Aspects of Biochemical Engineering
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Lecture – 60
Summary and Conclusion

Welcome back to my course aspects of biochemical engineering today is the last lecture; I shall make some summary and conclusion of the course and try to point out, what is the purpose of this course? How we design the course? What is the different things we covered in this particular course at the end? I shall discuss that what are the things you should get out if this course and lastly I shall give the little introduction to my tas and the and also I want to show you some kind of video of 20 liter bioreactor for producing hydrogen it is the continuous operation system.

So, let us start with that you know how we design this course; if you look at this that you know that we divided into 3 different areas.

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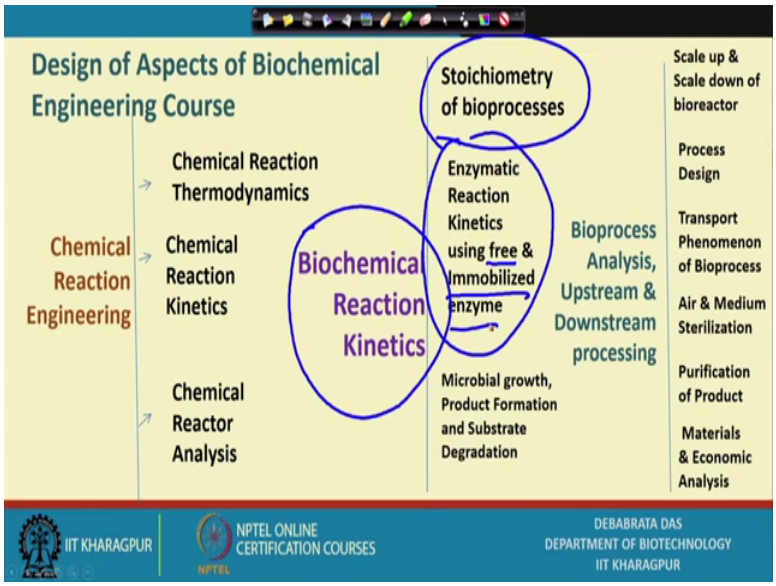

Now if you look that first is we have the chemical reaction engineering I told you to now the biochemical engineering that first we should know should have some kind of idea on the chemical reaction engineering and to know the chemical reaction engineering first we try to discuss the chemical reaction thermodynamics and we know the chemical reaction thermodynamics plays important role as per any chemical reaction is concerned and from

the that any reaction thermodynamics we can find out, where the nature of the reaction whether it is spontaneous or non spontaneous to what extent the reaction take place.

Then we have we discuss the chemical reaction kinetics which is the appears to be the most important part of the any kind of chemical process to understand the chemical process, we want to find out different kinetic constant rate equation we develop try to do the simulation of the equation to find out the validity of the equation and this equation and this particular kinetics we use for the reactor design and in the reactor design is a very important part in the chemical engineering because here we try to find out what is the volume of the reactor to get a desired amount of product.

So, we do the detail analysis of the reactor, now after having this information then we switch over to the biochemical reaction kinetics in the biochemical reaction kinetics first we try to understand what is the stoichiometry of the bioprocess which is very important because the reason is that the if you know the stoichiometry of the bioprocess. Then we can find out the material and energy analysis of the process which is very important from this stoichiometry, we can find out what is the theoretical yield of the process and for that. So, that we can we can design our process accordingly and then we after that we cover the enzymatic reaction kinetics both by using free and immobilized enzyme.

Now, we know the free enzymes when we have we have 2 type of enzymes, one is the soluble enzymes and in soluble enzymes when we and our substrate mostly is soluble in nature. So, if we substrate is soluble enzyme is soluble then we consider as a homogenous reaction, how the homogenous reaction is the reaction kinetics can be explained that we discuss in this enzymatic reaction kinetics, but another situation that we have the heterogamous reaction kinetics where the particularly we have immobilized cells immobilization of the cells take place on the solid matrix.

As the it is a fixed on the solid matrix then in the medium in the particular liquid in a reaction mixture you have 2 phase one is liquid phase another is solid phase and we know in case of heterogeneous reaction one phase suppose until unless is come in contact with in with the other phase the reaction cannot take place and after reaction is over then the product should diffuse to the previous phase then you know we can get the product.

So, after having these information then we try to understand the microbial growth product formation and substrate degradation kinetics and if you look at the microbial system, we find out they follow the metabolic pathways and in the metabolic pathways we have a chain reaction and in the chain reaction we have number of steps involved in the a each and every step usually governed by different enzymes. So, it is a multi enzyme system.

So, we try to and we try to discuss what is the basic difference between the living system and the nonliving system and then we also discuss that what is the how you study the kinetics of the process. I told you that we the major advantage of the biological process our biochemical process is that as the here from the same substrate we can produce n number of products. I have given the example that sugar can be converted to acetic acid sugar can be converted to citric acid sugar can be converted to the that your acetic acid sugar can be converted to lactic acid.

