Aspects of Biochemical Engineering
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Lecture – 16
Different types of reactors

Welcome back to my course Aspects of Biochemical Engineering. Now last couple of lectures I try to concentrate on kinetics of homogeneous reaction. Now, today I want to discuss one very important topic that a different type of reactors. Now a question comes of what do you mean by reactors? A reactors means kind of vessel in which the reaction takes place, now that means; it is very simple that in a container, a basin minion's continent when you put different reactant where the reactions take place that is called reactor. Now what do you mean by bioreactor?

Because we have another term, because since we had this particular course is on biochemical engineering. So, bioreactor also it is same vessel in which the reaction take place in presence of some either from biomolecules; may be it might be living cell, it may be not living cells, I can give the example; suppose some reaction take place in presence of living organisms, we call this is a biochemical reactions or it is suppose the reaction carried out with a help of some enzyme which does not have life, but enzymes that is also we considered as a bioreactor.

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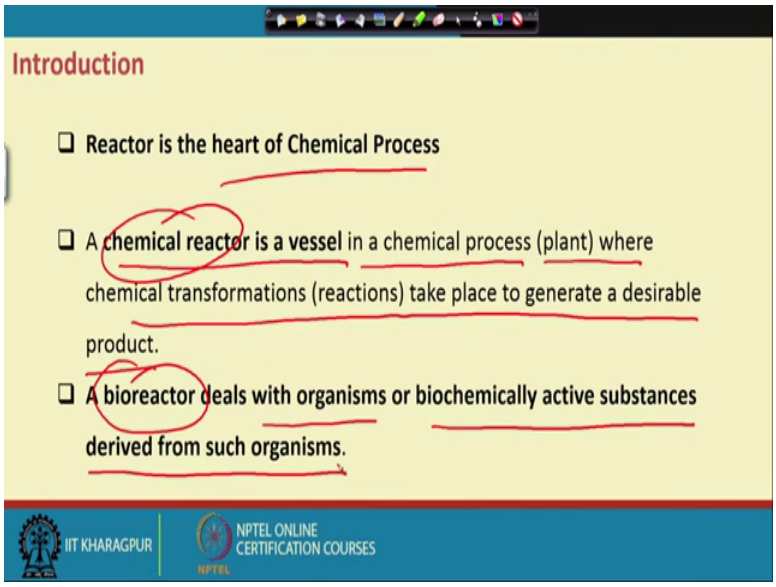

So, if you look at here, the reactor is the heart of Chemical Processes because they here where the reaction take place. Am I right! And chemical reactor is a vessel in a chemical process or plant where the chemical transformation or reactions take place to generate the desired product. So, it is very simple say; in the vessel in which the reaction take place that is called chemical reactor this is like this. Now, if you look at the bio reactors, deals with organisms or biochemically active substances these are derived from such organism. If the reaction take place with the help of this organism or biochemically active substances derived from the organism, because as for example; enzymes can be secreted by the living cells, maybe plant cells, may be microbial cells, may be you have animal cells. So, if we if the reaction takes place with the help of enzymes, that also we can considered as the bio reactors.

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Now question comes, what are the bio reactors and the unit operations? So, if you look at, this is the bio reactors; what do you call the heart of the chemical process, after the reaction is over, we pass through the separator well. So, any biochemical or chemical industry, we have different separator process. What do you mean by separator process? Separator process means, where the solid is liquid separated from the liquid or liquid separation also will be there.

Then there is the involvement of the heat exchanger, because as you as you know any kind of chemical reaction or biochemical reaction that depends on temperature. So, you

have we shall have to maintain the temperature, so we required the heat exchanger. The utility, different utility that that all also present in different industry, utility like; we might be requiring the soft water, we might be requiring some steam requirement, all these under this all under comes under the this utility. Then process control that is another important to operate the process that we shall have to maintain the temperature, we shall have to maintain the hesitated speed, we shall maintain that that pH of the solution; some cases we shall have to maintain. So, this all are under this unit operations. And as for example, for controlling the temperature, we shall have both the cooling and heating arrangement; for maintaining the pH, we shall have both acid and alkali tanker. Your palm should be connected with that. As the pH going down, you have to add some alkali to it. As the pH going out, you shall have to add some kind of acid to control the pH. So, these are the things that we have.

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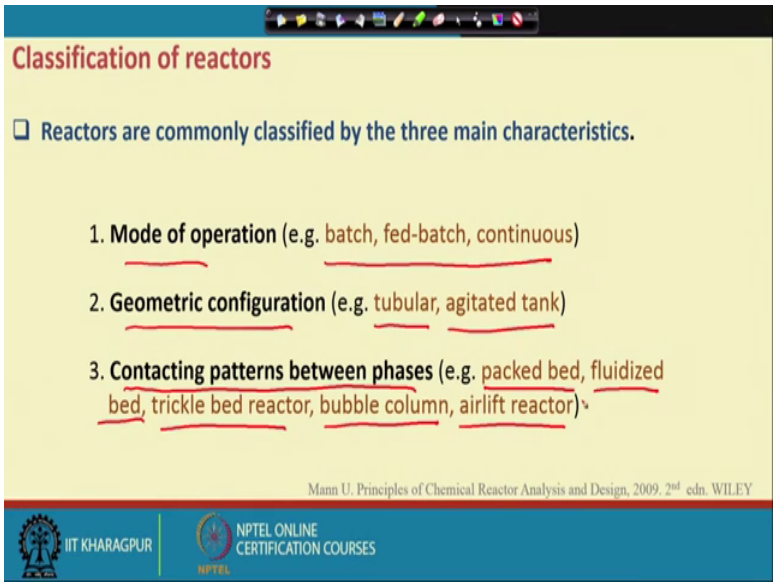

Now, let us see the; what is the classification of the reactors? Now, we look at the classification of the reactors, we can; this may be classified in three different ways. One is called; mode of operation, the geometrical configuration, the contact pattern between the phases.

So mode of operation, Mode of operation means three, the three different mode of operation we have. One is called; batch process, another called fed batch process,

another is continuous process. Now question comes what do you mean by that you know batch process?

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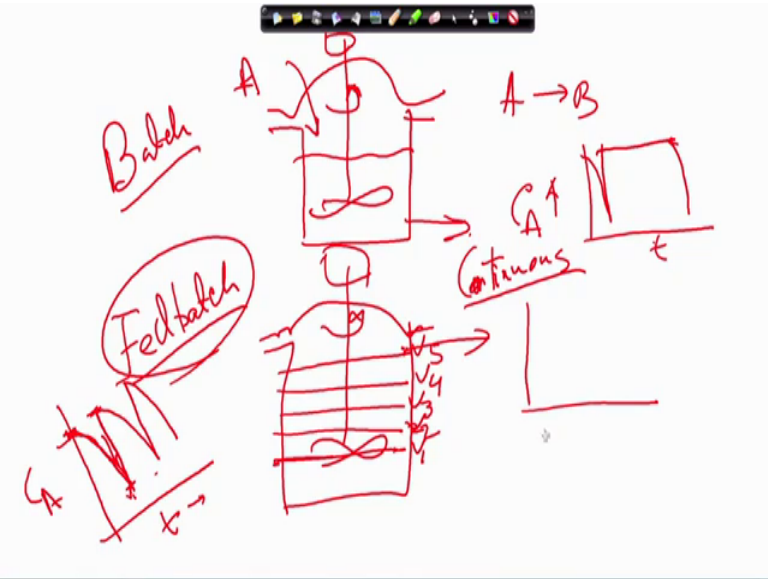

Batch process means, if you look the batch process is like this, and suppose this is the reactor and here you have a starter and this is liquid. So, we put the substrate here, we want to reactor to be; we put the subsidy and then at a time we shall have to put the substrate at a time in the batch reactor, this is the batch reactor at a time we shall have to put that substrate. Let the reaction take place after the reaction is over, you take the material out. In between you are not putting any material inside the system. Now if you look at the fed batch, what do you call fed batches? Fed batch is similar to that reactor whatever I have shown you. That only the thing we start with small volume, and then slowly we increase the volume. Fed batch you know, different batches we put it like this. Now what is the basis of that? Why you do that? Because, I how we do that? If you look at like this, this is the substrate concentration C A. So, if you consider this is V 1; am I right. This is V 1, this is V 2, this is V 3, this is V 4, and this is V 5.

