the flow equalization basin here and the wastewater which is coming it goes through a screen and grit removal and if the flow rate is above certain average value or some predetermined value, the overflow a overflow will go into the flow equalization basin and the rest flow will go into the main treatment plant, after a certain time when the average flow is much much lower than the desired flow rate, then under those conditions, the water from flow equalization basin is taken into the main line and then further treatment is done in the main treatment plant. So, this is via this method, the variation in the loading rate can be reduced considerably. Offline equalization is commonly used for the capture of the first flush from the combine collection systems. So, it has lots of uses. Also it is possible that aeration can be performed in the flow equalization basin itself or via using various aeration methods. So, aeration can also be done in the flow equalization basin itself.

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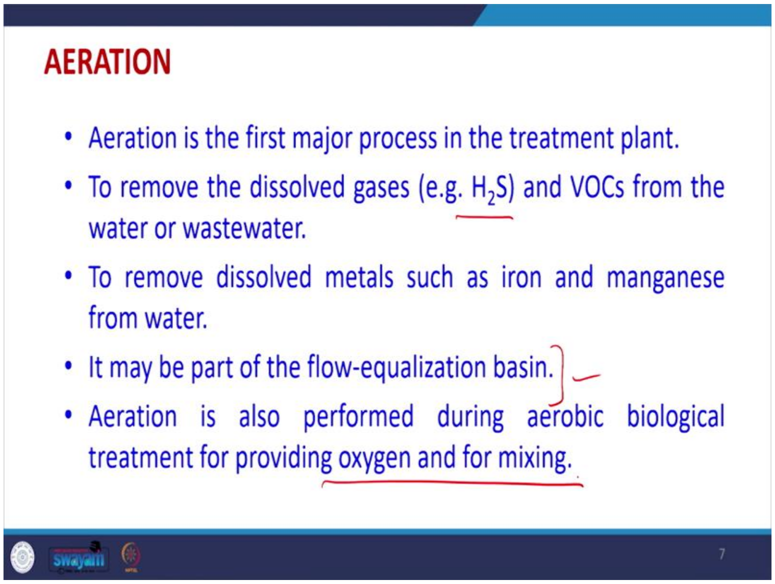

Or aeration may be done in a secondary step. Now, aeration will try to study the aeration in greater detail and it is not only used separately, it is used along with the biological treatment where the aerobic treatment processes are being performed. So, that is why aeration is not only important as individual unit, it is also essential part of all aerobic biological treatment methods. So, aeration in is the first major process in the treatment plant and it is generally used to remove the dissolved gases and VOCs from the water and wastewater.

So, we can remove the dissolved gases such as H_2S and also other types of volatile organic compounds if present in the water including benzene, xylene, toluene, etcetera. It can also remove dissolved metals such as iron and manganese from water, it may be the part of flow equalization basin as I already told, aeration is also performed during aerobic biological treatment for providing oxygen and for mixing. So, for both purposes, aeration is done in the biological treatment processes.

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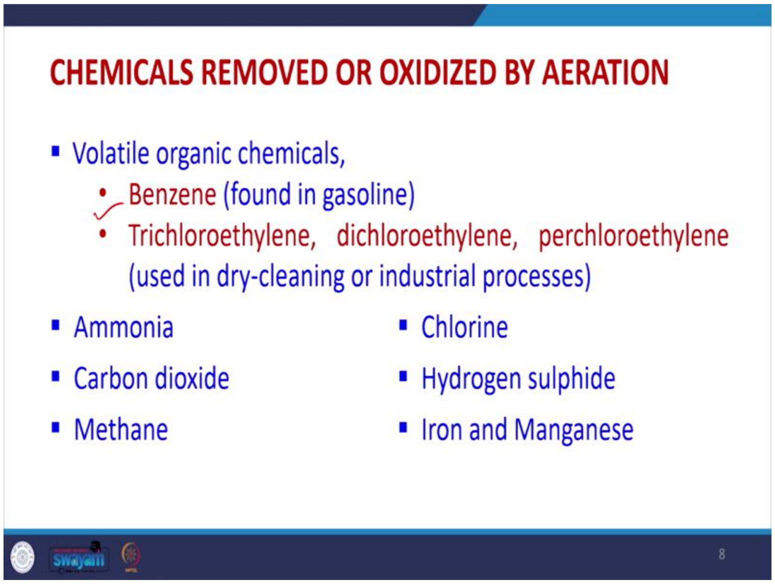

During aeration not only we provide the oxygen for molecules or for removal of various types of volatile organic compounds, including benzene which is found in gasoline or other types of compounds including Trichloroethylene, dichloroethylene, perchloroethylene, which is used in the dry cleaning or industrial processes, it can be used for removal of various types of gases including ammonia, carbon dioxide, methane, chlorine, hydrogen sulfide, it can also be used for removal of iron and magnesium. So, overall aeration has lots of uses in wastewater treatment.

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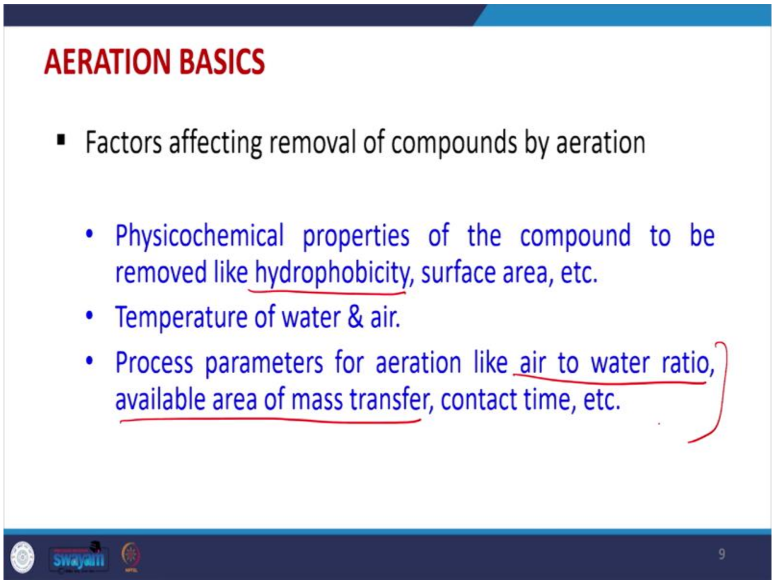

Now, there are various factors which affect the removal of compounds by aeration. So, these factors include physicochemical properties of compounds to be removed, like what is the hydrophobicity of the compound? So the compound which has to remove which has to be removed, what is its physio-chemical properties including hydrophobicity hydrophilicity etcetera, surface area, it affects the overall aeration process.