So, different products you can get, but if you look at the chemical process as your product changes your raw material changes though that is that is and here in the biochemical process what we do, we change the microorganism and as we change the microorganism we get the different type of products.

So, micro the leaving system main emphasize is to be given how we can allow our desired organism to grow in the reactor. So, that we discuss in details in these and how the microbial growth and product formation and substrate degradation can be taken into accounting this system, after having all this information then we switchover to the very one important thing that is bioprocess analysis upstream and downstream processing.

Now, I told you that when whenever we have any kind of bioprocess that before whatever processes we involve before the bioprocesses we call off stream processing and after the bioprocesses is over then we shall have to do the purification of the process that we call downstream processing.

So, here that in the bioprocess analysis first we discuss the scale up and scale down of the bioreactor which is very important because in that in the day 2 when we do any kind of research in the laboratory we develop the things in the lab scale, but lab scale we it might be carried out either in the test tube or in the conical flux or in the very small

reactor of capacity 2 to 10 liters, but that is not good enough for the commercialization of the process.

But when you do the commercialization of the process the wrongly the very big scale their main purpose of doing this with the environment that we have in the small reactor similar environment should prevail in the big reactor so, for doing. So, how the different operational parameter changes that we discuss in the scale up of the bioreactors and then there is another term very important, what you call scale down? Scale down basically suppose we cannot do any kind of optimization strategy in the big fermenter because if some negative results we are we get then this incur lot of loss in the fermentation process.

So, it is better we should do all the optimization study in the small scale reactor and when we develop all the optimized parameter then we can apply the bigger scale study that we call scale down. Then after having this then another very important thing is the process design as per design is concerned that is 2 type of design involved in the biochemical processes, one is called process design, another is called soft flow design.

Process design basically involve that what are the parameters involved for operating the process and soft flow design basically it is a mechanical design. So, the scope of this particular course is on the only on the process design not on the machine design or that you know soft flow design. So, we try to discuss what are the parameters, how you can monitor different parameter for the process design and after having this idea that we discuss the transport phenomena of the bioprocess we try to discuss 3 different type of transport, transport phenomena one is momentum transport another is the a that heat transfer another is mass transfer.

That all the things plays very important role as per example momentum transfer if you look at it is a something similar to the fluid dynamics that mixing characteristics of the fluid plays very important role and second we have heat transfer that greatly involve for the sterilization of the bioreactor because the I told you sterilization that we shall have to allow our desired organism to grow in a in the medium then naturally that all other contaminant should be free. So, that in our desired organism can grow so, that you know that.

So, heat transfer is very important then I told mass transfer because most of the fermentation process are operated aerobically and major bottlenecks of the master that aerobic fermentation process is the dissolve oxygen concentration because oxygen is sparingly soluble in the fermentation process. So, mass transfer how we can improve the mass transfer that we discuss in these transport phenomena.

Then after that we have 2 upstream processes one is we have air and medium sterilization and air sterilization how we can do the air sterilization I why I told you that 2 type of air is to be sterilized one is called stagnant air another is moving air and suppose we sparge the air through the bioreactor that is the moving air and stagnant air means suppose we want to do some kind of operation in this particular room then and then the room is to be sterilized that is the stagnant air and for the stagnant air sterilization usually we use the uv rays or you know germicidal spray that sterilizing this environment.

But for the moving air usually we use the physical separation technique we use some kind of filtration technique just to remove the contaminants present in the air and in case of medium sterilization we find the heat is a good medium for the medium sterilization because water is good conductor of heat. So, you know that we try to design both air filter and medium sterilization process that we discuss several numerical problems during covering this course.

And then finally, we come to the purification of the product what you call downstream of this downstream processing because whenever we produce any kind of product that should be marketed in the purified form and to get to purify the product several steps are involved before the products is purified.

So, how the different this downstream processing can be operated different filtration solid liquid separation process, liquid the extraction process, how the crystallization process evaporation process all we try to explain in this downstream processing and finally, we did this material and a economic analysis of the process though give you idea how you can whatever knowledge you acquired during this course how we can apply it in real fermentation process. So, this is the way we have designed the whole course I hope it will be very useful those who are really working with the biochemical power processes.

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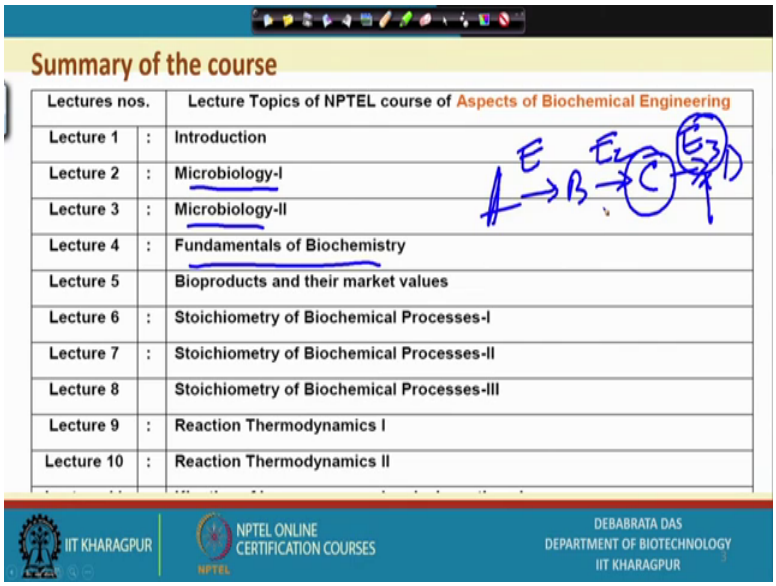

