Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Lecture 19
LHHW Kinetic Model Continued Part 2

In the last class we have developed two surface reaction models, one is kinetic control the other one is adsorption control, okay. So let me write those and then try to identify something in that and also I will not give the solution but I will simply give the equation and in between steps and finally the rate expression where adsorption, surface reaction, desorption all three are there. Not one controlling, all are controlling, okay.

It is only mathematics so then I think you will have some nice things in your room to do things, okay. So that is one problem and before that we will write the same equations what we have written earlier the last equation. Final equation just to discuss some more things this is LHHW model continued. The equation for surface control and then I have A gas, B gas, C gas plus D gas, catalytic reaction. This one you already solved. If it is surface reaction control the rate in general form is given as some k C A, C B minus C C, C D by capital K, right, or K not.

Whole thing divided by we have all those terms. 1 plus K A C A, K B C B, K C C C, K D C D plus K I C I if you have inert. If you do not have inert that term will not be there. So this is one equation. And for the other one I have simply A gas going to R gas. This is surface reaction control, right? Reaction control and when I have here adsorption control what is the equation?

Again rate equal to in the form some k C A minus C R by similar K not, okay, divided by 1 plus K 3 by K 2 plus K 3, C R plus K I C I. If you do not have again I inert then you will have this term will vanish. You will have only this one. Can you see any commonality in this equation and the next equation?

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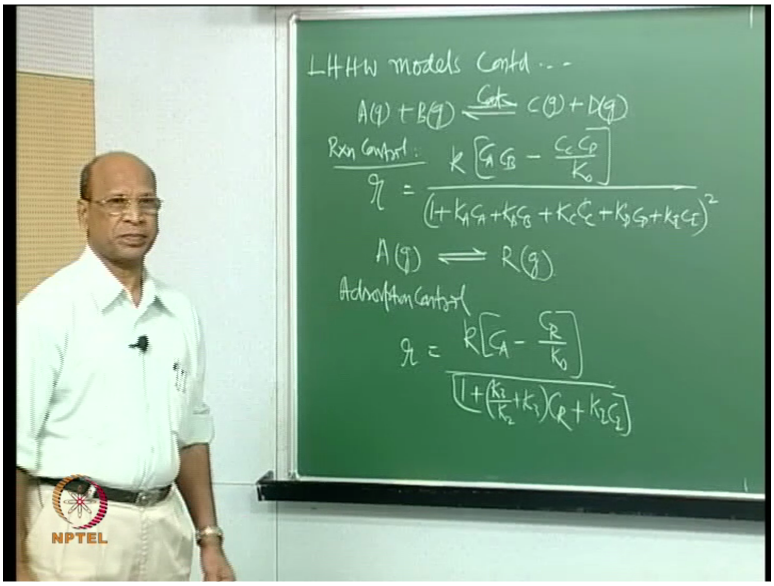

See generalizations are very important in engineering. After two three problems you can say that you know there is some general things there around that. Anything? Numerator what? What do you call this term or this term? Driving force term. So in any equation when you take you will have a driving force term, you will have a kinetic term constant and you will have resistance or adsorption terms, okay. I mean they are generally called adsorption terms, okay.

So that is why whatever equations you try to derive with whatever mechanism for example here we said adsorption control, you can also have here surface reaction control. Here also you can have adsorption of A control or desorption of C control or desorption of D control. In all these things you will have this general format.

So all Langmuir Hinshelwood kinetics will have a kinetic term, a driving force term and a resistant term or we call normally it is adsorption terms, okay. So those three terms and if the reaction is not reversible, this term will not be there.

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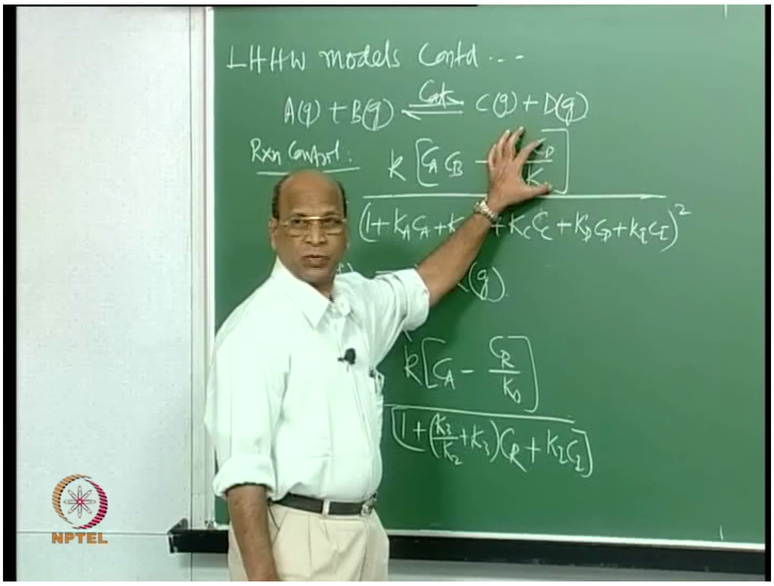

You have the magnitude driving force. This is zero, okay good. So now the other problem which I want to tell you is similar. A are going to R only. Similar problem A going to R but all the steps are controlling right, okay. Another example is A gas going to R gas of course cat. Here also cat you have and you know in this the steps already we have written. Step 1 is A plus S, A S. Step 2 A S giving R S and step 3 R S giving R plus S. So this is we know adsorption step, surface reaction step and desorption step.

And when you use this one similar notation as we have done earlier k 2, k 2 dash, k 3, k 3 dash. Now in this the problem is that all steps are rate controlling. So let me also write that. When I have r adsorption I will call a, as treat all these steps, okay. Let me also write the equation numbers. These two have already been given, right? So then I will have here 1, 2, 3, 4, good.