Now, the temperature of water and air are also important because it changes the solubility of the compound. Then process parameters for aeration including like air to water ratio, which is being used available area for mass transfer. So, how the mass transfer is happening from air to water side, the contact time all these parameters affect the removal efficiency.

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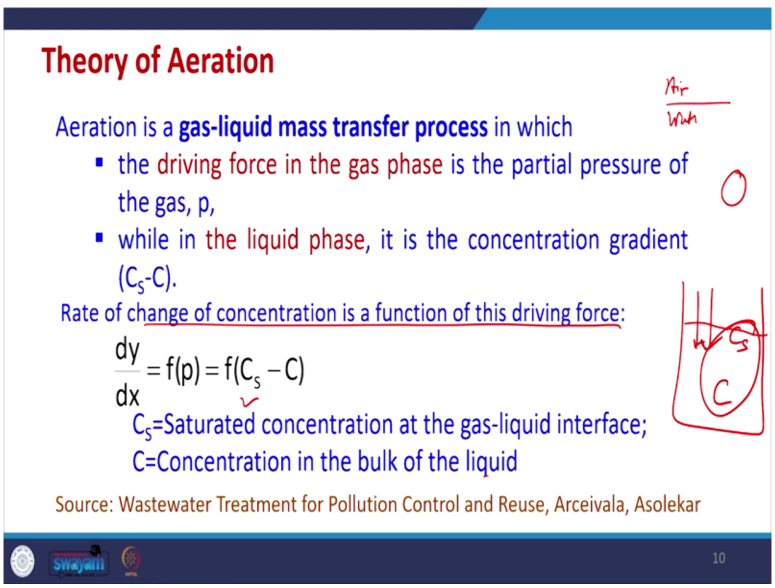

Rate of change of concentration is a function of this driving force:

$$\frac{dy}{dx} = f(p) = f(C_S - C)$$

Now, little bit of the theory, aeration is like a gas liquid mass transfer operation, it is a interface where one side air is there, another side water is there, it may be in the form of bubble it may be at the surface. So, there are various possibilities. Now, there are various mass transfer processes which are involved in the aeration. And the reason how it happens the essential is that the driving force in that gas phase is the partial pressure of the gas P, while in the liquid phase it is the concentration gradient.

So, aeration depends upon the concentration gradient, the rate of change of concentration is a function of this driving force, the saturated concentration at the gas liquid interface and the concentration in the bulk of the liquid. So, suppose there is this beaker or something and we have interface. So, what is the concentration here and what is the concentration at the interface. So, the difference between this forces the air to go inside the water. So, this aeration will depend upon this driving force and this driving force is ultimately the partial pressure difference.

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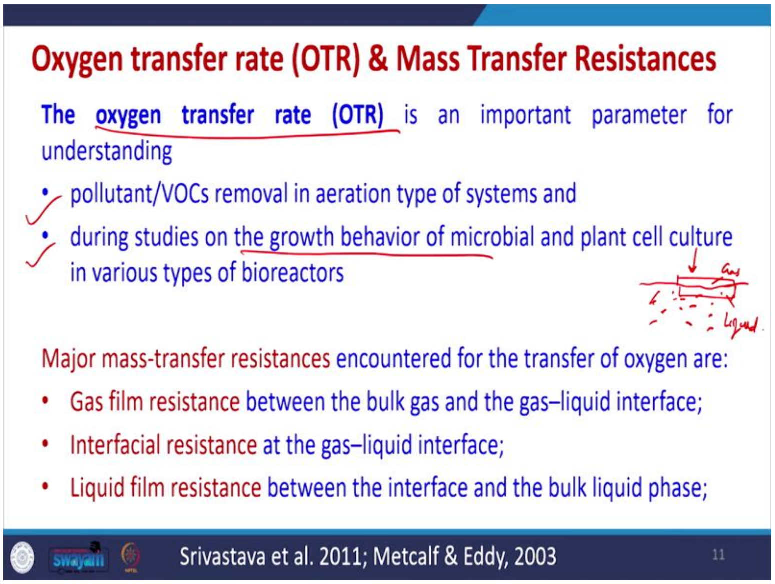

Now, the oxygen transfer rate this is OTR and mass transfer resistance there are essential part of aeration theory, the oxygen transfer rate is an important parameter for understanding the pollutant or VOCs removal in aeration type of systems. During studies on the, also OTRs is used during the growth studies on the growth behavior of microbial and plant cell cultures in various types of bio reactors. So, OTR is used both where pollution treatment or wastewater treatment is being done and also during the microbial plant cell culture.

There are various mass transfer resistances which are encountered for during the transfer of oxygen from air or gas phase into the liquid phase. So, we have gas film resistances, interfacial resistances and then the liquid filmed resistances. So, in a nutshell suppose this is the interface, so, and this is the water phase or the and then this is the top air phase, so when oxygen is moving, there will be always a liquid film which is surrounding and which will always stick to the surface of the interface and similarly, this will be the gas film.

Then similarly, there will be a liquid film on the liquid side there is a liquid film. Now resistances will be offered by both and then there will be resistance at the interface also, now this is being described here. Now, whenever transfer takes place, there are certain steps which are involved.

