Chemical Reaction Engineering 1 (Homogeneous Reactors)
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Lecture 43
Non-Isothermal Batch Reactors

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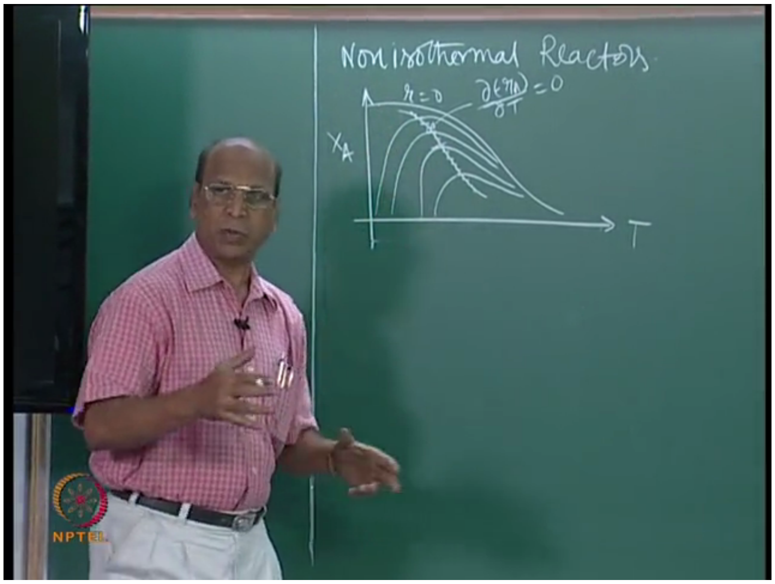

So this diagram I hope you remember. Yesterday also we have been discussing this. This is reversible exothermic reaction where this line is the locus of maximum rates where doh R by doh T equal to 0 and we also discussed that how can I use various sections for various stages for the minimum volume. But I want absolutely minimum volume, what I should do with that diagram? You cannot have less than that.

“Professor-student conversation starts.”

Professor: Yesterday we had three stages. So how many stages we should have if you want to have absolutely, absolute minimum?

Student: Infinite.

Professor: It is infinite, why?

Student: Because infinite it should be…..

Student: It will be isothermal definitely.

Professor: Yeah, is isothermal.

Student: Sir.....

Professor: Cannot be isothermal here.

Student: Adiabatic.

Professor: It cannot be isothermal. So but where I should be?

Student: T method.

Student: Along the T max.

Professor: Where is T allowed? Here this is reversible exothermic reaction. Where is T allowed there?

Student: (())(1:29)

Professor: Yeah, I should be on this line, then you will get absolute, that means all these the rates just touching all these points corresponding axes, that is the maximum rates that are possible. All maximum rates will be on this line. So when I have all maximum rates and then if I am able to operate my reactor with all that possible maximum rates along the length of the PFR, then I will have 1 by R and R is maximum. So 1 by R will be minimum, so you will get minimum reactor volume.

“Professor-student conversation ends.”

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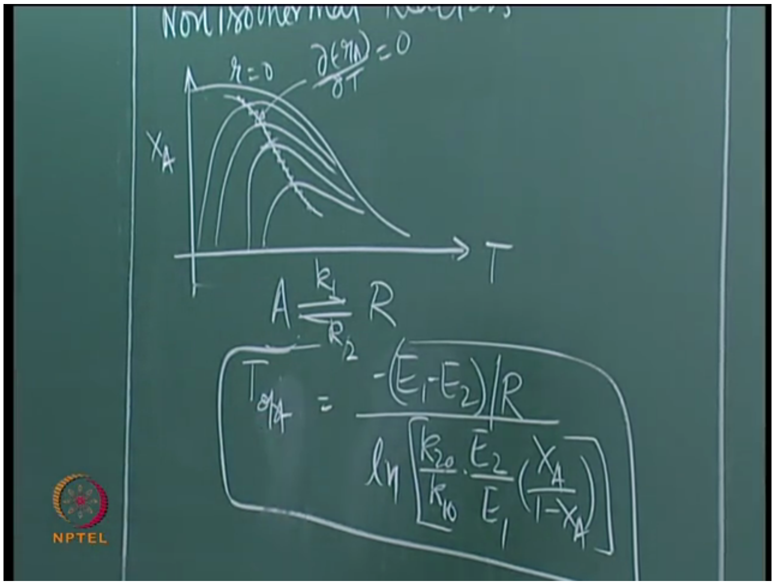

How do you get this equation? I will just give you for reaction A going to R. This is k1 and k2. You can show that, I am not giving the final thing, tau optimum equal to E2 minus E1. I should have changing all this, so write E1. E1 minus E2, this minus will be there, divided by R, yeah so ln of k2 not by k1 not, that is you know meaning of this k1 and E2 by E1, XA by 1 minus XA. Yeah, this is the equation, very beautiful equation which connects tau optimum. Tau optimum is corresponding to maximum rate or the rate corresponding to this tau optimum will be the maximum rate. And this is now related with conversion.

“Professor-student conversation starts.”

Student: Sir, why is tau optimum? T optimum.

Professor: T optimum not tau optimum, T optimum. Yeah, temperature optimum.

“Professor-student conversation ends.”

Temperature optimum is corresponding to that optimum temperature you will have the rate is maximum. So if I able to draw this profile, X versus T, all other things are known. In fact E1 minus E2 is nothing but delta Hr, this is minus delta Hr. The center I think is minus delta Hr. So you can also write this one as minus delta Hr by R. And then E1, E2 I know. k20, k10 I know. XA versus T, I can imagine, I mean I can calculate for XA equal to 0.1 what is tau or T, not tau. And again 0.2, 0.3, 0.4, that is what is this line.

If I am able to stay exactly on that line, then I will have absolute minimum that is possible. And if you have mixed flow reactors, it is very easy to operate. So I will have large number still but in each reactor I can show that okay, this optimum is 1, next one here, next one here, next one here, next one here. Right? Yeah, so let that, it is very easy to operate that kind of thing in mixed flow reactors. Whereas for plug flow reactors, that is not that easy to maintain at each point what is the tau optimum.

So that means you just imagine now. You have to put the heat exchanger such that, that every cross-section you should have the T optimum. Correct now, you should have your scheme either removing heat or adding heat such that always you maintain in that small cross-section, kinetically speaking it is 0 width through each cross-section. You should be able to maintain that T optimum where you can get the minimum, absolute minimum reactor volume that is possible.