So, you know that, when it when it comes here, then you stop the operation and after the after the reaction is over you take the material out. So, what is the fed batch? You give the feeding, but you are not taking anything out from the reactor.

That is why we call it fed batch reactor. Now here, I can give the example; suppose your substrate concentration keeps on decreasing with respect to time, this is with respect to

time. Then again you are giving a feed here so that you increase that, now, this level this level of substrate should be much below the inhibition level, what is the inhibition level? Inhibition means the every substrate above this concentration which retards chemical reactions, if retard the chemical reaction that is undesirable, then your product formation will be less. So, we want to operate the system below that inhibition level, so what we do? Initially that we fix that a concentration much below the inhibition level let it go down, then after certain time again we give the feed to rise the at same level, again it goes down like this, again rise it again go down like, this is how we want this is B 1, B 2, B 3 like the different volumes we get. Now, we can have another pattern; here that we can this suppose C A, this is repeated feedback and this is another we can we can do. We can this is the decreasing either that increases this, then we slowly food in such a way the rate at which the substrate consumption take place at the same rate we are feeding it, and we feed up to this level continuously, and then we stop the feeding then it goes down like this. So, there a different way we can operate the feed batch. Now why we why you go for the fed batch system? The fed batch system is applicable where there is the substrate inhibition. In case of substrate inhibition, we prefer the fed batch reactor, will discuss when we discuss some different process as ill discuss in details.

Now, another reactor we have the continuous reactor. What do you mean by continuous reactor?

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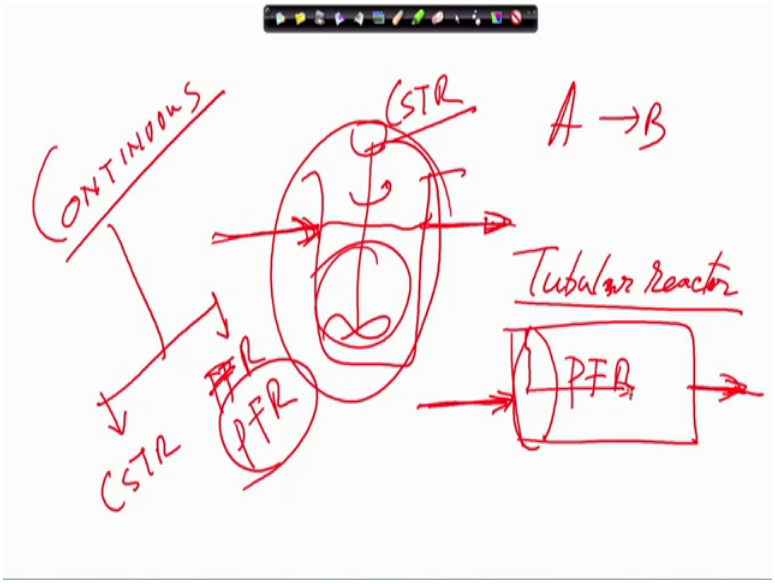

Continuous reactor, Continuous reactor means suppose; this is the reactor that we have here we have we started. So, there is a continuous inflow and continuous outflow. Now here I want to point out one typical thing that; whenever we operate any kind of continuous process, first usually we operate in a batch mode. Suppose we want to carry out that A to B, we want to carry when we want to operate in the batch mode let the reaction take place. When rate of reaction is maximum then we start reading this, continuously we take the some product out continuously, this is how the continuous system has been operated. Now continuous system may be of two types, one is called CSTR, another we called Plug Flow Reactor, PFR, Plug Flow Reactor. So, two type of with the Plug Flow Reactor looks like this; we will discuss in details. The difference is that in case of in case of CSTR, this is the CSTR, is the continuous stirred tank reactor. Now continuous stirred tank reactor means you have a started and continuous inflow and continuous outflow, and this is very easy to operate. Now if you look at the; this is the Plug Flow Reactor, in Plug Flow Reactor, you giving the feed to bonnet and it is something similar to the Tubular reactor.

So, one end you are feeding another end you were taking. When liquid flows like this, there should not be any kind of back mixing or axial mixing take place. There might be radial mixing, radial mixing is ok. But you know that back mixing does not take place, but here we have back mixing, but here we do not have any back mixing.

So, we have here at the fed different mode of operation. The batch fed batch and continuous. Then if you look at the geometric configuration, we have tubular and agitated tank reactor, tubular means is this kind of tube liquid is flowing through the tube hesitated reactor; I have already shown there is a hesitation that we have. And then contacting pattern between the phases, we have the packed bed reactor, we have fluidized bed reactor, we have trickling bed reactor, we have bubble column reactor, and we have airlift reactors, so different type of reactor, so this is the heterogeneous reaction. The heterogeneous reaction means more than one phase is present in the reaction mixture. So, this I shall discuss in details when I shall discuss the individual processes.

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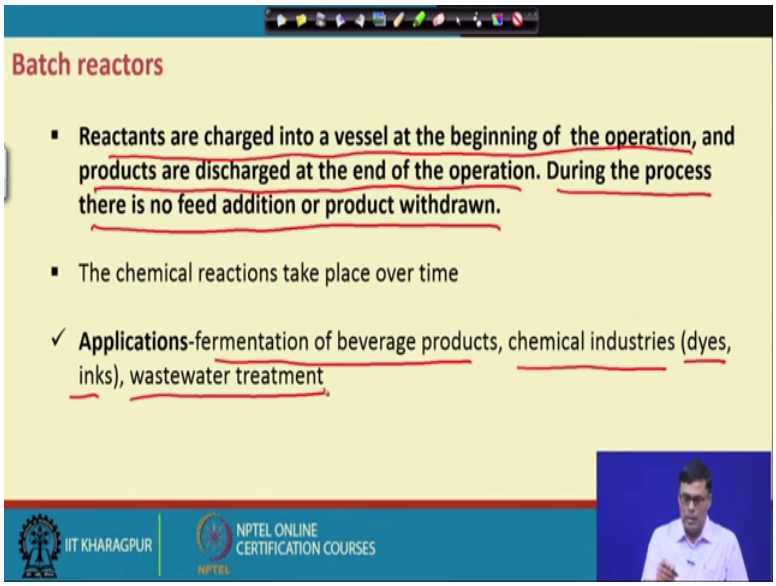

Let us look into this the Batch reactor that we have. Batch reactor is the reactants are charged into the vessel at the beginning of the operation, and the products are discharged at the end of the operation and during this process there is no feed addition or product withdrawn. So, this is the exactly what I told and batch system is very easy to operate. Just you take the substrate and put it in the reactor and let the reaction take place after the reaction is over you take it out, this is called batch process.

Now the chemical reaction, this is application is the fermentation of the beverage production, chemical industry for dyes and ink production and wastewater treatment process, it is largely use.

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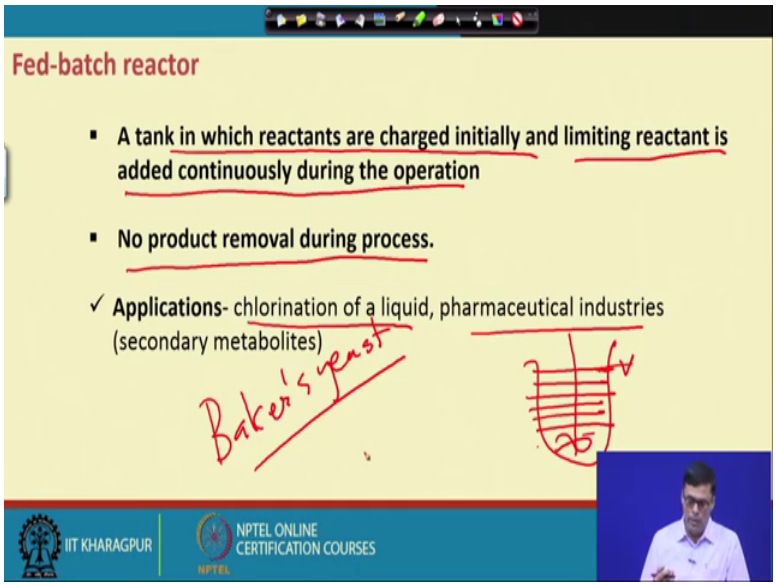

Now let me talk about this fed batch reactor. Fed batch reactor is the tank in which the reactants are charged initially and limiting reactant is the added continuously during the operation and no product removal during the process. So, I told you that in this reactor, we start with small volume then let the reaction then small slowly we feed this liquid like this and until this is the final volume. When this final volume is coming then, let the reaction take place after the reaction is taking place, you take the material out. So, they, but during feeding they you are not taking out any product from the reactor, the application is the chlorination of a liquid, pharmaceutical industry particularly I can mention the Baker's yeast fermentation process. Baker's yeast fermentation process is it largely used.

