# Advanced Chemical Reaction Engineering

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## Lecture - 2
## Course Overview- II

Welcome to this edition of advanced reaction engineering. We will look at what we will do in this course over the period of the next forty lectures. Quickly, let me tell you what we planned to do for you. In the last edition of course overview, we looked at some of the features that we might do. So, we go on with that.

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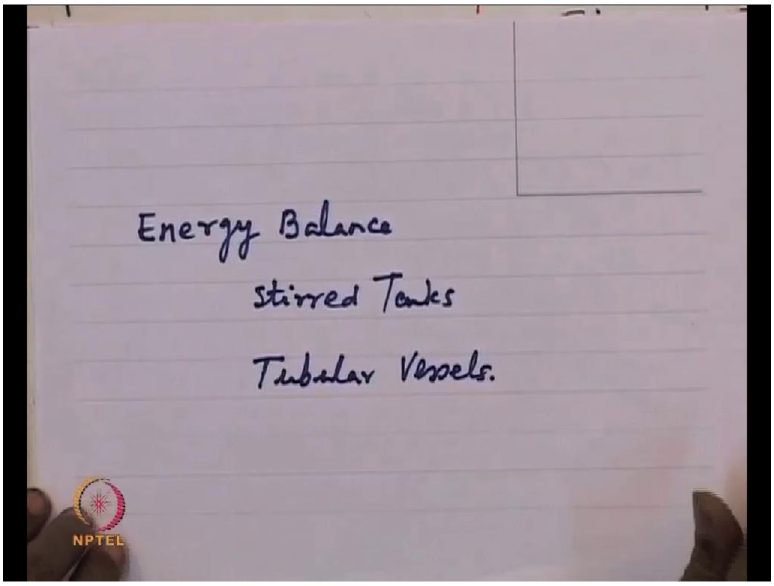


We look at energy balance and mentioned in the last edition that in energy balance, we look at two issues; one is stirred tanks and tubular vessels. Now, we also mention that stirred tanks are quite popular, particularly, in a small scale processing while, tubular vessels are generally, very large scale processing. Now, whether it is small or large, we need to be able to conduct the chemical reaction of our interest and therefore, adding and removing of heat and controlling the temperature at which we will conduct the reaction is crucial to success of the operation; that is what you and I will do. So, we have to write the energy balance and understand how the energy, heat is generated in the reaction and so on. Therefore, the balance is right that we take into account all the features which, we will do. Now, a related issue that all of us recognize is that when you are running a process, clearly, there is something called start up; something called shutdown; there is something called safety and sudden issues as a result of which, you may have to shut down the processes and all.

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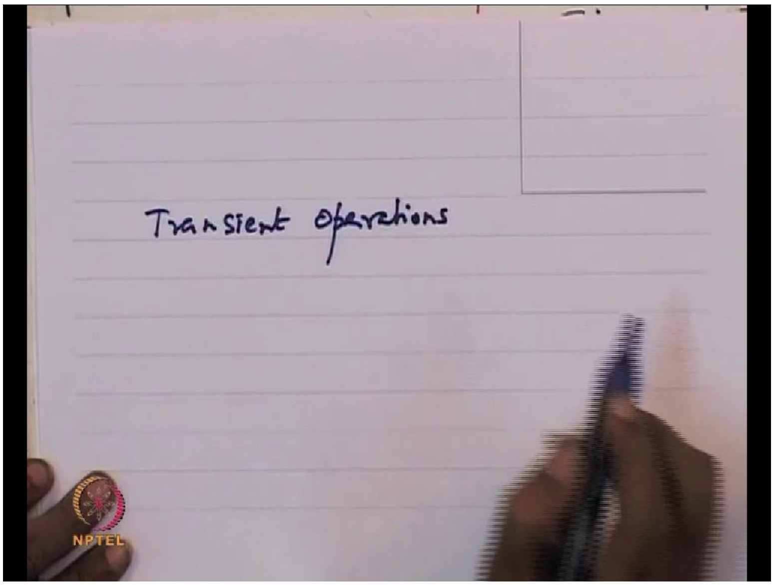


But transient operations become crucial. Now, transient operations are issues in which, we have to understand how the process deals with various kinds of disturbances that might happen in the process. On other words, when there is a disturbance to a process we must know whether, that disturbance will cause irreversible damage to the process or the disturbance is such that, the process is able to adjust itself and return to its original state.

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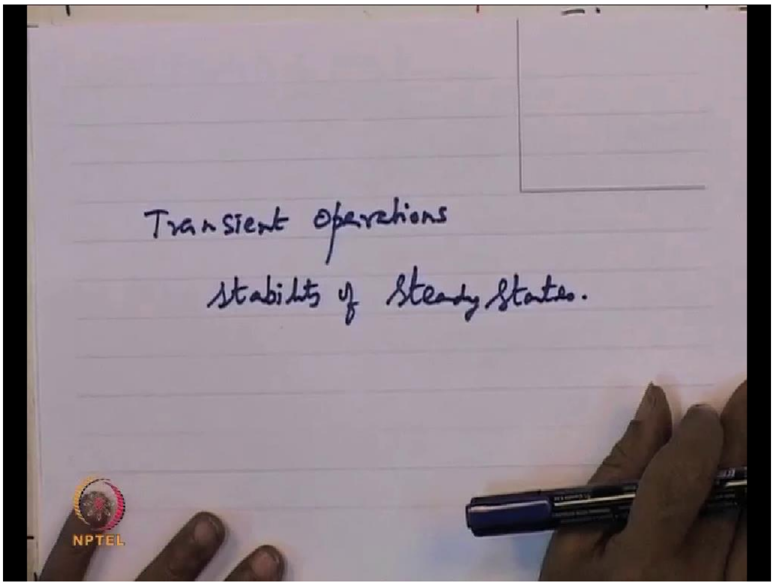

On other words, we need to understand what is called a stability; stability of, we call as steady states. So, we will look at some of these issues as you go along. On other words, what we trying to say is that what is of most important to us is that our process should run, should be safe; number one. Two; that is there is a disturbance, it must return to the original state in reasonable period of time. Therefore, the design must take into account whether; this is able to do that. On other words, what is it that we must do in designs, so that, it happens the way we wanted to happen. So, this is what we mean by steady stability and we look at some of the issues as you go along.

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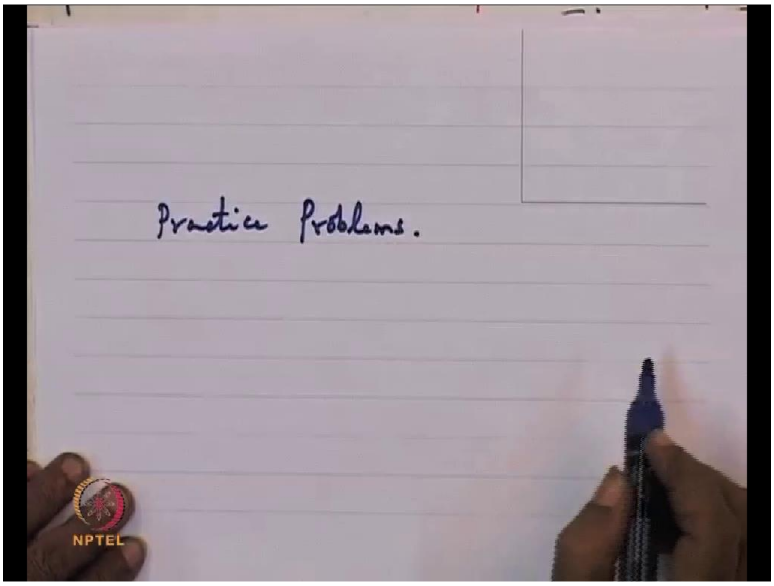


Now, a related, perhaps, more or less important is we must look at, we must know how to apply the equation that we have derived for various situations and therefore, we look at practice problem; great variety of practice problems wherein, we formulate our problems in such a way that we are able to come as close to reality as possible. On other words, you look at situations, which are as close to reality that we might counter. So, what we are saying is that all practice problem that we will do in this course, will be something that we might be able to be make use of in daily life. That is a kind of selection that we have done. Now, there are few things that we must draw retention. Let us say we have a chemical reactor.

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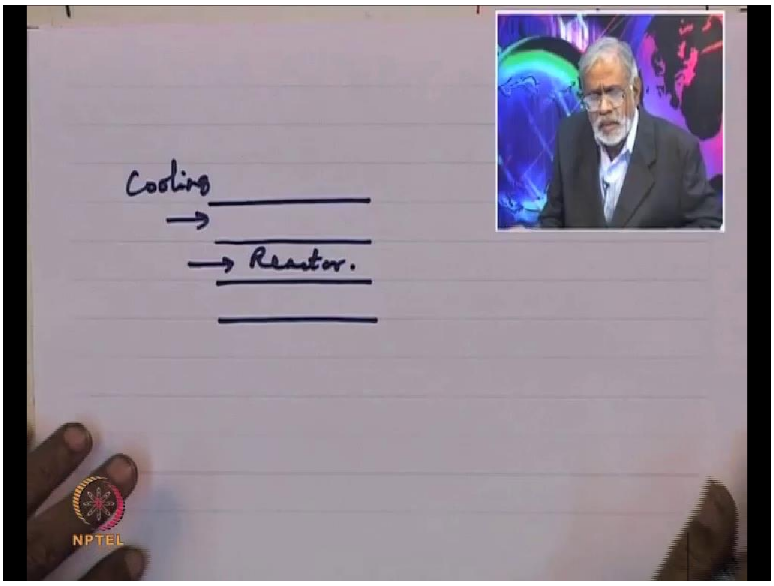


Let us say we have this chemical reactor, is heated. This is a cooling or heating; let us say cooling. Typically, it is cooling or it can be heating as well; this is the reactor.

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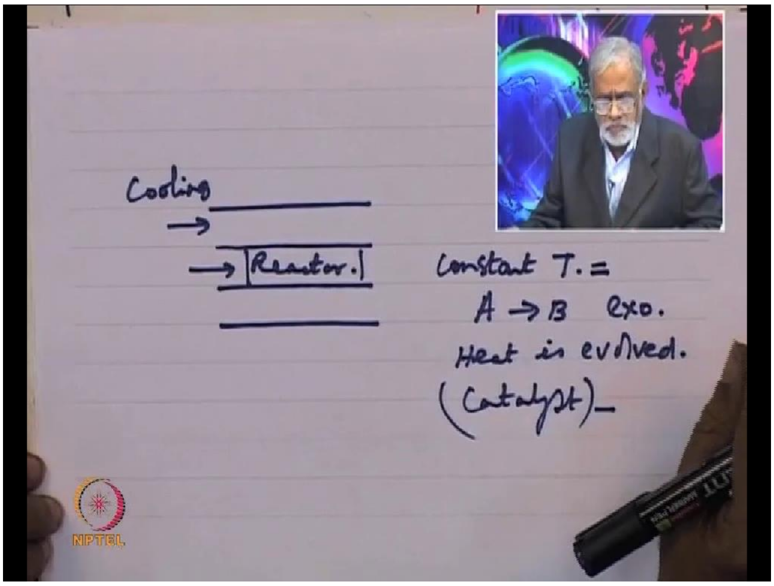


Now, frequently, our interest is to be able to operate this at constant temperature; constant t. Now if this is an exothermic states reaction, goes, A goes to B; let us say exothermic. Therefore, heat of the action; heat is evolved, but there might be catalyst. Let us say this is called a catalyst; inside here, is the catalyst, which might undergo some deleterious processes, may take place. As a result of this, the catalyst may lose its activity and so on. So, our interest would be to operate this at temperature, which is more suitable for this catalyst, say, some temperature, which is more suitable for this catalyst.

