Biological Process Design for Wastewater Treatment

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Lecture 28

Advanced Biological Wastewater Treatment- Fluidized Bed Bioreactors

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. Up till now we have studied the water quality parameters and further on we studied the wastewater or water treatment, during this process we have studied that there are various types of unit operations which are performed for water or wastewater treatment and these include the physico-chemical processes as well as the biological processes.

In the physico-chemical processes we studied that there are processes like flow equalization, aeration, sedimentation, etc., along with coagulation and flocculation which is performed for the physico-chemical treatment for removal of various types of pollutants and in particular the pollutants which can be easily be removed like solid, etc.

Now, further on we studied the biological treatment of wastewater and in this case we studied the simple biological treatment which can be divided into aerobic and anaerobic and in the aerobic we studied regarding the activated sludge process, trickling filter. Similarly, in the anaerobic we studied regarding the UASB reactor, bio towers, etc.

Now, we are going further ahead for understanding the advanced biological wastewater treatment processes. There are few advanced biological wastewater treatment processes which are now coming into picture for wastewater treatment. However, these are generally not present in the industries or for the municipal wastewater treatment, their forthcoming processes which are used some places for wastewater treatment.

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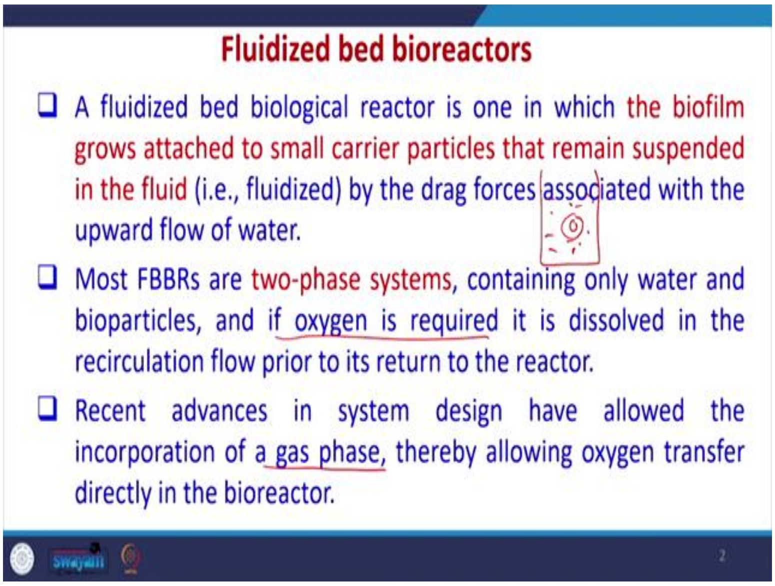

So, we are going to study regarding the fluidized bed bioreactors today. A fluidized bed biological reactor is one in which the biofilm grows attached to a small carrier particle that remains suspended in the fluid, which is actually fluidized by the drag force associated with the upward flow of water.

So, actually in this case there is some reactor in that reactor the biofilm is grown on a small carrier particle. So, we have a carrier particle on which a biofilm is grown and this particular thing is suspended in a reactor in which the fluid is there, the wastewater which has to be treated, so this is the fluidized bed reactor.

Now, most fluidized bed reactors are two phase system that means they contain only water and bio-particles, and if oxygen is required it is dissolved in the recirculation flow prior to its return to the reactor. So, it is possible that oxygen can also be dissolved. Recent advances in the system design which have happened recently have allowed the incorporation of the gas phase also, so thereby align the oxygen transfer directly in the bioreactor.

So, that means the with recent advances the system have become three phase system also and so fluidized bed reactors nowadays may contain not only water and bio-particles, but may they contain the oxygen also or the air.

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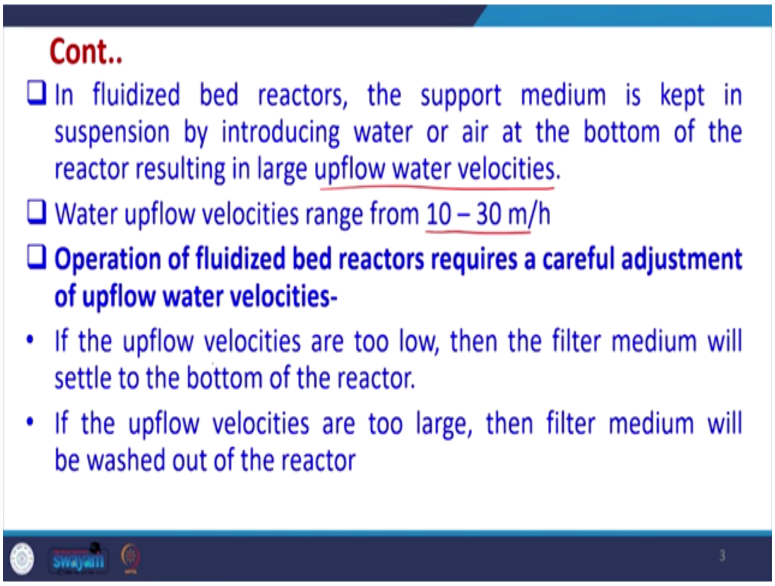

In fluidized bed reactors the support medium is kept in suspension and this is done by introducing water or air at the bottom of the reactor resulting in large up-flow water velocity. So, we decide the water velocities in such a manner that the bio particles which are there inside the fluidized bed reactor are suspended and this water up-flow velocities may vary in the range of 10 to 30 meter per hour. So, these are the range of velocities under which the bio particles are generally suspended inside the fluidized bed reactor.

Operation of a fluidized bed reactor requires a careful adjustment of the up-flow water velocity which is the most important parameter considering the fluidized by reactor. If the up-flow velocities are too low, then the filter medium will have to settle to the bottom of the reactor that means the bio-particles will settle down. If the up-flow velocities are too large, then the bio-particles will be washed out of the reactor. So, we have to decide the up-flow water velocities very carefully.