Now if you look at the course content that, we started with this microbiology, then we started with microbiology that we try to understand what are the different microorganism present and the how what is the classification, how their characteristics differ from each other, how they looks under the microscope, how morphologically they differ from each other, then what is the how their size varies from each other.

The all these thing we try to discuss in the microbiology lecture, after that that we try to give you some information on the biochemistry of the process because that is the I told you that all the organism they follow the metabolic pathway, in the metabolic pathway you have chain reaction you have to find out that reaction so, that you can have your strategy how we can get your described product.

I can give the example suppose A to B, B to C, C to D like this you are doing. So, you are interested the product of C. So, we the enzyme that is involved here so, this is suppose this is E 1, this is E 2 and this is E 3. So, we shall have to put some kind of inhibitor here so, that the formation of D can be reduced. So, that more accumulation of C take place in this process.

So, that, biochemistry of the process is very important and then we find out that we try to discuss the what are the different bio products that is the available in the market and their market values because that is very important because since those who are involved with a by technology or biochemical area for processes they should know what are the

different products that are available in the market and we try to classify that this products in the 3 different types the low value high volume products, medium value medium volume products and high value and low volume products so, this is how we do the classification.

After that we try to discuss the stoichiometry of the biochemical process I told you it is very important to do the material and energy analysis of the process and after having this we started with a chemical reaction chemical reaction thermodynamics we try to discuss how thermodynamics plays important role in the chemical process.

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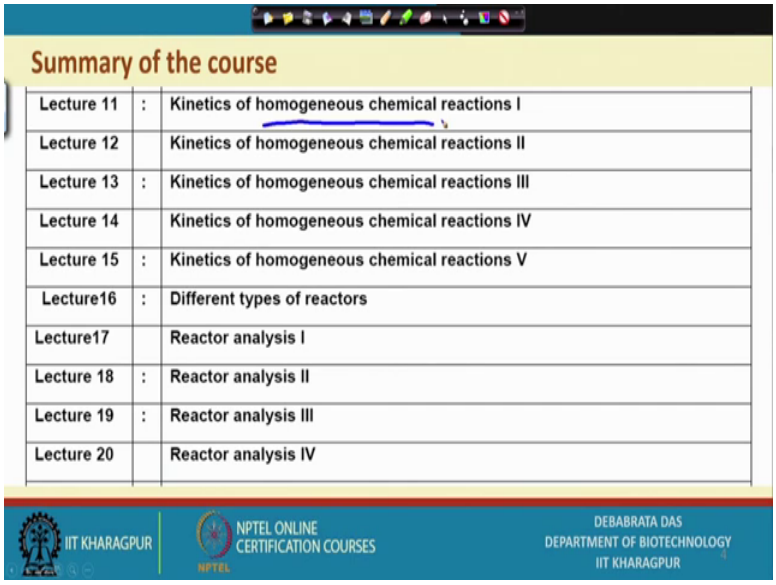

Now, after this we covered this kinetics of the homogenous reaction chemical reaction how there are different type of reactions as per example we have a irreversible reaction, we have reversible reaction, we have chain reaction, we have autocatalytic reaction, the different type of reaction how this can be we can write the mathematical expression for this type of equation, how we can find out the rate constant, how we can find out the order of reaction this is very important.

I told you that the rate constant and order of reaction all are experimental parameter with the help of experiment experimental study you can find out all these values and after getting all the information then we go for the we try to give you the information, what are the different type of reactors are available and reactors basically is vessel in which the reaction take place and then this idea we discuss that reactor analysis and reactor

analysis is very important I told you just to find out who that you know what is the volume of the reactor not only the volume of that reactor we can select what type of process will be most suitable for your process.

I can give the example suppose we want to produce a certain amount of products, suppose I want to produce 1 ton of product per day now getting 1 ton of product per day, what will be the minimum size of the reactor because as the size increases the involvement of the price for this process will be more that is that is to be taken into account.

So, that is why the reactor analysis plays very important role and I told you that 2 that 2 type of process is mostly we have batch process, we have continuous process, another process we have what do you call back feed batch process so, 3 different process we discuss in details.