Now, the question that is of interest to us is that is it really, possible for a reactor to be operated at a constant temperature while, we have dealt with a reaction, which is exothermic; a reaction which is called a catalyst; a reaction in which, a catalyst is undergoing some kind of deactivation of poisoning, whatever, because of the reaction. Now, the answer to this is that yes, it is possible. There is a design that you and I must do, so that, this becomes possible.

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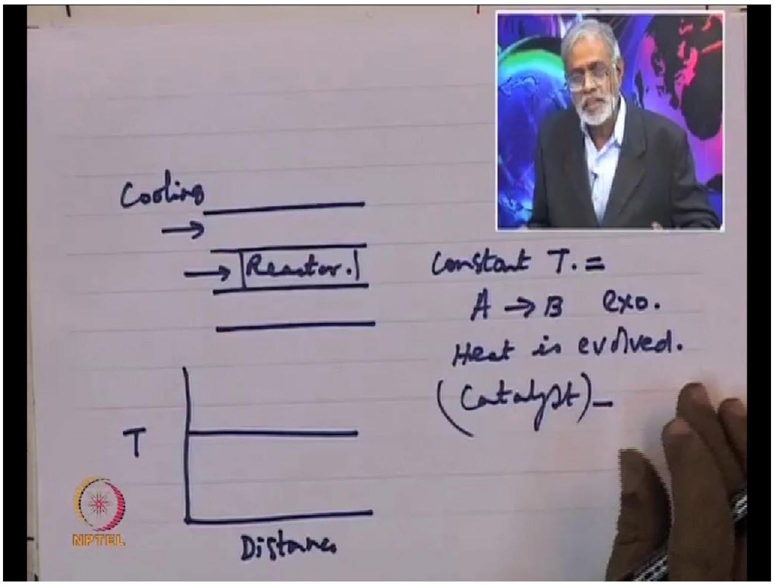


On other words, we must have a design. If this is the distance along the reactor, if this is temperature; we want this to be just the same, irrespective of what happens in the reactor; that is the design. In fact, as we go along, we will set up our equations, and then ask these questions to all of us; what is that we must do to see that the temperature does not change.

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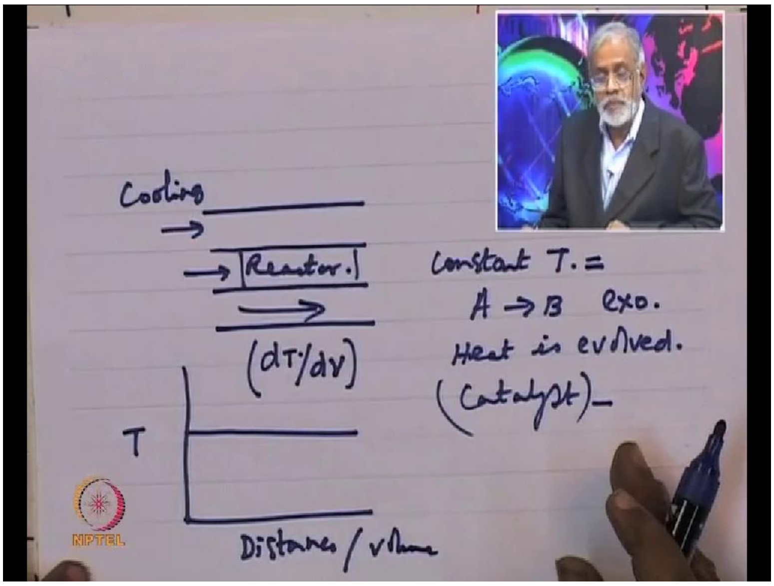


On other words, in formulated, in the language of chemical reaction engineering, what is that we must do; if this is volume, changes; distance or volume; what is that we must do, this does not change along the length of the equipment. So, these are very interesting situations and we will look at them and we will formulate equations, and then come to a stage where, we can tell exactly, how we can achieve constant c, which otherwise, seems not very easy, inside such kind of tubular vessels.

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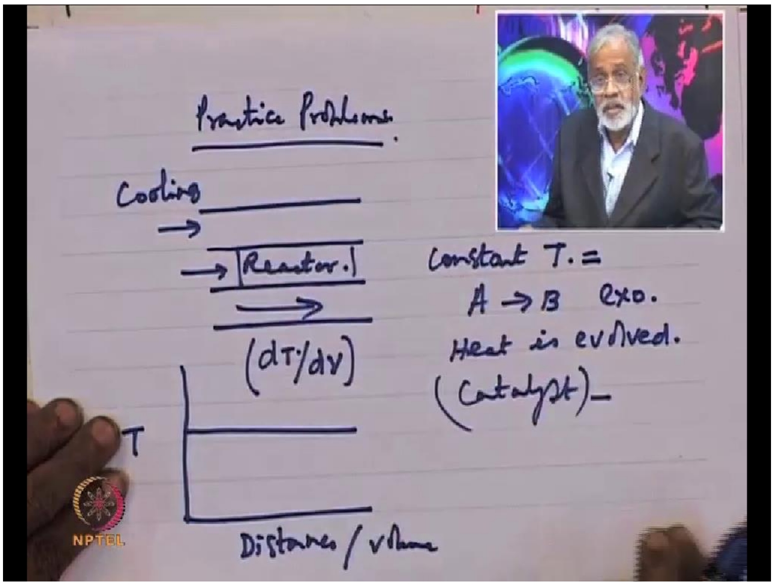

So, these are all, but we call as practice problems, in the sense, where we learnt to use the equations that we have derived to be able to describe our requirements or to achieve the requirements of our process.

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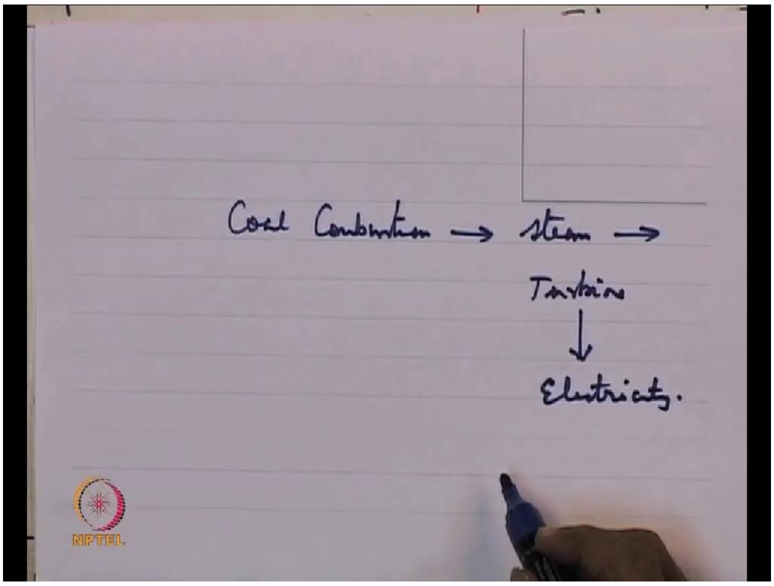


Now, there could be situations; let us say, for example, there could be situations. I mean all of us know that see, we burn coal; coal combustion. We burn coal combustion to generate steam, and then this is you know, derived us turbine, and then gives us electricity. This is something that we all know. On other words, what we generally, do in the industry is that we burn coal in a boiler, and then there is water, high pressure water, going through the pipes or tubes in the boiler. On other words, it is in indirect contact; contact is not there, but indirect.

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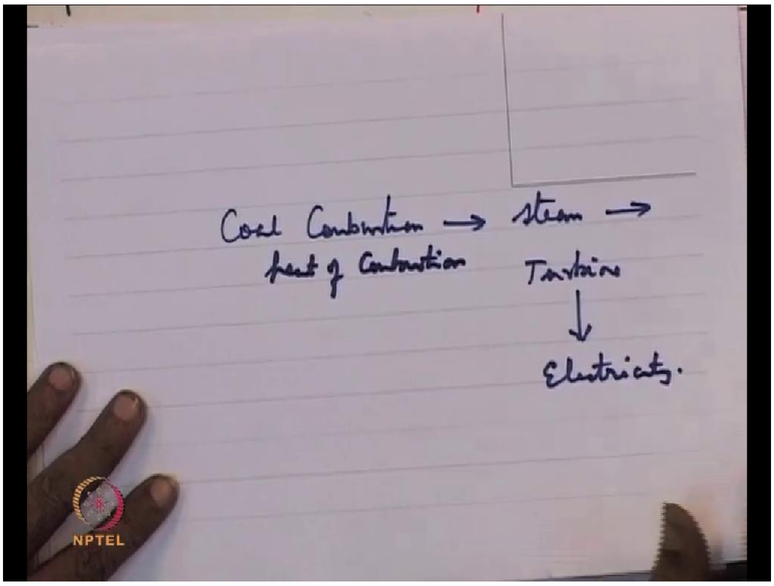


On other words, the energy or heat of combustion is directed into steam; that is how we derive energy.

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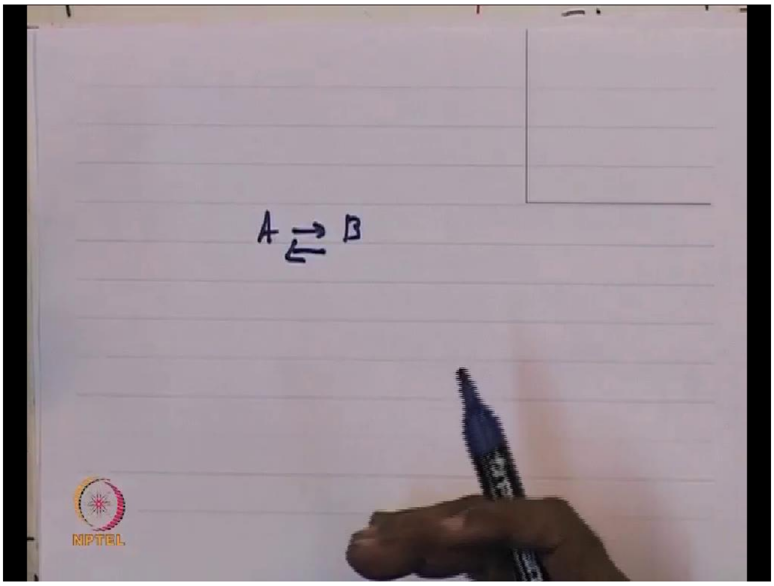


Now, as you go along, we will consider situations where, we have a chemical reaction. Let us say A goes to B, and then B goes to A; there is a chemical reaction. Can we conduct this chemical reaction, for example, in a turbine, so that, we derive energy or power directly, out of chemical reaction. On other words, we are used to conducting chemical reaction in a boiler, and then making steam, and then using that steam in the generator and so on, but we can also look at situations where, we can actually conduct the reactions in this turbine itself, so that, we derive energy directly. Is this possible? If so, what does it mean? What are the numbers that would be appropriate? What is the system that we might look at and things like that?

