Chemical Reaction Engineering 1 (Homogeneous Reactors)
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Indian Institute of Technology Madras
Lecture No 44
Non-Isothermal Plug Flow Reactors Part I

Yeah okay, yeah we have been discussing about this non isothermal reactors, batch reactor we have completed yesterday. I don't know how many of you have solved the problem.

Student: Sir.

Professor: Yeah how much?

Student: Analytical discussed there only graph.

Professor: Analytical, yeah.

Student: Analytical I tried but.

Professor: No you cannot, I think there is formula which I am going to give you for the plug flow reactor yeah, yeah but I think only under graphical thing you should get I think answer you got almost same?

Student: Point 1,2

Professor: Yeah, so again this is the problem. Most of the Mtech student are not doing that only MS, PHD students are doing, I think MS also is equal into Mtech because in there mind and all that age wise, emotion wise, so that is why I think MS equal to Mtech there also not solving the problem but don't blame me if you don't get the marks again I am telling you okay, one way of full learning subject is when yesterday or Friday when we solve that problem I gave the hint how to solve if you would have solved you would have been happy. Okay now he told something I did something it came alright I am happy.

Confidence always comes, but the moment you postpone till the third quiz, you are going to pay for it. I know third quiz I think okay, I will see just before 1 day before third quiz that is what the mentality of many people if you do that you will never get marks. Okay good so batch reactor I think you have not solved only Ramkrishna.

Student: Solved

Professor: You solved, you also solved it, okay. Yeah I know most of the non isothermal problems you will not have analytical solutions you have to draw the graph and idea of giving assignment is for you to experience the graphs, formula, the way you write the balances all that, that will give you experience if you solve the problems in your room. I know most of you are not listening to me also. Okay.

Student: Less time consuming sir, graph in analytical.

Professor: Yeah if you thought like graph that is the most beautiful way of doing problems. Really I think analytically you may make the mistake but graphically you can not generally make the mistake. Right so that is why I am trying to maximise your learning as much as possible and your optimisation is you are trying to minimize learning as much as possible and maximise marks as much as possible.

Okay so now I think particularly non isothermal reactors unless you do many problems I am going to send today or tomorrow another assignment on non isothermal but not many problems again may be 5-6 problems right. But unless you do that I think you will not get happiness in learning forget about marks. That ever learning ever happiness is only getting marks without solving a problem how do you get 100 out of 100. Correct no? Most of you feel that you should not work but you should get 100 out of 100, right?

How is that possible it is impossible? Right? I think you know on this planet even if you want to have child you have to wait 9 months you cannot have I want child in 2 days, how can you have the planet I think the nature of the planet is totally different that is why even learning also it is different for learning it takes time and talking in chemical engineering words learning is by diffusion now you see he is happily like that he is telling.

Okay that is the indication that I have to stop. Right? Because whatever you are saying I am not listening so I think why are you saying, so if you have that kind of attitude early morning 8 o'clock what do you learn you tell me, you can never learn anything that is what happening in India okay absolutely that learning happiness is totally gone. Right, so I think that is now which is left to you and there is (())(4:08) will now.

Okay so now plug flow reactor we will start I think batch reactor we have done, I think also problem we have done yeah actually batch reactor I gave this simplest one adiabatic reactor in fact, the same problem you can solve by taking for example I will write here this side, which side may I don't know where you can see okay, so this corner I will write.

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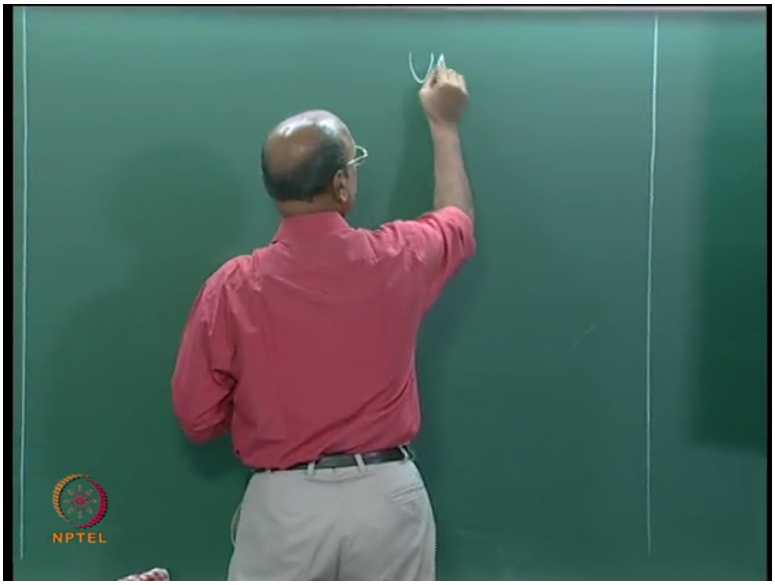