Now, if you look at the Baker's yeast, the one mole of glucose produced by about approximately 0.5 grams of substrate cell mass. So, naturally if you use more your system, you use utilize more glucose or more sugar, you will get more cell mass production. So, naturally we want that you know with the how this reactor can use more substrate, we know if you after certain substrate concentration it has some inhibition effect. So, to consider all this things we find the fed batch is the process through which we can increase our Baker's yeast product that production to a great extent.

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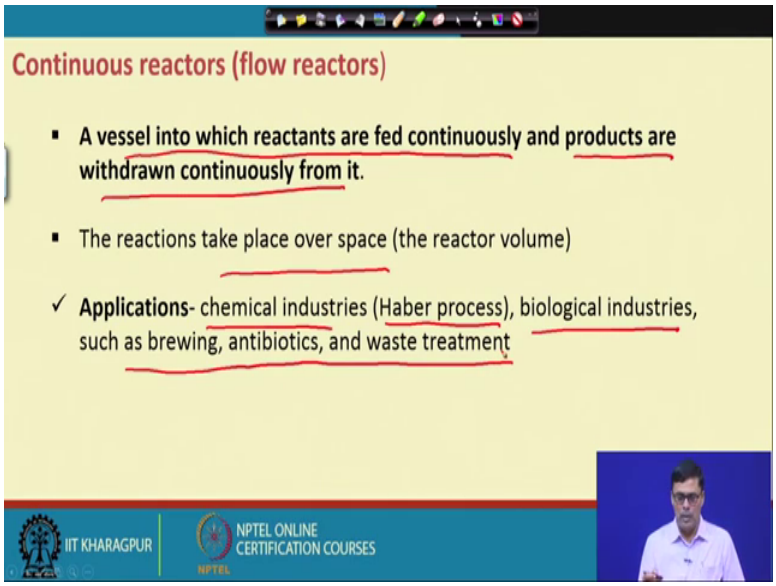

Now, let me talk about the Continuous process, the vessel in which the reactants are fed continuously and products are withdrawn continuously. Only the thing I highlighted before that continuous system when you operate, first we operate in the batch mode and after the when the rate of reaction is maximum, then we continuously put the reactor in and continuously take the product out. The reactant take place over space and that is application is the chemical industry like Haber process, by biological industry largely used and brewing antibiotics and waste water treatment process we use this particular process.

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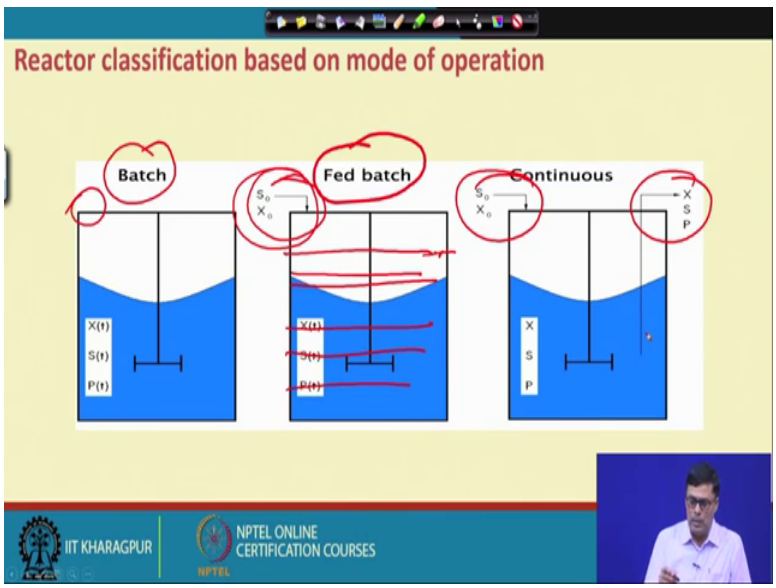

Now, pictorially that this process looks like that fed batch process, we put the material at a time, after the after feeding we are not taking the material out, after the reaction is over we can take the material out. But in the fed batch process, we small feeding we should have to give with respect to time, but at the here also we cannot we cannot; so, there we have a feeding continue, here we do not have a continuous feeding body here you have a feeding here, so until unless the final volume is reach, we do the feeding then we stop the feeding let the reaction take place completely then we take the product out.

In the continuous system, the continuous inflow and continuous outflow from the system that takes place, this is how we can explain in pictorially.

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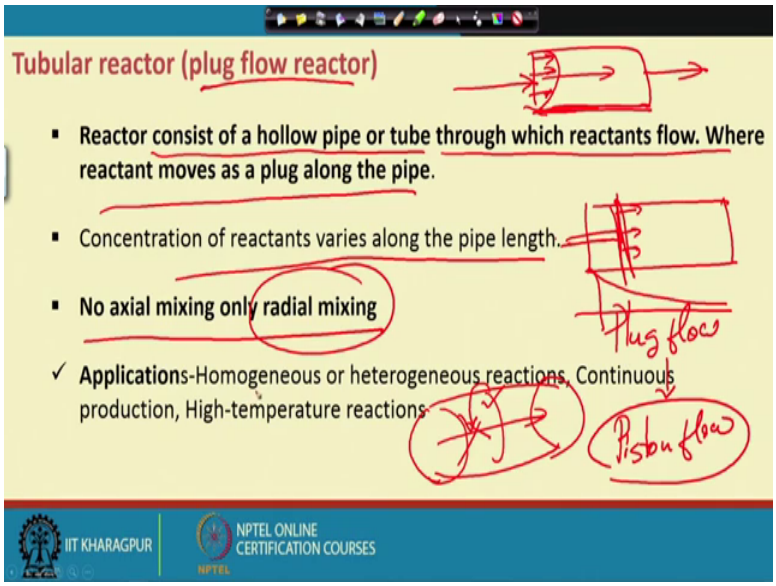

Let me talk about this a Tubular reactor. Tubular reactor is kind of Plug Flow Reactor, this is Plug Flow Reactor I told you; It is like this, this is the tube and you pass this and it flow like this. Now basically, the Tubular rector is a plug flow reactor is that, it is kind of plug flow; means is call it the plug flow, that is nothing but we call it Piston flow. What is piston flow? Because we know they if you have a piston, when it the picture the when you have a syringe we have a battery, we have when you when you put this that you know that sapped forward, then if the liquid is moving. When it moving there is the velocity across this liquid across this cross section will be more or less uniform. But when liquid flows through this tubular tube required a reactor, we have gradient of this velocity.

Because we find the liquid close to the cell wall with the wall of the tube and the less velocity as compared to that of the center, because there will be friction between the wall and the liquid. That is why the velocity reduces to a great extent.

Now, reactor concept of hollow pipe or tube through which the reactants flow; where the reactant moves has a plus flow along there now the piston flow basically, we considered as the ideal flow, ideal flow is kind of very rare to happen. So, you know that we can, what you if you make the flow the turbulent flow, then it is tends to piston flow not exactly piston flow it tends to, then velocity gradient across the reactor will be minimum because that a velocity gradient across the reactor will be minimum, if we flow pattern, if you change for laminar flow to the turbulent flow. Now concentration of reactant play that varies along the pipe line there so if you plot the concentration you will find keep on changing with respect to distance no axial mixing, but only the radial mixing.