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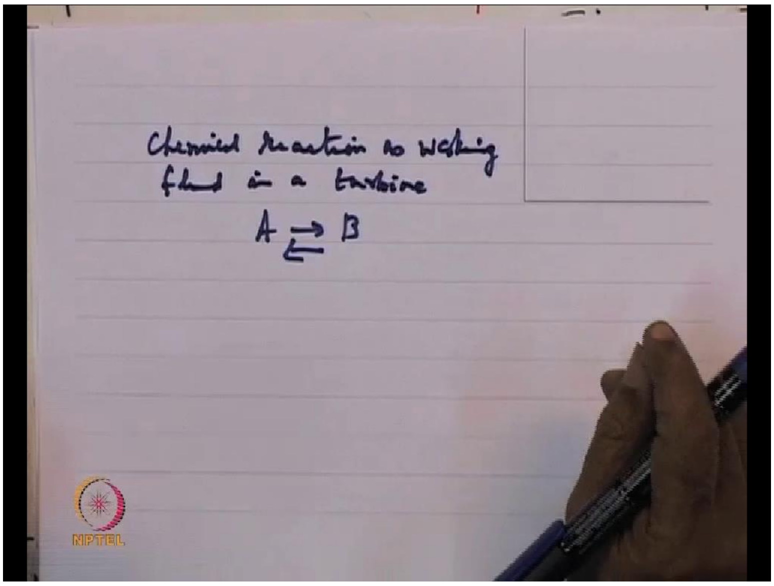


On other words, chemical reaction as working fluid in a turbine as an example; can you do this? We would like to pose this question and see, when there is situation where, we can look at, which might give us this kind of flexibility in deriving energy from a chemical reaction in the form of electricity and so on.

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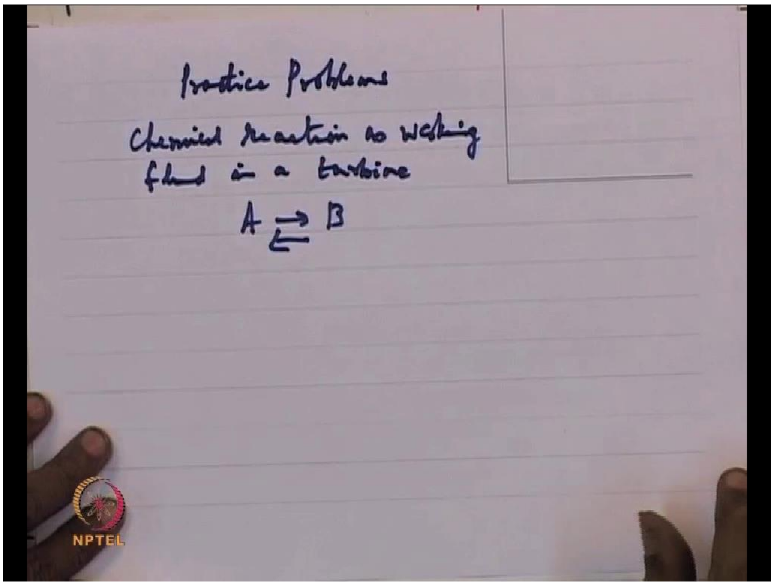


So, we mean what I am trying put across to you is that these practice problems are problems that try to present a way of looking at the equation that we derive in a form, that we can use them in daily life for our applications.

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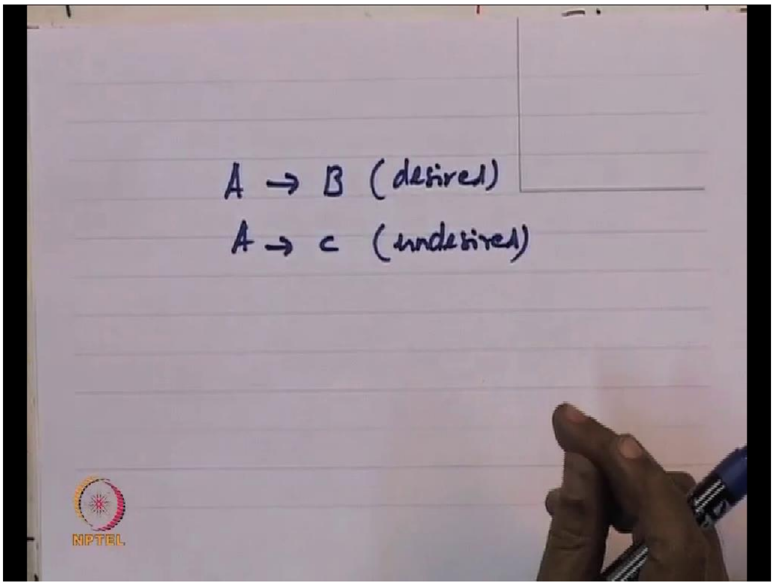


For example, this is common in a process industry; let us say there are reactions; this A goes to b, and then but A also goes to C and this might be desired product, and this might be undesired product, correct.

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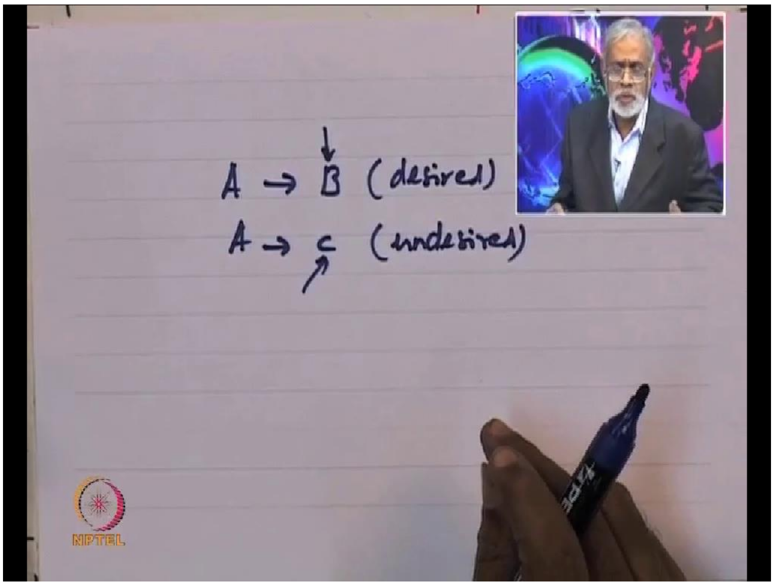


On other words, our concern, our interest in design is to see that we maximize the desired product, and minimize the undesired product. So, there would be design or criteria that we can derive, based on equations of material energy balance that will tell you how to how to find the condition about optimality, so that, we can drive a process in the direction of our interest. So, we look at such practice problems as well.

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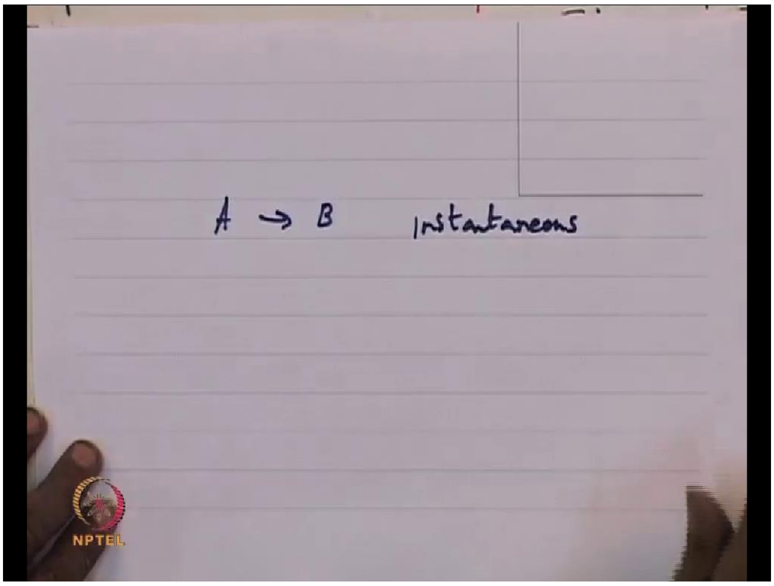


Now, there are situations, for example; a reaction is very rapid; instantaneous. When a reaction is instantaneous, on other words, the rate process is so large that we cannot write equations, which were very large quantities. So, there will be methods that we must derive from our basic principles that we will deal with instantaneous reactions where, heat energy is involved and the heat and energy exchange are involved. So, we will look at such practice problems as well.

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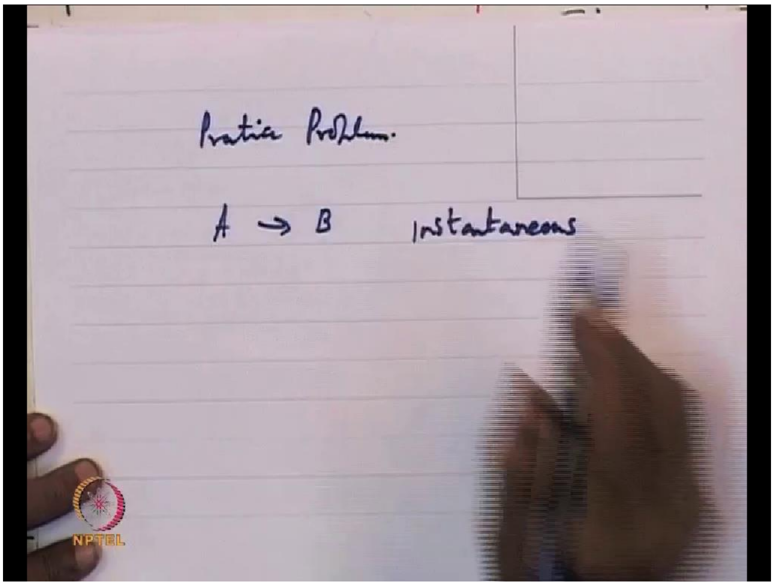


Practice problems wherein, we have to deal with very fast reactions; very fast reactions.

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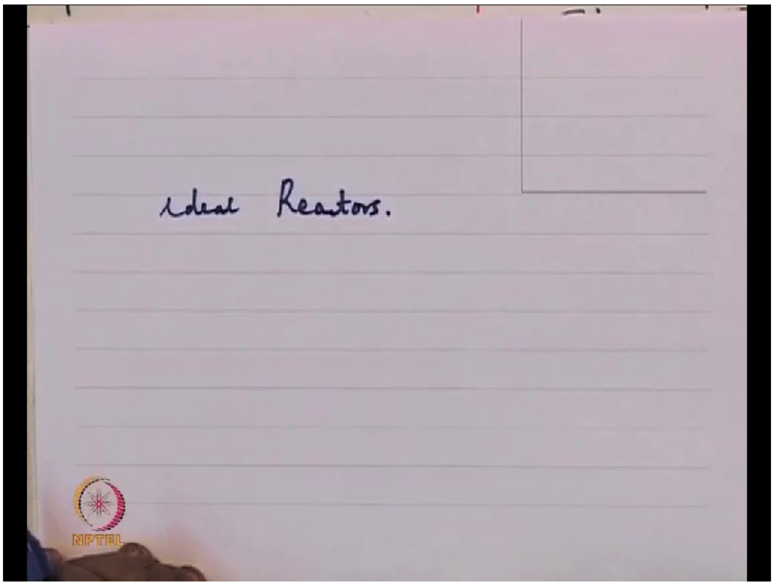


Having said this, that whatever equation that we have written for a long time is what we call as ideal reactors.