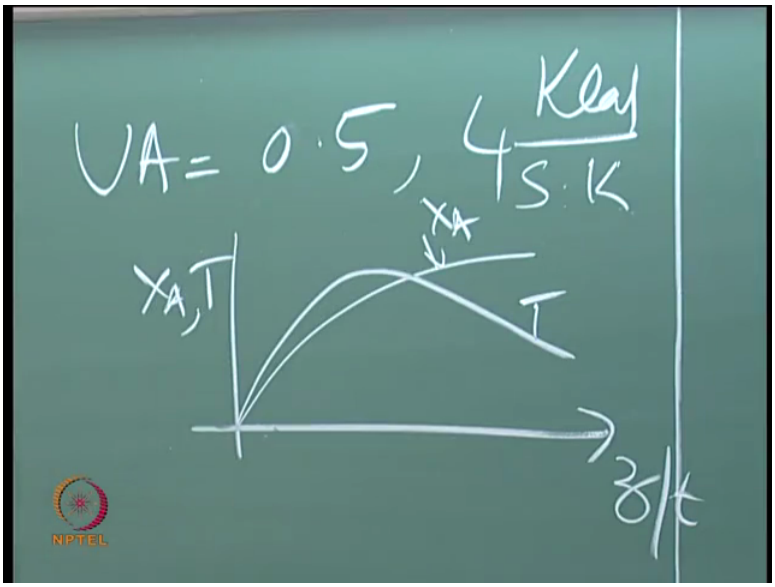

For UA equal to that is only data missing for solving non isothermal reactor I will give you some 2-3 values and then you can try that. Yeah, yeah so may be you can try UA equal to point zero point five and also 4 I have in between but I am just giving you this the units of this is kilocalories per second Kelvin. You have delta T write the other term where you are removing some of the heat.

Right it is exothermic reaction. You have to remove the heat so UA value is given as point five and also 4 those two values you can now take now it is no more even of course area under the curve also you will get later but now you have to do by trial and error, no, no, no you don't have to draw the graph there but you have to draw the graph in all this problems as conversion versus time and also temperature versus time.

In all non isothermal reactors volume directly you can get area under the curve if you have adiabatic reactor but in general what would we do is we try to plot XA and T versus length if it is plug flow reactor okay yeah if it is batch reactor this will be time. If it is mixed flow reactor very happy I think because I think distance dissolves itself because Z equal to zero because there is no variation inside the reactor so thats why you will have easy solution there right.

So this things XU will it may increase this is X and T depending on whether you have adiabatic reactor or non isothermal, non adiabatic, non isothermal, non adiabatic heat removal if there is sufficient heat it may go like this and then come like this. This is T if you are removing heat if it is adiabatic simply again increasing so these are the things and then normally you will be given that okay 90 percent conversion then you have to draw the line here okay this is point 9 sorry okay.

This one this one is point 9, XA point nine so automatically now when you are solving XA point nine also given by length, right so you have the length of the reactor anyway in the beginning itself you should assue some diameter right so that diameter length and diameter will give you total volume of the reactor. Okay otherwise if it is time same thing again X 90 percent I draw this line okay sorry yeah okay.

So this line it is crossing here X graph then this is the time, or Z so once you know time you know now how to calculate volume of the batch reactor you know we have done that right, time means that is the reaction time plus you have discharge time and all other times. Okay filling up cleaning all the timings you have to add and then total capacity must be given so much you have to produce.

So based on that you calculate what is the total volume of the batch okay good so that is the procedure now let us go for plug flow reactor. Where once you understand batch plug flow also is not difficult.