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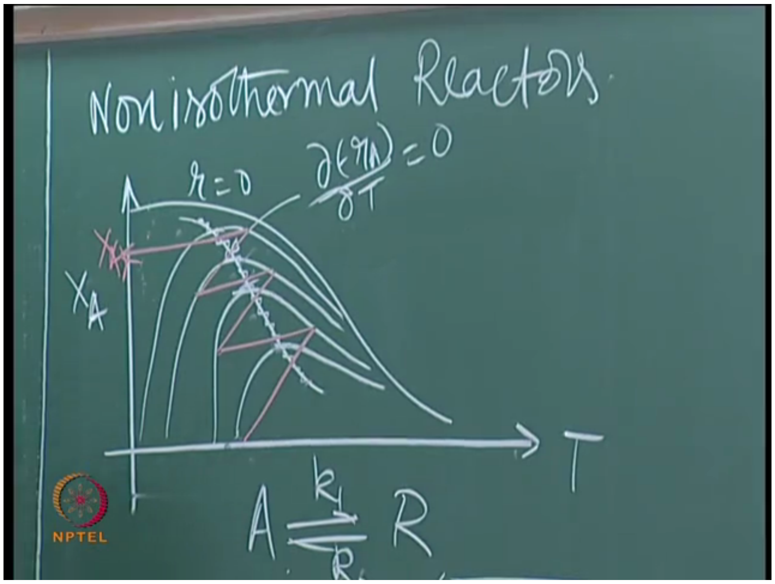

Because we cannot do that, that is the reason why yesterday we have gone and drawn that okay, I will start from here, go here, start, start, start, start. If this is the final conversion that is required, this is XF. This derivation is very beautiful derivation, please do that. It is just nothing but again doh R by doh T equal to 0. Okay? Good, very nice, yeah. Now I also told you that we should have some practice for drawing these lines.

So I will give this exercise, please take that. Develop conversion, develop, there is a problem, this assignment to you. Develop conversion XA versus temperature T plots. Develop conversion X versus temperature T plots with rate of reaction R as parameter using the following data:

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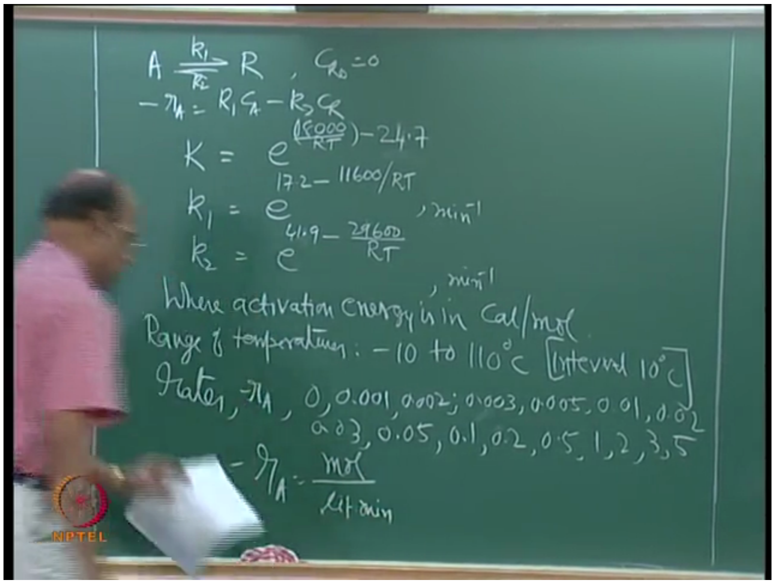

$A \underset{k_2}{\overset{k_1}{\rightleftharpoons}} R$, $C_{R0}=0$

$-r_A = k_1 C_A - k_2 C_R$

$K = e^{\left(\frac{18000}{RT}\right) - 24.7}$

$k_1 = e^{17.2 - 11600/RT}$, min^{-1}

$k_2 = e^{41.9 - \frac{29600}{RT}}$, min^{-1}

Where activation energy is in Cal/mol

Range of temperature: −10 to 110°C [Interval 10°C]

Rates, $-r_A$, 0, 0.001, 0.002; 0.003, 0.005, 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1, 2, 3, 5

$-r_A = \frac{\text{mol}}{\text{lit min}}$

I think I will write here. Okay, A going to R. Then of course minus rA equal to, this is k1, k2; CA, this is k2 CR. Of course CR not equal to 0 here, that is the pure. CA only what we are taking. And equilibrium constant K is e power 18,000 by RT minus 24.7. Yeah, everything is in exponential, that is K. Rate constants, k1 is e power 17.2 minus 11,600 by RT. Units are minutes inverse, k1.

k2, because both first order, I think better write minutes inverse. k2 is then e power 41.9 minus 29,600 by RT, this is also minutes inverse. Yeah, this is, where this activation energy, these values, where activation energy is in calories per mole. So I think normally in this when you are drawing this graphs, I think your range of temperatures will give you lot of problem. So that is why in this problem I am specifying the range of temperatures to draw that graph, you can try between minus 10 to 110 degree Celsius. And of course the interval you can have, interval 10 degrees.

That means minus 10, 0, 10, 20, 30, 40, like that. Yeah, okay? So then the parameter values, rates, that is minus rA or rA, they will be 0, 0.001, 002, 003, point is there, 0.002, 0.003. Then we can have 0.005, 0.01, 0.02, 0.03. I think we can shift to 0.05, yeah, this is 0.1, 0.2, 0.5. Then

1, 2, 3, 5. How many lines we will have? 4, 5, 6, 7, 8, 9,10, 11, 12, 13,14, 15 lines we will have here in that graph. Draw that, that is an excellent experience if you are able to draw that. And minus rA is in moles, liter minute. Because this our concentration also in moles per liter. CA also is in moles per liter. Okay, this one please draw.

And few of the graphs I may also ask in the examination because you have three hours now, the final examination. So what you do? You have to draw this kind of curve and other, three hours what you do, so that is why I may give this examination there.

“Professor-student conversation starts.”

Student: Sir, k1 by k2 is not equal to k.

Professor: k1 by, which k you are talking? K?

Student: Yes.

Professor: Yeah. Why then?

Student: It is not meant. 41 minus 178.

Professor: It is correct only, check because that is given in a different way. That is correct only.

Student: 17.2.

Professor: 17.2 and 41.9.

Student: Correct only this, sir.

Professor: Yeah. The other one is 7.6 and yeah.

Student: Matching.

Student: I think 172.

Professor: It will.

Student: 172. Just like 172.

Professor: It is a standard problem. It is not a new problem created by me. Okay, good, so that is what you can do it and then, yeah. So with this general discussion on graphical design is over, I hope you understood the essence of what we are trying to do in the last 3-4 classes. This will give you the overall picture for the actual analytical work also. Now what we are going to do is for batch reactor separately, plug flow reactor separately and also mixed flow separately, we are going to write the equations. But this gives me framework for the coming classes.

But I think here if you are able to use even graphical one, even if it is possible to draw in the examination hall, it is excellent. Because do not think that graphs are going to take more time. But I think if you are good artist, quickly you can draw that and all engineers must be artists. Otherwise you do not even know how to draw a straight line. And if you have a BTech degree or MTech degree or you are not able to draw the straight line, I think it is waste. Yeah, because I think straight line is the first simplest one what you can draw.