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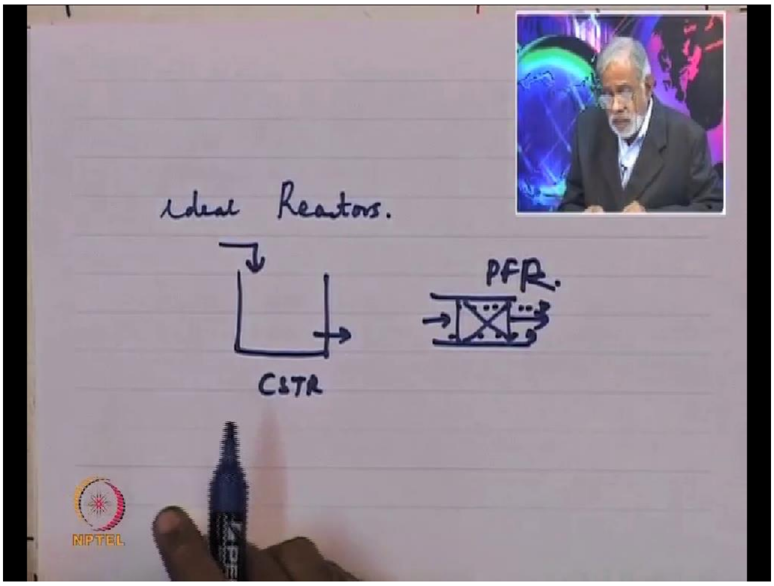


By the ideal reactors, what we mean is that we postulate that our reaction equipment has a certain; this is what is called as stirred tank, continuous stirred tank reactor; this is a plug flow reactor, what we call plug flow reactor. So, what is implied here is that the time of residence of these fluid elements, if all the fluid elements, depend same length of time; this is one type of device; this is an ideal reactor. Here is another instance where, all the residence time here, is exponentially, in the sense, as soon as the material enters here; it mixes. This is what is called the well mixed or the well stirred tank reactor. Now, in reality, there we might not have a situation, which is completely mixed or in reality in which, this residence time where, every element is the same.

On other words, in actuality, there could be lots of difference; the very difference from these two ideal situations. Therefore, our interest of course, is to be able to understand reality; number one. Number two to be able to change that reality the direction of our interest. So, first, of course, you should understand reality. In order to understand such reality, we will look at what is called as residence time distribution.

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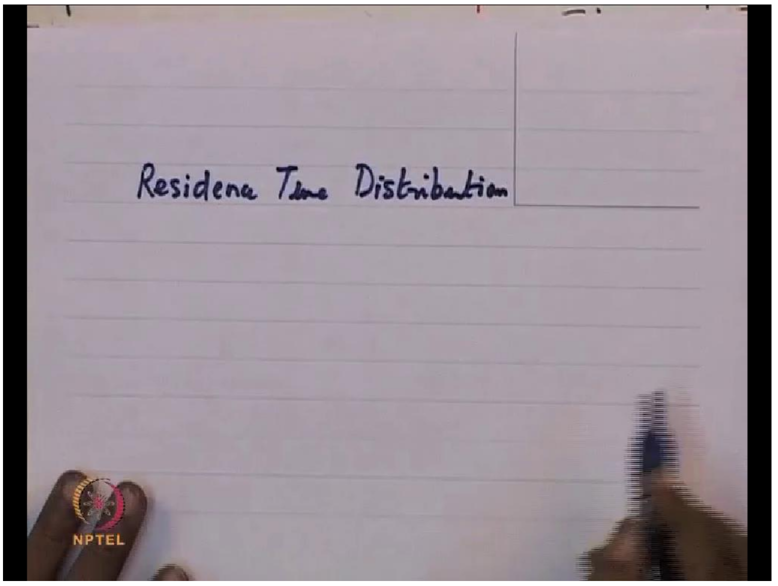


In the object of this kind of study is that if you have an equipment into which, your fluids come in and fluids go, what you like to know; a fluid element that enters now; how long does it stay here before it exits.

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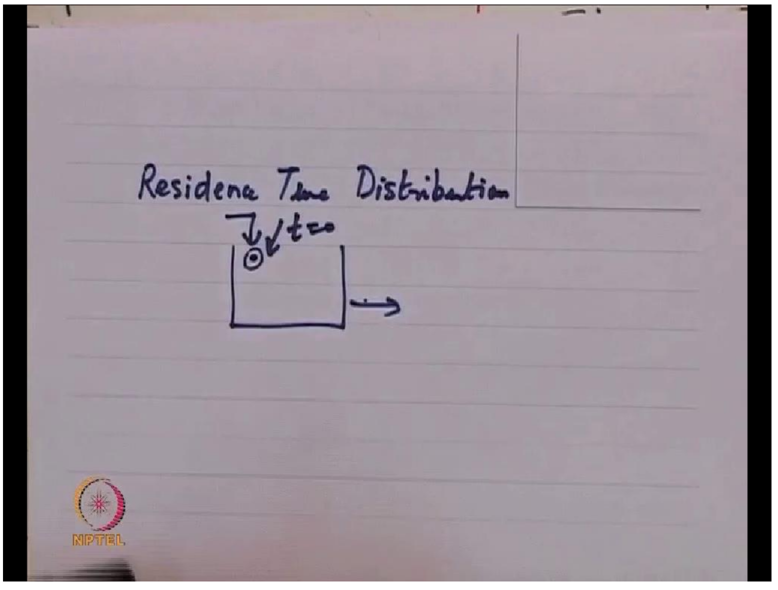


So, fluid element that enters now, t equal to 0; how long does it stay here before it exits? Now, this information itself is useful, because aftral, we all know that the extent which, reaction occurs is depending on the time that it spends in the reaction environment, correct. So, what is called as residence time in the reaction equipment, is something crucial to our understanding of what will happen to that reaction, or our understanding of how to drive that reaction in the direction of our interest. So, this an important study, which is able to give us insights into non idealities.

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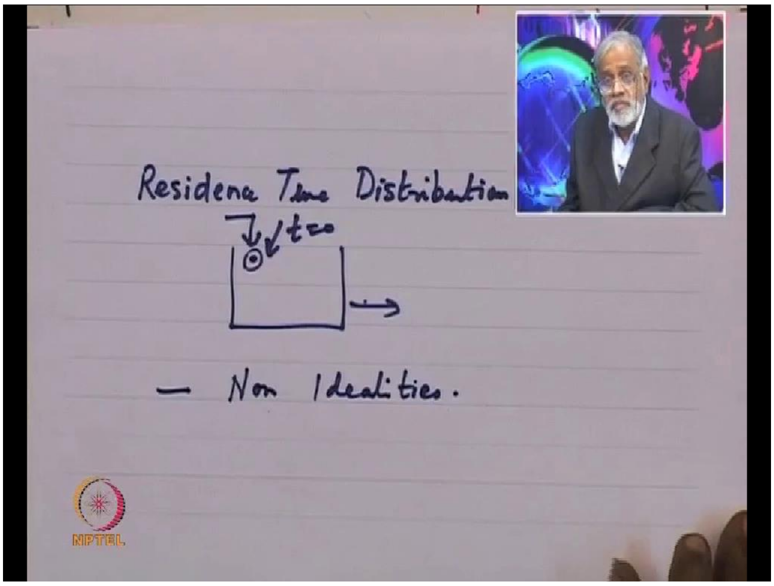


This is the way we try to quantify non idealities; that is by putting a tracer and trying to see, how long it stays inside the equipment. This whole study is called as residence time distributions. So, we will look at fundamentals of residence time distributions, and we will look at how to conduct experiments to get information on residence time distributions. We will look at how, what types of tracers that we can use, so that, we can measure them accurately; whether, it is a liquid; whether, it is a gas; whether, it is a solid; whether, it is a mixture; whatever; for its different situations, there are different methods that we can use; different techniques that we can use to measure and so on. We look at all that as we go along. Having said this, that now, we understand the fundamentals of trying to do a measurement of the residence time distribution. Of course, we look at practice problems.

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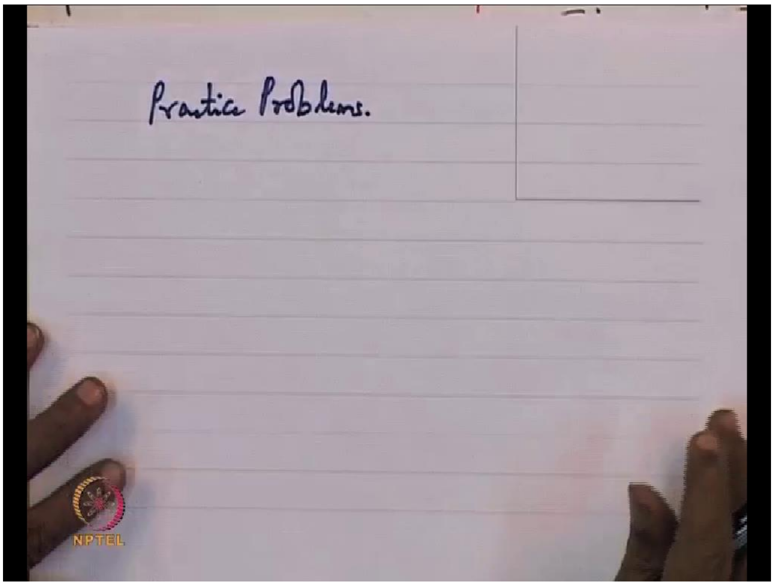


The whole object of taking this approach is that every time, we develop a method; we would like to see how that method applies in real life. How that method can be used to derive insights into what happens in a process; this process can be in the chemical industry or in our daily life; that you and I experience, whatever, we experience in daily life. So, we would like to see that how closely, can we use methods to understand what goes on around us. That is the idea of residence time.

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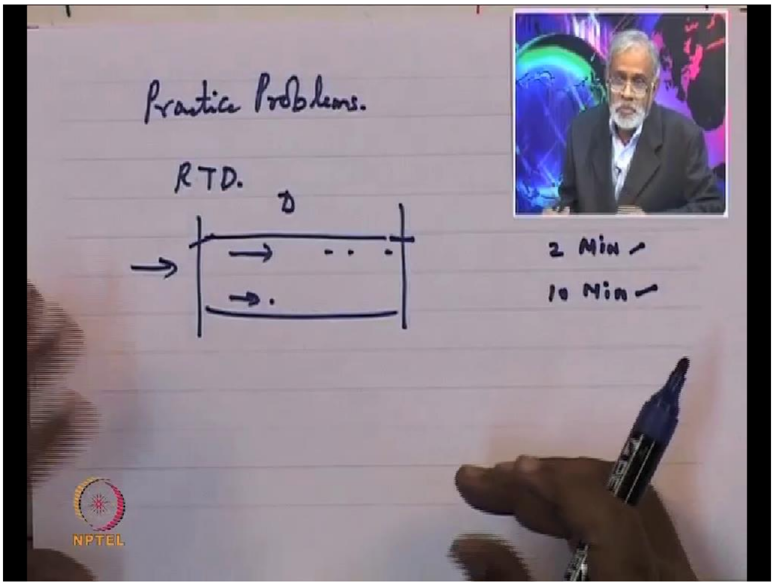

Let me just give you a small example; residence time. Let us say, suppose there is a crowded railway station and lot of people are moving along railway station. Now, let us say, from here to here, there is a distance D. How long does it take for going from here to here, if I ask? Now, on a day when there is no crowd, it might take say, two minutes. On a day when there is lot of crowd, it might take ten minutes. On other words, the same device, if you call this as device, the same device; the residence time can be small or it can be large. Now, the fact that the residence times change, because of the load, this is the load, because of the load, we must be able to understand how the load affects residence time.

That is why we have to do such measurements, because we will be loading our equipment and therefore, we want to know how that load affects a residence time, because that residence time will determine the extent to which, our reaction occurs. So, these kinds of practice problems are crucial to getting insights into how, we are able to derive information about non idealities in a process, so that, we can account for it in our design and in our operation, so that, we avoid failures, troubleshooting, safeties, and all those issues, arise from uncertainties in the process that we are dealing with.