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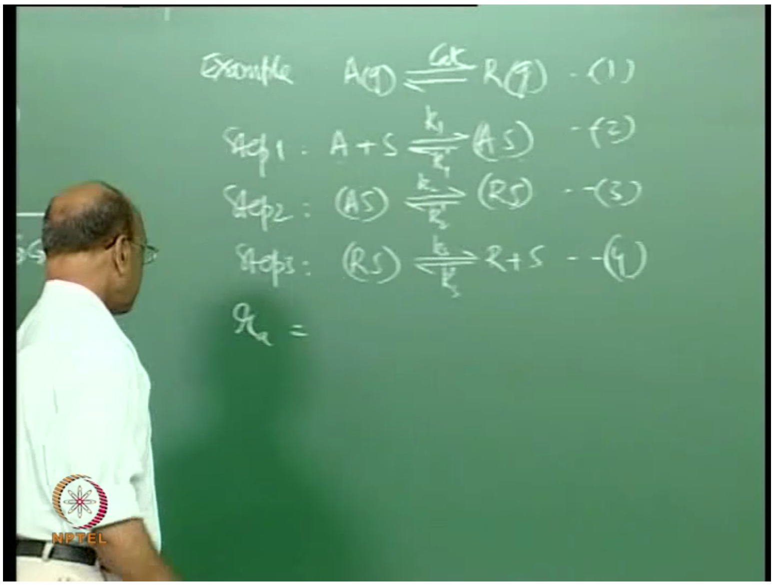

So our general thumb rule is that every reaction is an elementary reaction. I am again repeating. I know you may not be interested you know but still if I tell hundred times then you cannot come out of that. May be somewhere it will be there in the brain. When you want to recall you can recall it. Otherwise just once only if I tell it goes. It evaporates very quickly. Vapour pressure is very high, okay. So then we have r a as this one k 1. I am writing slightly advanced stage. C A S by K 1, this is one equation so this is equation 6, right?

That means the small k 1 do you know meaning of capital K 1. It is k 1 by k 1 dash. That is why I said slight advanced stage. And reaction step is k 2 small because it is the reversible reaction, right, k 2. Then I have C A S. C A S is the surface concentration after joining with A and active side, okay. That is what? C A S. So C A S, this will be C R S by K 2. This is equation 7. And r desorption will be k 3.

This will be C R S minus C R dot S. S is again separated, divided by K 3 where K 3 is defined as reverse of normal equilibrium constant. This is 8, okay.

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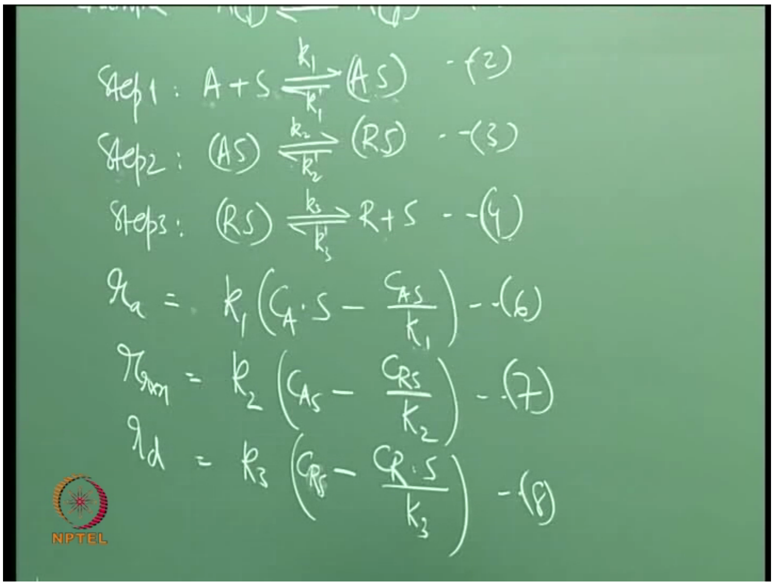

Step1 : $A + S \underset{k_1'}{\overset{k_1}{\rightleftharpoons}} (AS)$ - (2)

Step2 : $(AS) \underset{k_2'}{\overset{k_2}{\rightleftharpoons}} (RS)$ - - (3)

Step3 : $(RS) \underset{k_3'}{\overset{k_3}{\rightleftharpoons}} R + S$ - - (4)

$r_a = k_1\left(C_A \cdot S - \frac{C_{AS}}{K_1}\right)$ - - (6)

$r_{rxn} = k_2\left(C_{AS} - \frac{C_{RS}}{K_2}\right)$ - (7)

$r_d = k_3\left(C_{RS} - \frac{C_R \cdot S}{K_3}\right)$ - (8)

Very happy Anurag. I mean that shows your interest I said. That is what is the said because I also got because I think some Korean people came and started giving presentation. I also did the same thing, okay. But I think it is not allowed in the class. I am allowed there, okay good. So if I take all these three steps controlling what is the procedure now? Unknown concentrations procedure is same universal, okay. So this one, all unknown concentrations have to be eliminated.

And we know that at steady state conditions this must be equal to this must be equal to this. R a equal to r r x n equal to r d under steady state conditions. So we have to equate all of them and then remove all intermediate concentrations which you cannot see, which you cannot measure. And then finally express only in terms of C A, C R, okay. What kind of equation you will get I will write now. And I will ask you to do that, okay. In the examination also I can give.

And I tell you if you have not done this in your room at least once and if you start this doing in the class without doing once, in the examination hall okay, even 3 hours will not be sufficient, okay. Do not blame me at that time that you know he gives very lengthy question paper. As I told you if your writing speed is zero you will take infinite time. And who will wait till infinite time? No one can wait there, okay. So the overall rate r is given by some constant k which will be here S 0 and all that, okay.

C A minus C R by capital K, I will just, okay, K not. Bracket is here. So I have to write the whole thing there. Then I will have here please carefully note down this one. It is capital K 1 small k 2 plus 1 by small k 1. My small k 1 will be something like this, plus 1 by K 0 small k 3. This is a constant, plus 1 by capital K 1, capital K 2 plus 1 plus capital K 2, capital K not, small k 3 into small k 1 C A some more.

Oh my God I have to go further, plus I also have 1 by capital K 1 K 2, 1 plus K 2, capital K 2, k 1. I have to extend it further, into capital K 3 C R, very simple expression. So this is equation number 9, okay.