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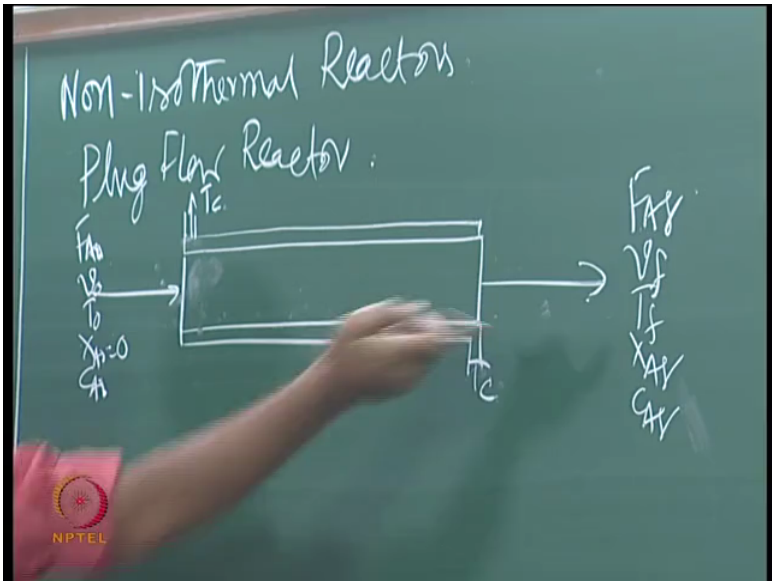

We will show that we have the reactor something like this okay good so now anyway we have the jacket outside yeah so for easy assumption it is TC entering and TC leaving. Otherwise I have to also find out the logarithmic temperature difference between you know this is TC 1, TC2, then I have temperature1, temperature2 or temperature (())(9:02) T zero, T final then you have to find out what will be the logarithmic temperature difference but that is one thing normally we don't take in this simple problems unless you really go to industrial problems there you have to do all that right okay so this is the one.

But as usual here we need the mass balance and heat balance, so let me write. V nought, T nought okay XA nought equal to zero. Of course CA nought is not there sometime here also I have FAF, VF, TF, XAF and CAF all this and earlier we have take a small strip here and then wrote what is entering, what is leaving.

But now for this energy balance we will take that strip somewhere very near so that I will know T nought and what is the increasing temperature T then I will go to T2, T1, T2,T3,T4, T5 like that because here also because of the distance Z okay or correspondingly time presence of time in the batch reactor I have only two I am going to have only two equations and three variables, here also same thing same thing here it is Z earlier it is T, right delta Z will come and Capital T, temperature and conversion X, so again by trial and error.

So by trial and error, it is easy to start with this small strip and then go one by one right, so that is why we will show that our strip just select the exaggerated strip something like this. okay yeah something like this will have this is the strip then my outside heaters will also till

hear only, and this is TC everywhere TC so this is also TC, these also TC right okay, so this is the one and this area because heaters (())(11:26) is taking place in this area because the tube is okay like this correct no?

Tube is like this and of course entry for reactants outside we have this jacket and heaters through this area, how do I get that, that area? Pie into D, right ya okay so that is the one which we will have but total area of heat transfer let me say this is DA dash okay in that small strip DA dash is nothing but PIE D into delta Z, if I take this one as delta Z for DZ okay (()) (12:12) here also I wrote that but anyway this is small one.

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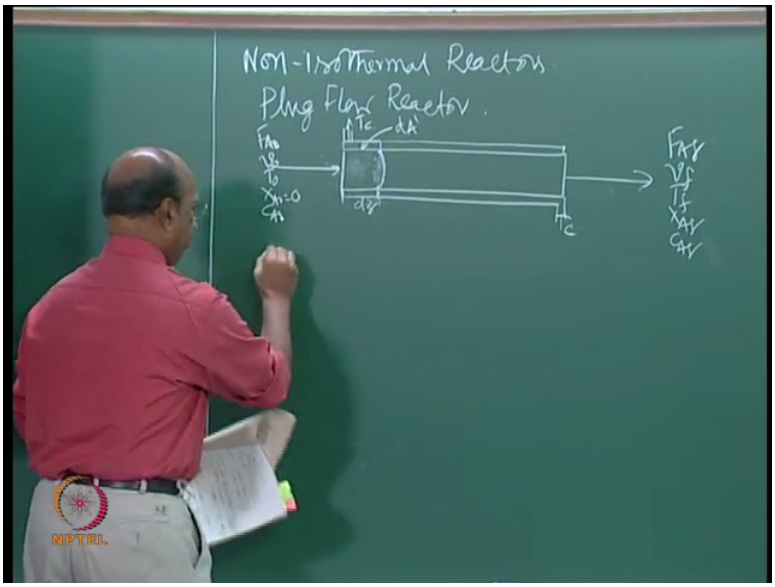