Good, yeah, so that is one. Now let us take batch reactors. And if you have any questions, I am sure you will not have any questions because most of the time I have to question, I have to answer. Okay and you will be seeing there, sitting. Now let us take batch reactor. Good, so I think to summarize, just Abhishek which will be really thrilling out of all these reversible reaction? Reversible endo, reversible exo?

Student: Exo, Reversible exo.

Professor: Why?

Student: Thrilling sir.

Professor: Why thrilling? Just thrilling?

Student: Dynamic programming.

Professor: Dynamic programming, yeah. That condition comes through dynamic programming because here the problem is challenging. Challenging in the sense that there are two opposing things. High temperature, yes, we like it. High rate of reaction, we like it but you do not have sufficient conversion finally.

“Professor-student conversation ends.”

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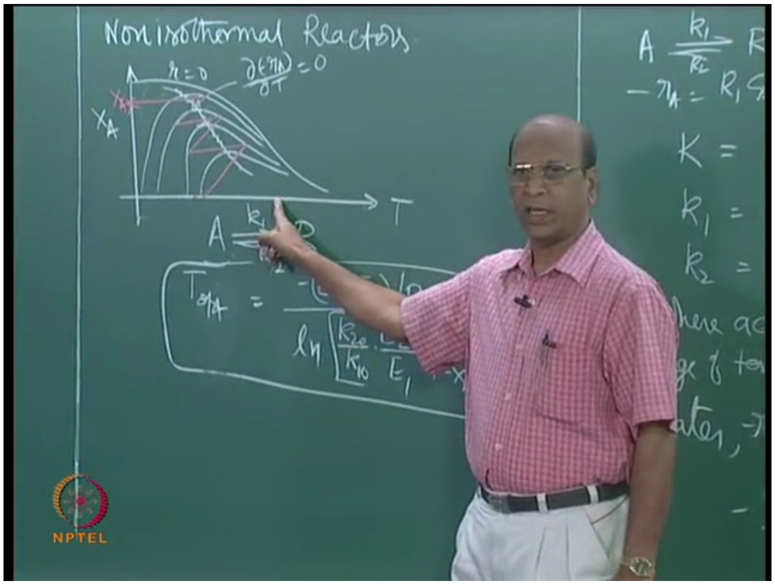

At the end you cannot get, if I start at very high temperature, rate of reaction will be very high. But maximum temperature is (())(14:43) is only this much temperature. If you go to adiabatic, now that only this much. So that is why how do you make this one use high rates, that means high temperatures plus still get maximum conversions. So you start here and then go slowly and you find out what is the required temperature and how many stages you need.

That is what exactly the question I have asked in the first 0th examination where I asked why for SO2 to SO3, multi-bed adiabatic reactor is used. Multi-bed adiabatic reactor for V2O5, vanadium pentoxide catalyst and is a catalyst, catalytic reactor. And they need generally 2 to 3 beds in series. In between they have heat exchanger.

“Professor-student conversation starts.”

Professor: I also asked another question, why in ammonia reactor heat exchanger type is used? It is not adiabatic reactor but also I asked. Have you thought any time that also comes under non-isothermal. Question is clear first of all (())(15:56), question also not clear. What did I tell you just now?

Student: Why in ammonia…..

Professor: Why in ammonia…..

Student: …..we use heat exchanger.

Professor: So then why question is not clear? That is to evade answer, first thing student says is that question is not clear, sir. So even the simplest question we ask in the interview, they say no sir. I think as if drama, acting. So as if he has not understood at all, no sir, not understood. Then again I have to tell the same question in a different way. Answer may not come but anyway question will be repeated many times. So but why should we use? Now can you expand your brain and then try to think?

Now why we have to use for SO2 to SO3, this multi-bed adiabatic reactor? There we need high conversions in SO2 to SO3, usually around 85-90 percent conversion. It is reversible exothermic, V2O5, and that catalyst is reversible exothermic.

“Professor-student conversation ends.”

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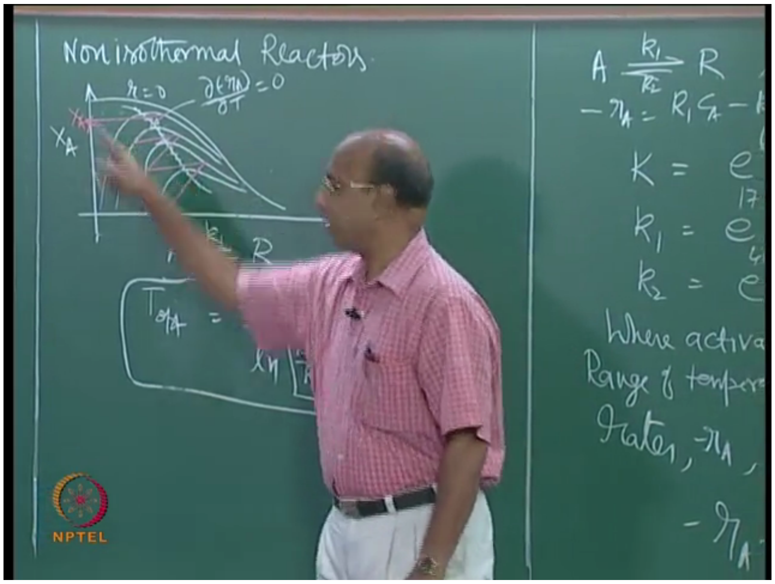

So if I straight away start here, because here I have 85 percent conversion. If I just use only isothermal and then 85, what are the rates here? Very less.

“Professor-student conversation starts.”

Professor: Then what will be the volume? Equivalent to IIT campus. You know what is area of IIT campus?

Student: 600 acres.

Professor: Very good, yeah, 632 acres. Okay, so one reactor you cannot have that area. So that is the reason why we have to go for high, use, high means high rate of reaction and then at least the first part will be less and next part will be slightly bigger, second reactor. Third will be slightly bigger than the second one. So like that it increases. Because you are moving towards lower region. Whereas in ammonia for example, that is very very highly exothermic reaction. So that is why moderately exothermic reactions where you have reversible, then only we use adiabatic reactors.

“Professor-student conversation ends.”

And when we use adiabatic reactors, of course reversible exothermic, then you will have definitely, have to move from low conversions to high conversions. So that is why you use multi-bed. Stage 1, at this level, at this range, high ranges, high rate range. So then move to low range, still further move to low range depending on your conversion. So that is the reason. I think now you appreciate these reasons I said. So wonderful theory behind that and everything is thermodynamic and kinetic data, wonderful. Okay? Good.