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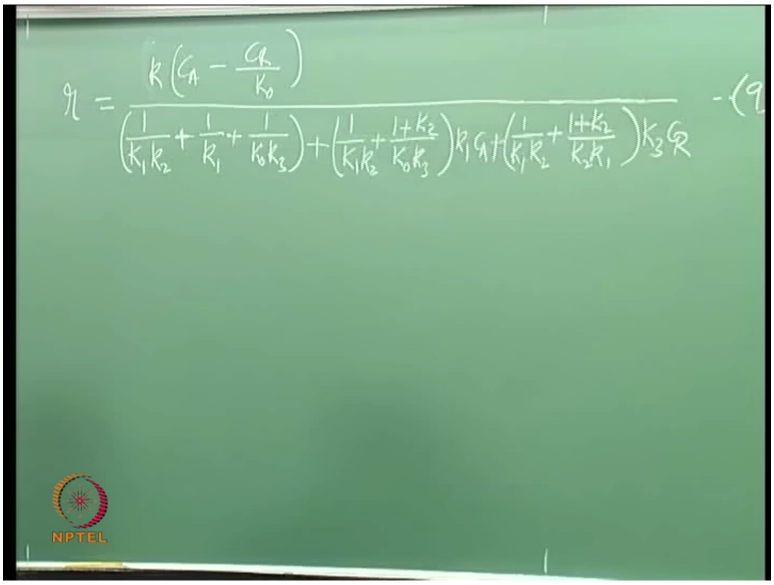

$$r = \frac{k\left(C_A - \frac{C_R}{K_0}\right)}{\left(\frac{1}{K_1 k_2} + \frac{1}{k_1} + \frac{1}{K_0 k_3}\right) + \left(\frac{1}{K_1 k_2} + \frac{1+K_2}{K_0 k_3}\right) K_1 C_A + \left(\frac{1}{K_1 k_2} + \frac{1+K_2}{K_2 k_1}\right) K_3 C_R} \quad -(9$$

My handwriting you have to identify. Small k will have this kind of thing, okay. These are all small. You see I made a mistake here. K 1 C A, this is capital. I may check once more. 1 by K 1 k 2 plus small k 1 plus K not k 3 small one, capital small, capital, capital small k 3, then K 1 capital C A, K 1 k 2 small, K 2 capital, K 2 capital, k 1 small.

This is capital K 3 and C R, okay good, where we will write that K 1 equal to small k 1 by k 1 dash. K 2 also equal to k 2 dash and small k 3 is the reverse, k 3 dash by k 3. This is capital K 3, this also capital K. Next one is K not. K not equal to capital K 1 capital K 2 by capital K 3. Even here you have the same format.

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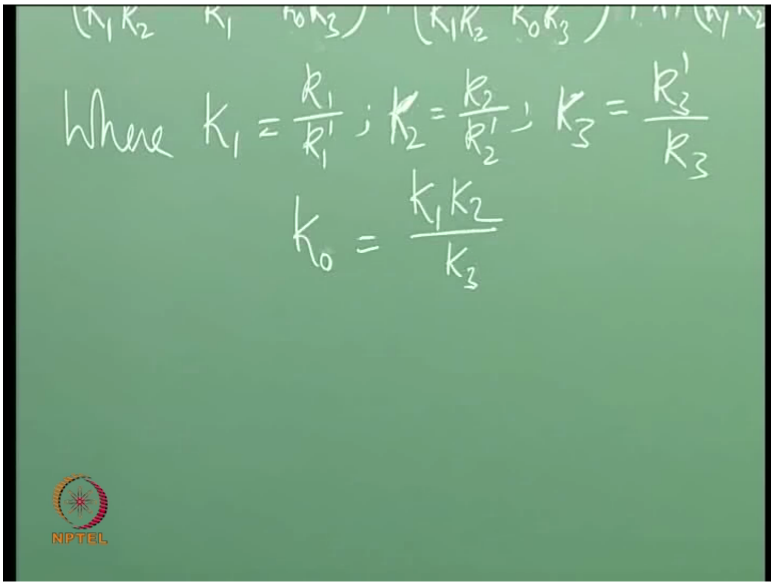

Where $K_1 = \frac{k_1}{k_1'}$; $K_2 = \frac{k_2}{k_2'}$; $K_3 = \frac{k_3'}{k_3}$

$$K_0 = \frac{K_1 K_2}{K_3}$$

What is the format? First is kinetic term. That kinetic term will be changing depending on what are the other constant that will come, okay. And the other things of course, in all you know all these things are adsorption terms or resistance terms where the total rate of reaction will be decreasing with these things. I do not know the physics of these problem you have understood or not. If I do not have a catalytic reaction what will be the rate? Rate will be this.

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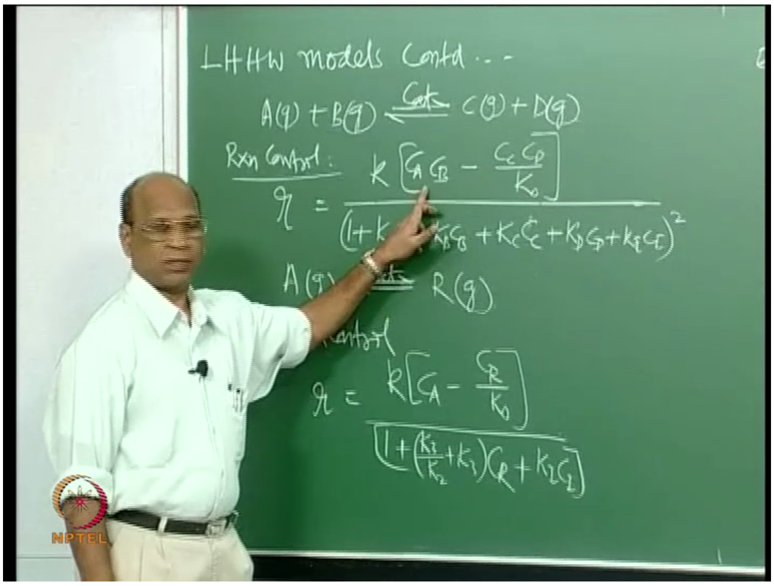

LHHW models Contd . . .

$A(g) + B(g) \xrightleftharpoons{\text{Cat.}} C(g) + D(g)$

Rxn Control:

$$r = \frac{k\left[C_A C_B - \frac{C_C C_D}{K_0}\right]}{\left(1 + K \quad K_B C_B + K_C C_C + K_D C_D + K_I C_I\right)^2}$$

$A(g) \xrightleftharpoons{\text{Cat.}} R(g)$

Control

$$r = \frac{k\left[C_A - \frac{C_R}{K_0}\right]}{\left[1 + \left(\frac{K_1}{K_2} + K_1\right)C_R + K_2 C_I\right]}$$

This will not be there. Then why in our catalytic reaction this is coming? Concepts, phenomena.

Student: The pore diffusion.

Professor: Pore diffusion you are not taking. Pore diffusion and external mass transfer we thought that you know it is. Attraction, attraction between what? So if there is more attraction happy? Why it should decrease? Kavya you were trying to say something?

Student: Reaction happens inside the pores.

Professor: Inside the pores it happens but I think you know the mass transfer through the pores is very fast. That is assumption. Only three steps you have taken. The remaining four steps are very fast. The three steps are adsorption, desorption and surface reaction.

Student: Active sides are occupied by all four.

Professor: Okay, how does that decrease the rate?