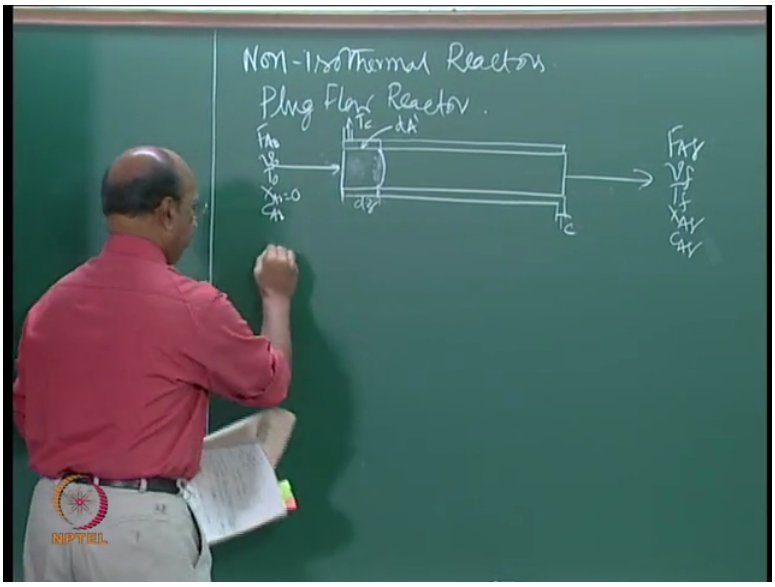

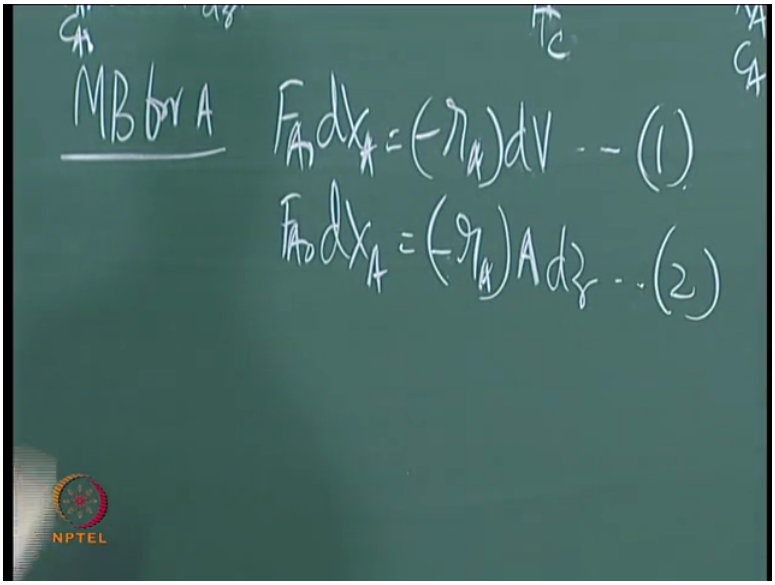

So let me write now the MB for this MB is always for key reactant and in our case it is A going to R, R is only one reactant that is the key reactant or if I have 2 also normally we are taking A and this I don't have to tell you FA nought DXA equal to minus RA into DV this is equation one and now this DV I can write in terms of dZ so that will be minus RA into if I take A as the cross sectional area that is why A dash I put there this is DZ.

Okay so that means volume of this element. Okay this A is nothing but again Pie D square by 4. Okay good if D is the diameter yeah.

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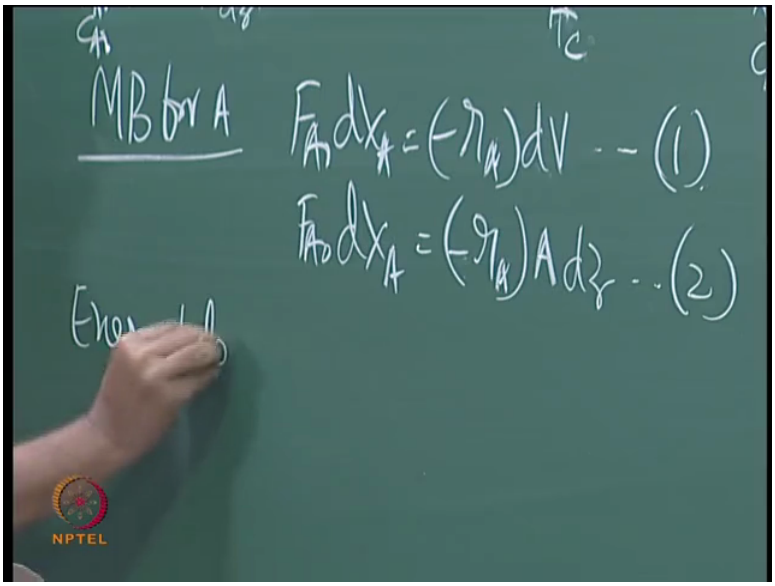