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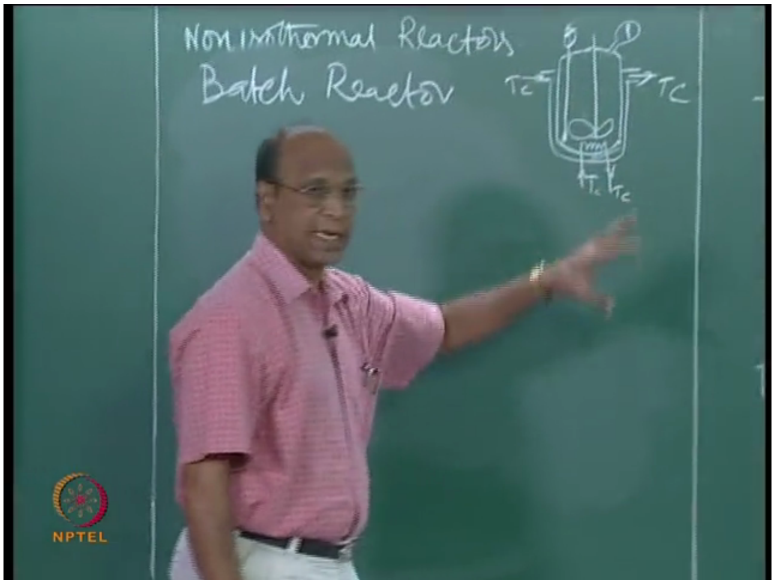

Now let us take batch reactor, so I think we will remove this. Where is this, yeah, now let us write this material and energy batch, material and energy balance equations for each reactor.

First, let us take batch reactor. Batch reactor, we have been telling that normally we will show like this, okay. Then you may have the, yeah, maybe coolant in, TC, TC. Then we will have the stirrer. Here I may have temperature, rope maybe thermocouple. Somewhere here I will have pressure gauge. If possible, we have to also use internal coils again, TC, TC et cetera. Not only bottom, I think you can also use side, you can also use side. All this is possible. Okay? Good. So now we need the material and energy balance for this. And of course I do not have to draw again the profiles.

“Professor-student conversation starts.”

Professor: Like with here with time again depending on if I have adiabatic reactor, what kind of temperature profiles you get? Conversion and temperature profiles if I have adiabatic reaction. That means all this is insulated and simply, so okay draw in the air. Air means like this.

Student: XA end.

Professor: XA, what is this, what is other variable?

Student: Temperature.

Professor: I have asked Abdul means Abdul represents the entire class. Everyone has to draw. I mean you are enjoying, when we are talking and all of you are laughing at me. Yeah, like this?

Student: Yes sir.

Professor: What is this, what is this?

Student: (())(20:54).

Professor: First you have to draw like this, like this. So now you have to draw sides, temperature like this. Okay, that is adiabatic. Now tell me for non-adiabatic non-isothermal.

Student: Not adiabatic and isothermal.

Professor: Non-adiabatic, non-isothermal. Bala?

Student: Increases.

Professor: Adiabatic also increases, non-adiabatic non-isothermal also increases.

Student: Sir, exothermic will increase.

Professor: Exothermic we are talking. What do you mean by non-isothermal non-adiabatic? Exothermic reaction where Kelvins…..

Student: Increase or decrease temperature.

Professor: Non-isothermal can increase or decrease, how? Under what conditions it will increase and what conditions decrease?

Student: Exothermic will increase, exothermic.

Professor: I am asking I have a system where it is not adiabatic, it is non-isothermal, non-adiabatic. What is the meaning of (())(21:57)?

Student: Non-isothermal.

Professor: Good. So what is the meaning? What is the real meaning?

Student: We have heat exchanger.

Professor: You have heat exchanger. Okay, so when they have exothermic reaction, we are removing some heat.

Student: Heat sir.

Professor: Now Bala.

Student: Increase and decrease it.

Professor: Uhh?

Student: Increase and decrease.

Professor: Yeah, depending on the heat removal, it may go maximum and then?

Student: Decrease.

Professor: Decrease. Yeah, if you are removing only very, very, very small amount of heat, then also it may slowly increase and then maybe flattening out. So there are many many possible curves. Isothermal, that is very easy, straightening. Okay? Good. So that is what is applied and conversion also increases. So that is no problem.

“Professor-student conversation ends.”

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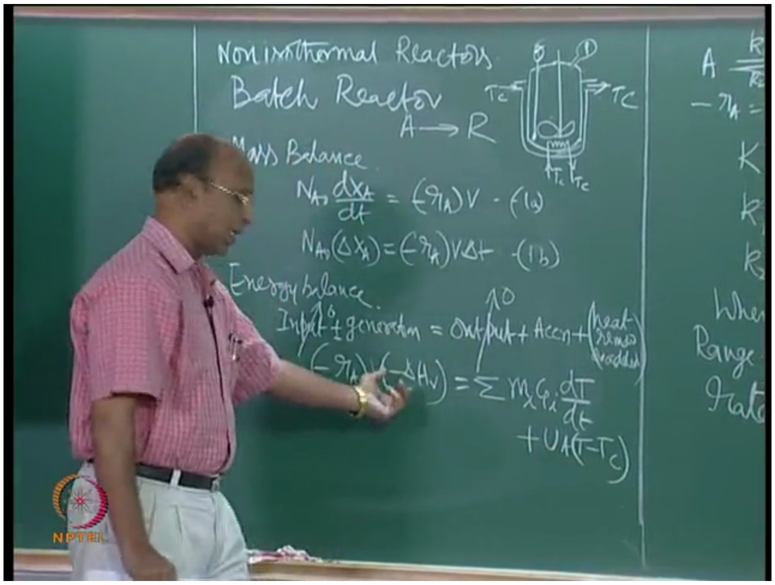

So now we have to have the mass balance equation, always we have a reaction something like this, A going to R for the simplest cases. Okay? So mass balance of A only normally we write only for one component. Mass balance of A, this is NA not, dXA, but this one we have already done it. So that is why I am not writing again, elements and all that. Okay, minus rA. And this equation can also be written in terms of deltas, that is required. Delta XA equal to minus rA V delta t. So this is equation one.

Okay, this is 1a, this is 1b. Okay, good. So this minus rA can be also variable volume, means it will have k into CA where variable volume means CA by CA not equal to 1 minus XA by 1 plus XA and all that are there. Okay, good. So energy balance, this is input plus generation equal to, generation will come if it is exothermic heat. Yeah, then output plus accumulation, sorry, this fellow is inherently unsteady fellow, batch reactor. Plus accumulation and heat removed or added. Okay?

Of course again here also I have to write in general, minus generation means endothermic. Right? Okay, good. So this is the general one. So now let us write for only exothermic so that we will have some feeling for that. And we know that it is a batch input 0 and output 0. We are writing for exothermic. Exothermic, let us maintain minus delta Hr as a positive quantity, that is our convention. Please write there somewhere, minus delta Hr equal to some positive, maybe 30,000 calories per mole or something like that.