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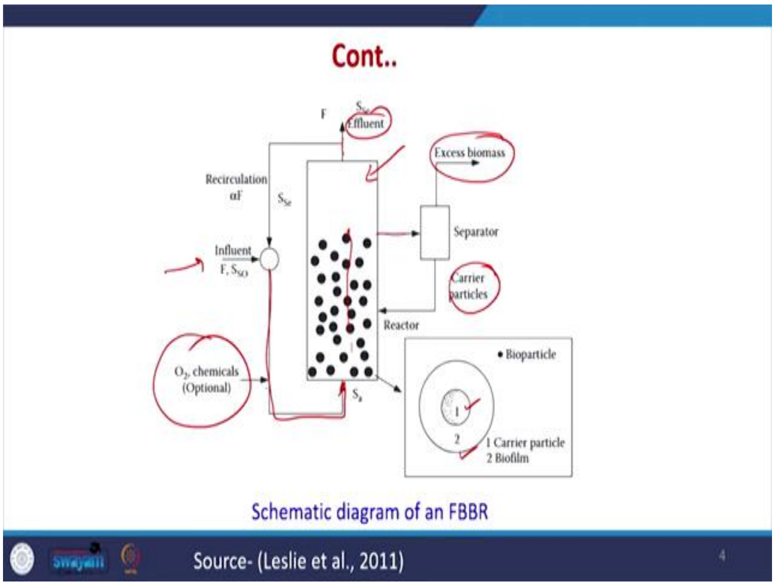

Now, this is the schematic diagram of a fluidized bed bioreactor, so we can see here that this is the FBBR the influent comes from here and it is going from the bottom of the reactant inside the fluidized bed. Now, fluidized bed will contains the bio-particles which are shown by this dark circle here these bio-particles essentially contain a carrier particle on which a biofilm is grown, so these are there.

Now, once the water passes through the system then the treatment happens after some time a separator some water may be taken a separator unit will be there which will separate the carrier particles and excess biomass, now the career particles will be recycled back into the reactor, so that we can maintain the essential required concentration of bio-particles. The treated effluent will be going out from the top.

Now, some section or some part of this treated effluent will be recycled back, also the oxygen the chemicals required etc., may be added in the influent section itself. So, this is how a simple schematic diagram of FBBR looks like.

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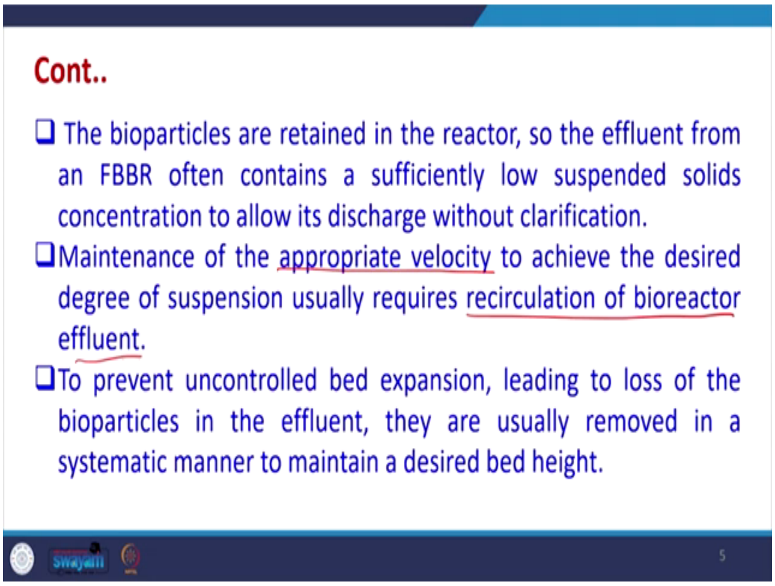

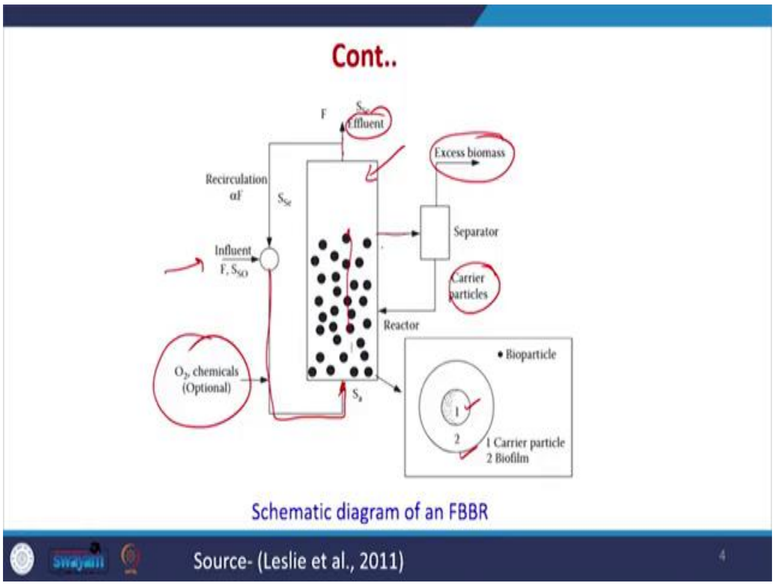

Now, the bio-particles are in retained in the reactor, so the effluent from an FBBR often contains a sufficiently low suspended solid concentration to allow its discharge without clarification. So, from FBBR generally the effluent which will be coming out it will be containing very low suspended solids. So, that means there is no further clarification required and we can allow the discharge as such, so this is there.

Maintenance of the appropriate velocity to achieve the desired degree of suspension usually requires recirculation of bioreactor effluent. So, that is why we recycle some of the treated effluent, so as to maintain the appropriate velocity to achieve the desired degree of suspension. To prevent uncontrolled bed expansion leading to the loss of bio-particles in the effluent they are usually removed in a schematic manner to maintain the desired bed height.

So, this is done here you can see the system has been installed, so as to maintain the desired bed height.