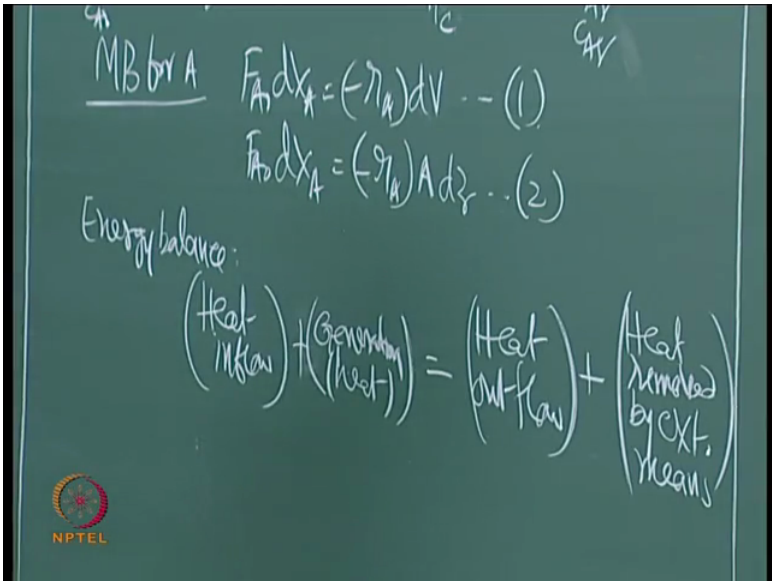

So now energy balance for the entire mixer that is entering yeah will be heat in flow equal to no I think we are writing for exothermic so this will be generation heat generated okay heat okay. Yeah equal to heat out flow plus heat removed, heat removed by EXT, external means that is the one okay, Sushmita are you looking at that I think not able to follow this my delta that is only this.

Studnet: No sir, it was like the area heat transfer that is the in the I mean Pie D only

Professor: Yeah Pie D yeah pie D into, pie D is only length area is multiplied by DZ, DZ this one this is the area not able to follow okay this is the strip and what is the diameter, D if I open it what is the length of that yeah if you say Pie D it is only this length you are taking then now this is the area through which it is transfer so that is how okay yeah so writing the equation for this for individual things here for all total streams you have to take.

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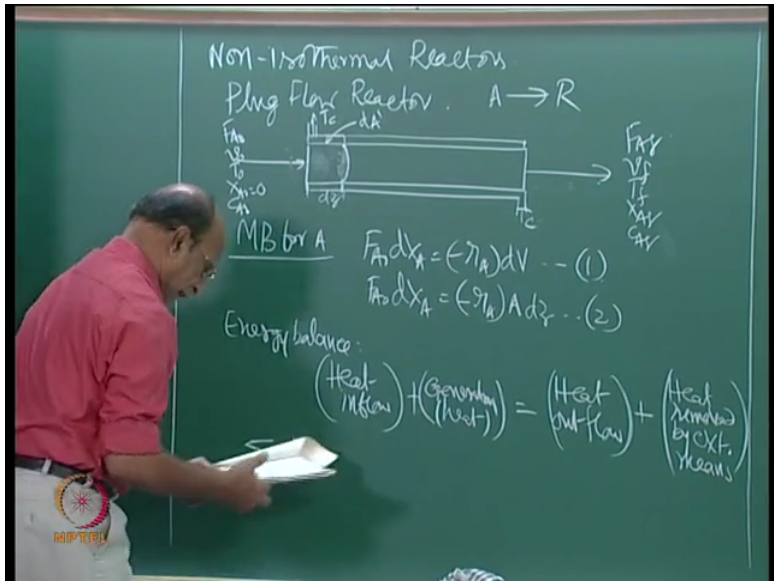