So generation when I write for, this is minus rA, V minus delta Hr. That is equal to, yeah, that is generation, that is equal to, then I have sigma of Mi Cpi dT by dt. That is accumulation. Plus I have heat removed, UAT minus TC. So I have only three terms now: generation, accumulation and heat removal. Because we are talking about exothermic reaction, minus delta Hr, so that is why this is UA T minus TC. Good, so this is the equation. And now let me go to other side. So this equation, this is maybe 1 and this is 2. This is equation number 2.

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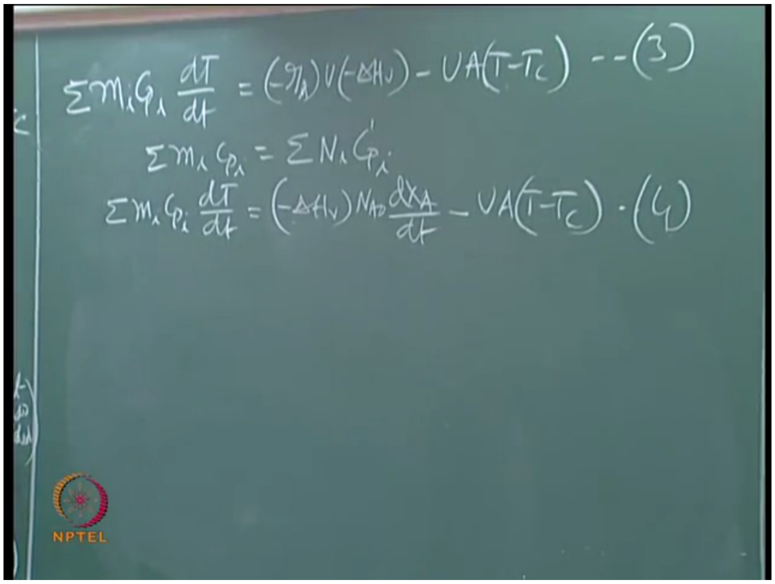

$$\sum m_i C_{p_i} \frac{dT}{dt} = (-r_A)V(-\Delta H_r) - UA(T - T_c) \quad \text{--}(3)$$

$$\sum m_i C_{p_i} = \sum N_i C_{p_i}'$$

$$\sum m_i C_{p_i} \frac{dT}{dt} = (-\Delta H_r) N_{A0} \frac{dX_A}{dt} - UA(T - T_c) \cdot (4)$$

So this equation I will just simply try to write like that, sigma, see if you have the average properties for the entire bulk reaction mixture, okay so then that will be simply M Cp. That is all. Otherwise if you want to write for individual components, Ma, M is the mass and Cp. Or M also can be moles but Cpi will be in terms of moles. They are the calories per mole per degree centigrade. So that is why, that one please do not get confused. So this is dT by, this is temperature and this is time, that is equal to minus rA V minus delta Hr. Yeah, minus UA T minus TC. So I think maybe for continuity sake or as a clue, I can also write here Mi Cpi where M is mass. Cpi is the specific expressed per mass.

This is also equal to Mi, this is Ni Cp dashed A, where Cp dashed is for in terms of moles. Normally here you will make mistakes, that is why I am trying to write all those simple things also. Okay, good.

“Professor-student conversation starts.”

Professor: So you know most of the time we have been talking about energy balance in terms of, energy balance gives me the relationship between XA and?

Student: Temperature.

Professor: But this equation 3, will it give me relationship between temperature and conversion?

Student: No.

Professor: It will not give me. So then how do you make that?

Student: Cannot use.

Professor: Now we will use, yeah, we use this relationship and then substitute it there so that you will have the relationship between conversion and temperature. So that is why substituting equation 1a in 3, this is dT by dt equal to minus rA V, no, this rA V only we have to change. This is minus delta Hr, this is minus RA into V, so this is NA not, dXA by dt minus UAT minus TC. So this is equation number 4. Okay, now the problem here is that I have to use these two equations. This is energy balance equation, this is meter balance equation, this is energy balance equation to solve my conversion versus rate.

Finally the design is only 1 by minus rA versus XA only. Then area under the curve will give me here total time that is required for certain conversion. But here I have only two equations and how many variables I have?

Student: 3.

Professor: What are the three variables?

Student: XA, T, and….

Professor: Temperature…..

Student: Conversion, and height.

Professor: And height. Three are there. So that is why we have to go by parallel. We do not have third equation.

“Professor-student conversation ends.”

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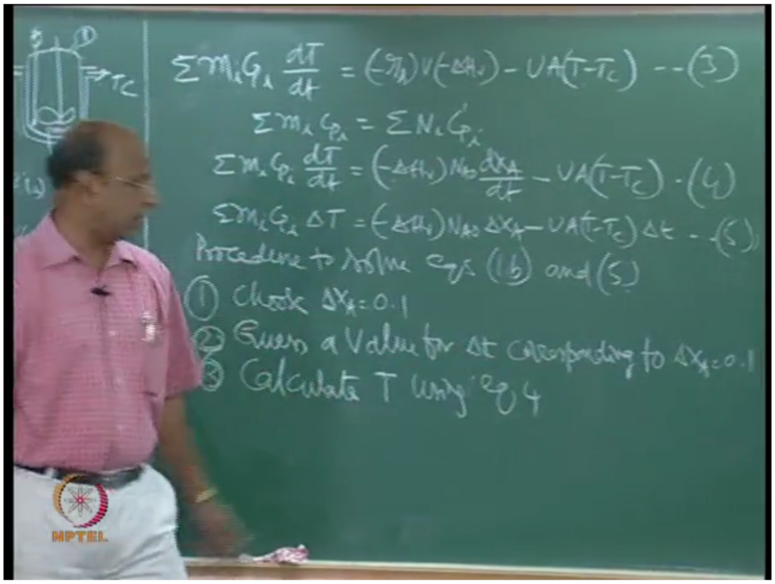

$\Sigma m_i C_{p_i} \frac{dT}{dt} = (-r_A)V(-\Delta H_r) - UA(T-T_c)$ --(3)

$\Sigma m_i C_{p_i} = \Sigma N_i C_{p_i}$

$\Sigma m_i C_{p_i} \frac{dT}{dt} = (-\Delta H_r) N_{A0} \frac{dX_A}{dt} - UA(T-T_c)$ ·(4)

$\Sigma m_i C_{p_i} \Delta T = (-\Delta H_r) N_{A0} \Delta X_A - UA(T-T_c)\Delta t$ --(5)

Procedure to solve eqs (1b) and (5)

① Choose $\Delta X_A = 0.1$

② Guess a value for Δt corresponding to $\Delta X_A = 0.1$

③ Calculate T using eq 4

So that is why what we write here is in terms of deltas, sigma Mi Cpi delta T equal to minus delta Hr NA not, delta XA, minus UA T minus TC into delta t, this is time small. Just divided by dt and then written this in terms of difference equation. So now what is the procedure? Because I have to get the relationship between temperature, conversion and rate. And of course indirectly that you know this time, rate has dX by dt, so that comes there.