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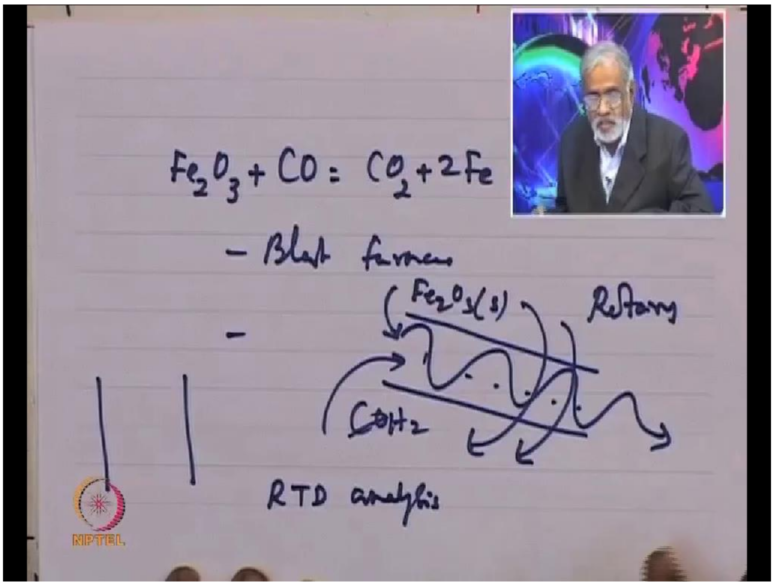


See, what seems to be important is that let us say; we have a gas solid reaction. Let us say, we have iron oxide. Let us say, it is reacting with carbon monoxide, giving you carbon dioxide and iron. Now, at this reaction; this reaction, we can conduct, let us say, in a blast furnace all over the world or it can be conducted in a smaller scale. It is what is called as sponge iron technology. Now, what I am trying to put across to you is that if there is a device; let us say, is a rotary kill where, you have, let us say, iron oxide is coming in, and then you put your carbon monoxide. So, that the reaction occurs. This is just an example.

This is not the way it happens in the industry. If it is sponge iron, they put hydrogen here. If it is blast furnace, the whole device looks different, but that is not the point I am trying to get across to you. The point I am trying to put across to you is that the solids that enter the process; they may travel like this, and get out, depending upon if it is a rotary kill, we are rotating it to see. Now, we know that it is important that we know what is the time, it spends in the equipment, because that depends the extent of reaction. So, if you will find that this whole RTD analysis, because very valuable when we need dealing with solids, because solids have a residence time and therefore, they have the extent to which, the reaction will occur, will depend upon how long it spends in the reaction equipment. This something that we know from our understanding that residence times are crucial, of course, crucial for all processes, but in the case of solids, we need special devices to be able to handle solids, so that, the gas solid reaction can occur.

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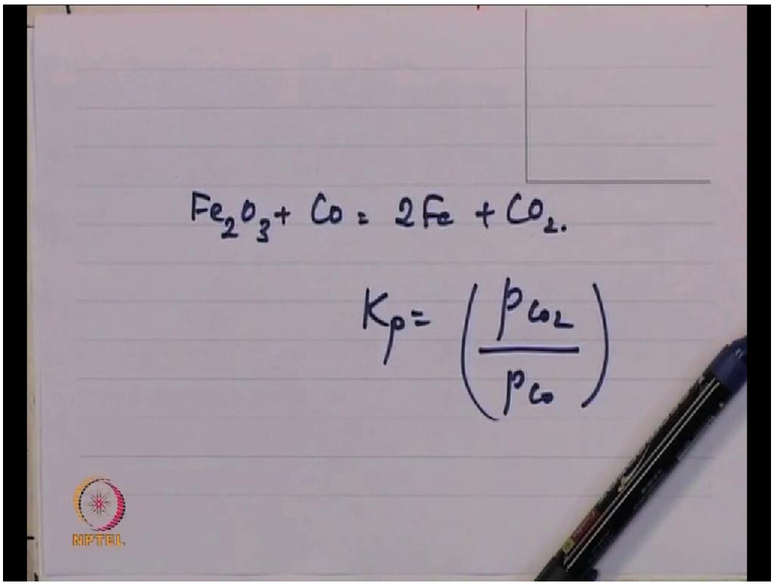


Now, what is crucial; let me just put this down once again. Now, what we all know is that every reaction is governed by a certain equilibrium constant. In this case, it is this.

So, the reaction stops when it reaches the equilibrium and the value of the equilibrium constant is determined by what is called some thermodynamics. You know this that which is dependent on the partial pressure carbon dioxide and carbon monoxide. What is important is to recognize that since, the reaction stops when the value of Pco2 by Pco becomes Kp; it also means that as the products accumulate, the reaction starts to slow down, because you know, the driving force for the reaction has come down, correct. So, I mean, as you go along we will setup methods, and then derive equations, which will tell us how the equilibrium or thermodynamics have fixed the rate at which, the reaction occurs. That is something important to us, and then we use thermodynamics principles to setup equations, which will tell us how the thermodynamics affects the rate of chemical reaction. We will look at that as well, some of these features.

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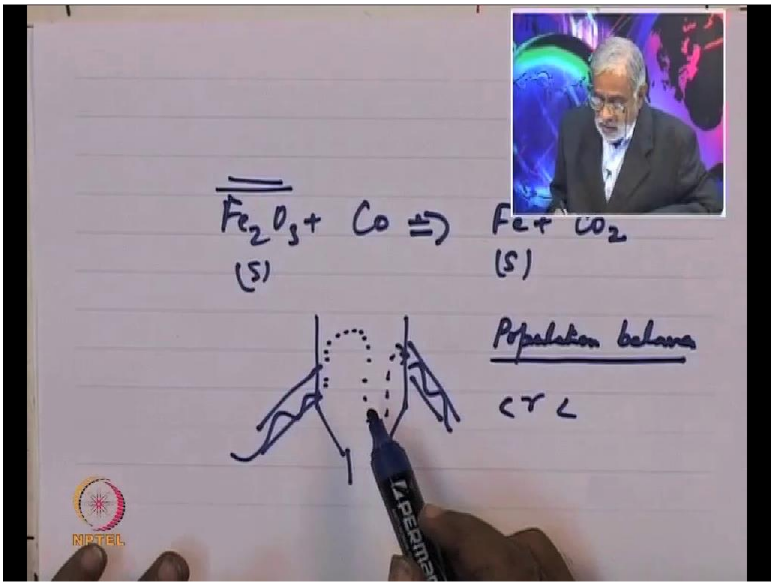


When you are looking at solids, let us once again, let as look at Fe2 O3 give plus Co give you F e plus C o 2. Now, whenever we have a reaction in which, solids have to be managed, then we know that if the reaction equipment; if this, let us say this is the reaction equipment, into which, you are putting solids, and then that is where the solids come out. Therefore, solids going in, and solids coming out. So, we need techniques to look at the particle, which goes to the equipment and probably, exits through the exit pipe. On other words, we need to be able to setup what is called as population balance. Why is it important? Why is population balance important, because as a technique, this population balance is able to write balances on the number of particles, then able to deal with number density. So, it becomes very useful when you are dealing with populations, to deal with number densities.

Then, we can translate it to any other form, depending upon what is required, but population balance is one technique by which, we can deal with those kind of populations. Now, a question that is of interest to us is that this material, it is iron oxide; they may come with different particle sizes. The particle sizes may be distributed between two exits. So, as this particle size of different particle size enters the equipment, of course, they will react in forms, which are dependent on particle size. Therefore, the inlet particles with different particle sizes will react differently, and therefore, emerge differently. So, all those effects; you have to account for population balance, is a very (( )) technique, which is available in the literature.

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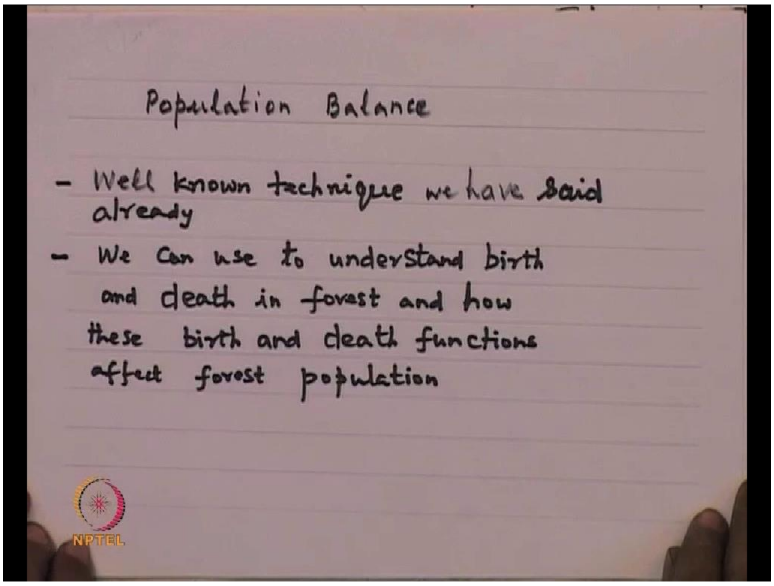


Now, population balance, we have said, is useful for understanding and modelling particular systems, but it is a technique, which has got might wider uses. We can look at what happens in a forest and we can understand how the birth and death functions affect the population of forest and so on, and we will look at some of these issues as exercises, as a part of this course. Now, I mean, environment is something that we all are, you understanding, trying to understand various issues.

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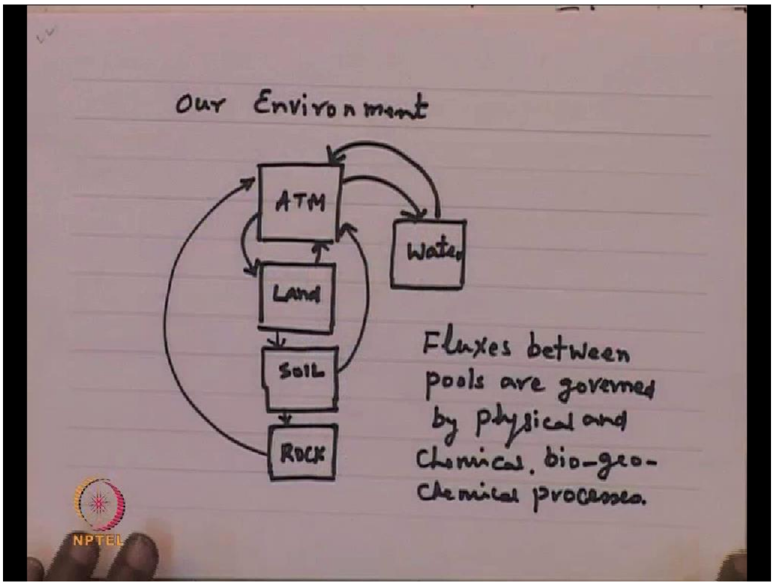


Now, if you look at our environment, I mean, what is with the atmosphere; we have the biosphere of land; we have the soil and we have rock and here, water, and there is carbon, which is circulating between the pools as carbon dioxide, and there are other gases, circulating like nitrogen, in the form of protein, etc. So, all these fluxes are essentially, the cause, I mean, cause of various chemical reactions; a bio-geo-chemical and bio-chemical and so on, and modelling these bio-chemical reactions will help us understand how the ecosystem is performing, and how we can regulate our lives to see that you know, the atmosphere and the biosphere, etc. are in good shape and good health etc. So, these are some issues, which will look at and through certain exercises, which will give us some insights into how we can understand, what is happening around us.