Student: Number of effective correlation decrease.

Professor: Effective correlation decreases.

Student: Collisions.

Professor: Collisions. Where, on the surface or?

Student: If catalyst is not there then there is no surface.

Professor: Catalyst is not there, there is no.

Student: No surface the reaction can take place.

Professor: Then what will happen?

Student: The reaction can take place anywhere in the space.

Professor: Molecules can easily?

Student: React and collide.

Professor: So then the moment you have the surface then adsorption takes slow. It is a slow step when compared to random collision of the molecules, okay. Desorption also (sto) slow step, right? You know it is like you know when you are writing only that JEE entrance or any state entrance you are very active, free molecules. After coming here year by year adsorption, nothing comes out, stops there. Then afterwards surface reaction 2nd year 3rd year. And 4th year desorption, the rate is tremendously decreasing because this will be infinity, that term.

So then your rate of doing anything will be zero, okay. Exaggerating but still that is true, right? So that is why the physics of that is that if in a catalytic reaction you have the other two steps which are really controlling. Even though we do not say it is controlling, they are not fast steps because first of all the molecules has to search for active sides, okay. I mean in that terms it may be very small but still that is comparably very large when compared to free molecules moving in the free stream, okay.

So that is why even non elementary reactions, homogeneous also same problem because in between you have some other intermediate forming. That intermediate has to decompose. In fact this is nothing but the intermediate reactions here, correct.

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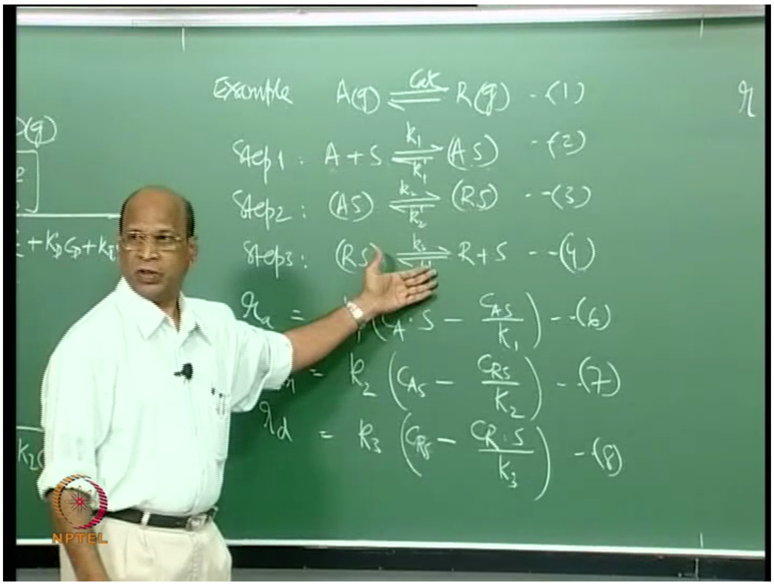

This is the reaction, this is the reaction, this is the reaction. But if you do not have all these, if you have simply homogeneous reaction then all these things you do not see, collision product, collision product, collision product, okay. So that is why at least remember this as a story. Like you know what happens in a catalytic reaction and what happens in a homogenous reaction, okay. So that is why always you have the catalytic rate is little bit less then, okay, the homogenous rate.

Of course then there is a big assumption, if the activation energies are same. That is very important otherwise the point of using catalyst will not come into picture at all, okay. I mean always we say that go for catalyst, go for catalyst, right? But the activation energy here is tremendously reduced then so that you will have more number of collisions and all that.

Overall rate will be more but that term will not be there if you have homogeneous reaction if you are comparing at the same energy levels, okay.

So that is the one. So now in general what you have here is rate of reaction in all LHHW models can be written as, this also you just remember because I think this is interview question. People may ask again decent interview if you have. Kinetic term, driving force term, driving force divided by resistance term. These are the three terms, good.

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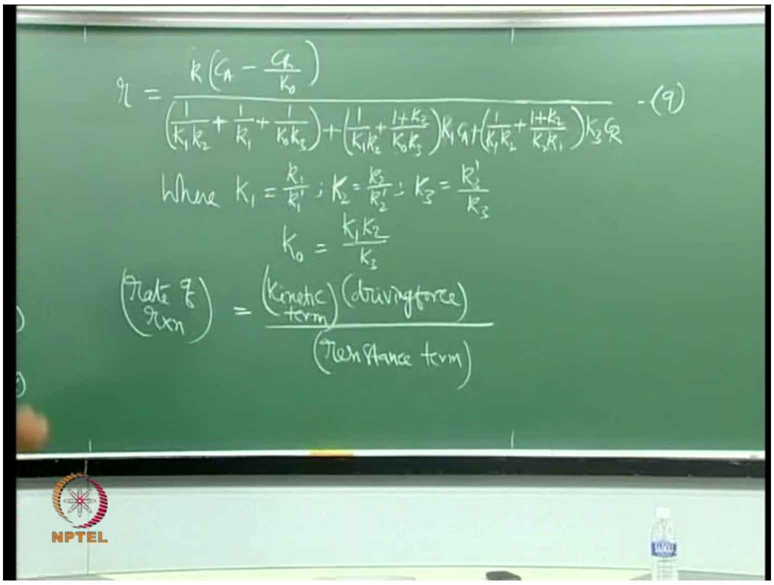

$$r = \frac{k\left(C_A - \frac{C_R}{K_0}\right)}{\left(\frac{1}{k_1K_2} + \frac{1}{k_1} + \frac{1}{K_0k_3}\right) + \left(\frac{1}{k_1K_2} + \frac{1+K_2}{K_0k_3}\right)K_1C_A + \left(\frac{1}{k_1K_2} + \frac{1+K_2}{k_3K_1}\right)K_3C_R} \quad -(9)$$

Where $K_1 = \frac{k_1}{k_1'}$; $K_2 = \frac{k_2}{k_2'}$; $K_3 = \frac{k_3'}{k_3}$

$$K_0 = \frac{K_1K_2}{K_3}$$

$$\left(\text{Rate of rxn}\right) = \frac{\left(\text{Kinetic term}\right)\left(\text{driving force}\right)}{\left(\text{resistance term}\right)}$$

So now let me give you something. You can pass it on. So what do you see from that tables. You have table 7 point 3, 7 point 4. Anyway that does not mean anything to you number, but only matter in the table. What table shall we take first, 7 point 3? By looking at the first one can you say anything? It is not a reversible. That is one thing. Which one will be rate controlling? Where do you say it is adsorption?