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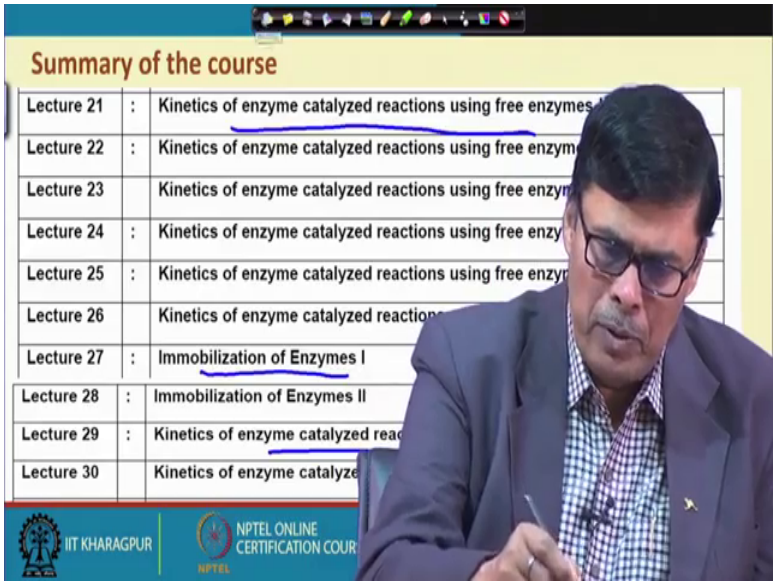

After getting the information of the chemical reaction engineering, then we started discussing the kinetics of enzyme catalysis reaction by using free enzyme systems. We try to discuss that what do we understand by enzymes, enzymes basically they were they are globular protein not necessarily enzymes are protein due to the advancement of organic chemistry now it is possible to produce some enzyme that synthetically, but those n number of those enzymes are very few.

Basically the enzymes are protein and they are globular in structure and the protein with active side we call it that enzyme that you know that. So, and purpose of the enzymes just like a catalyst and role of a catalyst as you know to lower the activation and energy as we lower the activation energy the rate of reaction increases, but after the reaction is over is remain unaltered.

So, all the different type of that different type of enzymatic reaction we try to discuss then we discuss the Michaelis Menten equation which is used for explaining the enzymatic reaction kinetics and how later on that how Briggs and Haldane they justify the Michaelis Menten kinetics equation with the help of reaction kinetics.

We try to discuss their different type of envision process, we discuss competitive envision, we discuss that noncompetitive envision, we discussed the uncompetitive envision because on the basis of the envision, it is possible to estimate different type of chemicals present in the reaction mixture particularly complex chemicals. I had given the example of pesticide which is very complex chemical that can be estimated with the help of the enzymatic reaction kinetics.

Now, after having all this information then we try to discuss the immobilized enzyme system, immobilized enzyme system is advantageous as compared to few enzyme system the reason is that in the free enzyme system after reaction is over enzyme remain as the impurities in the reaction system mixtures. So, you have to take it out and per in case of immobilized enzyme system you can reduce the again the enzyme again and again and after the reaction is when your product is coming out this is more or less free form enzyme though your purification process will be little bit simpler.

So, then we try to discuss the kinetics of the immobilized enzyme system how the heterogeneous reaction kinetics can be explained, we have come across 2 new term one is called Damkohler number and the effectiveness factor and we try to find out how these 2 parameters that that you know changes as during the new immobilization system and I told you that you know 2 type of things that happen in the heterogeneous reaction kinetics either is mass transfer control or reaction control.

Now, if you have mass transfer control; that means, we shall have to improve the mass transfer of the process. So, that we can get maximum amount of product if the reaction

control you have to improve the characteristics of the reactions so, that we can get the maximum amount of product.

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Now, after that we switch over to that you know cell growth kinetics substrate utilization product formation and that biomass formation which is the heart of this biochemical engineering. So, we have discussed this under we have been that several lectures we discussed it is different type of different type different type of numerical problems.

One thing that is very important here I want to emphasize that when you use any kind of leaving system we shall have to be very careful that about the that age of the culture, because why the age of the culture if you look at the life cycle of the cells we have lack phase, we have block phase, stationary phase and the death phase the every phase has it is significance because if you look at lack phase it is known as the accommodation phase, lock phase is active phase, stationary phase is a starvation phase and death phase is the death of the mostly the death of the cells occur.

So, if you look at that the organisms where it is very active that is in the lock phase and usually that when you do any kind of inoculation of the organism in the production medium or in the inoculum fermenter we should have to know that midlock phase and the late lock phase now it age of the culture if it is in between the mid lock phase and late lock phase a you will get very good results. If you inoculate culture close to the

stationary phase you may not get the appropriate results your desire results in the fermentation process.

So, this plays very important role and then we discuss this Monod equation, which is Monod model which is something similar as compared to the Michaelis Menten equation, then we have come across with different type of other models like part equation, we discuss the Luedeking - Piret model part equation mostly deals with the maintenance of the cells and Luedeking - Piret model discuss the how the product formation where with the relate with the growth of the cells and then there are other equations we have with the envision of the cells we have here also we discuss the comparative envision on competitive envision of the process that we also may occur in the microorganisms system so, all these thing we try to incorporate in this particular lectures.