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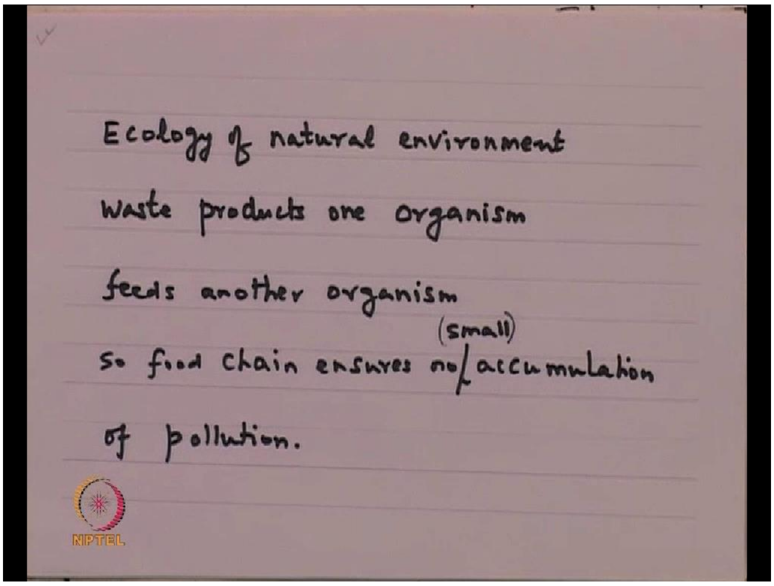


Now, having said this, I mean, all of us know that ecology is what ensure that our environment is in excellent shape. In ecology, what happens is that there are many organisms; one organism living on the other and so on. Therefore, this food chain ensures that the accumulation of pollution in the environment is very small or very so small, that it does not affect the population's performance, etc. Now, we would like to design systems in which, we are able to integrate the ecology in such a way, that in our systems, are able to make good use of the ecological benefits, and we will look at some problems of this nature, as we go along. Having said this, I mean, one issue of great concern, great interest to all of us is what happens to our rivers.

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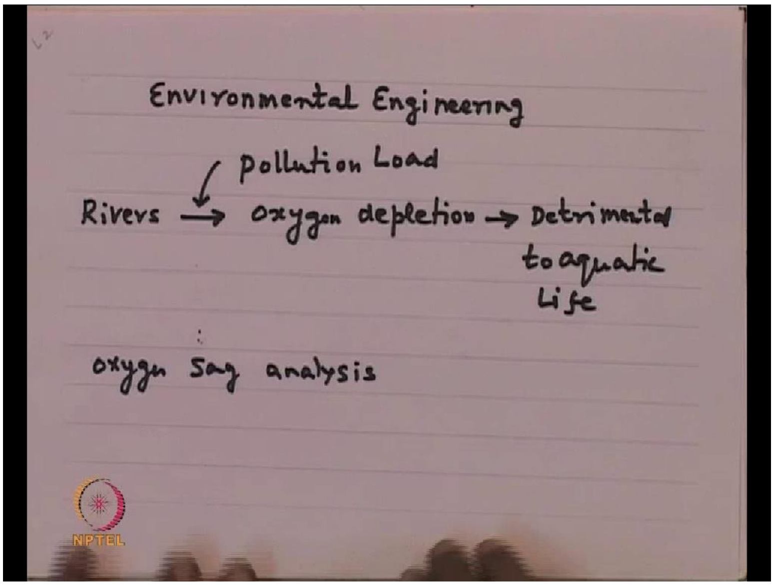


We know that our rivers are not in very good shape, because of the great amount of pollution load that comes into the rivers. As a result, we find that the oxygen levels in the rivers are depleting and to that extent, the aquatic life, which depends upon the oxygen source, also tends to deplete, and then loose its fatality and so on. Of course, I mean, we need rivers, but the same time, we also need to manage the problems of populations and so on. Therefore, we have to understand how we can manage the pollution, entering the rivers, so that, the rivers' health is kept in good shape. These are some of the issues we would try to look at when we look at reaction engineering as applied to environmental engineering and so on. We look at some of these issues as we go along.

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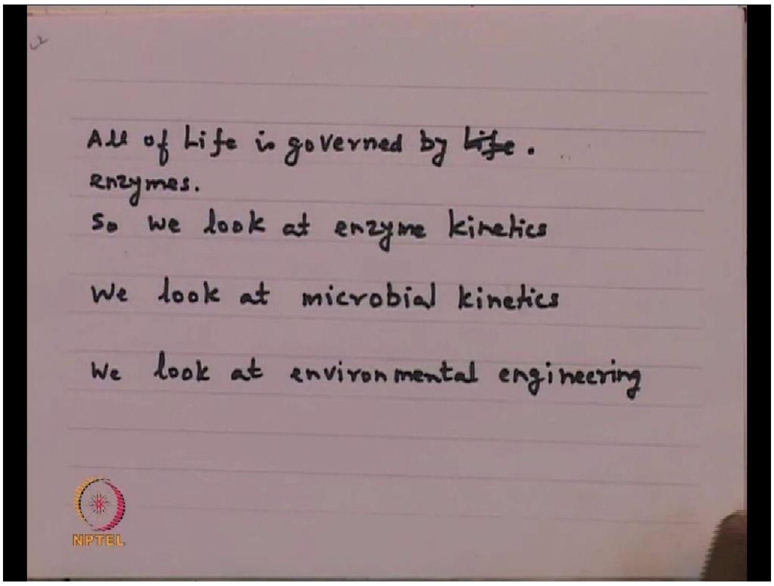


We all know, I mean, it is not new to us; we all know that life is governed by enzymes, and therefore, we must understand the fundamentals of enzyme kinetics and to that extent, fundamentals of microbial kinetics. After all, microbial processes are also governed by enzymes in its fundamental way. Therefore, we would look at enzymes, microbes and microbial reactions, all of which that affect the environment and so on. So, we look at some of these issues as we go along. Now, we know in our industry that we make alcohol, we make antibiotics; we make various enzymes.

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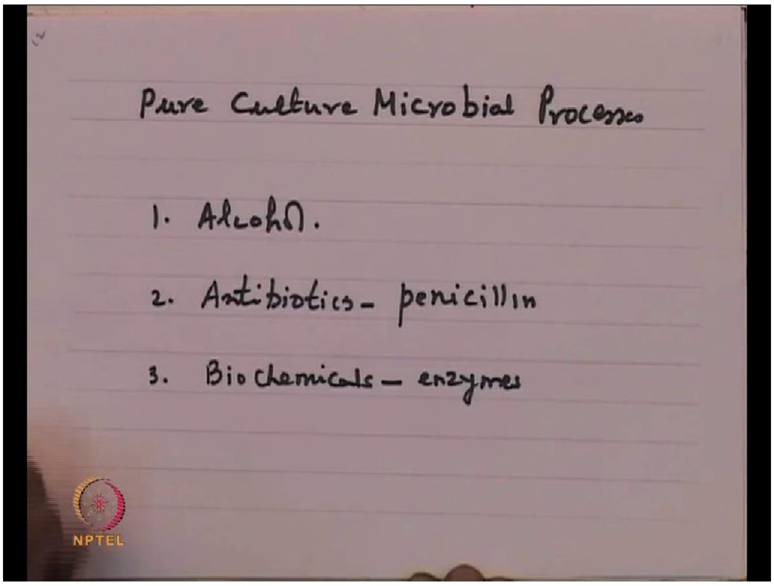

Alcohol is a pure culture process; is a sachromisis. Many antibiotics are produced; penicillin is an example, uses penicillin chrysogenum and so on. We also want to like to use our principles of reaction engineering to understand how these processes can be understood; how they can be designed; how they can be operated and so on. So, some basic issues of reaction engineering is applied to this process; we will look at as exercises as you go along. Now, from the stand point of trying to understand environment and poly culture and so on, there are several reactions that we all know, that which uses poly culture.

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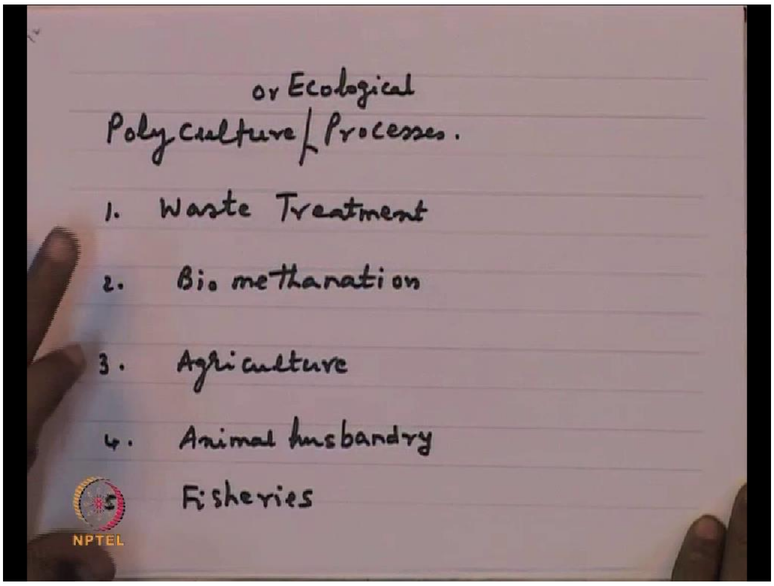


For example, waste treatment, biomethanation and most importantly, agriculture, animal husbandry, fisheries; all of these are poly culture processes where, there is a food chain, which is operating and that food chain is what we must be able to understand and design for, and we will look at some of these issues as exercises as you go along. So, to cut this long story short, what is the contents of this reaction engineering course, is something like this.

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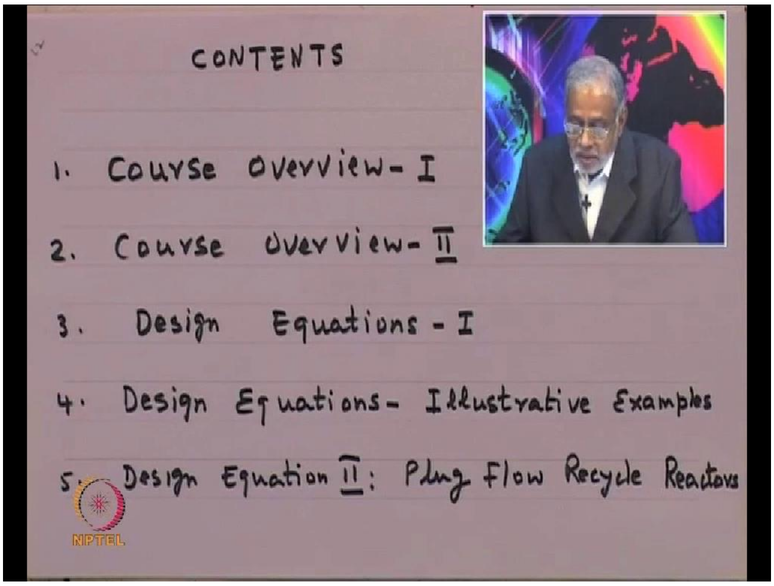


The first five lectures, we look at course overview in some detail. Then, we look at design equations, and then we will look at some illustrates, the examples concerned with design equations and if we go to design equations two where, we look at wider issues concerned with design equations. Now, in lecture 6 to 8, what we have tried to do is that try to spend some time on illustrating how these design equations can be used for variety of purposes and several types of examples we have taken to illustrate how this equations applied. Under lecture 8, we are looking at multiple reactions, I mean, important point is that in real life whether, it is an industry or an environment or bio chemical procesess and. so on; we look at, we deal with multiple reactions. So, some basics of multiple reaction is what we have tried to introduce in lecture number 8.