Student: It is written sir.

Professor: That is what I was thinking. At least someone will see the title. There itself it is written surface reaction control. Without seeing always it happens you know. You do not read which question paper you have taken you know the moment we distribute the question paper. You first go to only question number 1 to read, okay. General case partially covered surface, fully covered surface. You know I just want to tell you that there are so many possibilities in these models, okay.

And the second one is like this one, A going to R. But here it is adsorption control. But if you have reaction control you can easily write that equation without even deriving it, okay. Of course there is no inert involved there but it is given in partial pressures and also theta coverage. You see that theta is nothing but you're a S, theta A, A S. Theta B if I have there B S like that. I told you there are two schools of thoughts about derivations. One is the

Langmuir Hinshelwood, the other one is Hougen and Watson. Hougen and Watson we will write A S active sides, okay. And Langmuir Hinshelwood we will write in terms of fractional theta coverage. Theta is the fractional coverage. Both are same. At the end you will get the same thing. So I can ask any of these derivations in the examination or including separators, okay good. Again you know below you have got the general expression given as kinetic term and then driving force and adsorption term and also it is called resistance terms, good.

Very good, excellent. So just keep that with you. Do not throw that away. The other side you have adsorption control, good. So some more things about these equations I have to tell you that I have so many constants here, too many k here, always k, right? K 1, K 2, K 3, K 4 and all that, okay, too many k. So that is why you have problem always. How do you evaluate them all these constants? Experiment only but after doing the experiment you should use many techniques to do that.

See one simplest thing is let us say that rate is increasing with one simplest example I will tell you. When you plot let us say rate versus P A or C A, okay, concentration of A. And then this is outward concentration only, not in the bulk concentration only. Otherwise this is overall rate. So then what kind of curve you may get here? Question is not clear?

Student: Depend upon the type of reaction.

Professor: Depend upon?

Student: It will depend upon reaction.

Professor: Only I have given A, but let us say of course any reaction. Even this A plus B also because stoichiometrically A and B, okay. For the simplest one you take A going to products. A going to R product. You can take reversible. Yes Abhinav, you are drawing something like this. Like what?

Student: Initially it will increase until an optimum or a maximum point and then decrease.

Professor: Why decrease? Because, C A is still increasing. You said decreasing. Why it should decrease because C A is increasing? This is what I think beautiful I say, really the imagination of something happening. Trying to first imagine in the brain and then try to draw the curves. I told you know as a hobby you can develop that. That means when you are free just take you know a pump, how does that work?

And then if you are increasing the input for example HP, how the delivery how much you have to pump out, so how it increases? (())(26:18) columns for example. Change the temperature, how the concentration change? Adsorption, okay. Again change the flow rates, how the concentration changes? Just sit down and then draw. And it is not that easy I told you.

I have the simplest example you can try in your room that is taking an iron ball of maybe 6 inch diameter big ball, put it in a furnace at 500 degree centigrade, allow it to come to thermal equilibrium, okay. 500-500 just take it out. Imagine that it is hanging. Draw the temperature profiles there because it has to cool. You brought it out, hang it there imaginary and then after you wait sufficiently then the temperature throughout the particle also should come to room temperature. How the change occurs?

Same thing when I think you are eating Bonda in your Himalaya, I do not know whether they are giving you Bonda. Bondas are spherical particles, beautiful particles. Vadai is flat plate circular, okay. You know Abhinav Bonda? You know? Samosa is a peculiar structure so you cannot imagine. But I think spherical particles are always better, okay. Why Bonda? I think you can also imagine your Gulab Jamun. That is beautiful sperical. MTR Gulab Jamun much more sperical or much smoother, okay.

Then very hot thing they have given to you and then now you sit down in the mess till it cools to room temperature. How the temperature decreases? Just try to draw that. You have already drawn once like this. It is not that easy if you just go deeper and deeper and try to observe what is happening. So like that I think this is very good. I think of course here coming to this it has to increase with C A. As the concentration of A is increasing, rate has to increase. So you may have something like that, okay good.

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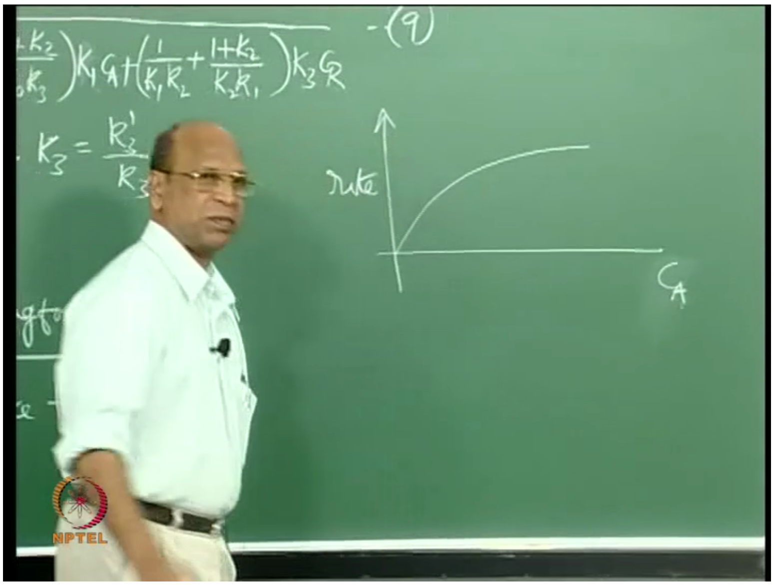

So why I told this? This is experimental curve, right? Once you have this experimental curve, theoretically speaking how I can find out K 1, K 2, K 3, K 4 and all that? I will go to my model for example this one or maybe this one. Now I go to mat lab, right? And then give initial guess values of K 1, K 2, K 3 all these.

How many I have here? One, two, three, four constants and if you remove this you will have only three constants. Give these three constants the guess values and then ask mat lab fellow who is inside that, okay, to calculate for different C A because this equation has C A.