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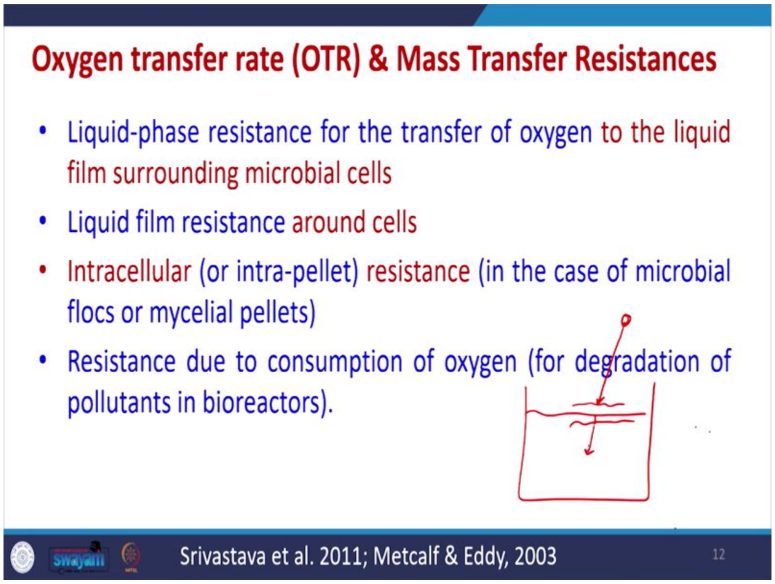

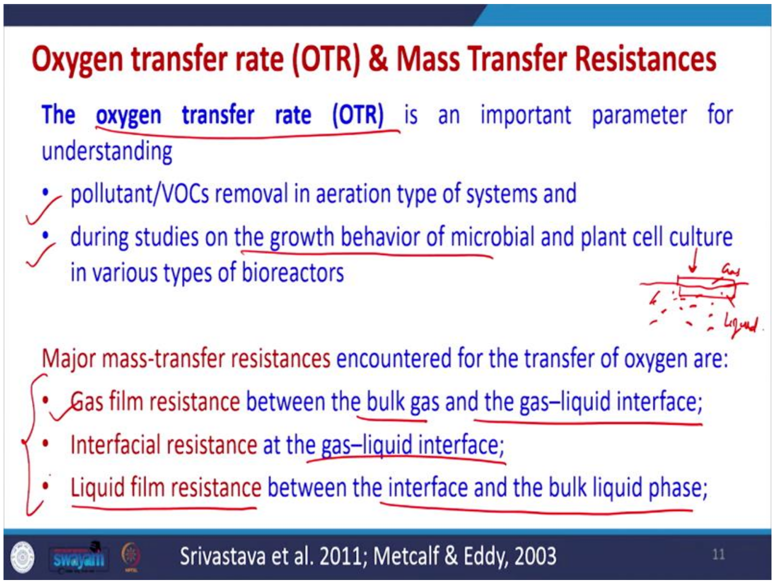

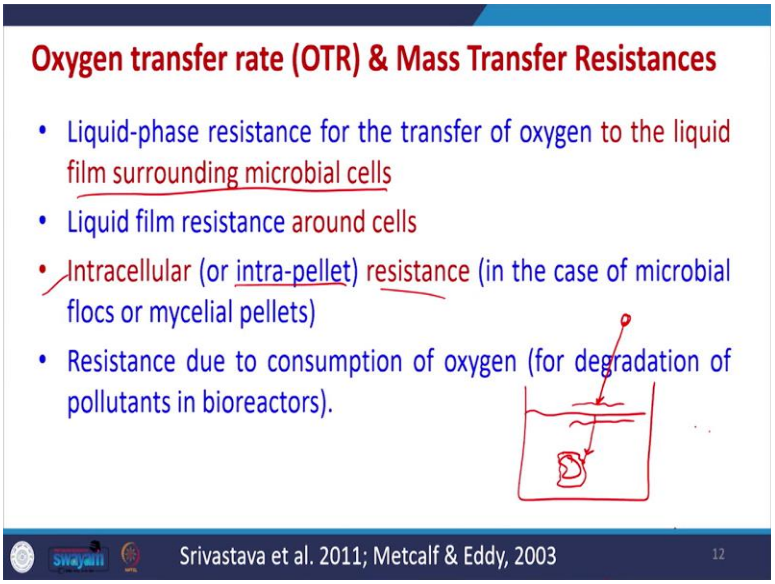

So, first suppose if you take individual case that suppose the transfer has to take place. So, suppose this is the oxygen molecule and this is the these are the liquid films. Now, in the first system this oxygen molecule has to travel to the surface of the gas film. After that, the second step the this molecule will travel across the gas film, then it will cross the interface and then it will cross the liquid side film and ultimately it will go into the bulk of the liquid.

So, these are the various steps and resistances. So, the major resistance is gas film resistance between the bulk gas and the gas liquid interface. Then we have interfacial resistance at the gas liquid interface and then the liquid film resistances between the inner interface and bulk liquid phase. So, these are the major resistances. Also, there is liquid phase resistance for transfer of oxygen to the liquid film surrounding the microbial cell, so it is possible that a microbial cell may be there and there is a liquid film which is surrounding this microbial cell.

So, resistance will be offered by this film also, also that the liquid film resistance around cells, this is there, then intercellular or interrupt pellet resistance in the case of microbial flocks and ultimately resistance due to consumption of oxygen for the degradation of pollutant in the bioreactor. So, these are the various mass transfer resistance during the transfer of oxygen from bulk air phase to bulk liquid phase. So, overall, we have a lot of mass transfer resistances but we want to combine them together.

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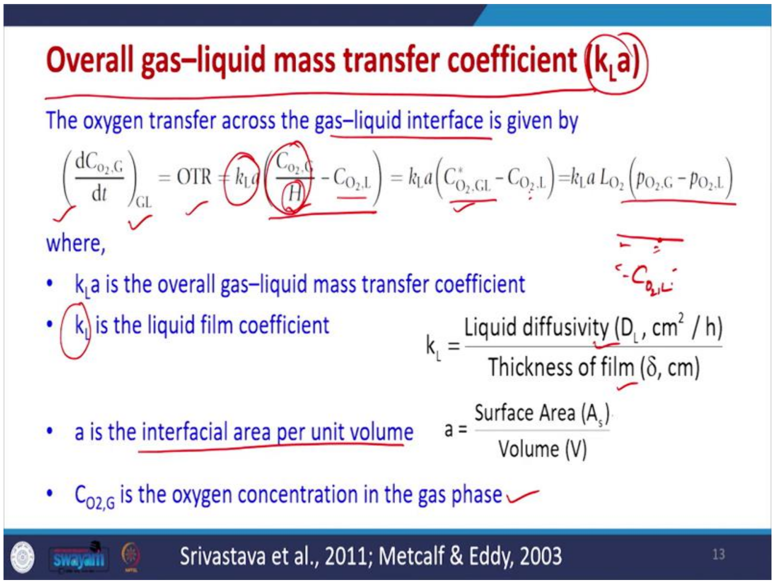

The oxygen transfer across the gas–liquid interface is given by

$$\left(\frac{dC_{O_2,G}}{dt}\right)_{GL} = OTR = k_L a\left(\frac{C_{O_2,G}}{H} - C_{O_2,L}\right) = k_L a\left(C^{*}_{O_2,GL} - C_{O_2,L}\right) = k_L a\, L_{O_2}\left(p_{O_2,G} - p_{O_2,L}\right)$$

So, there is a term which is called overall gas liquid mass transfer coefficient and this K_La, in this term. So, we try to use this K_La term for overall resistances. The oxygen transfer across the gas liquid interface is can be given by this equation. So, the rate of transfer of oxygen at the gas liquid interface which is called as OTR also and this is dependent upon the concentration difference at the gas phase and the liquid phase.