What do you mean by radial mixing? I told you, this is the tube; if your tube is there so the liquid can have the radial mixing that in a circular direction, not in the axial direction, this axial direction is not the permissible, but radial mixing is permissible. The homogeneous if you look at homogeneous and heterogeneous reaction, it is use the application and continuous production and height high temperature reaction this is use.

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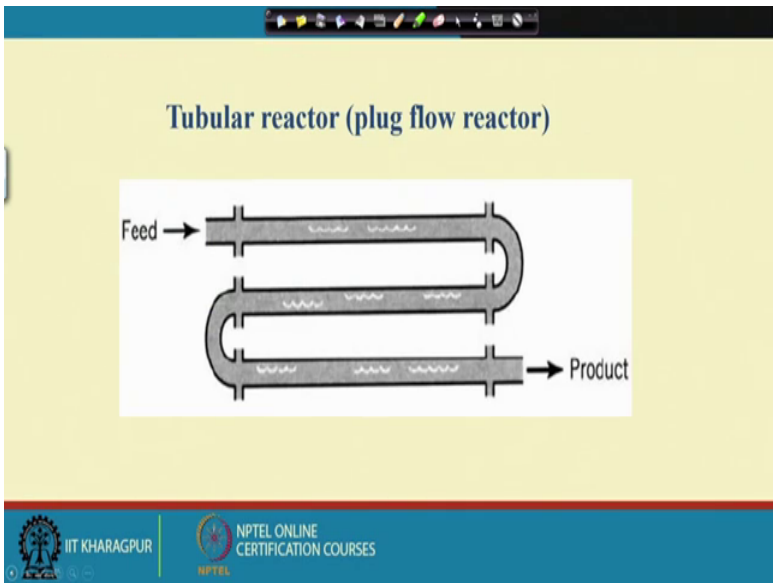

Now, this is how pictorially this process looks; this is tubular reactor, this is tube you can see however if we if we put the feeding one end it take the product in the other end.

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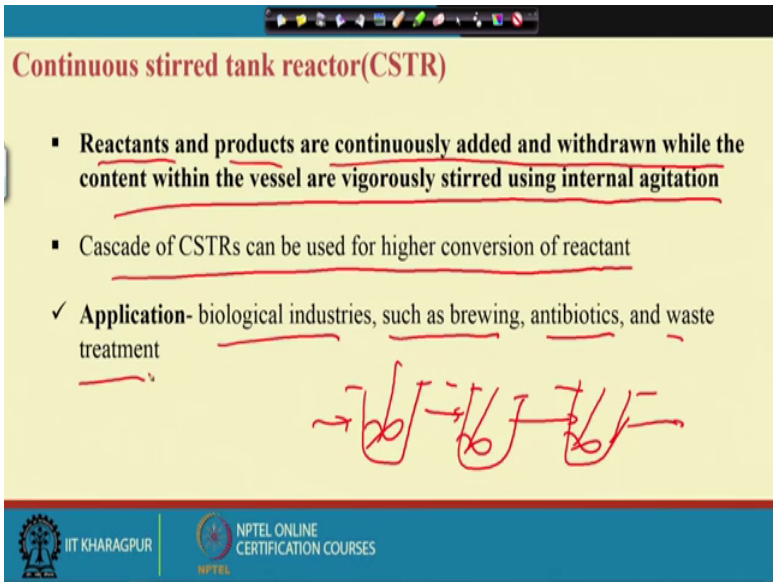

Now, CSTR is a kind of reactant and products are continuously added and withdrawn while the content within the vessels are vigorously start with the internal agitation the cascade CSTR can be used for high higher conversion of reactant what is cascade reactor? Cascade reactor means, if we have the CSTR in series because this is CSTR if we connect with the series then we call it cascade reactor, this is we call it cascade reactor. The application is biological industry such as the brewing antibiotics and waste treatment processes were largely used.

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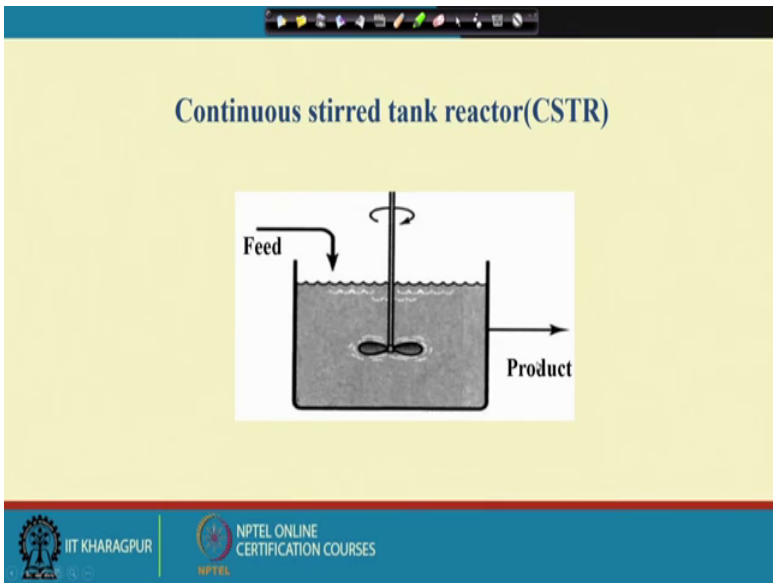

That is the continuous stirred tank reactor looks like this is the Bessel in which the reaction till this is the stirred and purpose of stirred to maintain the homogeneity in the reaction mixture we put the feed imminent and take the product in other end.

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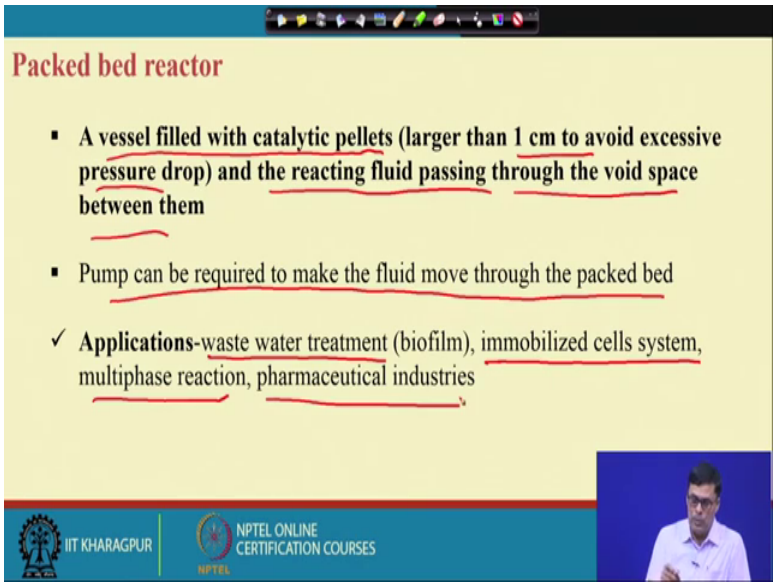

Now, let me now take let me discuss the packed bed reactor. Let me show you that packed bed reactor. Suppose this is a this is a packed bed reactor and here this is the this is the tubular reactor without cylindrical reactor and this is populated disk and here you pack the solid material like this they are lying one after another like this, what I call packed bed reactor.