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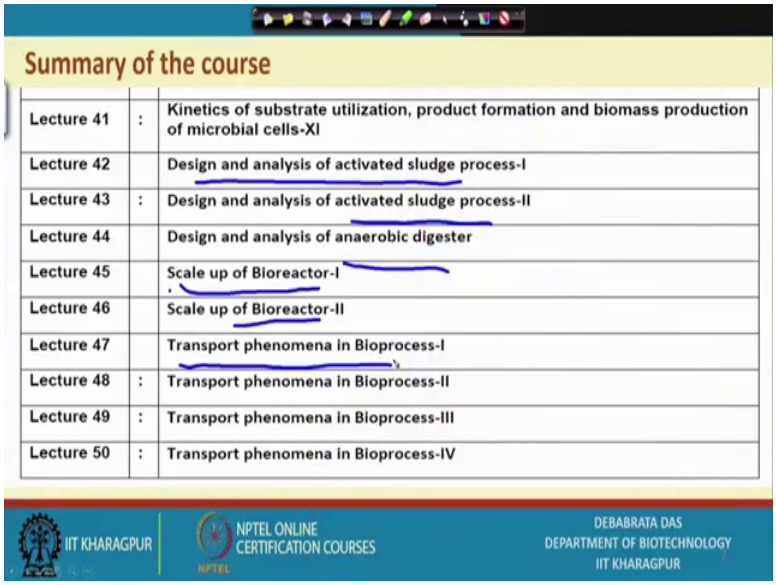

Now after having all this information then we switch over to the process design the design and analysis of activate sludge process that we have taken this as the instance that how a when you when you talk a particular process how the process design can be done, how the different operational parameters can be monitored or calculated that we try to discuss in this lecture. We have taken into consideration activated sludge process which mostly use for the treatment of the waste water and also we discuss anaerobic digester

where we can convert the waste through some useful products some kind of methane or hydrogen which is can be used as a source of the energy.

After having all these information then we switch over to the scale up of the bioreactor I told you told you this is very important because whatever we develop in the small scale that directly we cannot apply to the bigger scale until unless you have some kind of analysis of the process. The one analysis that is very much required is the scale up of the process, how during the scale up of the process we take into a account that whatever environment under what the environment you get the for your maximum product formation similar environment you have to maintain in the bigger scale of fermentation process.

So, that you have to for doing so, how the operational parameter changes that we discuss in this particular lectures and then here all we also taken into consideration I told you that scale down of the process that how suppose some I work with citric acid industry now suppose we find out some parameters plays important role may has some significant role to increase the productivity of the process.

But directly we cannot apply to the big fermenter we first try give the trail in the small fermenter and if satisfy then and only then we can go for the bigger fermentation process and after this we try to discuss the different type of transport phenomena of the bioprocess. I told you three different type of transport plays very important role one is the momentum transfer, another the heat transfer, another is the mass transfer so, we discuss all these thing in details.

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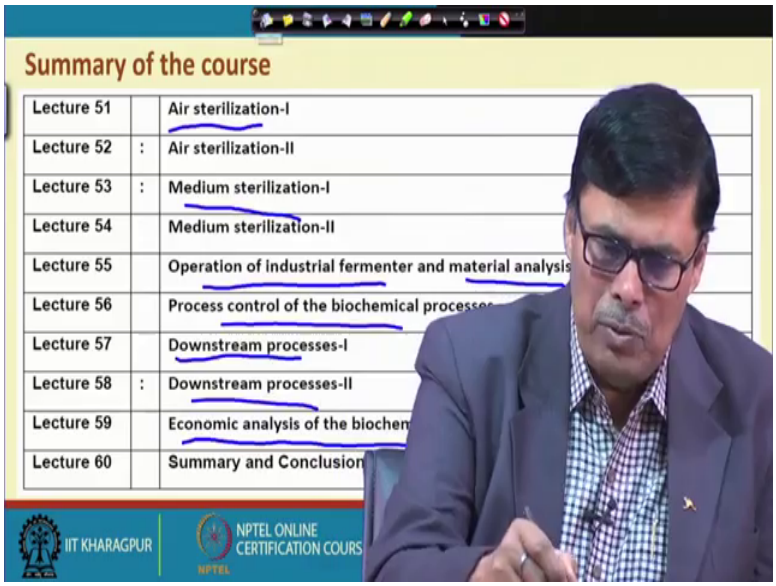

Now we also discuss the air sterilization and medium sterilization of this process in details, how this processes can be designed I and then operation we have given the instance of the operation of industrial fermentation process I have given the instance of citric acid industry and how you can do the material analysis of the process.

How different how we can calculate, how much a material we required in different throughout the operation of the different process as per example how much cane molasses is required for getting a desired amount of citric acid that how you can calculate, how much lime is required for the precipitation of citric acid.

So, all these thing we try to show you here then process control is any we know that you know slowly we step into the automation process and as we switch over to the automatic of the process then we put lot control devices and how different control devices are there and the biochemical process couple of controls the plays very important role as per example ph temperature agitation speed foam control so, you know that all this control plays a very important role.