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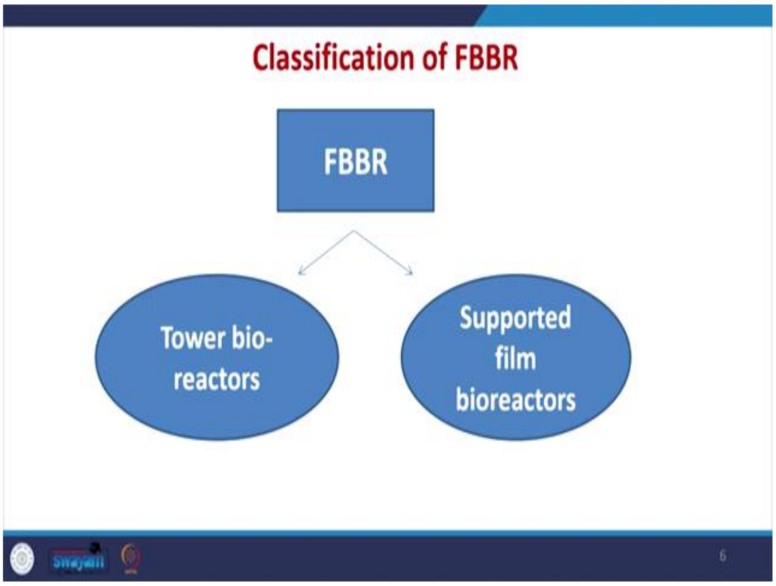

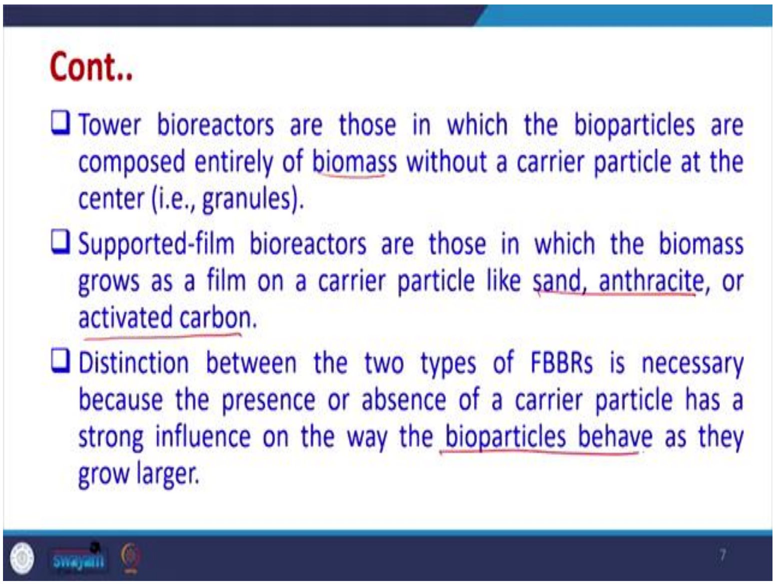

Now, FBBR can be classified into two categories basically the tower bioreactors and the supported film bioreactors.

Tower bioreactors are those in which the bio particles are composed entirely of biomass without a carrier particle at the center. So, this is the tower bioreactor. Supported film bioreactors are those in which the biofilm grows as a film on a carrier particle like sand, anthracite, activated carbon, etc.

The distinction between the two types of FBBR is necessary because the presence or absence of carrier particle has a strong influence on the bio-particle behavior as they grow larger and also it affects the up-flow velocities that have to be maintained inside the reactor.

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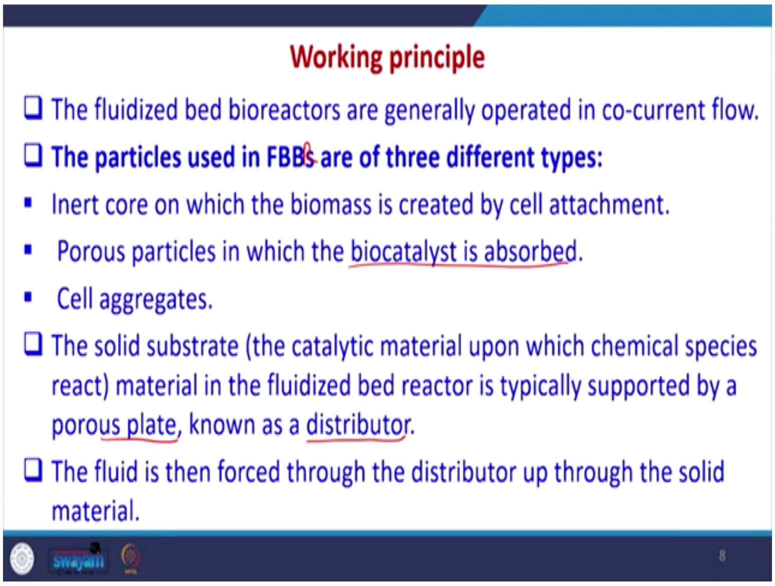

The working principle of FBBR is described here, the fluidized bed reactors are generally operated in a co-current flow that means the air, the water etc., grow from the same side and that is the bottom of the reactor. The particles used in FBBR three different types inert core on which the biomass is created by cell attachment, then the porous particles in which the bio catalyst is adsorbed and also some cell aggregation may also happen.

The solid substrate the catalytic material upon which the chemical species react that is the material the substrate material in the fluidized bed reactor is typically supported by a porous plate, which is known as distributor. The fluid is then forced through the distributor up through the solid material, so this is there.

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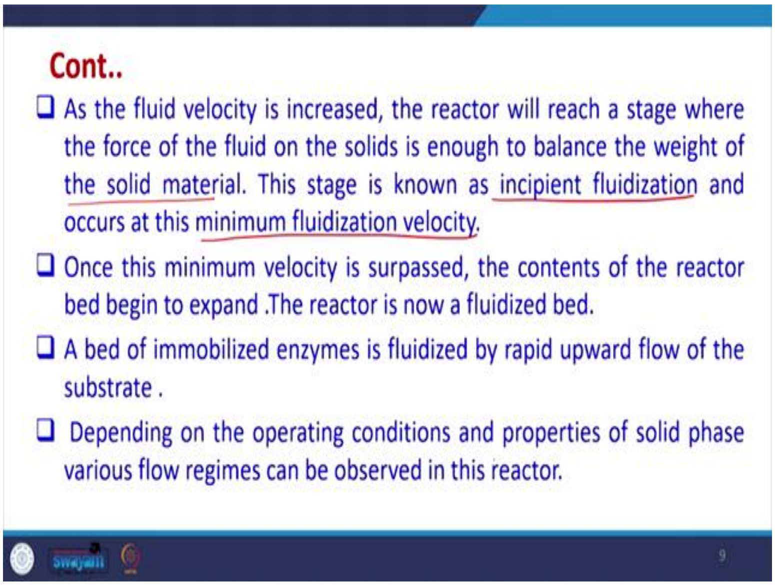

Now, as the fluid velocity is increased the reactor will reach a stage where the force of the fluid on the solids is enough to balance the weight of the solid material and this stage is known as incipient fluidization and this occurs as the minimum fluidization velocity.