That is why there is a procedure now by trial and error, what we have to do is that procedure to solve equations 1, this 1b, that is also difference equation and 5. So what step 1 is we will just try to have, you can start with anyone but I am starting with conversion. I will assume that I have delta XA equal to 0.1. Choose delta XA equal to 0.1. And Abhishek may say no sir, I do not want to take delta XA equal to 0.1, I want to take only delta T, temperature for degrees, T.

And Abdul may say, no sir, I do not want to follow him, so I want to take delta t. So then that is time. Then probably you may think that okay, in five minutes what is now you have to, whether if you assume delta X, now we have to imagine that or guess that in this 0.1 increment of conversion, what is the increase in temperature. Time also you can, anyone. Then the other one you will check whether your guess is correct or not. So now here guess a value for delta t, t I am taking.

To calculate temperature, t, delta t corresponding to this delta XA 0.1. Now so that means I know delta X from this equation, 0.1 and I know delta T, 0.5 and other things you should know. So other things means UA you should know, heat transfer coefficient and area. And here of course delta Hr I know, NA not I know. And these properties I know. Here I have T0 minus are exothermic now. T minus T0, T0 I know, TC I know, T0 is initial temperature. So that is why I know everything except T.

So you calculate T using equation 4. How do you I know that my guess is right? For this step I have temperature, conversion XA, XA initially equal to 0, right? Delta X, X0 equal to 0, so X equal to 0.1. Corresponding to that I have guessed time, 5 minutes.

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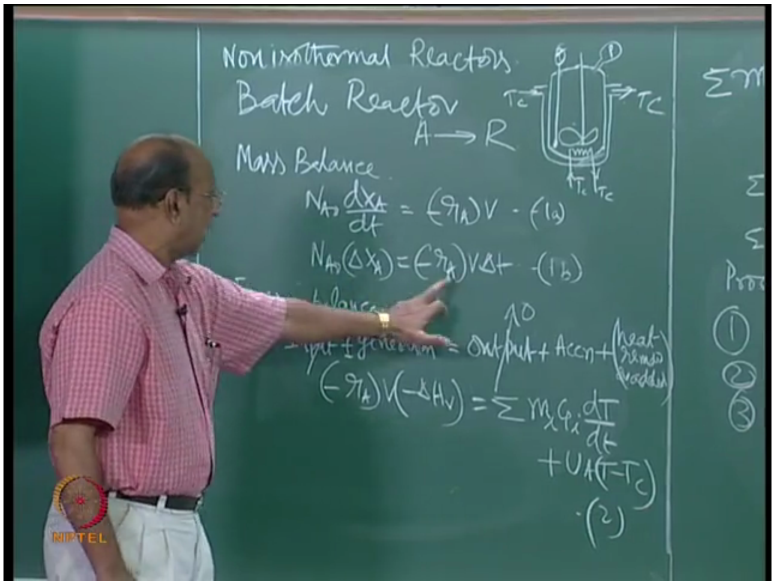

So then I know everything. Now I have to check this, so I will go here and then check in this. That means I will substitute whatever values I have there, I will put here. I know delta X and NA not I know. And here in minus rA, it can be very complicated. May not be simple kCA, it can be any complicated equation. So here this minus rA contains temperature and conversion. If it is the simplest case if you take, this is kCA. k is nothing but k not e power minus e by RT X. So I know X now, I know T now and I can calculate minus rA.

And V, in this problem, you have to assume some V in the beginning. And also you know that whatever volume you assume and you are finally calculating time, time will not change. For a batch reactor, time, whether you take large reactor or small reactor, time is same for given conversion. Even if you take 10 meter cube reactor, for 90 percent what is the time and even if you take 1 liter, time is same. But volume will come only when you are calculating productivity.

That is what you have also done that how many batches per day and each batch volume, and if you know the densities and all that, you can calculate volume of the actual reactor. So that is why some volume definitely you have to assume there. So that means yeah, I will now put all those values and then check whether LHS equal to RHS. If not, again start again. Okay? Good. So that is the procedure.

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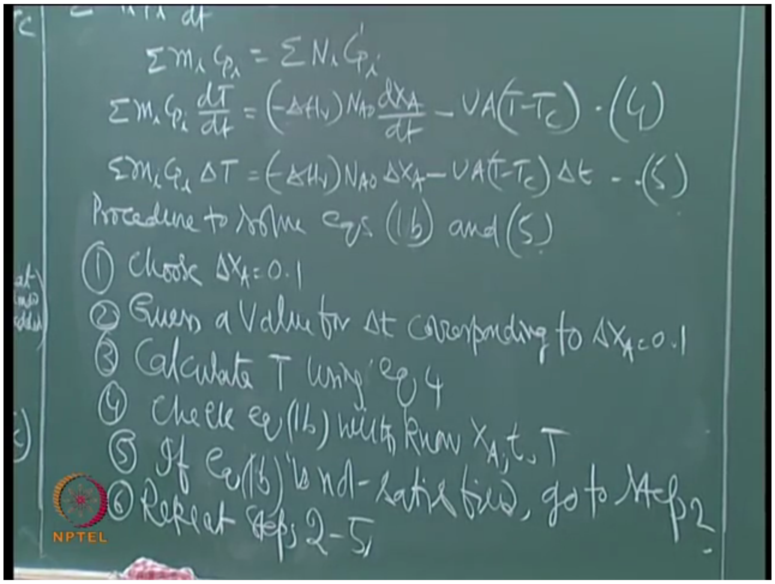

$$\Sigma m_i C_{p_i} = \Sigma N_i C_{p_i}'$$

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$$\Sigma m_i C_{p_i} \Delta T = (-\Delta H_r) N_{A0} \Delta X_A - UA(T-T_c) \Delta t \cdot\cdot (5)$$

Procedure to solve eqs (1b) and (5)

① Choose $\Delta X_A = 0.1$
② Guess a value for Δt corresponding to $\Delta X_A = 0.1$
③ Calculate T using eq 4
④ Check eq (1b) with known X_A, t, T
⑤ If eq (1b) is not satisfied, go to step 2
⑥ Repeat steps 2-5

So now, yeah, then step 4 is check equation 1b with at this time with non XA, t and T. So if 1b is not satisfied or equation 1 we have, if equation 1b is not satisfied, then go to, then you have to go to step 2. Satisfied, go to step 2. And you will easily get these things. And of course next one is repeat 2 to 5 because this anyway everything you are choosing that, so 2 to 5. So that is the procedure. Very good. This is actually the non-isothermal, non-adiabatic reactor.