So, we try to determine the concentration at the interface, suppose, this is a concentration in the liquid at the in the bulk of the liquid and at the interface what we do is that we use the Henry's constant for determining the concentration in the liquid phase at the interface. So, the through this we can determine the this term represents the concentration at the interface in the liquid phase. So, using the Henry’s constant and this is the bulk concentration in the liquid phase. So, through via using we can determine if we can find out the value of K_La, we can easily find out the oxygen transfer rate.

Now, this is how it is written. So, we can write like this $C_{O2,GL}$ at the gas liquid interface the concentration and also if we can take out the solubility of the oxygen in the water. So, we can represent this in terms of partial pressure. So, overall K_La is the overall gas liquid mass transfer coefficient K_L itself is the liquid film coefficient and it is wide determining the liquid diffusivity and dividing it by the thickness of the film, if it is can be found out so, this is K_L, a is the interfacial area per unit volume.

So, this is surface area per unit volume as $C_{O,G}$ is the oxygen concentration in the gas phase. So, generally this is known, then we tried to find out the value of h then we can find out that the interphase. Similarly, the oxygen concentration in the liquid phase can be found out. So, through this we can find out the overall rate of oxygen transfer.

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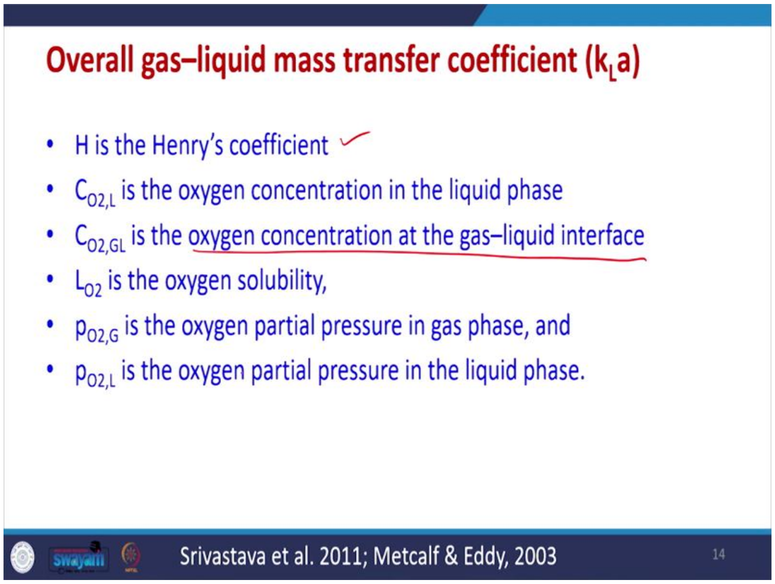

Overall, the gas liquid mass transfer coefficient have other terms also in the previous, H is the Henry's coefficient, $C_{O2,L}$ is the oxygen concentration in the liquid phase, $C_{O2,GL}$ is the oxygen concentration at the gas liquid interface, L_{O2} is the oxygen solubility. So, at different temperatures it is the oxygen solubility can be determined by the Henry's constant and the $p_{O2,G}$ and $p_{O2,L}$ are the oxygen partial pressure in the gas phase and then the liquid phase respectively.

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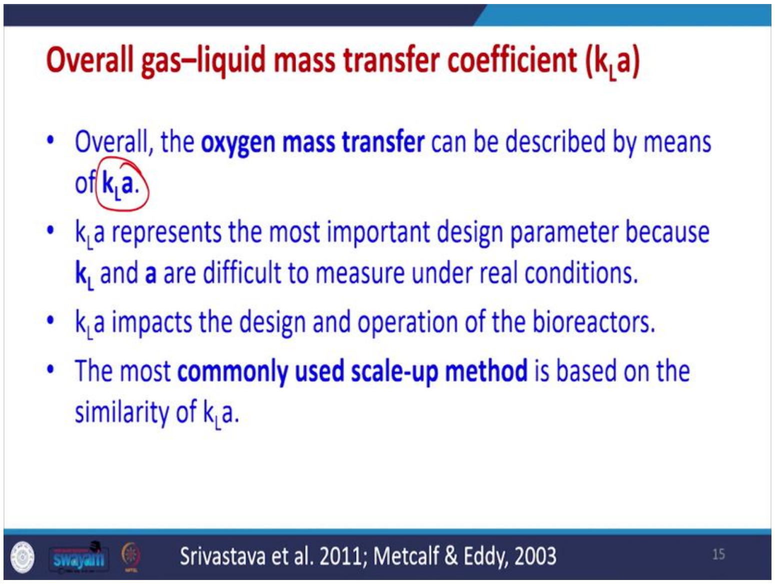

Overall, the oxygen mass transfer can be described by means of K_La if we can find out, so, K_La represents the most important design parameter because K_L and a individually are very difficult to measure under real conditions and overall we can find out the K_La. So, K_La impacts the design and operation of bio reactors including biological wastewater treatment units also. The most commonly used scale-up method is also based upon the similarity of K_La. So, K_La has overall very high importance and it has to be determined and it is used in the overall biological design.