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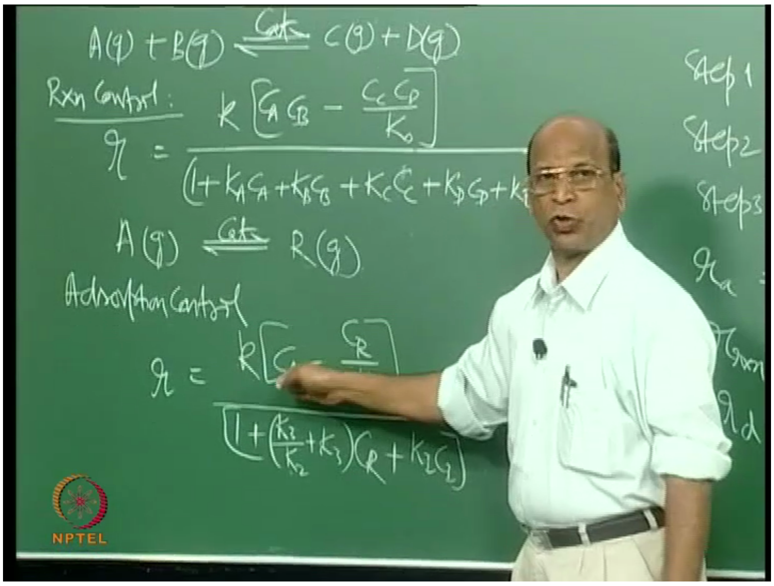

And once you know C A, C R is all you know because 1 mole 1 mole. There is a relationship. You now calculate this and then try to plot, okay. So this mat lab fellow inside this you know program you would also give some kind of difference between your calculating value and experimental value. At every point it calculates here, here, here, here, here, her, here and how many points you choose depending on your patience, okay.

So at every concentration you allow the mat lab to calculate R and then the difference between R experimental and R calculated should be minimal. Theoretically it is zero. But the moment you put zero or infinity, computer broke. It breaks, I mean it cannot say anything. Whenever you want to spoil the computer put infinity or zero. I think divide you know explanatory mark all that things will come, right?

So anyway that is why you have to have at least 10 to the power of minus 10 if you want to go to zero almost. That is the difference between those two and then you allow it to calculate and finally put that point here, point here, point here, point here.

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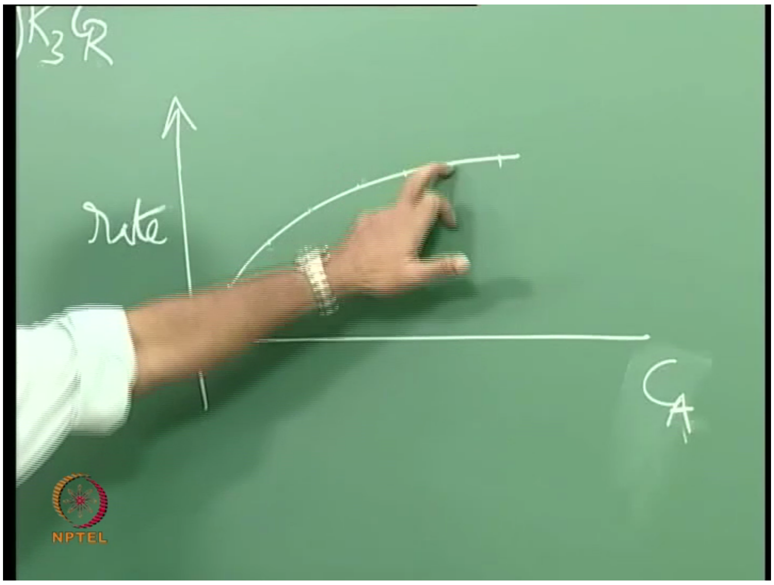

If both of them are matching then your K values you will know because that will have K 1 value, K 2 value, K 3 value. There is a lot of thing that is required again like a story, okay. Once you have K 1 you gave the initial guess values K 1, K 2, K 3 let us say 1, 2, 3, right? So then it calculates. If it is less then it will try to increase. If experimental value is higher than the calculated value then again computer will take now K 1 increase, calculates K 2 increase, calculates K 3 increase, calculates.

So, there is lot of programming going on in there. But if it is moving towards this then it will go. I think (())(31:17) beautiful it tells that in optimization, his course, okay, how do we match these. The match between that optimization also here is matching between experimental values and model value. So finally when all of these things when you have 10 to the power of minus 10 matching then that will give you that K 1, K 2, K 3 values, it prints out.

But unfortunately if I do separately, if you do separately, if Ashok Kumar does separately, all three will be different. But beautifully it fits. It fits much more beautifully if you have more number of constants, not point, constants, okay. So that is why (())(32:01) always says that do not use your parameters more than, each one is a parameter here K 1, K 2, K 3 and all that, more than two. Three also is very difficult because that uniqueness will not be there. See the physical system is only one, right?

We have done only one experimental run and as far as physics is concerned that is not changing. But how can it change depending on who gives the guess values. So it is the mathematical technique problem. So that is why when you have more number of K 1, K 2, K 3, uniqueness in the constants is questionable. But it fits the data. If you are only trying to fit the data without thinking about what is K 1, K 2, K 3 it is fine.

But if you also want to get some physical meaning for K A, K C, K D, K B and all that then you have to use some optimization programs where you have unique optimization where anyone does it will give the same constants, whoever does it. That is the best method if you are able to do that. Otherwise divide and rule. We are excellent in that, okay, because our British people have told us so we still follow that. So that means divide this equation into two. This you remove this fellow. Only forward reaction, okay.

And forward reaction means only this term will be there. Even C R term also will not be there, okay. And then now this equation is simplified. This is all this is one constant, this is another constant, right? So you heard of what is called initial rates.

Here only very profusely used these methods you know initial rates particularly for catalytic reactions because forward reaction you take, conduct the reaction such that it is not going towards this equilibrium or this side and only initially and again start with r because you are doing experiments, right? You are not producing anything. R you can start and then with r backward reaction, this reaction both reactions will be there, okay.

But again now when you take r, C A will be removed from there and you will have only this reaction. This reaction will be going on but most of the time this you know backward reaction that is the starting point initial rate.

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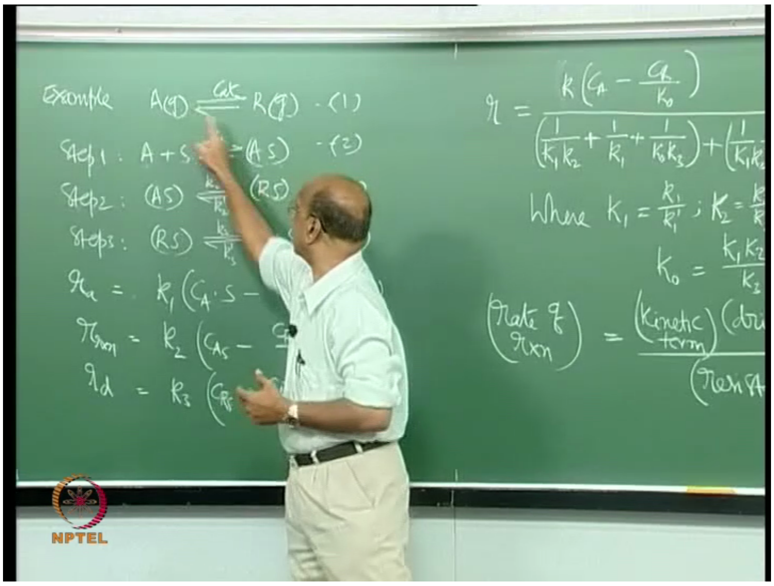

So then finally you conduct one reaction completely taking A alone and then see that whether the constants which you have evaluated from this technique that is you know initial rates, forward direction, backward direction, whether it is also completely matching with this. This is experimental. That is experimental, okay. So if you are able to get your excellent match, okay. Even here also excellent match.