Then we have downstream processing we have we discuss the different units of the downstream processing like filtration process, like a different solid liquid separation process, then we have comodographic process, crystallization process, vaporization process, adsorption process all these thing we try to discuss in the downstream processing and finally, we discuss the economic analysis of the bioprocess just to give

you a idea of what are the because we have come back close to two type of expenditure, that is involved in the bioprocess or any kind of chemical or biochemical industry one is the fixed expenditure another is the operating expenditure.

The fixed expenditure how we calculate and operating and expenditure how we calculate how and that that we compare with our selling of the product over the that price revenue we get after selling the product we try to compare with that and from that we can calculate the profit you get in the particular industry so, this is all information we have given.

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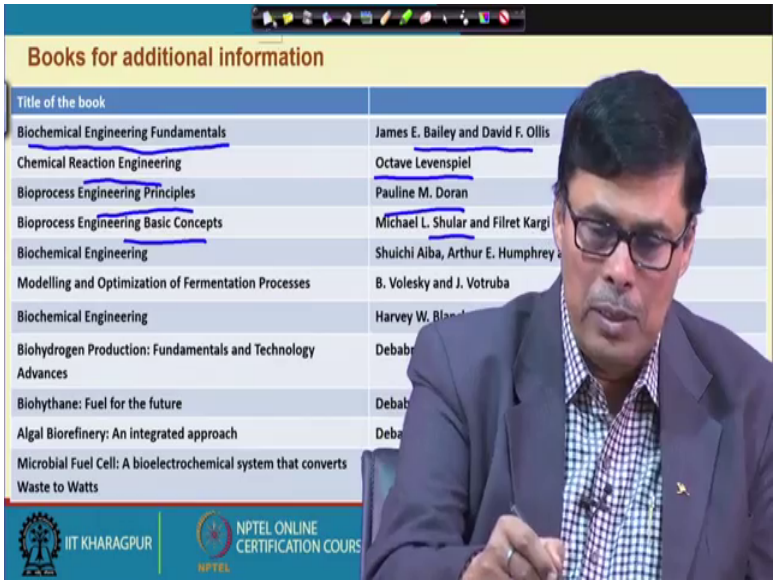

Now after that now the I recommend to you couple of books you just go through this I must say that this books is very good this is the biochemical engineering the fundamentals written by Bailey and Ollis then chemical reaction engineering by Octave Levenspiel bioprocess engineering principles the Doran and bioprocess basic concept that is Shular and Kargi. So, these are the different books you can consult to under to clear your concept on this process.

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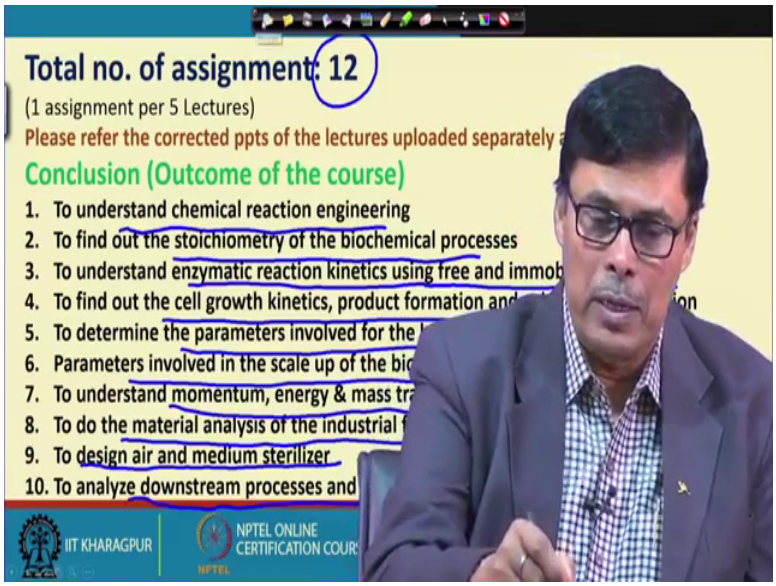

Now, total assignment of this project this particular course will be 12 and one assignment for 5 lectures. So, that will be given to you and this is the outcome of this particular process to understand the chemical reaction engineering that you should understand I hope you have some idea on this what do we mean by chemical reaction engineering, to find out the stoichiometry of biochemical process though you get the idea how you can do the stoichiometry of the bioprocess.

To understand the enzymatic reaction kinetics using free and immobilized enzyme and then to find out the cell growth kinetic product formation and substrate degradation to determine the parameter involve for the bioprocess design, parameters involved for scale up of the bioreactor to understand momentum energy mass transfer involve in bioprocesses due to material analysis of industrial fermentation process design to design air and medium sterilization to analyze the downstream processes and also economic of the bioprocess, this is at the outcome of this particular course.

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And I have two teaching assistant for this course one is that Jhansi L Varanasi she is a very active person and she is doing PhD at the department of biotechnology if you have any question and her background is mostly on biotechnology and we have Chandan Mahata his background is chemical engineering. So, if you have any question you can in the forum you can raise that question they will answer your question and to clear your doubts.