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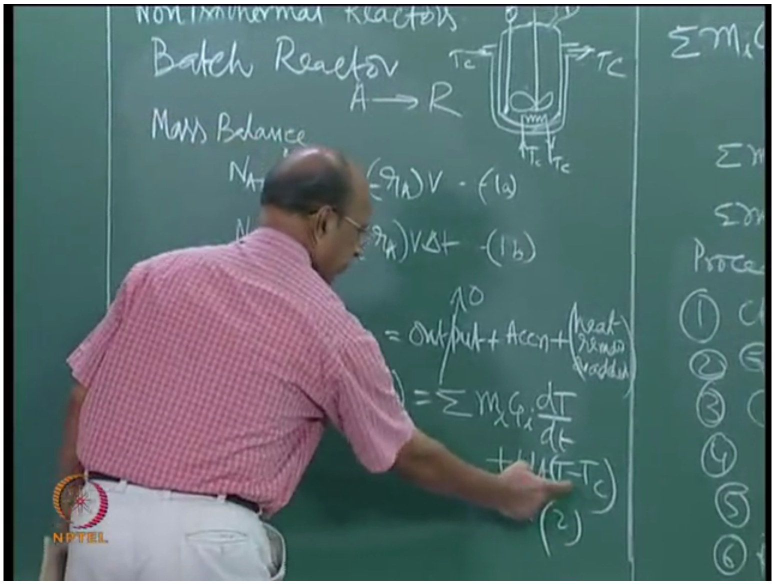

Non Isothermal Reactors

Batch Reactor

$A \rightarrow R$

Mass Balance

$N_A \ldots (r_A)V \quad -(1a)$

$N \ldots r_A)V\Delta t \quad -(1b)$

$\ldots = \text{Output} + \text{Accn} + \begin{pmatrix}\text{heat}\\ \text{remov}\\ \text{added}\end{pmatrix}$

$\ldots) = \sum m_i C_{p_i} \frac{dT}{dt} + UA(T - T_c) \quad (2)$

Because you have that, you have the heat transfer term here. So now let us see for adiabatic system, what will happen. For adiabatic system, yeah what should be missing?

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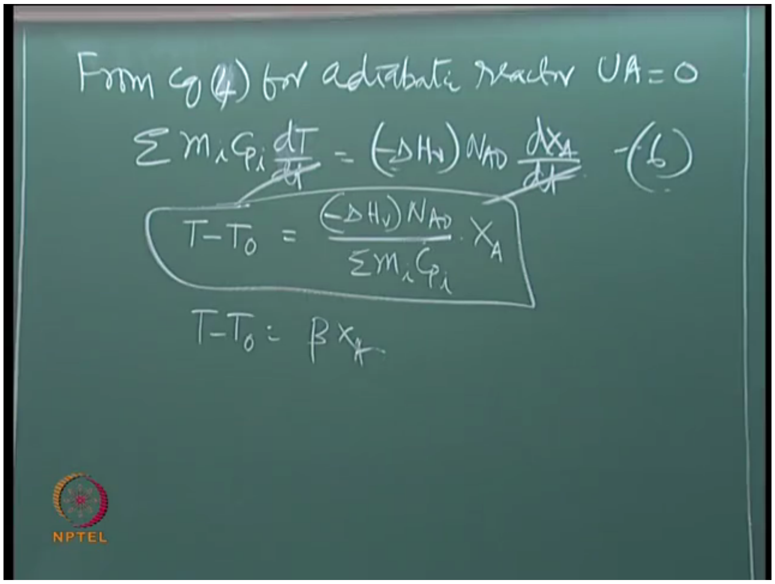

From eq (4) for adiabatic reactor $UA = 0$

$$\sum m_i C_{p_i} \frac{dT}{dt} = (-\Delta H_r) N_{A0} \frac{dx_A}{dt} \quad -(6)$$

$$\boxed{T - T_0 = \frac{(-\Delta H_r) N_{A0}}{\sum m_i C_{p_i}} \cdot X_A}$$

$$T - T_0 = \beta x_A$$

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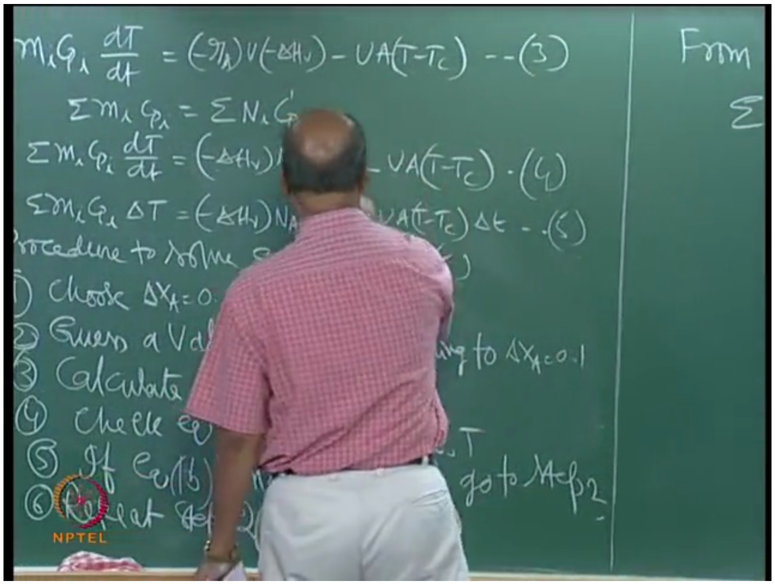

From equation 3, for adiabatic reactor UA equal to 0, then this term will not be there. Then we will have sigma of Mi Cpi dT by dt equal to not 3, 4. 4 is easy for me because I want relationship between conversion and temperature. So equation 4 gives me that. So this is minus delta Hr, NA not dXA by dt. So this, this can get canceled. So this 6. So now if I take this side, this is, yeah integrate that. T minus T not equal to minus delta Hr NA not into XA, minus XA not. XA not usually we take 0, XA not. So this is the equation.

So this is what we have been telling also earlier that you get T minus T not equal to this is beta XA. This is easy to solve for me because time is getting canceled here in this equation. So this is the one and you know how to use this. This is the beta is the slope and you have to plot. If you want to plot on the X versus time T diagram, so then you can plot that 1 by beta as the adiabatic line and then see what are the intersection points.

And now you take corresponding X, corresponding R, 1 by R, plot 1 by minus rA versus XA. Area under the curve will give you T by C not or the way how you write that equation. Okay? Good. This is what I think we already discussed about adiabatic system long time, so I think we do not have to discuss anything further. Good, yeah.