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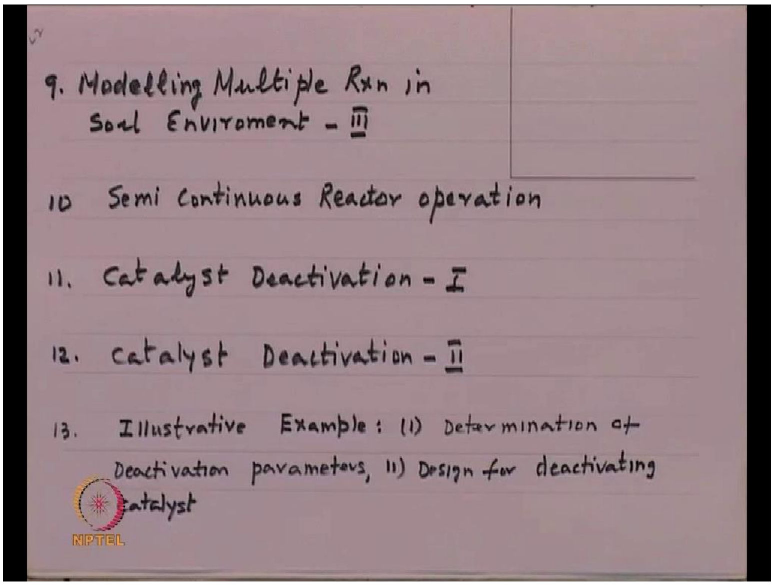


Now, going on from 9 to 13; in lecture 9, what we look at is whether, how to use our understanding of multiple reactions to understand reactions in soil; how these relate to various productions and soil and so on. Then, we go on to lecture 10; semi continuous operation, particularly, this batch, semi batch operation where, time is a critical element in the operations and so on, and 11, 12 and 13; we looking at catalyst deactivations. I mean, catalyst deactivations particularly, in chemical process of the industry catalyst is a crucial thing. They are all time dependent processes. So, you have to understand some fundamentals and how these fundamentals can be used for design of deactivating catalyst processes. That is what we try to do in lecture number 11, 12 and 13. What is being said in lectures 1 to 13, is assuming that we are system is at (( )) conditions, which is, may not be the case always. There is energy balance which, we may consider.

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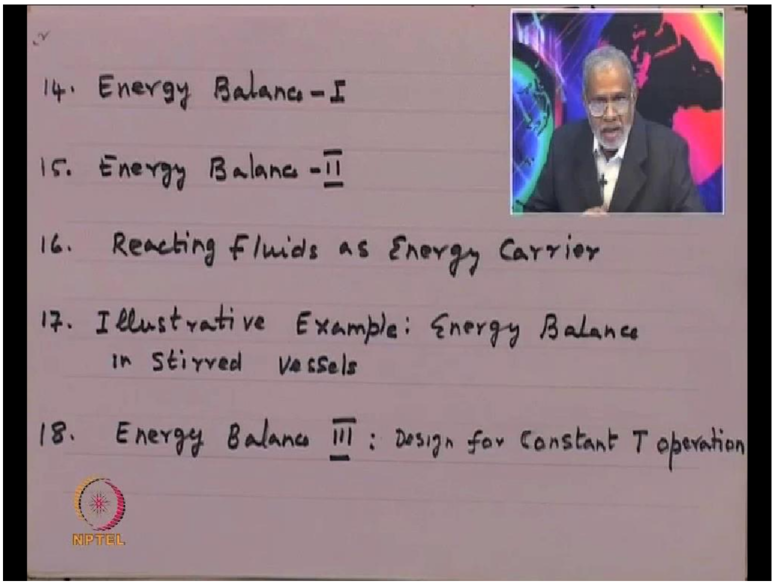


So, in lecture 14 and 15, we set up the basics of energy balance and that is required to deal with stirred vessels, and then plug flow vessels and so on and 16, 17 and 18; we are looking at the applications of this basics of energy balance, coupled with material balance to understand certain applications of energy balance in reacting systems. So, under 16, 17 and 18, we illustrate how our equations and energy balance can be put to use for various purposes, including design.

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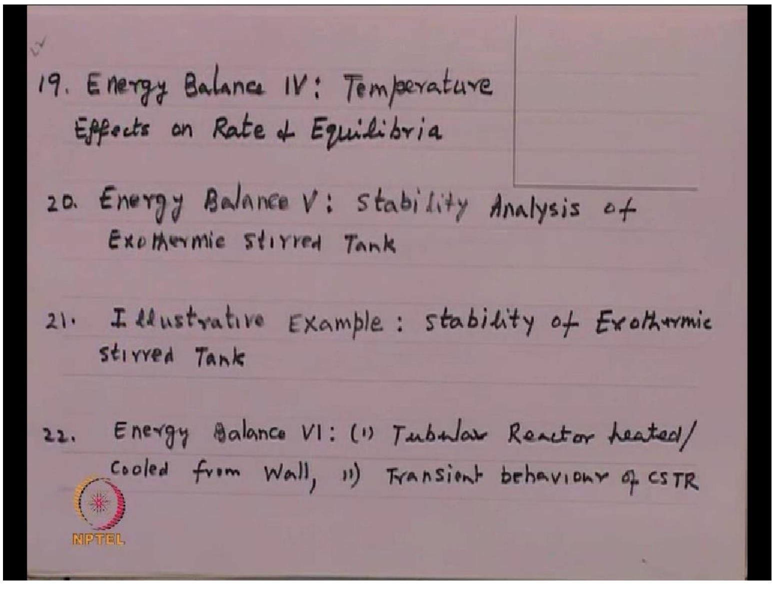

In lecture 19, 20 and 21, essentially, we are, sort of taking the energy balance to greater and greater detail, trying to understand how the temperature effects rate equilibrium; how we can understands stability of stirred tanks; how we can understand, illustrate this through various examples and so on. So, lectures 19 to 22, are instances where, we are trying to see various ramifications of energy balance for our applications.

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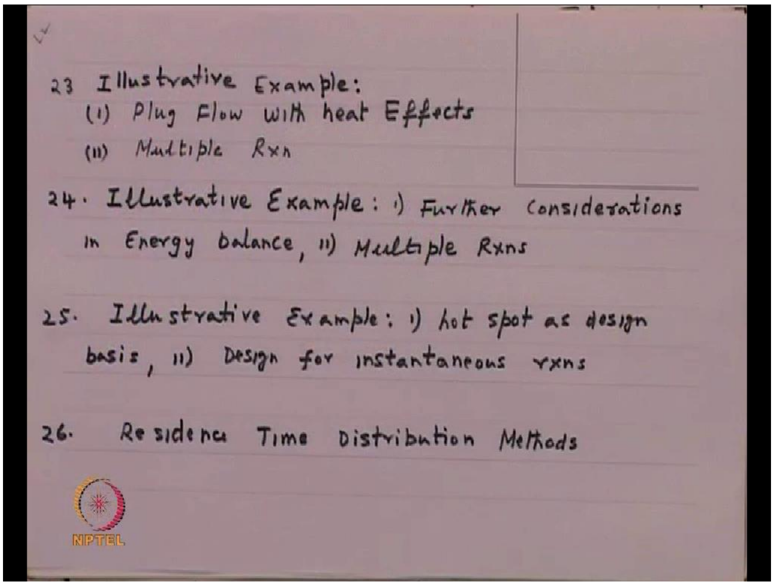


In lecture 23, 24 and 25; 23 and 23, we are still dealing with energy balance where, of course, we look at some new features particularly, heated, I mean, tubular reactors heated and cooled and so on. So, 23 and 24 are still, further extensions or further considerations of energy balance. In 25, we do something interesting where, we try to use some measurements of operating data to see how we can design for situations, but we can use some data of the process. 26; we try to introduce a new technique called residence time distribution. Of course, we have talked about it already where, we try to understand how long the fluid elements spend in the environment by using a tracer, depending upon it is a gas or a liquid or a solid; we choose an appropriate tracer and so on. Under lecture 26, we introduce the fundamentals of residence time distributions, and how they can be measured and so on.

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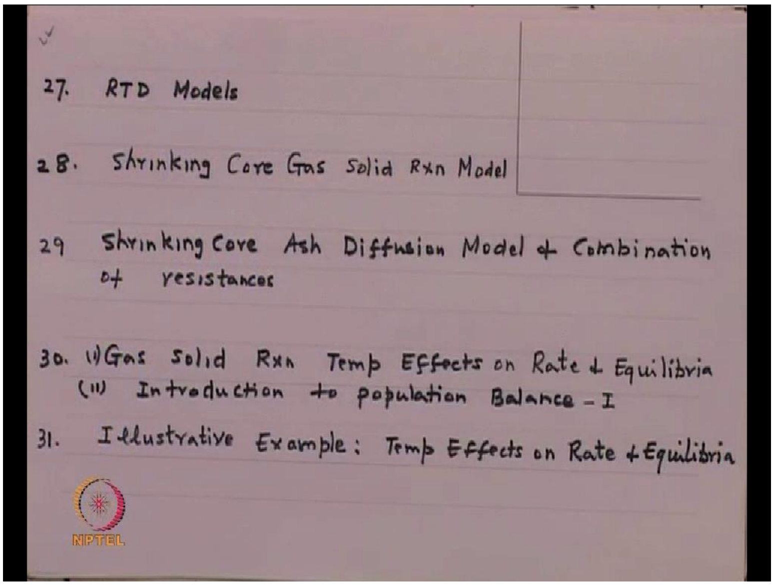


In lecture 27, we look at models by which, we can understand residence time distributions and, so that, lecture 26 and 27; we introduce the basics, so that, we are able, we are in a position to model real vessels and understand the performance of real vessels. Using these basics of residence time, we go on to an important area of gas-solid reactions in lecture 28, 29 and 30 where, we try to understand how gas-solid reactions occur. We introduce the concept of shrinking core, set up models to understand shrinking cores and different controlling regimes and so on,, and then we illustrate this through examples under lecture 31, so that, the idea of lecture 28, 29, 30 and 31 is to favour, way by which, we can understand gas-solid reactions under the concepts of shrinking core models. Now, gas-solid reactions; we are dealing with particulates. So, when a particulate material moving through an equipment, it has certain features of residence time and so on we pointed out. So, when we have such variations, such interesting features in our system, population balance modelling becomes very useful.

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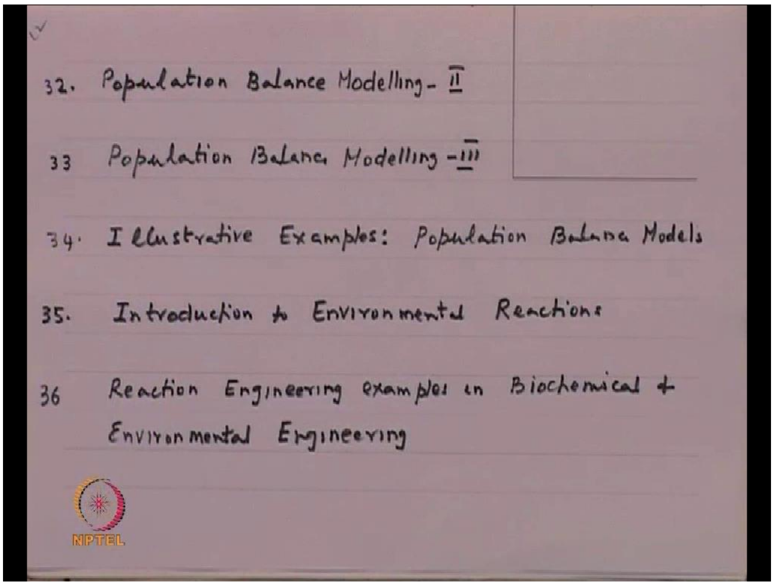


In population balance modelling, what we try to do is that we try to understand how population behave and set up equations. So, it is able to describe the performance of the populations, etc. So, under population balance model lecture 32 and 33, we introduce the basic concepts and 34 and 25; we try and illustrate how these concepts can be put to use variety of applications. So, basically, 32, 33 and 34; we try to introduce population balance through simple examples, and then try and illustrate how these can be pet to use for our applications. So, in 35, we try to move on to a new area where, we try look at reactions in our environment; whether, it is for example, in soil or in the atmosphere or in the biosphere; some examples that keep this planet in good shape.