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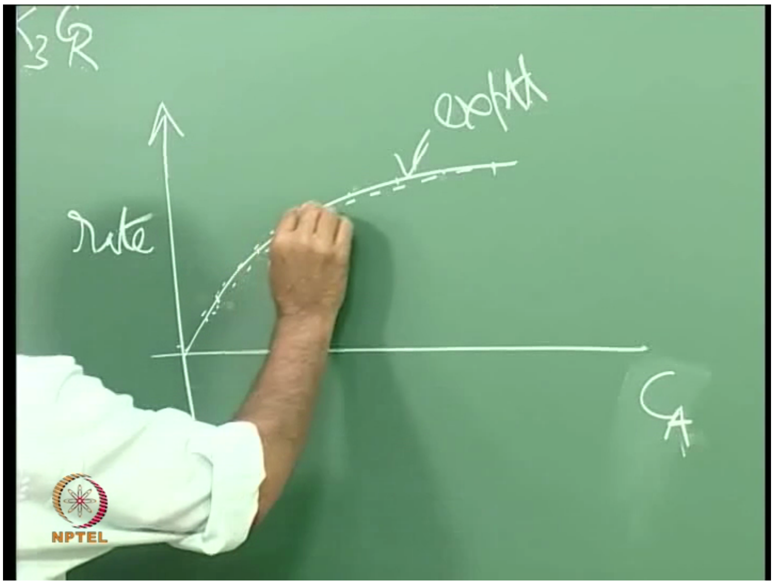

That is why nowadays we are not doing this at all, okay. I mean first of all nowadays who is doing Chemical Engineering? At the industrial level where you have the catalytic reactions you have to model it and all that. So that is why as engineers there is another technique, okay. That technique is you have this kind of equation. Do not worry about what kind of model you have. Model will give you more information for understanding what is happening, right?

And if you are not able to spend that much time another easiest engineers way is assume that we have this rate proportional constant is this, C A to the power of a, C B to the power of b minus C C to the power of c, if it is reversible reaction that is all, okay.

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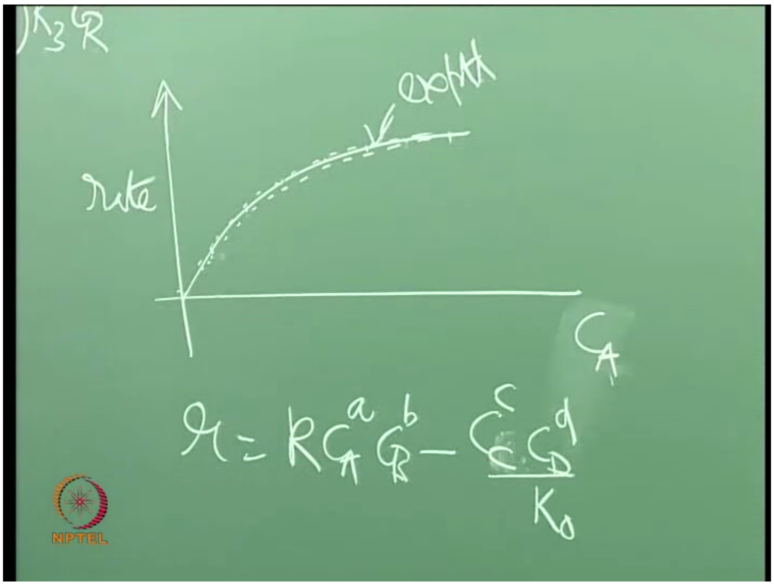

That means you are now trying to have some kind of empirical relationship which will satisfy your experimental data, okay. This is (())(36:24) model, understood. If it is only reversible, irreversible reaction even this term will not be there. If it is irreversible this term also will not be there, you will have only C A, C B. So you have to evaluate a, b and k and do not care whether some mechanism exist there or not. Purely empirical rates, in the bracket. Purely empirical rates, thank you.

That is how we do most of the time we have minus r a equal to k C A to the power of a, C B to the power of b and all that, okay. It is valid in chemical engineering because our idea is to develop a rate expression such that this rate expression I can use it in my reactor design expression, okay. That is one style of doing things. The other way of doing things is that, okay let me now understand. I think most of us will do that, okay.

Every subject when you start you think that you know it is interesting and then after sometime you know you think let me read everything. But finally before the examination you cannot read anything but also you know you did not solve any problem so like empirical, okay. Then try to remember something, come, vomit in the examination hall on the answer paper that we have to clean it. So then I think some marks you will get and then you get the marks, okay.

So that is another way. I think you know to start with every student thinks that this subject is very good. But after sometime because he is not able to concentrate, there are so many other things because he has to take care of things in the India. How many things are going on and all that so that is why I think he may not have sufficient time to read that. And finally before I think the other day we were talking. Prabhu was telling it is our night out.

Yes night out. Night out when? Before hardly maybe 12 hours, okay. 12 hours is also too much I think you know. You start I think around 2 o'clock in the night and next day 8 o'clock class, okay. I mean these are the realities. You do not have to get angry with me, okay. But these are the realities, okay. Not only you, I told you all Indians are brothers and sisters, okay. Nothing will change, okay. All of us have the same mentality so at the end the result is that we do not learn anything.

Student: We already done that earlier.

Professor: So now you become this is another senior. One year you become senior to your junior then you feel that everything in the world you know and you advice also that fellow as if you know everything, you solved all the problems of the world and now this fellow is very small, okay let me give the advice. And that fellow does the same thing you know for each juniors one year. I mean even 20 years difference also I think you know that the wisdom you do not have much difference.