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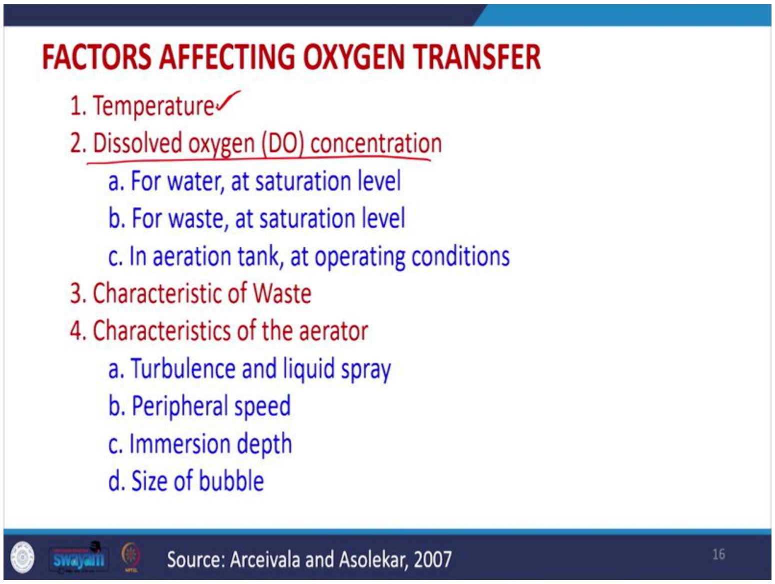

Now, there are various factors which affect the oxygen transfer. So, the temperature is the foremost important because the solubility of oxygen and in general that gases depend upon temperature. So, the oxygen solubility generally reduces with increase in temperature. So, that is why the temperature is the most important parameter. After temperature, that dissolved oxygen concentration for water for waste in the aeration tank etcetera is very important.

So, DO level for water at saturation level we can find out if waste is dissolved also then the DO level we can find out it is possible, then the in the aeration tanks etcetera at operating conditions what is that DO level. So, the oxygen concentration or the oxygen transfer greatly depends upon the dissolved oxygen concentration. Characteristic of waste also determines the overall oxygen transfer if the organic content is high, so oxygen will consumed also very quickly if microorganisms are present.

So, the oxygen transfer rate is also to be likely to be high whereas, if organic content is not much saturation level will be reached very quickly and the oxygen transfer rate may not be enhanced. Similarly, the characteristic of aerator what type of aeration unit we are using, where what is the level of turbulence whether it is liquid spray or not.

What is the peripheral is speed of the aerator, what is the immersion depth up to which the aerator is being immersed inside the liquid size of the bubble which are produced inside the liquid all these factors affect the oxygen transfer. Now, discussing one by one that temperature is the important factor parameter aeration involves gas transfer at the interface followed by diffusion within the liquid phase.

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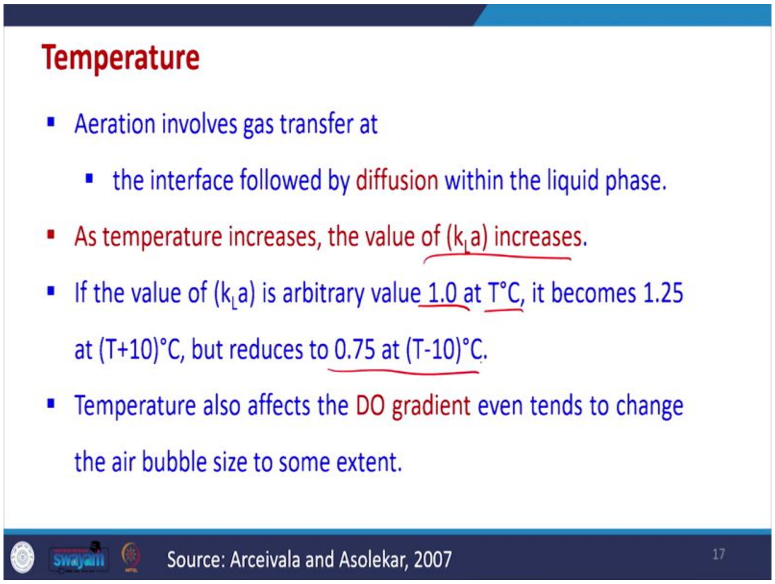

So, as the temperature increases the value of K_La increases, if the value of K_La is taken some arbitrary value of y 1, unit at T degree centigrade, it will become 1.25 a 10 t plus 10 degrees centigrade, but may reduce to also 0.75 at t minus 10 degrees centigrade. So, this is like so, Kla increases with increase in temperature and decreases with decrease in temperature. Temperature also affects the DO gradient and even tends to change the air bubble size to some extent. So, temperature is important parameter in the oxygen transfer rate.

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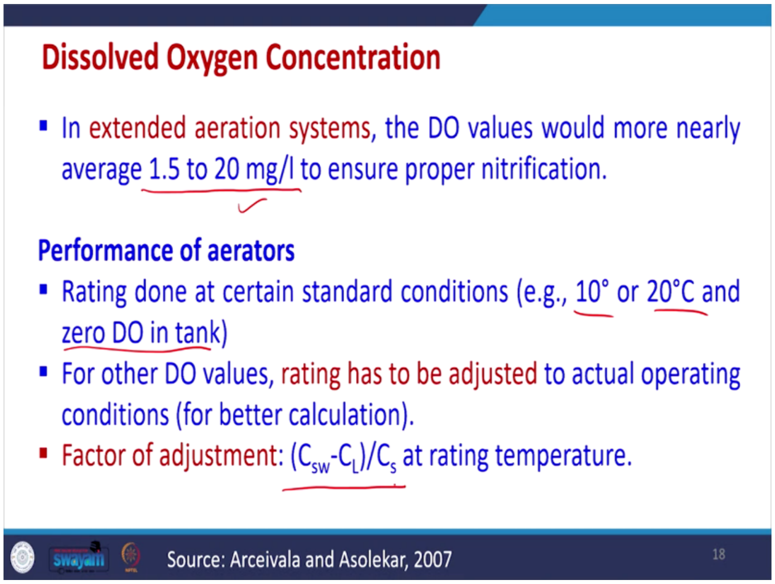

Dissolved oxygen concentration in the extended aeration systems the DO value would nearly be average around 1.5 to 20 milligram per liter to ensure proper nitrification. So, far and thus saturation level all the solubility level may be different. So, this is very important. So, we have to see that how the dissolved oxygen concentration can be enhanced, so performance it will depend upon the performance of aerator.

Rating of the aerator is done at certain standard conditions either 10-degree 20 degree or 0 DO level in that tank. So, we have to see that at what conditions rating is been done, for other DO values rating has to be adjusted in to actual operating conditions for better calculation. A factor of adjustment depend upon this factor C_{SW} minus C_L upon C_{SW} and add the rating temperature. So, we had to find out this parameter then only we can adjust with respect to the DO concentration.