I mean, what we try to say here is that reactions in the environment whether, it is photosynthesis; respiration; there is what is called as nitrogen fixation; then, there is something called bio methanation; then, there is something called nitrification; de nitrification; a variety of chemical reactions, meant revisiting and so on, which actually, put this, I mean, make this planet do what it is doing, as far as life processor is concerned. So, what we try do in lecture number 35 is to, sort of overview; what these reactions are and what are the basics of chemical kinetics and thermodynamics, and how we can understand, and we can put our basic understanding of these reactions in our design of systems that we require in daily life.

So, that is essentially, lecture 35 is to sensitize all of us to the applications of chemical reaction engineering in dealing with our environment. With this, we go on further, under lecture 36 where, we look at specifics of bio chemical engineering in environmental engineering. For example, we try to look at what are basics of enzyme kinetics; basics of microbial kinetics and how fundamentals of these kinetic processes can be put together in the form of design for our requirements in daily life.

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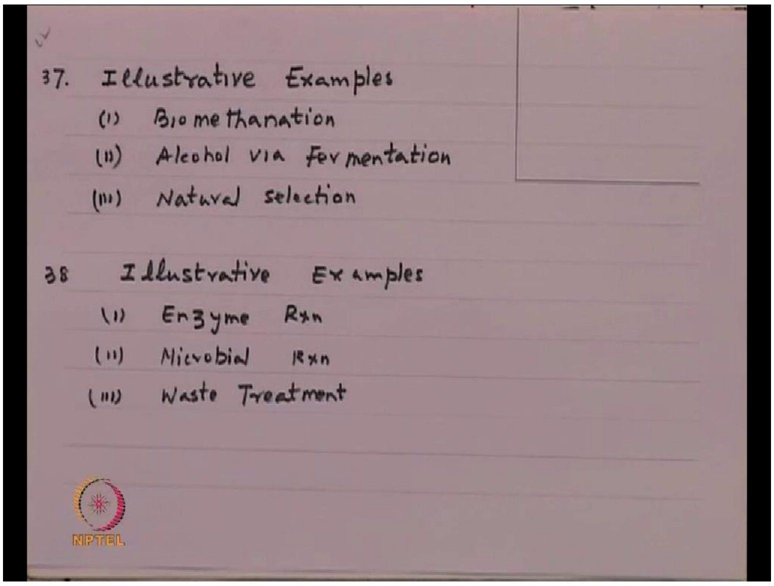


Having said this, we look at some illustrative examples where, we take what we have learned in our basics so far; enzyme kinetics and microbial kinetics to understand important reactions like bio methanation, alcohol fermentation and natural selection. How natural selection happens in our environment? I mean, some simple example to illustrate how we can understand, why this great variety of natural things that we see in our natural environment; how we can understand them from relating simple mathematics to illustrate how things happen. So, lecture 37 is a way of trying to apply what we have learnt in the basics of microbial kinetics and enzyme kinetics to what we will see in daily life. Then, we go on in the lecture 38, to look at some simpler things in the enzyme reaction, in microbial reaction, in waste treatment and so on, and trying to, sort of gather more insights into the applications of basics for understanding biological reactions. Having said this, one of the prime problems particularly, of water systems in India, for example, is that is the great amount of pollution that the rivers have to face, because of various kinds of population pressures.

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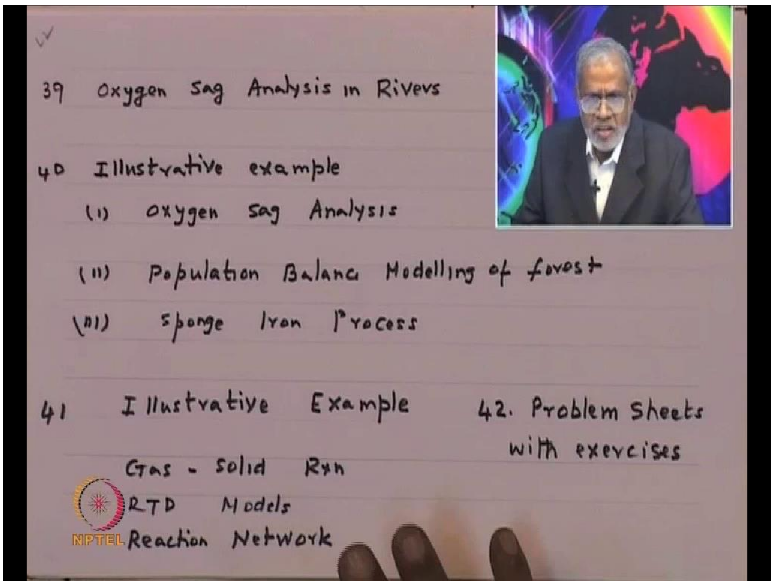


Therefore, we take some examples of oxygen sag analysis of rivers; how the oxygen demand of the rivers in terms of it is natural process, as well as due to the interference from various pollution loads; how they can be understood and how we can regulate pollution entry into the rivers, so that, the river quality remain satisfactory and what kind of design interventions can be thought of and so on, in the form of mathematical formulation under lecture 39. In lecture 40, we try to illustrate this, using various kinds of miscellaneous examples; for example, on oxygen sag analysis, we take some examples. Similarly, population balance modelling; we take some examples. On other words, in lecture 40 and 41, what we try to do is that try to look at miscellaneous problems that we have looked at over the entire course, and try and illustrate how and what has been learnt over the last number of lectures. They can be applied to understand various kinds of situations. In 42, essentially, what we would like to do is set of problems sheets, which compiles a large variety of problems that can provide insights into the applications and the equations that we have derived, so that, these are all summarized in the form of problem sheets in lecture 42. On other words, what we are trying to say here is the lecture 1 to lecture 42 is trying to, sort of foray into subject of chemical reaction engineering and try to illustrate how we can use basic principles to understand how things happen around us, and how we can intervene through design to make our environment in our designs of chemical process of industry and so on, so that, safety, security, productivity, economics, etc can be achieved. Now, this whole material that we have been talking about over the last 42 lectures, has been taken from various sources and I have listed some of these sources.

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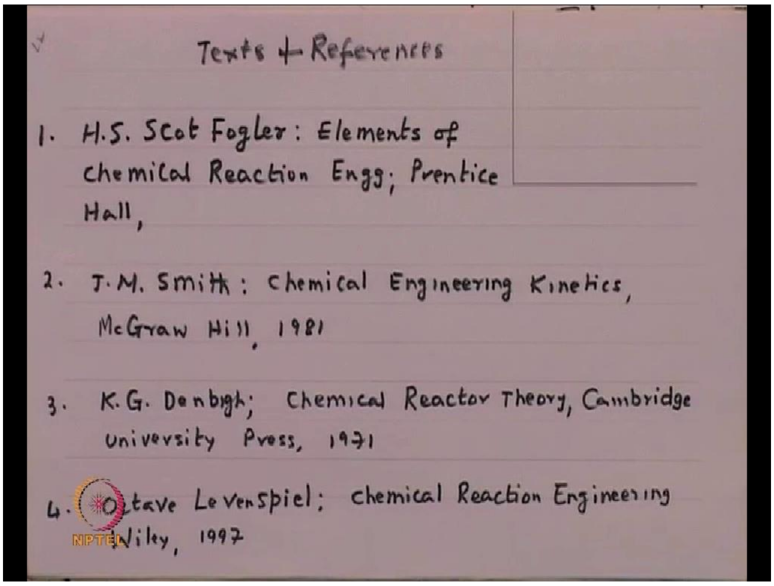


One is H.S. Scot Fogler; fantastic book written in the 1986, was the first edition, and 2000 also is there I think. Lot of the material that I have done and this is taken from Scot Fogler. There is also material taken from James Smith: chemical engineering kinetics, McGraw Hill publication and there is some material that is being taken from K.G. Denbigh's chemical reactor theory from Cambridge university press publication, and also, taken some material from Octave Levenspiel's chemical reaction engineering from Wiley publication of 1997. This and these books have been published even earlier. Even, Fogler book was first published in 1974, and has gone through several editions and it is a great book which, I have enjoyed. Similarly, James Smith book, of course, has been there for a very long time, is a fantastic book. It has been revised, and then edited number of times. Similarly, K. G. Denbigh and Octave Levenspiel; all of them are great textbooks and material that is done, taken in this lecture series, will be adopted from these sources.

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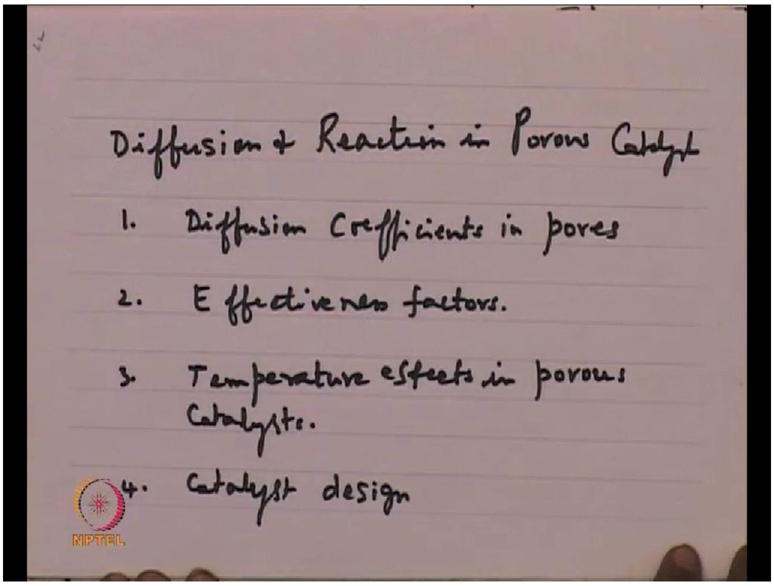


Having said this, there are few things which, we have not been able to cover, which I am hoping that we will include in course of time; that is diffusion and reaction in porous catalyst. We will look at diffusion coefficients in pores, effectiveness factors in pores and temperature effects in catalyst,, and then catalyst design; it is a very important area and not having the time to look at these issues which, you will do so, in future and shortly. Similarly, this is a huge area of gas-liquid reactions, I mean, of the industry all of us know. The most important application of gas-liquid reaction; carbon dioxide removal in the fertilizer industry; it is developed beautifully, over the last 40, 50 years; do not have the time to look at gas solubility in liquids, effect of chemical reactions, and various examples to illustrate how gas-liquid reaction can be understood; can be can be modelled; can systems can be designed for our daily use. We have not been able to do this and hope to include this material in course of time. With this, I thank you for your attention.

Thank you.