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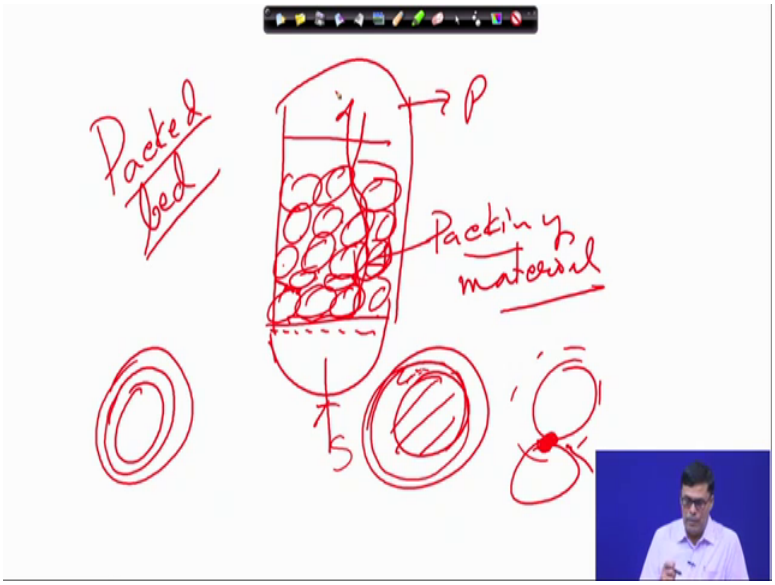

So, you pass your substrate and you take out the product like this from this is the packed bed. Now the interesting feature is that in the packed bed reactors solids they will touching with inner they packing with this is the packing material am I right? This is called packing material, now there they pack to one after another due to the gravitational force of attraction. Now when you pass your liquid due to the packing what will happen? This portion, where the solid they are lying after another liquid cannot penetrate this because the liquid will flow wherever there is a voice face, then the voice face liquid will go, liquid can it go where the solid they are touching with each other. So, though what I want to say that you know suppose this is the solid matrix and whole portion of the solid max matrix will not come in contact with the with the substrate, suppose we want to do the immobilization of the enzymes and enzymes are immobilized on the on the particular solid surface then whole surface the enzymes are now if the other solid material they are touching with each other this portion whatever enzyme is there that will not come in contact with the substrate, so that is the problem with the packing bed reactor and not only that in case of cell mass growth the when you when you do the immobilization of the cell will multiply and when cell multiply what will happen? It this layer will be becoming thickening and when the layer is the becoming thickened, then what will happen? The pore size of the of the of the particular pack column will be reduced, as the pore size reduces then water flow will be affected and liquid flow will be affected and then you will they will they will be channelized channel the channeling of the liquid

flow, if there is a channeling of the liquid flow then the rate of reaction will drastically reduce then you have to stop there you process and regenerate the system again.

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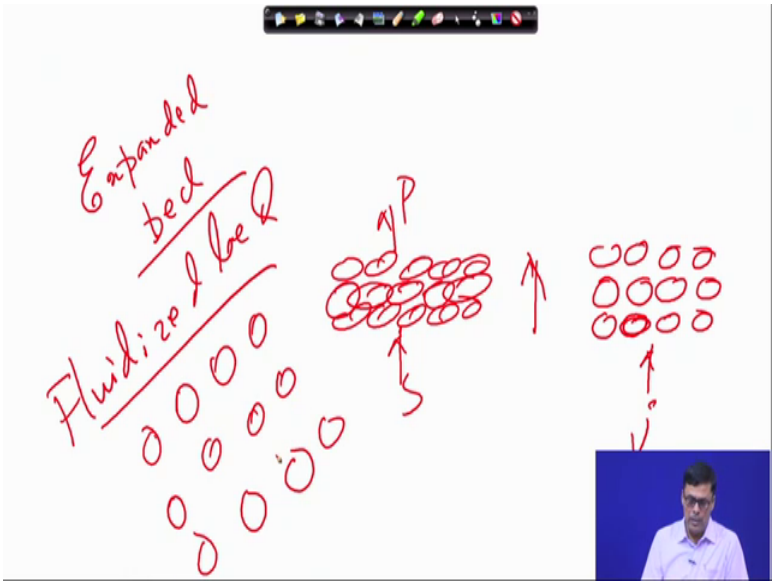

Now, let me tell another reacted what we call? Expanded bed reactor, what now this solid particle they are lying with each other am I right they are lying like this due to gravitational force of attraction then this is like, now if you increase the velocity this substrate is coming product is say now if you increase the axial velocity the axial force if it increases a time will come, this will overcome this gravitational force of attraction then particle will be separated from each other.

What you call expansion of the bed will take place, now as soon as the expansion of the bed will take place; then whole portion of the solid matrix will come in contact with the substrate, then naturally your rate of reaction will increase the in case of expanded bed reactor the expansion of the bed take place. Now in case of fluidized bed reactor fluidized bed reactor, this velocity will be much high and since the velocity is high this particle separation also very high, there also the expansion of the bed also very high, so this is like this is the how we differentiate this. So, packed bed reactor if you look at that a vessel filled with catalytic pellet us larger than one centimeter to avoid the excessive pressure drop and the reacting fluid passing through the void space between them.

Pumps can be used to make the fluid moves through the packed bed, application is the worst water treatment by using then immobilized cell system then multi phase say reaction and pharmaceutical industries.

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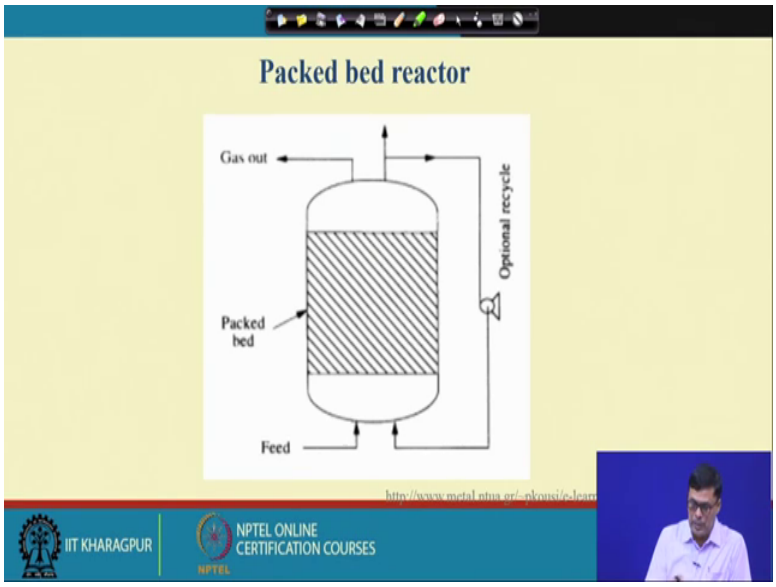

Then example is like this is the packing bed we sometimes we recycle back to have more conversion efficiency of the process and we take the product out from the top.

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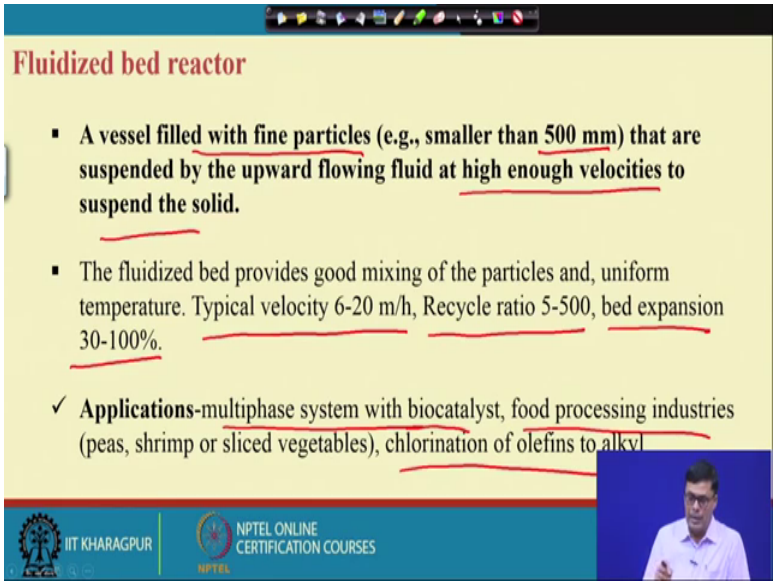

Now, fluidized bed reactor I have already explained only I want to highlight here; a vessel filled with a fine particles smaller than 500 millimeter and then that are suspended

in the upward flow fluid at the high enough velocity to suspend the solid. And what is the typical velocity is that? 6 to 20 meter per hour, and what is recycle ratio? Is 5 to 5 100 and expansion of the bed is about 30 to 100 percent, now in case of expanded bed it is 30 to 40 percent you know here it is about 100 percent expansion take place, the multi phase system with bio catalyst food processing industry chlorination, olefins, alkyls this is largely used.