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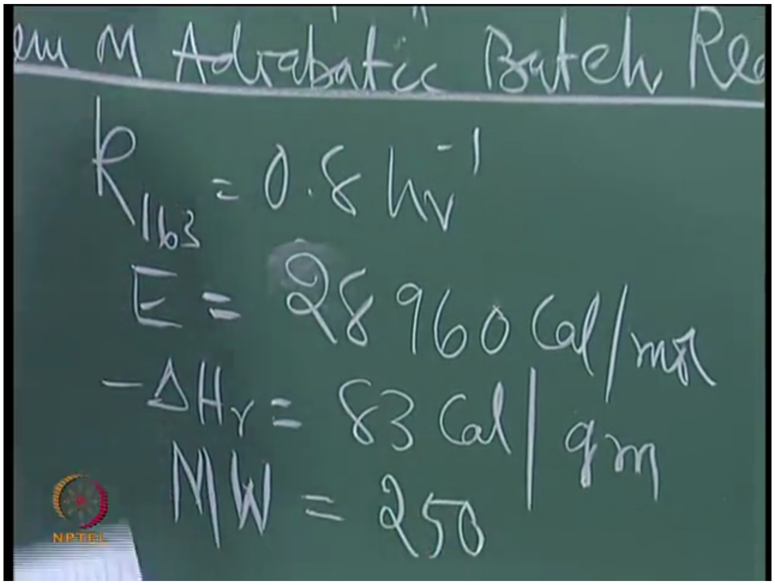

em on Adiabatic Batch Re

$k_{163} = 0.8 \ hr^{-1}$

$E = 28960$ Cal/mol

$-\Delta H_r = 83$ Cal/gm

$MW = 250$

So one problem quickly you can do it. I will just dictate and I will give the answers you can check. This is adiabatic reactor batch. Problem on adiabatic batch reactor, problem on adiabatic, okay good. Reagent A undergoes an essentially reversible first order reaction A going to R. Both A and B are liquids at room temperature and both have extremely high boiling points. Determine the reactor volume necessary to produce, I just want to give this one as it is.

2 million pounds of R, I hope you know the conversion between pounds and kgs. So that I think still this kind of units are required in chemical engineering because we have still lots of data in various units, still lot of heat transfer data and all that available in BTUs. No more joules and all that. So that is why I think we should be familiar with all that. That is why I just would do, tell this 2 million pounds of R in 7,000 hours of operation. That means you have to determine the reactor volumes necessary to produce 2 million pounds of R in 7,000s of operation.

One, if reactor operates isothermally at 163 degree centigrade, if reactor operates isothermally at 163 degree Celsius. B or 2, okay 1 I said, now 2, if reactor operates adiabatically, so that means two you have to do, one is isothermal case, other one is adiabatic case. Use the following data. Just below write, minus rA equal to k into CA, first order reaction very simple. And liquid phase also we told. Minus rA equal to kCA.

Then next one is k at 163, k is k, at 163 degree Celsius is 0.8 hours. k at 163 is 0.8 hour inverse. Activation energy E, equal to 28960 calories per gram mole, calories per mole, mole means always gram mole. So then minus delta Hr equal to 83 calories per gram. Molecular weight, MW, 250.

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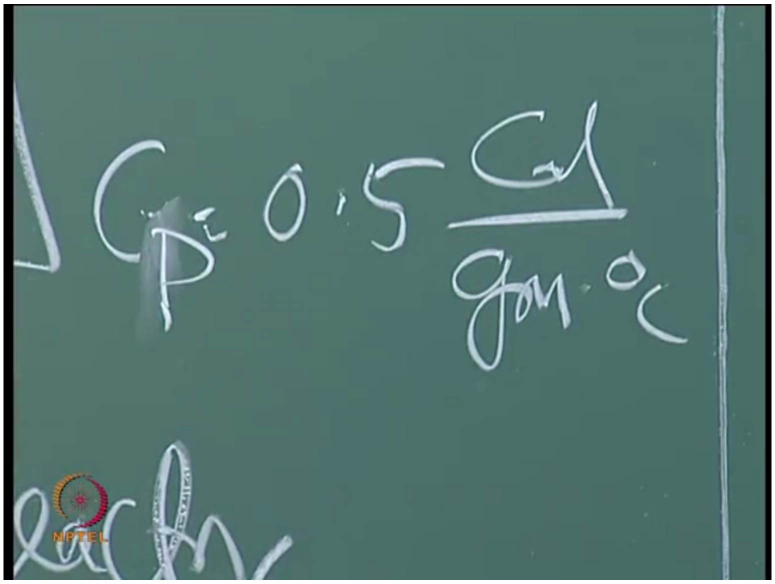

$$C_p = 0.5 \frac{cal}{gm \cdot {}^\circ C}$$

The heat capacities of A and R maybe assumed constant, equal to Cp, 0.5 calories per gram or degree centigrade. That is Cp, both are same, Cp value. It does not look like Cp. Okay. Still, now it may be looking. Good.

The density of the reaction mixture maybe, density of the reaction mixture is 0.9 grams per cc. All kinds of units we are giving. The densities, the density of the reaction mixture is 0.9 grams per centimeter cube, centimeter. Next line, the times necessary to fill and drain the reactor may be assumed. Next sentence, it may be assumed that negligible reaction occurs during the 14 minutes, during the 14 minutes. It takes to heat the feed from the temperature at which it enters the reactor to 163 degree Celsius.

In simple words it is heating time required is 14 minutes, heating time to 163. After 97 percent of A has been converted, the product mixture is discharged. So the answer to this problem is that now I think you have to go now. See for the first case, isothermal, the answer is T, the time. Time is 4.383 hours. T is 4.383 hours and the volume is 740 liters, plus or minus 5 this way that way. The volume required is 740 liters.

“Professor-student conversation starts.”

Professor: For non-isothermal case that is adiabatic reactor, you expect lower volume or higher volume? Which one, Rahul?

Student: Higher volume.

Professor: Higher volume. Devoy?

Student: Higher volume, sir.

Professor: Higher volume, why? Anyone? Sania? Okay, Rajashree? Who said decrease? Savita, why?

Student: Exothermic.

Professor: Exothermic, decrease it.

Student: Decrease it.

Professor: Mind, mind, mind. Because in exothermic reaction temperature increases. When temperature increases, then you have rate of reaction increasing. When rate of reaction increasing, in the design expression that fellow is there in the denominator. So time will decrease. So total volume also will decrease. In fact time you will get only 0.12 hours, 7.2 minutes. For adiabatic case time required is, for 97 percent conversion is only 7.2 minutes. And what is the earlier number for isothermal?

Student: 2.03.

Professor: Yeah, see. Okay, good. So that is one and volume required is maybe around 105 or 110 liters, volume required for adiabatic thing.

"Professor-student conversation ends."

This is a wonderful problem I have chosen. The reason is you will know the effect of this adiabatic reaction, for exothermic reactions particularly because naturally it also increases the rate of reaction. Only irreversible, reversible exothermic only is the problem. As the temperature increases, conversion falls. But this is reversible reaction. So temperature increases, rate of reaction increases, your time decreases and volume decreases. See those things I think you know, that should be permanently there in your brain. No? Should be. But I think, okay, good, we will stop here.