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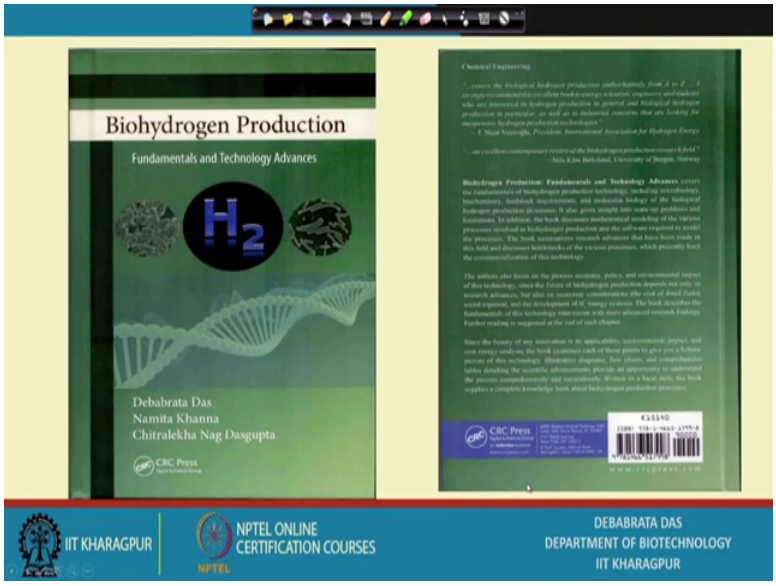

And this is some I want to show you some of my published book this is the Biohydrogen Production fundamentals and technology as advance this is published by CRC press.

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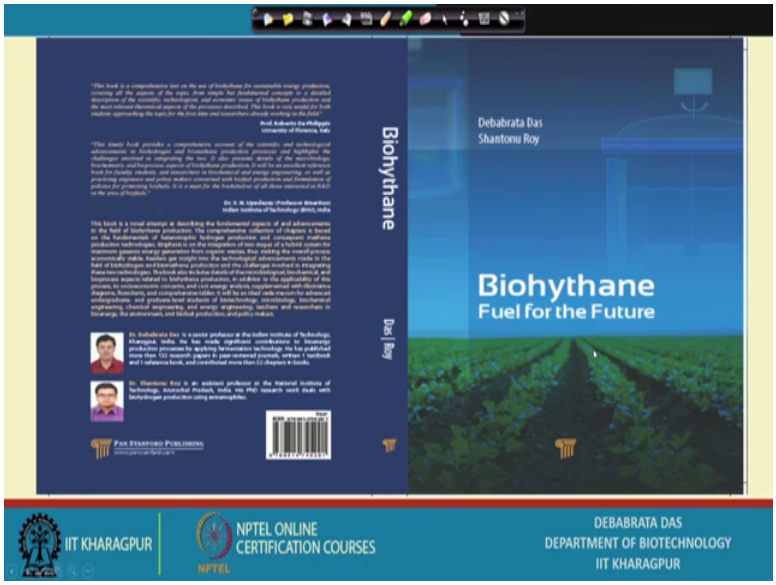

Another is Biohythane fuel for the future this is the first book in the world we have published, this is published by pan Stanford publishing company.

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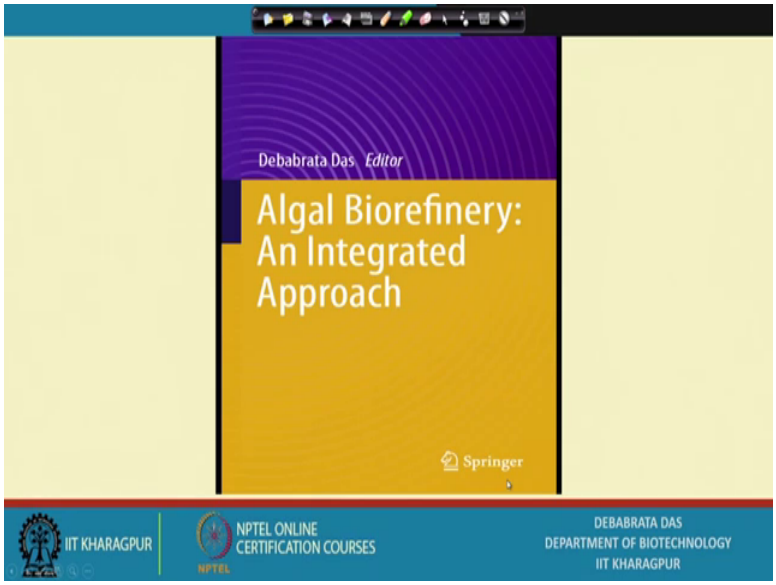

Then we publish Algal Biorefinery an integrated approach so, published by Springer.