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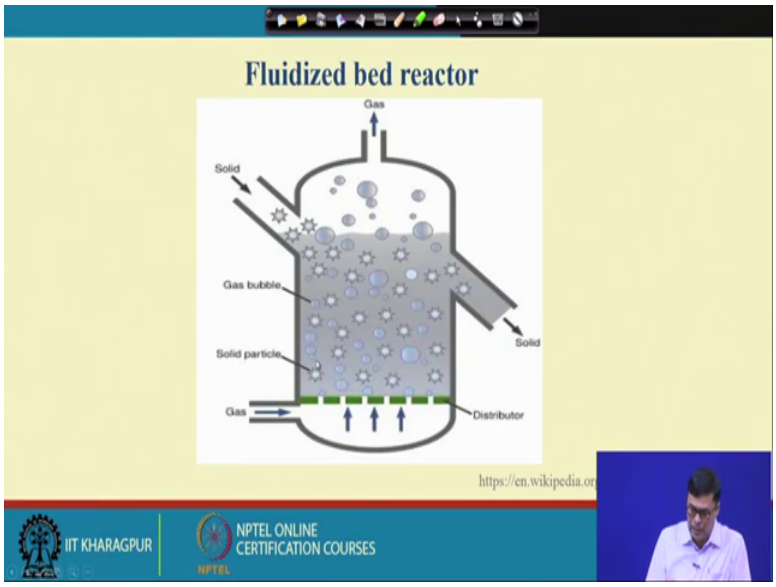

Now, this is how the fluidized bed reactor occurs you can see the particle they are separated from each other.

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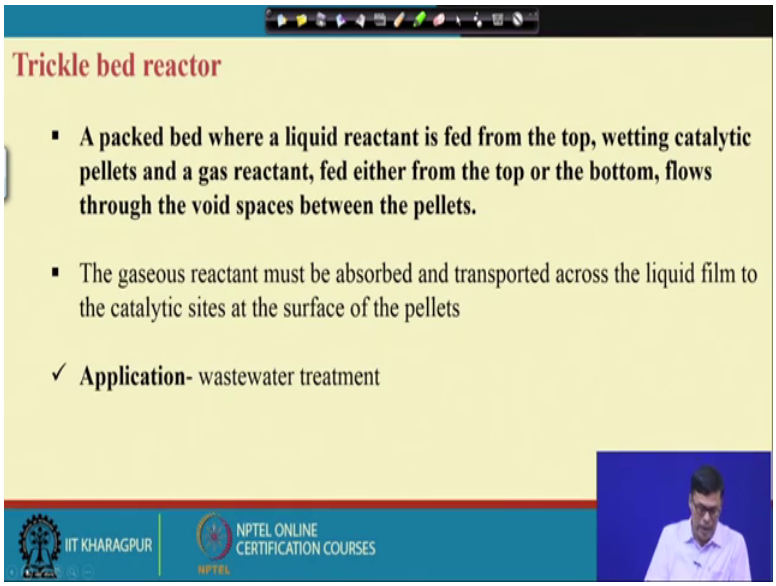

Now, trickling bed reactor is something similar to the back bed reactor I do not like to discuss again.

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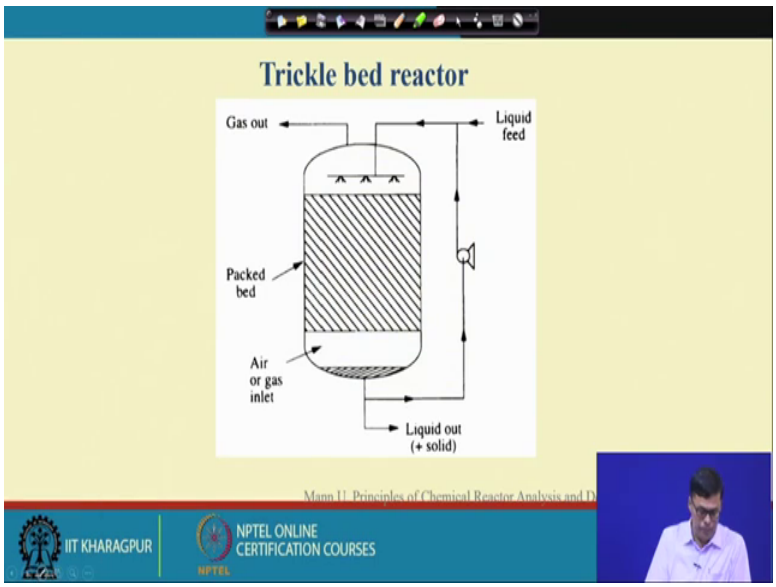

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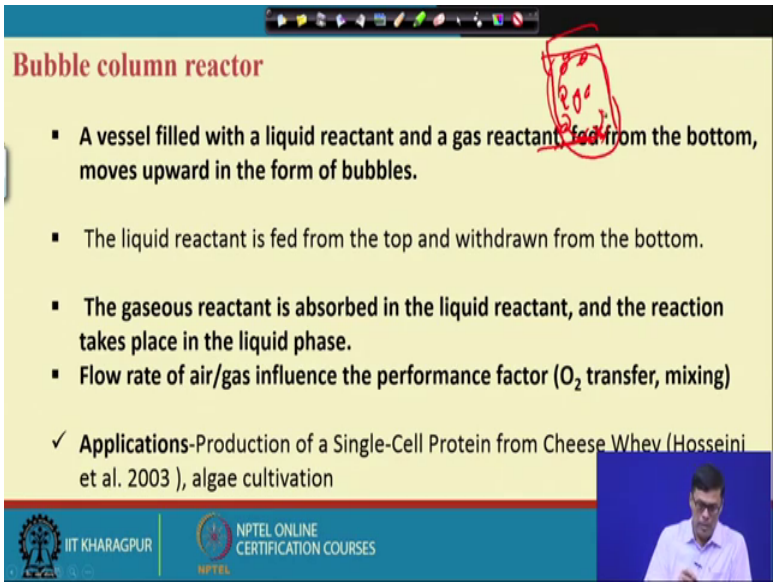

The bubble column reactor is a very simple reactor I can give the examples; that here and this is suppose this is the column and what we do there is a Spurger here we put a Spurger and this is the liquid and this bubble will go like this, so you have cell suspension here that will that will react there.

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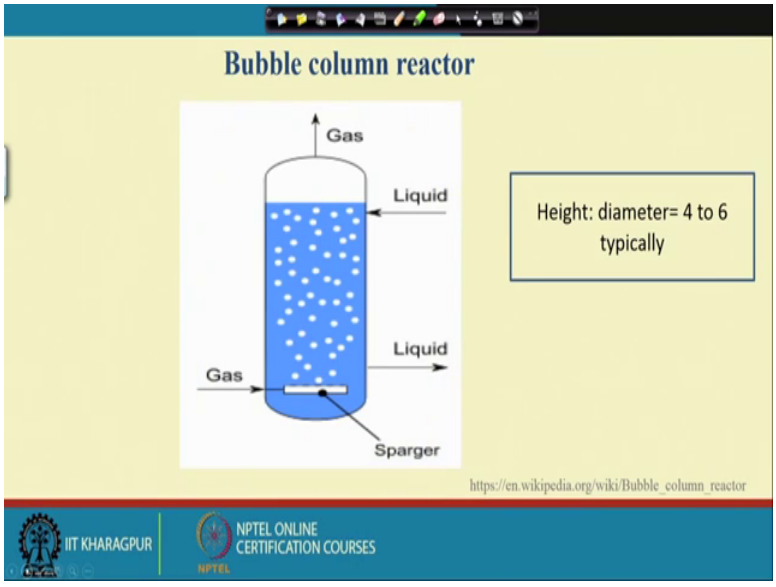

Now vessel filled with liquid and gas reactant and feed from the bottom and move upward in the form of bubbles, liquid reactant is a feed from the from the top and withdrawn from the bottom that their application is that single cell protein production

from which cheese whey it is used, now that this is largely using the a microalgae algal fermentation process. This is how it looks; this is what we called Spurger that you can see the Spurger and then this how the bubbles are moving upwards.