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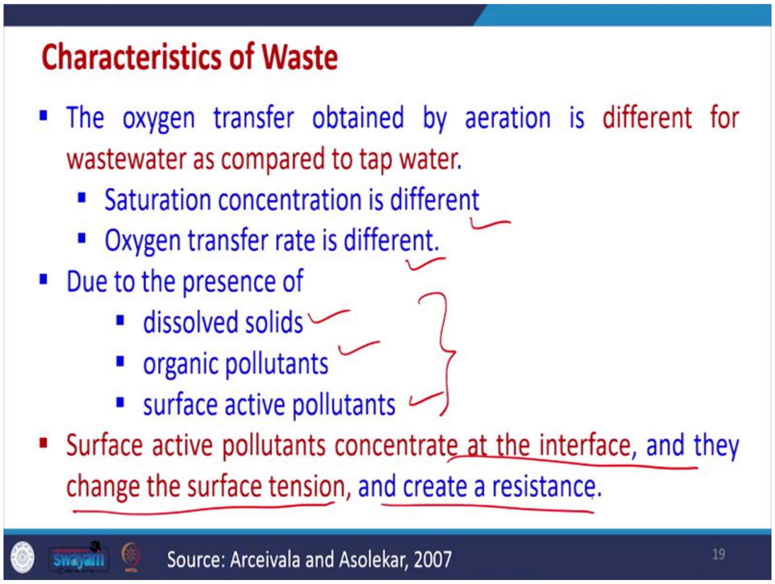

Then the characteristic of waste oxygen transfer obtained by aeration is different for wastewater as compared to for tap water because the organic content may be different. So, the saturation concentration of DO is different, thus oxygen transfer rate is also different and this is due to the presence of dissolved solids organic pollutant and surface active pollutants also, so depending whether these things are present or not in the waste, the oxygen transfer rate will also change. Surface active pollutants concentrate at the interface and they change the surface tension and create a resistance and thus they decrease the oxygen transfer rate.

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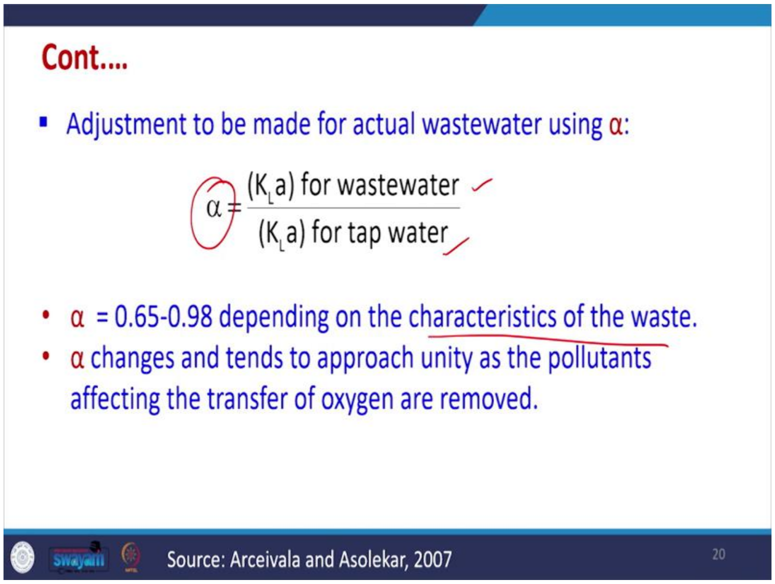

Adjustment to be made for actual wastewater using α:

$$\alpha = \frac{(K_L a)\ \text{for wastewater}}{(K_L a)\ \text{for tap water}}$$

Adjustment has to be made for actual wastewater using the parameter like K_La for wastewater divided by K_La for tap water. So, we use a parameter which is called alpha and alpha may vary in the range of point to point 98 depending upon the characteristics of the waste. Alpha changes and tends to approach unity as the pollutants affecting the oxygen transfer rate are removed. So with treatment the alpha value goes on increasing.

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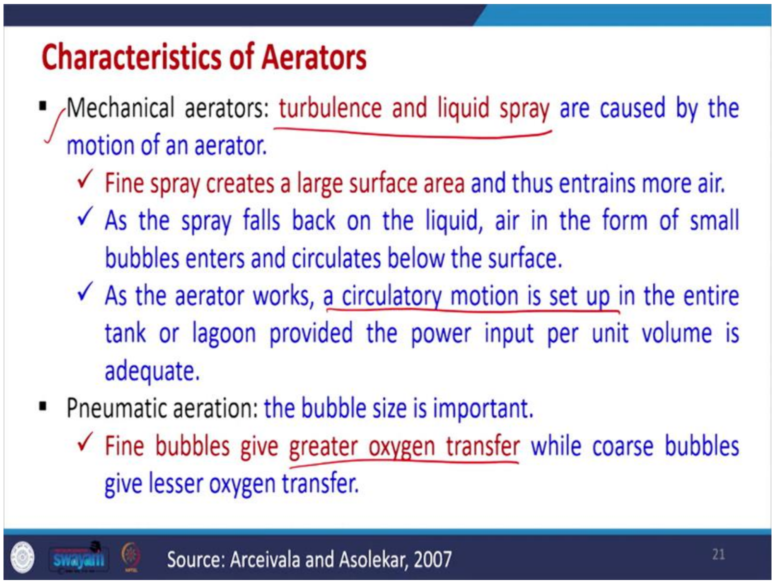

Then the characteristics of the aerators is also very important, what type of aerators we are using, whether it is mechanical aerator or pneumatic aerator. So, depending upon that, the characteristic of aerator, the oxygen transfer rate may change, so, in the mechanical aerators turbulence and liquid spray are caused by the motion of the aerator. So, fine spray creates a large surface area and thus entrance more air and thus the oxygen transfer rate is high as the spray falls back on the liquid air in the form of small bubbles enters and circulates below the surface.

And as the aerator works, a circulatory motion is set up in the entire time and lagoon providing the power input per unit volume, which is adequate enough for high oxygen transfer. So, mechanical aerators are very common in the during biological treatment methods also, but we have to see that the their operation should not be that high that it should break the film and it should cause damage to the microorganism biomass.

So, this has to be considered, but these are the common aerators which are used in the in the biological treatment of water in the equator sludge process etcetera. Then we have pneumatic aeration and here the bubble size is important fine bubble give greater oxygen transfer, while bigger size are course bubbles, gives lesser oxygen transfer. So, depending upon that what type of bubble size is required different types of pneumatic aeration units can be used.