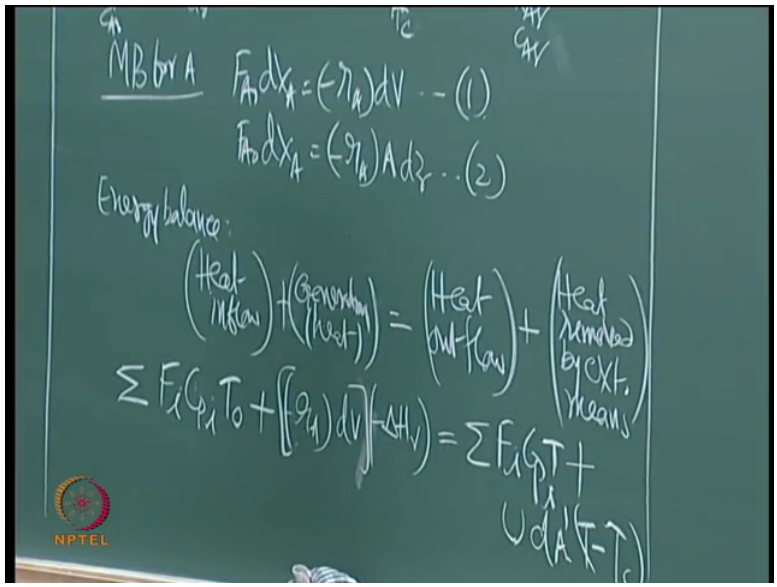

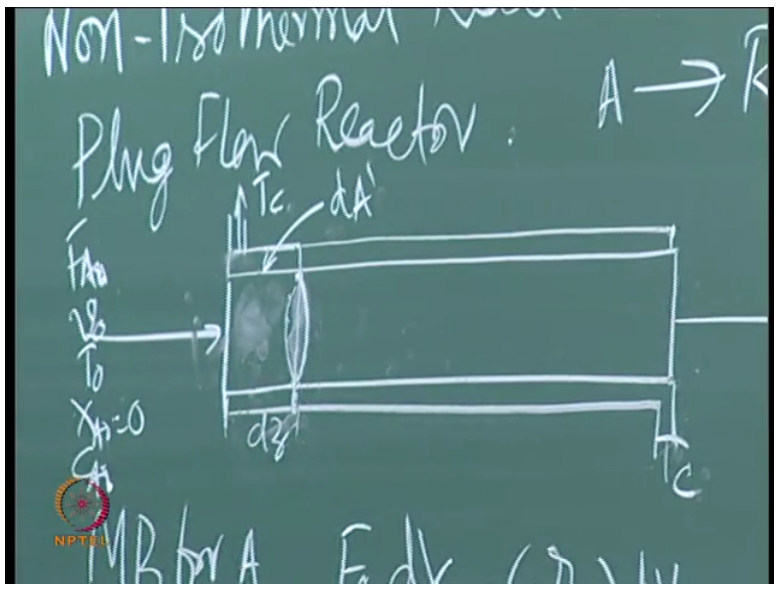

F of I sigma of F of I CPi T nought that is what is entering because we are taking here okay plus I have heat generated. Heat generated is minus RA yeah tell me.

Students: (())(15:44)

Professor: Delta HR into

Student: (())(15:49)

Professor: Into DV right. Yeah so minus RA into DV as one word as one thing multiplied by minus delta HR minus delta HR exothermic heat we are taking so minus delta HR is a positive quantity okay yeah so now this is equal to again same thing out at this point outside if I take yeah outside if I take that will be sigma of CPi T plus heat removed be external means is UA delta T. Right what is A here?

Student: U

Professor: U so this will be U DA dash T minus TC okay T minus TC correct? Okay so naturally even in this problem or even in the batch reactor problem unless you take that strip very very small you will not get accurate result. Correct? This strip this should be as small as possible if you take okay let me take 50 percent as one DZ the remaining 50 percent as another DZ then you don't get much I mean you get something.

But I think it will not be very accurate volume if you are asked to find out volume for given conversion so thats why that should be as small as possible because that will be see the T we are telling here correct? This is inlet this is outlet, T is coming out here, right. But if I have sufficient distance instead also have many other T's so that is why the average that means if I take smaller.

And smaller then you will get this T as close as possible then you are slowly slowly going step by step with a small increment then your results will be more accurate this I don't have to tell you any difference equation method always tells you that and you are doing mathematical methods in chemical engineering correct? You have that course? Or next semester?

Student: (())(18:00)

Professor: Yeah, so idea of those courses are only to help you to solve all this difference methods and all that good so now this is the one, so now I think numbers gone, this is 3, this is 4, equation 4. Yeah so as usual this equation I will try to rearrange.