I do not know in one year how suddenly you become that kind of very intelligent fellow to advise all your juniors, okay. And your advice I know. Do not this course because that fellow will tell you all this, okay. That is the kind of advice. And you know the other question papers, he gives same question paper, you do not have to read at all. So take question papers and then solve.

Student: Hitch circle.

Professor: Hitch circle they do not know poor guys, okay. When time is there I will tell you what is hitch circle later. Hitch circle is (())(40:06) that is what, okay. So that is how it is happening and unfortunately of course in engineering most of the time it is thrill I say. It is really thrills. Engineers are the people who run the world and doctors are the people who protect the world because they should not die. And lawyers are the people who, not kill the world. I think make the money. Teachers are poor fellow I say.

Do you remember your teacher? Okay, you do not remember your teacher. Teachers are you know on the way expendables. All these guys are expendables guys, okay. After my course is over do not care and if you do not care it is fine but tell everything opposite to him you know to other people. I can esteem, okay. Do not take this he will tell that, he will tell this and all that. I do not know that is why nowadays in every department we have angels faculty. The angel faculties are preferably deaf and dumb, okay.

Even if you go and as ask only their head works that is all, okay, either horizontally or vertically. You know horizontally means no, vertically means yes. And even if that angel also tells many times like this then you will also become devil. They also will not go to him because he is telling too many things like this. So that is the kind of things you never teachers respect nowadays, good anyway. So this is a wonderful thing really because it is very complicated to develop a rate expression.

That is what finally I want to tell you. I am not saying it is pessimistically. I am only trying to tell you the challenges that are involved in reactor design, okay. Why? The first challenge is rate itself. How do I get all this constants here or all these constants here? And you need lots of knowledge for that in order to evaluate all these constants accurately.

Otherwise empiricism, simple empiricism and you know there is much simpler than (simpricism) empiricism also. You do not need an equation at all still you can design. How? What is that?

Student: Thumb rule.

Professor: No, no thumb rule. You still design. You will find out weight of the catalyst. What is the equation? W by F A not equal to, if it is minus r a. You collect minus r a data experimentally. You know that is why you have to appreciate (())(42:48) I say. So what (()) (42:50) does? He gives this graph wonderfully, minus r a versus x A. So you simply plot. It may go like this.

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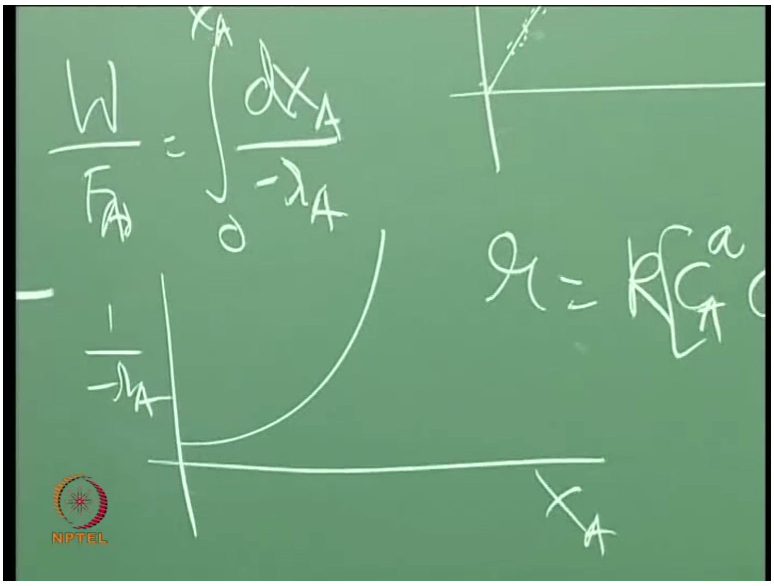

So you are designing a new reactor so you put 90 percent conversion and then area under the curve will give you W by F A not. F A not is already you got it, okay. So W can be estimated. That is much simpler one if you want to really quickly design a reactor like war time and all that. War time designs are there. You know during Second World War all these thrills where there you know.

One group will be theoretically working another group will be working like this very quickly to produce. In fact during Second World War only Denbigh has done wonderful work on. You know Denbigh? You heard of his name? Kavya? Denbigh, his initials are I think K G not M G, milligram K G, okay. So he is from UK. In fact he is the person who gave the name for the CSTR as mixed flow, okay. And you know he was preparing explosives to throw on Germans, UK.

And in explosive reactions the reaction is liquid phase reaction and temperature control is very important. So that is why he has chosen CSTR because the temperature can be controlled. So there again intelligent fellow so he used three tanks four tanks to get. In every tank you can control the temperature very well. And three four tanks if you use almost you will get efficiencies. The production rate will increase tremendously for a given conversion, okay. So why I was telling his name? Yes, okay.

Student: World War 2.

Professor: World War 2 yes, during World War 2 only our CSTR definitions have come, okay. So anyway I think he has also used lot of empiricism but I do not know. I think I sent you last semester some of his papers with minimum mathematics and maximum insight, really beautiful. Later he became philosopher.

I think last 10 years or 5 years of his life I think he just stopped chemical engineering and then start analysing philosophy in terms of thermodynamics because he has also written a book Chemical Equilibrium, okay. I do not know whether you would have not seen. Of course if you would have seen you would have remembered the author's name. Which book you have used in your course?

Student: Which course?

Professor: Thermodynamics.

Student: Van Ness.

Professor: Smith and Van Ness only. No another book, okay. And the classical book is Denbigh. (())(46:03) is.

Student: (())(46:06)

Professor: (())(46:07) This is private engineering college stuff. And (())(46:10) book is not used. No, he is from IIT but that is popular only in private engineering colleges. In IIT no one will use that.

Student: No sir it is very popular here for the first semester.

Professor: Where?

Student: M Tech first semester.

Professor: M Tech probably you are using but I think teacher is not using that.

Student: No sir, teacher follows that.

Professor: Oh, teacher follows that. Now this is surprising to me. But B Tech I think we never followed. Minimum is Smith and Van Ness. You reduce it to too much empiricism so it is only class notes. It is also not your class note, other class notes, okay. So I think in the next class what I tell you is based on this approach I will write at least some 5 or 6 industrially used rates. I am only trying to generate some kind of interest I say. But Anurag sits there always as if he is not in this world.

Student: I am.

Professor: You are? Physically yes, mentally also? Okay, next time I will ask you question okay, to check whether you are mentally there or not. So at least you know that kind of interest. You are going abroad I say you should learn this, okay. Anyway so tomorrow first of all I think you know it is a long time I have done surprise test so I think you may have surprise test also tomorrow, okay. Anyway thank you. Tomorrow morning we will see.