So, this minimum fluidization velocity will depend upon the type of solid, the density of the solid, the biofilm which has been grown on the carrier particle and also the thickness of the biofilm. So, many factors will determine the incipient fluidization or the minimum fluidization velocity.

Now, within this it also will depend somehow on the wastewater characteristics including the amount of suspended materials, the amount of COD etc., and the thickness and viscosity of the wastewater. So, many factors will affect the wastewater characteristics as well as the solid characteristics both will affect the minimum fluidization velocity. Once this minimum fluidization velocity is surpassed, the contents of the reactor bed will begin to expand and the reactor will now become a fluidized bed.

The bed of immobilizing enzymes are fluidized by rapid upward flow of the substrate, depending upon the operating conditions and the properties of the solid phase various flow regimes can be observed in the reactor.

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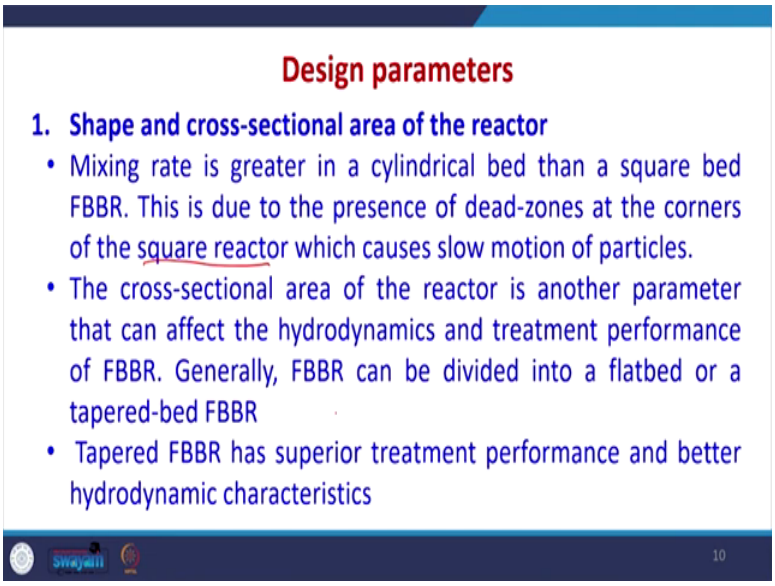

Now, there are various design parameters which affect the fluidized bioreactors will be discussing each of the design parameters one by one. So, one of the most important design parameter is the shape and cross sectional area of the reactor. So, the mixing rate is greater in the cylindrical bed than a square bed FBBR.

So, there are two possibilities we can have a cylindrical bed FBBR or square bed FBBR and generally the mixing rate will be better in the cylindrical bed. Now, this is due to the presence of dead zones at the corner of the square reactor. So, if we have square reactor then there will be dead zone and there will be no mixing happening in those corners. So, it is always preferable to have a cylindrical bed reactor.

The cross sectional area of the reactor is another parameter that can affect the hydrodynamics and treatment performance of the FBBR. Generally, FBBR can be divided into flat bed or tapered bed FBBR which will be shown in the next slide. The tapered bed FBBR has superior treatment performance and better hydrodynamic characteristics.

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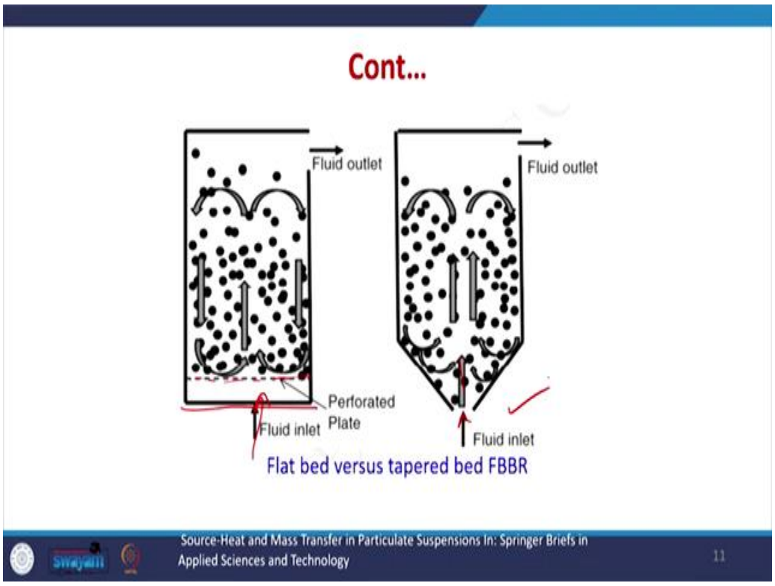

So, we can see here this is flat bed FBBR and where the perforated plates are kept here and the fluid inlet will be from inside and this particles will be fluidized at a certain minimum fluidization velocity. Similarly, this is another tapered bed FBBR, the fluid is going here and again at certain velocity the fluidization of the bio-particles will happen. So, generally the performance of the tapered bed FBBR is better as compared to flatbed FBBR, because of the hydrodynamics.