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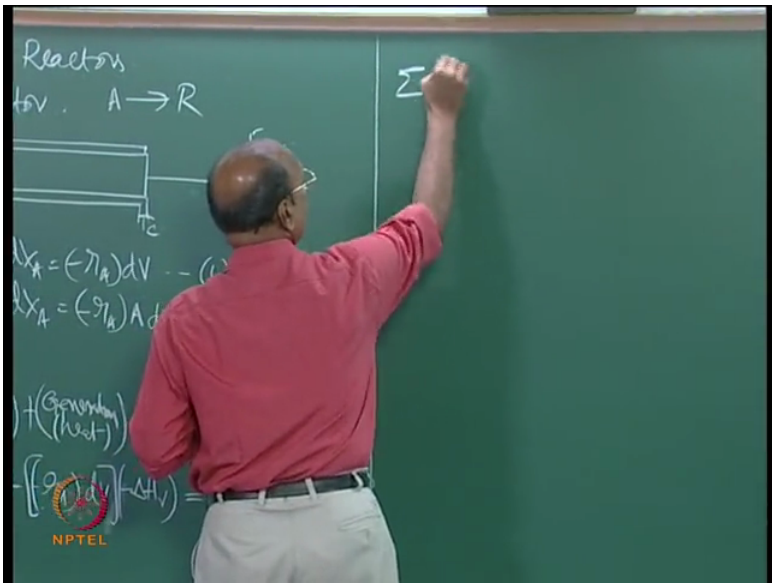

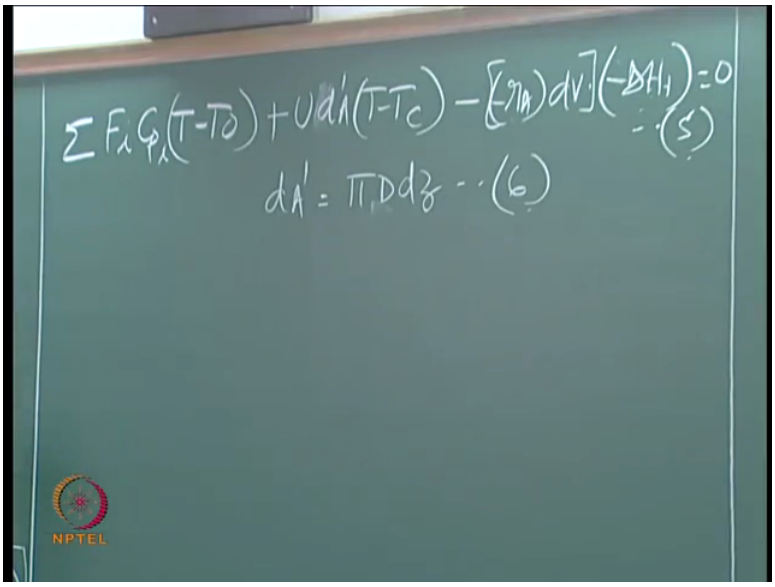

That is sigma Fi CPi T minus T nought now we are more comfortable instead of writing T nought here and T there yeah so that is equal to not that is equal to plus UA U D dash, yeah T minus TC minus minus delta HR equal to zero. Okay so now of course I can write what is this number 5? 5. Now let me write specifically even though I have not written now DA dashed is Pie D, D the diameter of the tube.

Okay so now substituting equation 6 and 2. We have to write somewhere substituting equation 2 and 6 in 5, 2 and 6 in 5. What you get is.

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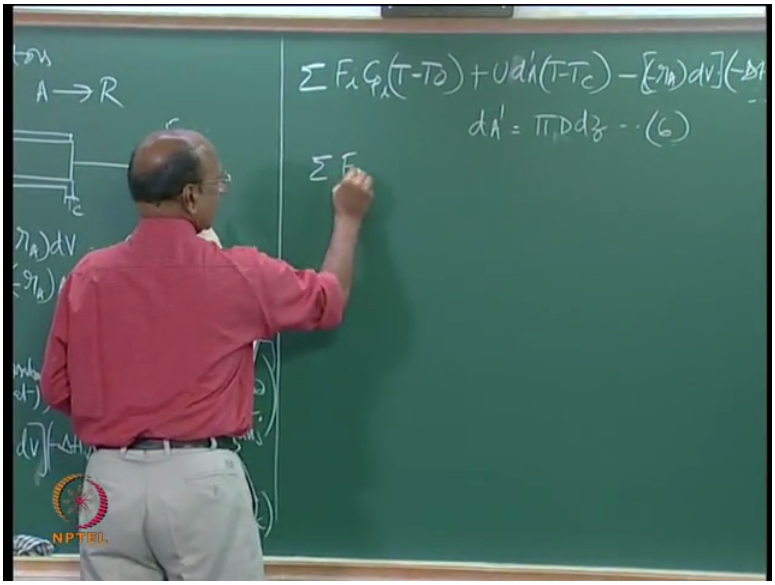