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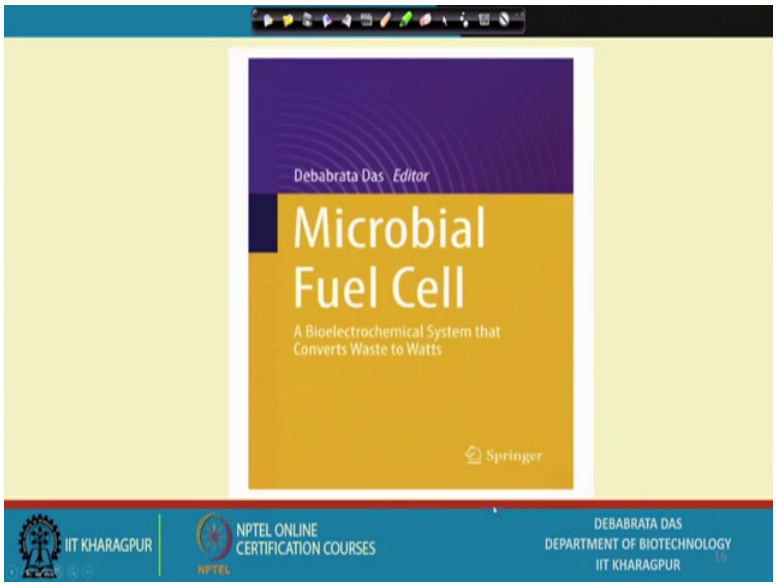

Another book we published the Microbial Fuel Cell that that published by Springer.

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Now, we are going to show you one video that is on 20 liter bioreactors for the continuous biohydrogen production by using Klebsiela the pneumonia at IIT Kharagpur to give you some kind of idea on the biochemical process and this is our website and the if you go to the website we will get the detail information of our of our group what kind of work we are doing.

At a Indian institute of technology Kharagpur we had a mission mode project on hydrogen production through biological roots.

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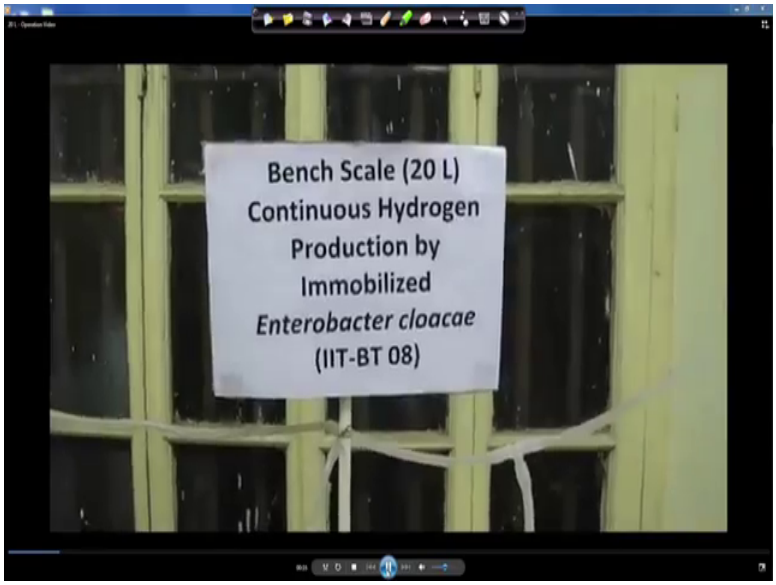

This is the under the sponsorship of MNRE and here we try to demonstrate that continuous hydrogen production by using immobilized whole sale by Klebsiela pneumonia at local isolate.

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This is the bioreactor and you can see this is the watch glass and through the watch glass you can find out the volume of the liquid medium present inside the reactor and these are the other different units.

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That is attached with this reactor first is the feet tank.

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Where you take the raw materials and this is the peristaltic pump and this is how the peristaltic pump is in operation in operation and you can see that and this is the way how aseptically we can transfer the feed from the feed tank to the reactor.

Now, here we you can see there is the thermostat to just to show the temperature in the bioreactor and the here we have some sampling port where from where we can draw the sample this is the recycle tank.

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Where we take the liquid which is coming out from the reactor and recycle back to the reactor just to increase the retention time of the medium.

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So, that percent conversion efficiency of the substrate increases.

Now, this is the kind of device we develop that is a just to maintain some kind of vacuum in the reactor and we have seen the le chatelier principle equilibrium constant equal to concentration of product differed by concentration of substrate now since our product is gas we can easily remove if we apply some kind of vacuum and then more substrate will convert it to product to maintain the equilibrium constant and this is the how the our pressure regulating system works.

Now, we open this pipeline so, that the gas whatever is accumulated that can be collected in the gas collector, but this is passed through the Carbon dioxide absorber.

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Here we use 50 percent of kos solution to absorb carbon dioxide and here we have a trap just to protect this kos is should not disturb our fermentation process finally, we try find out that you know how what is the nature of flame of the hydrogen we find it is perfectly blue. So, thank you very much I wish you all the best and I hope this course will be very much useful for you and for your future carrier.

Thank you very much.