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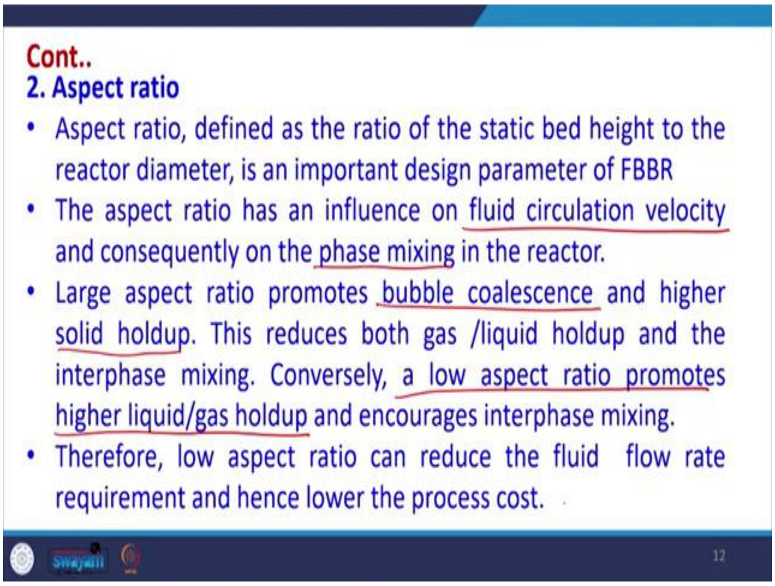

The second important design parameter is the aspect ratio, this is aspect ratio is defined as the ratio of the static bed height to the reactor diameter and it is considered to be important design parameter of the FBBR. It has an influence on the fluid circulation velocity and consequently on the phase mixing in the reactor.

So, aspect ratio affects the fluid circulation velocity as well as the phase mixing. Large aspect ratio that means if the bed height is larger as compared to reactor diameter, it promotes bubble coalescence and higher solid hold up. This reduces both gas and liquid hold up and the interface mixing. Conversely, a lower aspect ratio promotes higher liquid to gas hold up and encourages the interface mixing.

Therefore, low aspect ratio can reduce the fluid flow rate requirement and hence lower the process cost. So, aspect ratio has to be carefully chosen, so as to check over all the process cost should be minimum and the fluid flow rate requirement depending upon the fluid flow requirement because the water treatment that has to be done which will be beforehand decided. So, we have to choose the lowest possible aspect ratio at per that particular wastewater flow rate.

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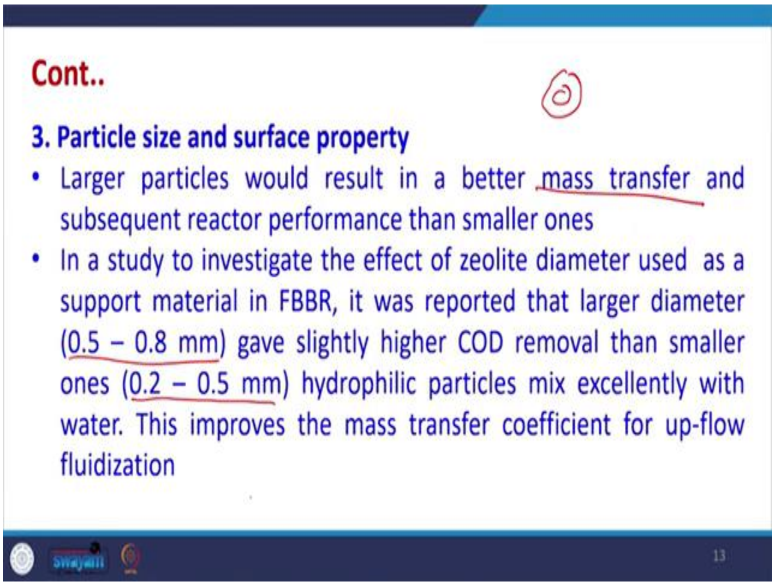

The third factor which affects the design of FBBR is particle size and surface property, so the particle size we have one core particle and then the biofilm. Now, overall particles are larger particle size would result in a better mass transfer and subsequently reactor performance will be better as compared to the smaller particles. In a study investigate the effect of zeolite diameter used as a support material in FBBR, it was reported that the larger particles that which were in the range of 0.5 to 0.8 millimeter gave slightly higher COD removal efficiencies than the smaller particles in the range of 0.2 to 0.5 millimeter, the hydrophilic particles mixing.

So, this improves the mass transfer, so that means larger size particles generally have better master transfer characteristics and because of that the performance increases. Certainly, if we have very bigger size particles, then the minimum fluidization velocity will also be larger, so we have to carefully choose that which particle size will be better.

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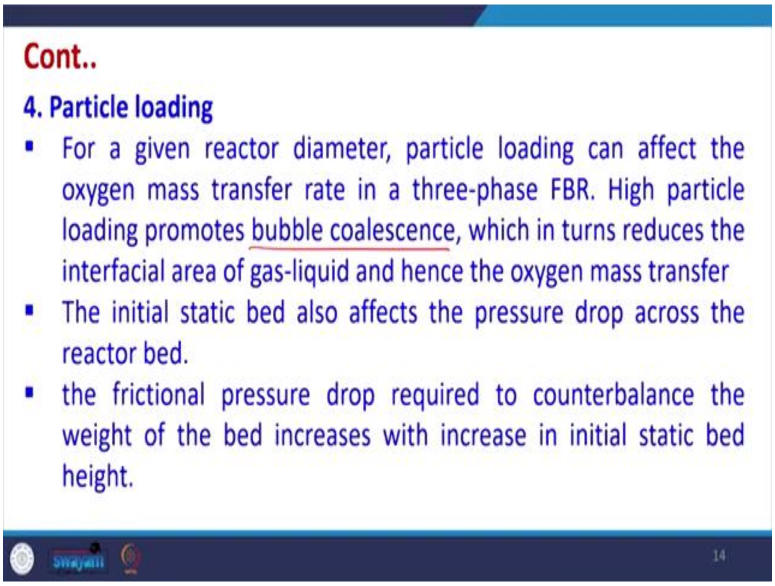

Now, the particle loading, particle loading means how much concentration of particle is present inside the reactor. For a given reactor diameter particle loading can affect the oxygen mass transfer rate in a three phase FBBR. Higher particle loading promotes bubble coalescence, which in turn reduces the interfacial area of gas liquid and hence the oxygen mass transfer the initial static bed also affects the pressure drop across the reactor bed, so this is important.