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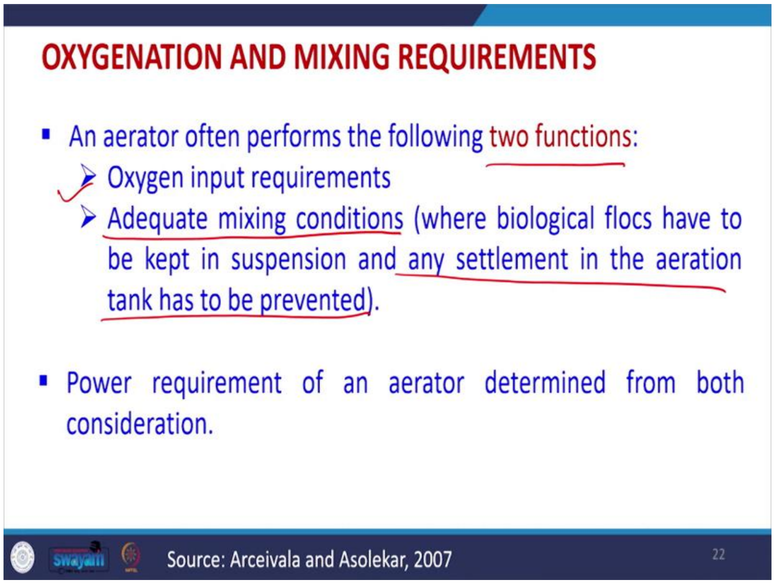

An aerator often perform the two functions, one is oxygen input requirement and second is mixing conditions adequate mixing condition where biological flocs have to be kept in suspension and any settlement in the aeration tank has to be prevented. So, in the biological reactors, we wish to have oxygen input also and we wish to have adequate mixing also. So, aerator functions both the things and so, selection of aerator is very important. And for selection of aerator power requirement of aerator has to be done and it has to be determined from both the considerations and then only we can choose the better aerator.

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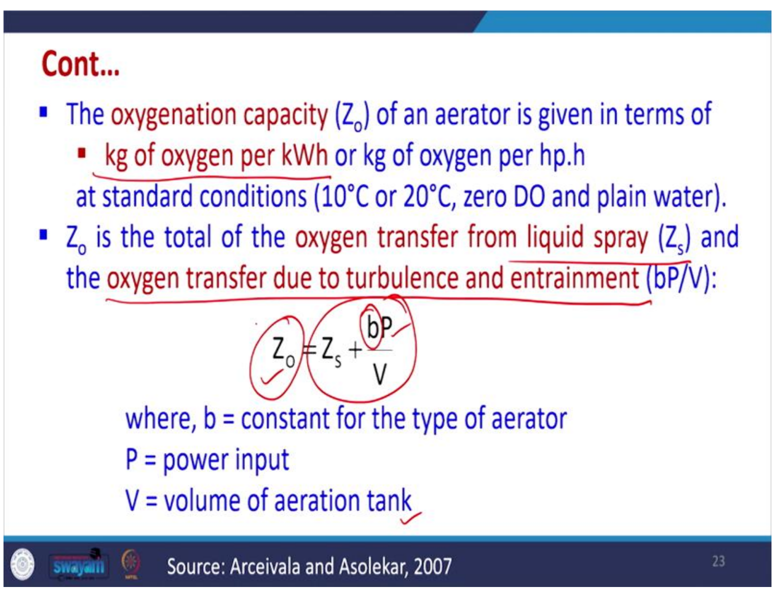

Z_0 is the total of the oxygen transfer from liquid spray (Z_s) and the oxygen transfer due to turbulence and entrainment (bP/V):

$$Z_O = Z_S + \frac{bP}{V}$$

Now, the oxygen capacity of an aerator is given in terms of kg of oxygen per kilowatt hour or kg of oxygen per horsepower per hour at a standard conditions which may be 10 degree 20 degree 0 DO or plain water and this Z_0 is the total of the oxygen transfer from liquid spray. So it will contain both from the liquid spray and oxygen transfer due to turbulence and entrainment. So, if when both factors are combined together, we get Z_0, in this equation B is a constant for type of aerator p is the power input and V is the volume of aeration tank. So, we need to know the value of b and once it is known we can find out the value of Z_0.

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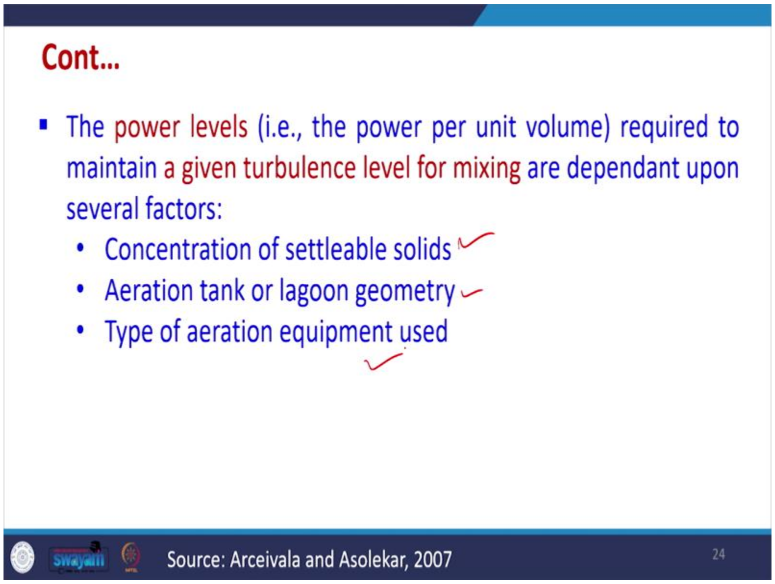

Now the power levels which is required in terms of power per unit volume, it is required for a given turbulence level for mixing and it depends upon several factors including concentration of settleable solids, aeration tank or lagoon geometry, what is the length, volume and dimension and type of aeration equipment used. So, we have to determine the power levels and overall, we have to determine the power requirement and then we should select the aerator for aeration unit. There are various types of aeration units possible.