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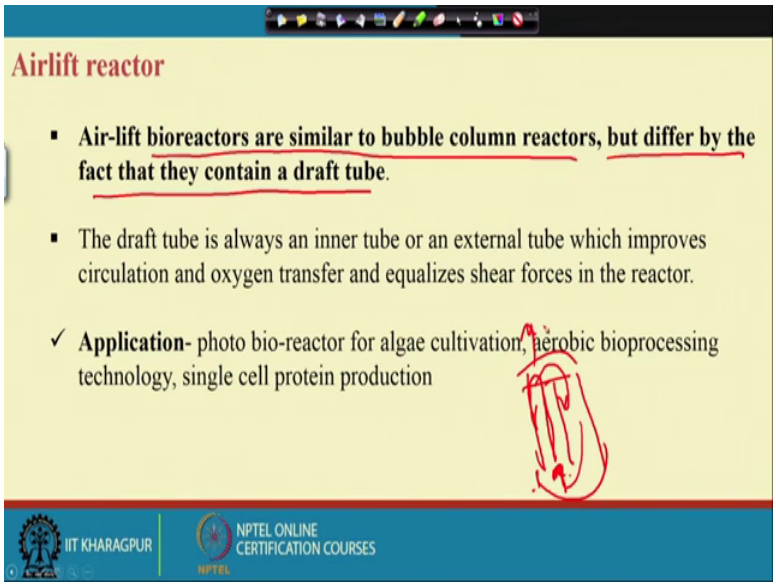

Now, then airlift fermenter is the we have here and there lived by reacted as similar to bubble column reactor, but differed the fact that the contents had dropped you. So, in the in the in the in the in case of bubble column reactor we do not have any adoptive the here he has adopt you. So, when you do move the aeration here the bubble will go and some of the bubble will recycle back here like this and most of the air that will go out of the system as I will explain pictorially in the next slide. Then application is the photo by reactor for algal cultivation largely we find this is very good for the growth of algae an aerobic bioprocessing technology and single cell protein production.

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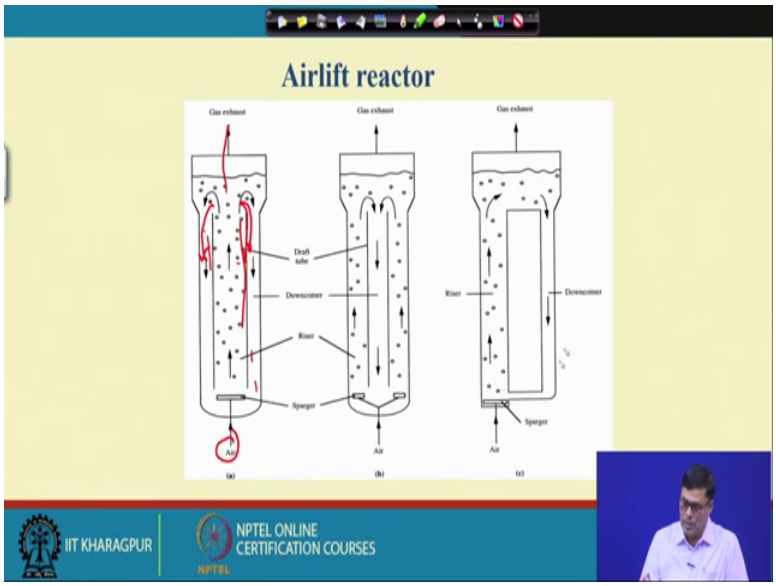

This is different types we have as I told you here if you if you look at that if you do the aeration at the bottom and this is the drop tube we have inside the drop tube, then air will go out and some of the air due to the dragging force it will comes in this area this annular area and it recycle back this and another way we can do that in outer; here we Spurger and it will go out and some of the air will go come this way which where the mole much transfer will required and this is how we can done externally this we can recycle like this that will take place, three different way the mode it can be operated.

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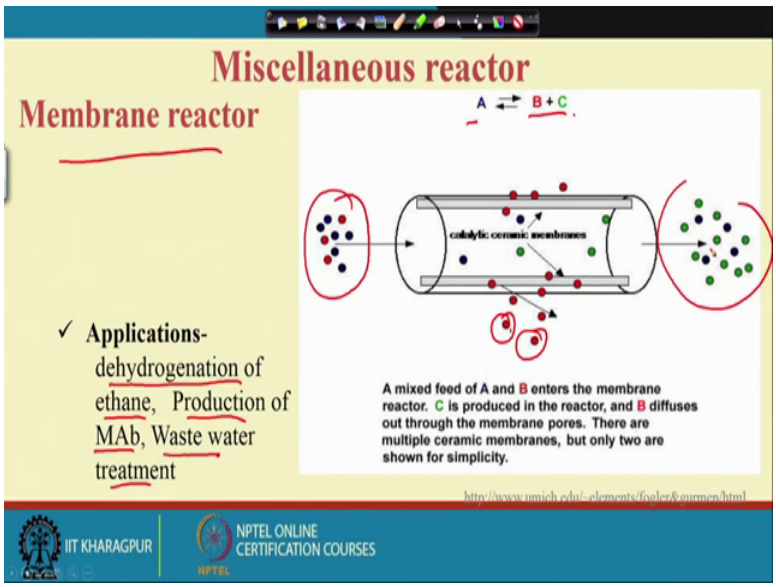

Now, another thing we have that is; the membrane reactor, this is also very important this is used for the dehydration of ethane, production of monoclonal antibody and wastewater treatment process. Now you can see that when suppose the; A reacts with gave B plus C, so you can you have different colored set here. So, due to membrane you take out the suppose you are interested for the product a red color, so red color you can you can diffuse out through the membrane product and you can you can get other than this from the main stream you can you can find out this.

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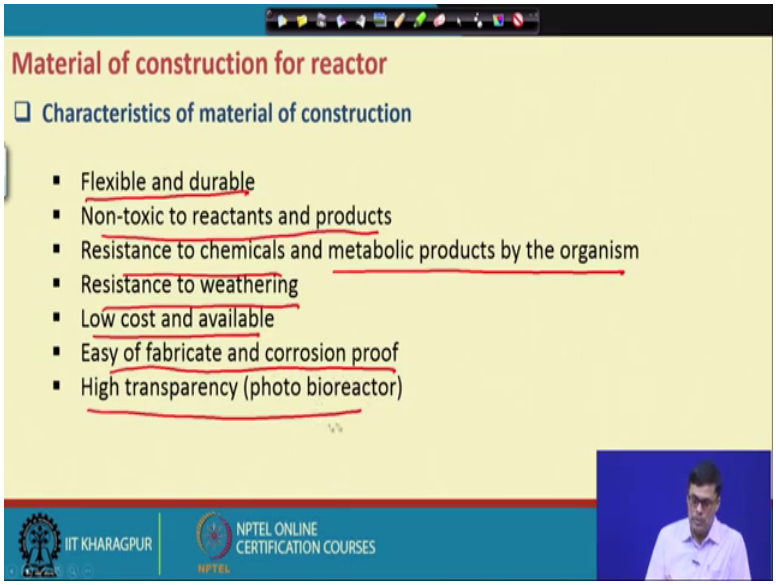

So, you know that construction of the material is very important and that of the reactor is very importance to be flexible and durable and non toxic to reactant and product resistance to chemical and metabolic products of the organism resistance the withering low cost and an available easy of fabrication and corrosion proven high transparent, so high transparent in case of photo biological reaction, because we want to use the light energy for the growth of the microbial cell.