The frictional pressure drop required to counter balance the weight of the bed increases with increase in the initial static bed height. So, the bed height along with the particle loading are important, we have to optimize the particle loading, so as to achieve the maximum COD removal efficiency. And this will be decided by a number of factors including the wastewater characteristics also.

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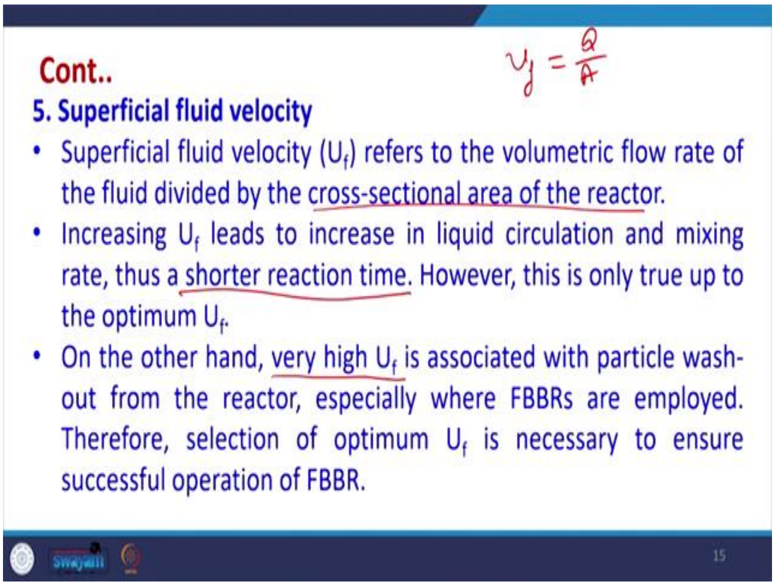

The superficial fluid velocity, the superficial fluid velocity refers to the volumetric flow rates of the fluid divided by the cross sectional area of the reactor that means the U_f is equal to the flow rate divided by the cross sectional area of the reactor.

So, increasing this superficial fluid velocity leads to increase in the liquid circulation and mixing rate, so that means higher is the superficial velocity, it will increase the liquid circulation because the flow rate will be higher and thus the mixing rate will also be higher. And overall since the flow rate is higher it will have a shorter reaction time. However, this will be this is only true up to a optimum U_f.

On the other hand if we have very high U_f which is associated with particle washing from the reactor, so it is possible that if you have very high superficial velocity the bio-particles may be washed away which is not desirable, especially where FBBRs are implied. Therefore, selection of optimum superficial flat velocity is necessary to ensure the successful operation of the FBBR.

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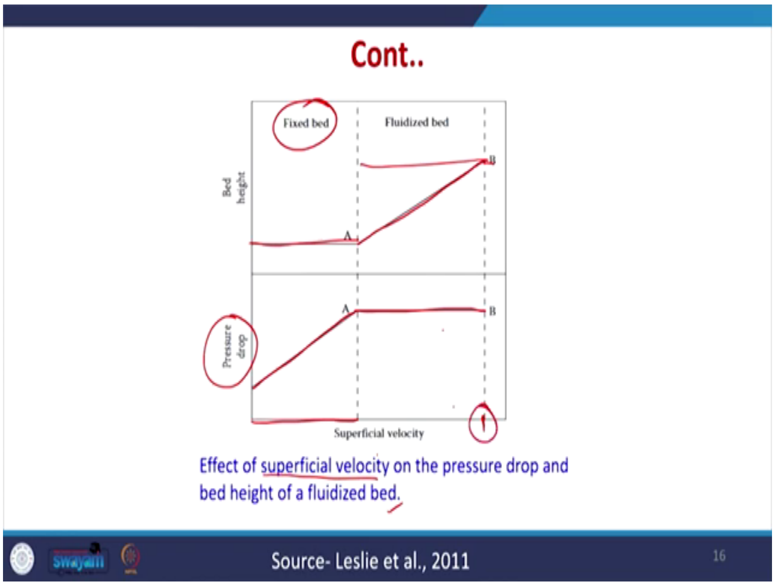

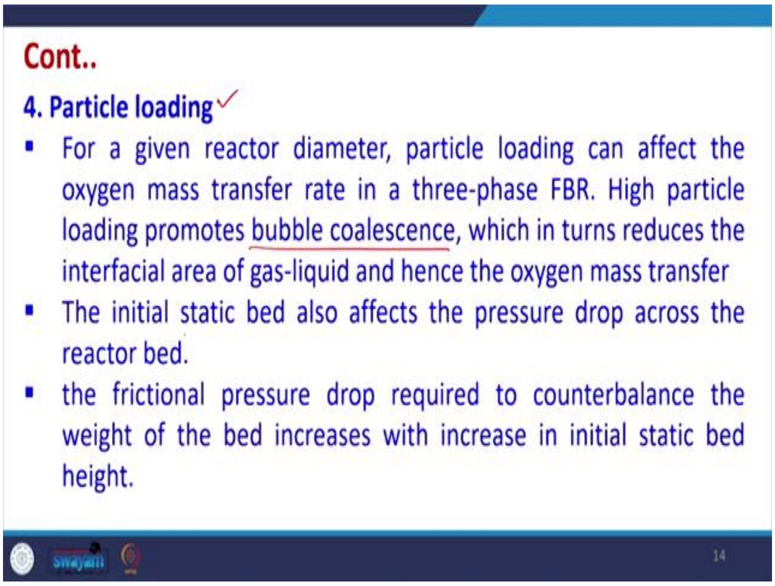

So, this is the effect of superficial velocity and the pressure drop and the bed height of the fluidized bed is given. So, you can see if the superficial velocity is increasing up to a certain height bed height will not increase, because it will require minimum fluidization velocity. So, up to that distance it will be fixed bed. However, the pressure drop still will be increasing in the next phase when we achieve the minimum fluidization velocity, the bed will become fluidized and its height will start increasing.

But under certain this condition the pressure drop still remains the same. So, we try to operate maintain certain bed height and under that condition the pressure drop remains the same we can see here from A to B. So, we have to choose that what should be the bed height and depending upon the band height the concentration will be different. So, this was the particle loading will depend upon the bed height and bed height we can fix. So, thus we can fix the particle loading also.