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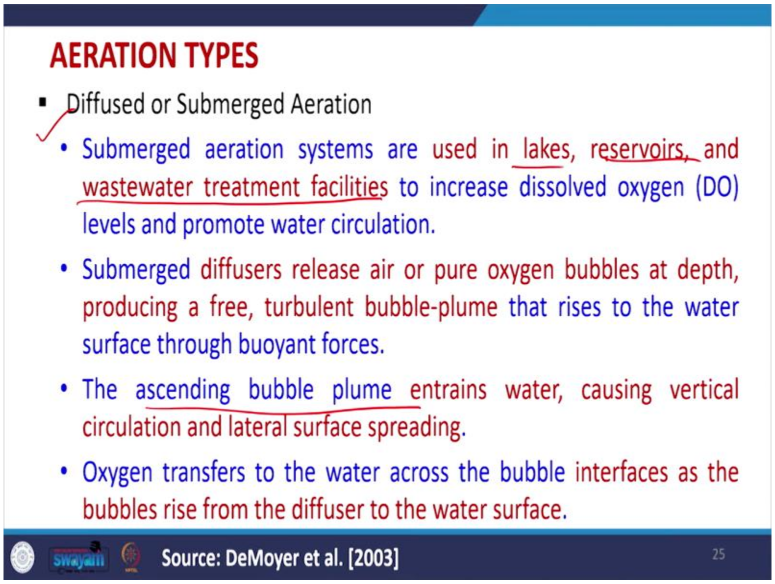

There may be diffused or submerged aeration. So this is very common. So, submerged aeration systems are used in lakes, reservoirs, wastewater treatment facilities to increase the dissolved oxygen levels and promote water circulation. Submerge diffusers release air or pure oxygen bubbles at depth producing a free turbulent bubble plume that rises to the water surface through the buoyant forces and these ascending bubble plume water causing vertical circulation and lateral surface spreading, overall oxygen transfer to the water across the bubble interface as the bubble rises from that diffuser to the water surface. So this is how it works.

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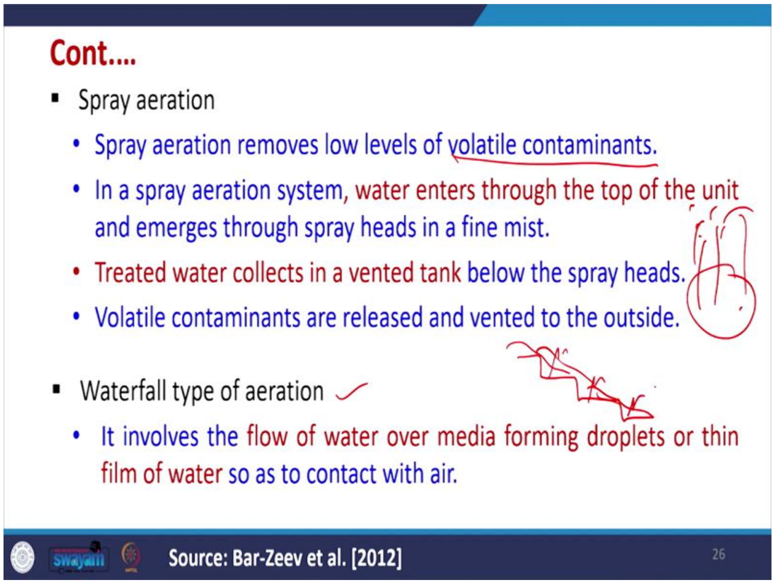

Then we have spray aeration also, air spray aeration removes low levels of volatile contaminants, we can see spray aeration units commonly used for removing low level of volatile contaminants are simply other types of organic contaminants if present in the water, and in the spray aeration unit water enters to the top of the unit and emerges through his spray heads in the fine mist. Treated water collects in a vented tank before below the spray head. So, we have this type of system maybe their water may be sprayed and the sprinkling is done and water is again collected back and volatile contaminants are released and vented to that outside.

So, through this aeration is done and this type of aeration unit can be seen in common places also for treatment of very less containing organic compound water. So, this is possible, then we have waterfall type of aeration, it involves the flow of water over a media forming droplets or thin film of water, so as to contact with air. So, we can have a cascade type of system where a water is flowing above this and the aeration taking place while the water flows above this cascade type of system.

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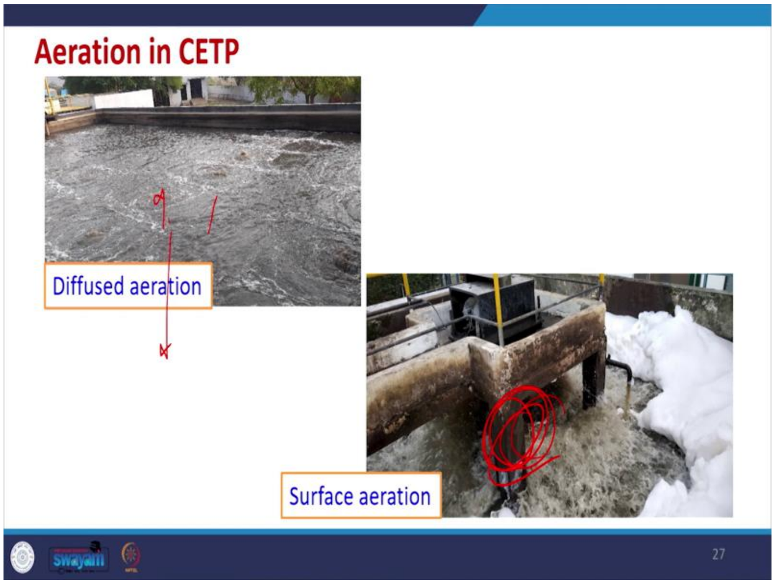

Then these are the aeration units, if you can see here the diffused aeration the air is being released inside the this particular tank inside much at the depth and then the air bubbles we can see air bubbles are coming out. So diffused aeration then this is surface aeration using some agitated type of unit. So, here we can see here revolution is taking place and lots of vigorous aeration is taking place.

So, these type of aeration units are possible. aeration is very common and it is the essential step and generally the first step for the water or wastewater treatment. Aeration is also important during the biological treatment of waste water and it is used in the secondary treatment units also and it may be used in the tertiary treatment also depending upon the type of performance or type of operation which is being done to remove the organic matter and other types of gases etcetera. So, this is all about aeration. I will continue further with respect to treatment of water in the next few lectures. Thank you very much.