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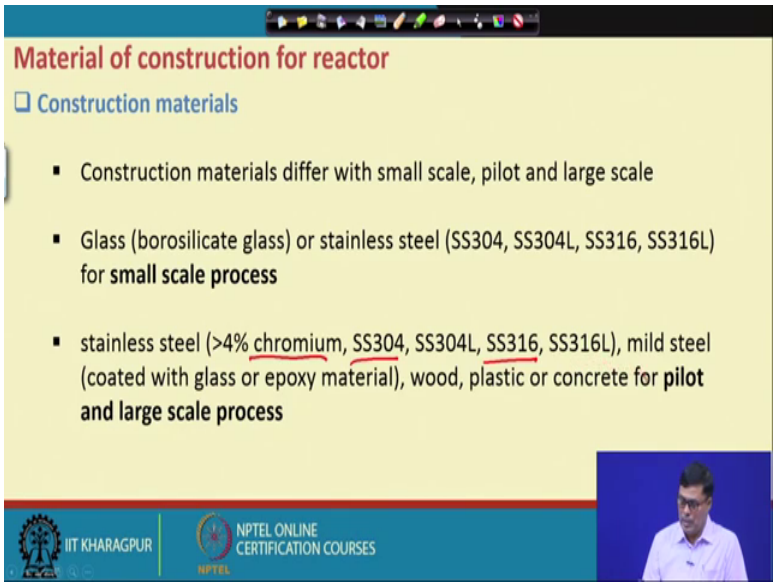

Now, our construction material I can give the typical example of chromium if we keep the chromium in the stainless steel then there is a acid register property of the stainless steel increase to a great extent, usually the we use the SS304 for our day to day requirement for in the fermentation industry we recommend SS316 sometime SS316L that is we use for pilot pen and large scale operation.

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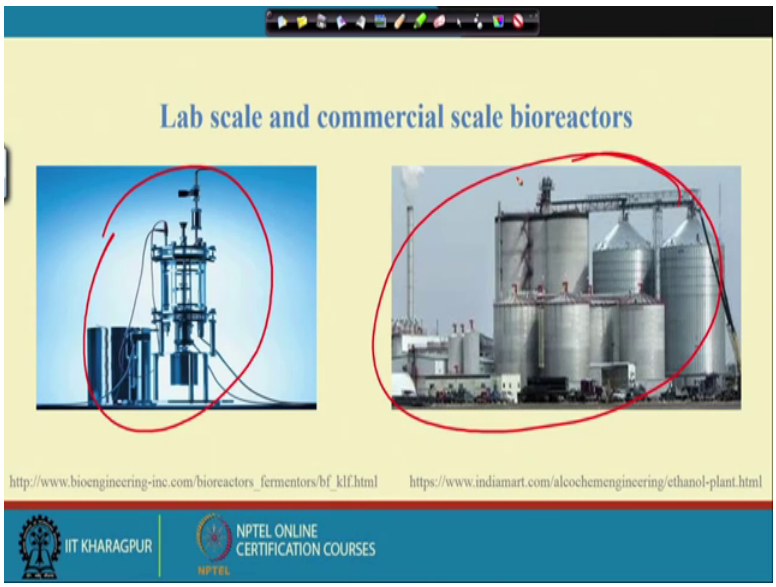

Now, this is the lab scale; this you can see that this is the lab scale and this is the count scale because operation how it looks.

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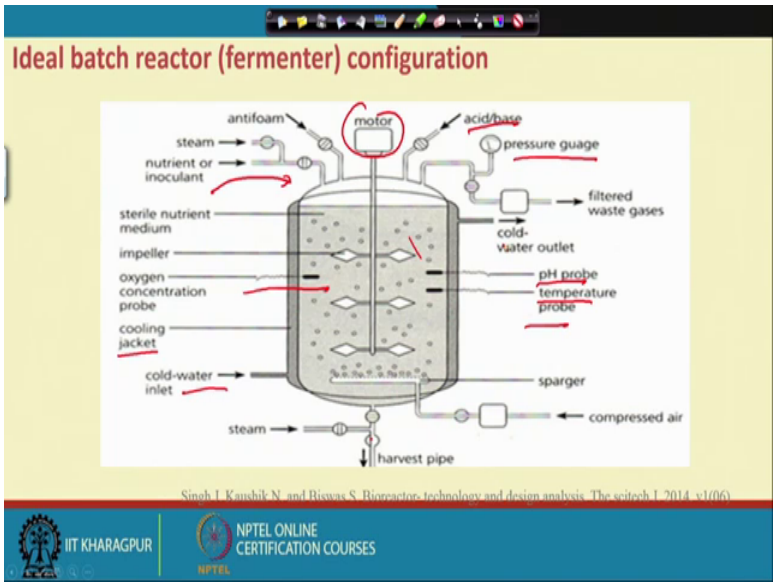

Now, this is the reactor how it looks; reactor will be having and so many things you can see in the reactor that we shall have the indicator, we have the stream for the sterilization part, but this is the harvesting line that we can after the fermentation is over you can take it out here the ph probe temperature probe that can be inserted, here is the dissolve oxygen probe that is the interested cooling arrangement we should have that cooling jacket we have with a nutrient which would act like this and this is the motor through the hesitation take place acid and bases added with the help of pump, pressure gauges this is used to monitor the pressure of the of the particular reactor.

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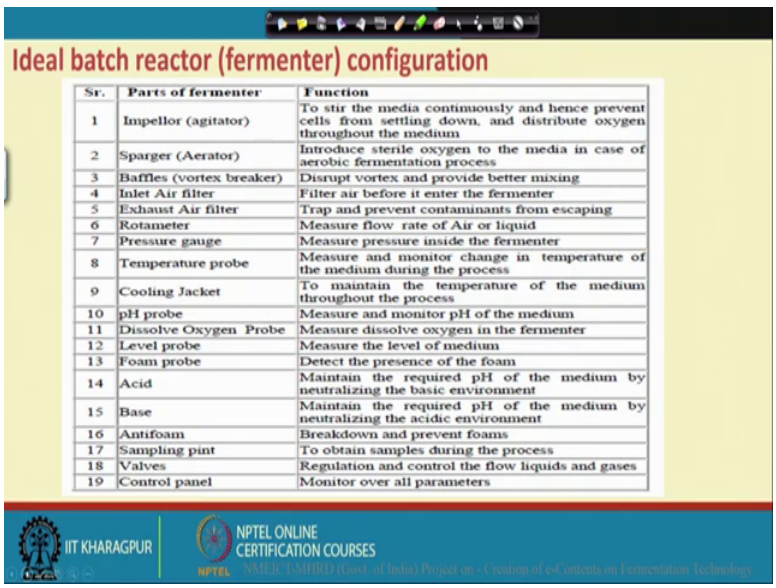

Sr.	Parts of fermenter	Function
1	Impellor (agitator)	To stir the media continuously and hence prevent cells from settling down, and distribute oxygen throughout the medium
2	Sparger (Aerator)	Introduce sterile oxygen to the media in case of aerobic fermentation process
3	Baffles (vortex breaker)	Disrupt vortex and provide better mixing
4	Inlet Air filter	Filter air before it enter the fermenter
5	Exhaust Air filter	Trap and prevent contaminants from escaping
6	Rotameter	Measure flow rate of Air or liquid
7	Pressure gauge	Measure pressure inside the fermenter
8	Temperature probe	Measure and monitor change in temperature of the medium during the process
9	Cooling Jacket	To maintain the temperature of the medium throughout the process
10	pH probe	Measure and monitor pH of the medium
11	Dissolve Oxygen Probe	Measure dissolve oxygen in the fermenter
12	Level probe	Measure the level of medium
13	Foam probe	Detect the presence of the foam
14	Acid	Maintain the required pH of the medium by neutralizing the basic environment
15	Base	Maintain the required pH of the medium by neutralizing the acidic environment
16	Antifoam	Breakdown and prevent foams
17	Sampling pint	To obtain samples during the process
18	Valves	Regulation and control the flow liquids and gases
19	Control panel	Monitor over all parameters

Now, this is the different accessories that we attached with the reactor or the bioreactor that I already pointed out before I do not like to discuss more. So, in this particular presentation I try to give you this detailed information of the reactor and what are the different types of reactor is there? And what are the different accessories that present in the reactor? So, in the industry we use three different type of reactor; we use the batch reactor, we have fed batch reactor, we continuous reactor, then we also we have seen the packed bed reactor, packed bed reactor may be of other types; we have expanded bed reactor, we have fluidized bed reactor and other type of reactors we have as for example; that bubble column reactor real leaved bioreactor, where this is used where the shear force is very less because in case of normal fermentation process if we use the mechanical starter there will be kind of shear force.

So, some of the living cell they are very sensitive to the shear force, so there we cannot use the mechanical stirred there we can use the bubble column reactor or really fermenter, so this is I hope you will get you have you get some information on the reactor which is used both chemical and biochemical industry.

Thank you very much.