The bed height as well as the pressure drop will be affected by superficial velocity and this superficial velocity certainly has to be higher than the minimum fluidization velocity but depending upon the how much particle loading we require that means how much should be the bed height we can maintain a certain superficial velocity, so as to maintain a proper height inside the fluidized bed reactor. So, that the separation of particle may also happen and treatment may also happen. So, that means this bed height has to be optimized depending upon the superficial velocity.

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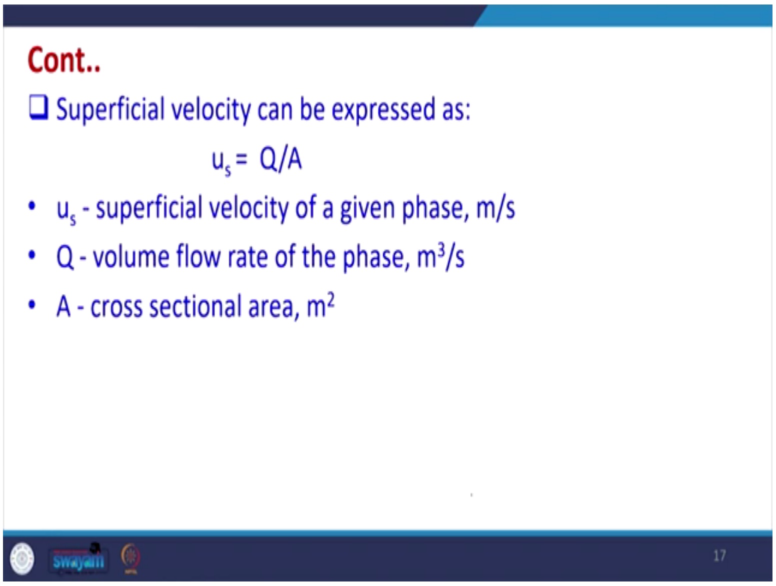

Superficial velocity can be expressed as:

$$u_s = Q/A$$

u_s - superficial velocity of a given phase, m/s

Q - volume flow rate of the phase, m^3/s

A - cross sectional area, m^2

Now, this superficial velocity can be calculated using this formula that already we discussed.

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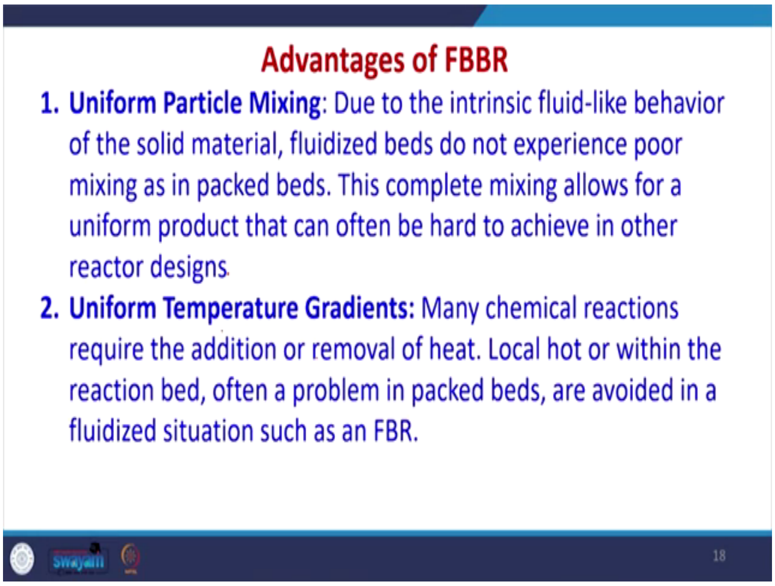

Now, there are certain advantages of FBBR one of the most important advantages of FBBR is the uniform particle mixing. So, what does it mean? Because, we have intrinsic fluid like behavior on the solid material that means the solid material all the bio particles are fluidized, so fluidized bed do not experience poor mixing as in the pack bed.

So, we have very good mixing which happens inside the FBBR and that is uniform particle mixing, the bio-particles are uniform all inside the fluidized bed up to whatever height they are present. So, we have uniform particle loading. This complete mixing allows for a uniform product that can often be hard to achieve in other reactor designs. So, we have uniform wastewater treatment that happens in the FBBR.

Also, uniform temperature gradients, mainly chemical reactions including wastewater treatment require the addition or removal of heat sometimes depending upon at what time the operations are being performed. So, local hot or cold zone within the reactor bed often may cause problem but this is not so in the FBBR, because the fluid is being recirculate and it is flowing, so under that condition we have uniform temperature gradients. So, the effect of temperature gradients on the treatment efficiency is minimal.

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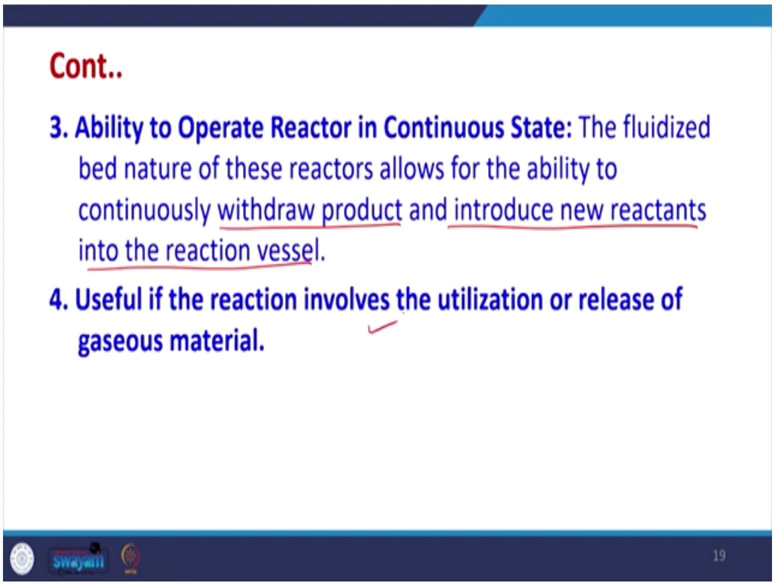

Also, the ability to operate reactor in the continuous state, so the fluidized bed reactor by nature they work in the continuous mode, so that means we can have a continuous influx of water which will be influent which will be mixed with the treated effluent depending upon the requirement and then that liquid will pass through the fluidized bed. So, that is continuous treatment which is happening.

So, the nature of this reactor allows for the ability to continuously withdraw the treated water and introduce the new wastewater inside the reactor. Useful if the reaction involves the utilization or release of gaseous material. So, we can use the oxygen etc., also and we can thus treat the wastewater very easily.

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Now, disadvantages of FBBR are certainly there must be lot of disadvantages also FBBR which have to be overcome if we want to use this FBBR more in the wastewater treatment. So, increased reactor vessel size because of the expansion of bed materials in the reactor a larger vessel is often required as compared to pack bed reactor. So, if you are using packed back reactor in place of that if we are using FBBR, so certainly FBBR will always require larger volume as compared to packed bed reactor. This larger vessel means that more cost will be there initial cost and the space requirement may also be higher in terms of height.

Now, the pumping requirements and pressure drop, so because this is a continuous reactor the requirement of fluid to suspend the solid material necessitates that a higher fluid velocity is attained in the reactor. In order to achieve this more pumping power thus higher energy costs are needed.

So, that means the operating cost of FBBR is higher, because we have to continuously pump the water inside the reactor from bottom up and thus it means that lot of energy is needed for using the FBBR for wastewater treatment. In addition the pressure drop associated with the deep beds also requires additional pumping power. So, both the pressure drop as well as the minimum fluidization velocity requirements increase the pumping requirements and thus the cost of the treatment.

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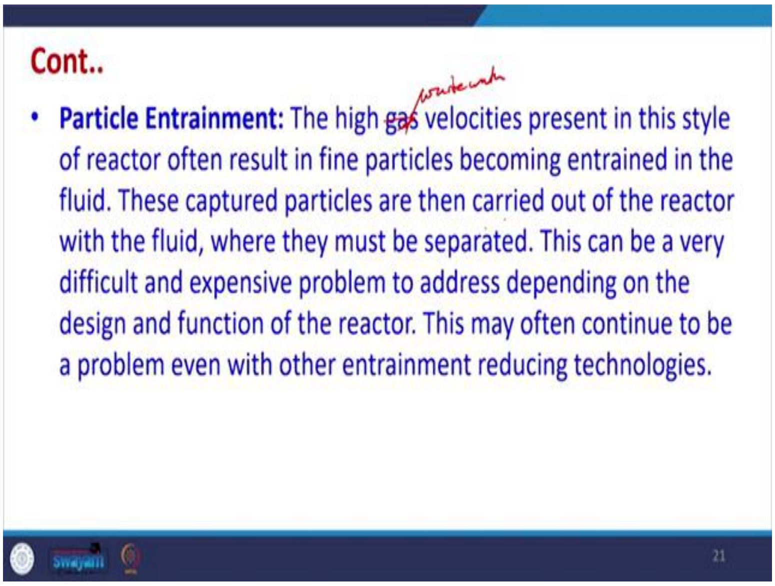

Now, now the particle entrainment, if we have higher gas or wastewater velocities present in the reactor this may result in the fine particles becoming entrained in the fluid. So, it is possible that the particles are not fully grown and their size are smaller, so that velocities which are lower than the minimum fluidization velocity is also this particle may be entrained.

So, these capture particles are then carried out of the reactor with the fluid and they must be separated. So, this can be very difficult and expensive problem to address depending upon the design and function of the reactor. So, that means if any entrainment of the bio particle is happening below the fluidization velocity, so it will cause problem and the treatment efficiencies etc., will go down.

So, depending upon the design and function of the reactor, this may often continue to be a problem even with other entrainment reducing velocity technologies also. So, we have to properly use the particles of a particular size with a certain density, so that we can properly decide the superficial velocity or the minimum fluidization velocity at which the FBBR has to be operated, otherwise we have to use the clarification system in the after treatment of the effluent also, so as to remove these particles and separate them as sludge. So, these are some of the disadvantages of FBBR,

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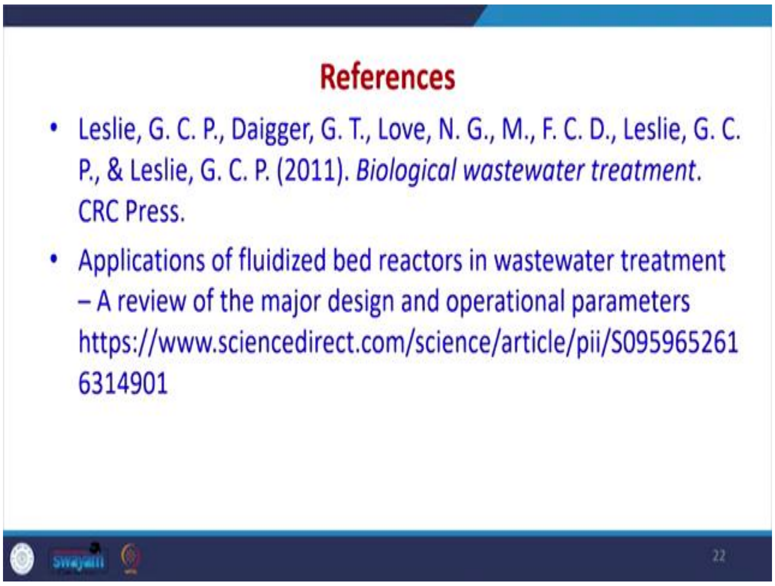

FBBR is currently a developing technology which is being used in some of the places in industries for treatment of certain wastewater and the fluidize bed system is already well used in the, came current process industries, but its usage in the wastewater treatment is still developing and hopefully with time this will evolve they have certain disadvantages which have to be overcome then only we can use the fluidized bed reactor more often and we can use the advantages of fluidized bed reactor for wastewater treatment. With this we will end this lecture on the fluidized bed reactor today. Thank you very much.