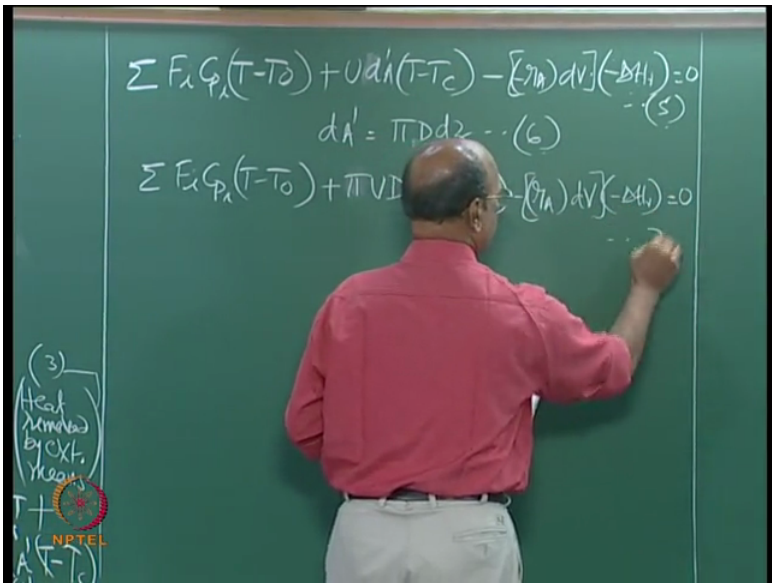

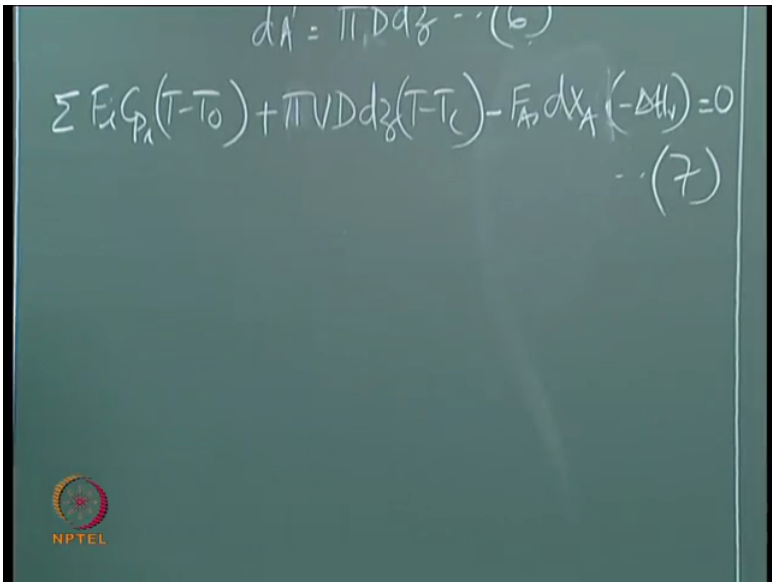

Sigma CPi T minus T nought plus U okay Pie U capital D dZ, T minus TC, minus RA dV minus delta HR again multiplied equal to zero so this is equation 7. Yeah good, so now of course we simply substituted equation 2and equation 6 in 5 and then we got this, but

Student: (())(20:48)

Professor: Equation 2, I did not substituted yet okay right, right, right okay. So we will write that sorry. Thats all no? I think I have to write only that, minus, minus yeah FA nought.

Student: DxA

Professor: Yeah FA nought DXA yeah okay. Good so now I have the relationship between temperature and conversion the way we expected for energy balance please remember don't forget that the extra information what you need for non isothermal reactor design is the relationship between temperature and conversion and that relationship you get from energy balance.

Right okay so now I have to solve equation 8, equation 7 and yeah using equation 2 for me to get that kind of profiles. Concentration versus temperature no sorry concentration versus length or temperature versus length right okay. And you would have seen now again we have only 2 equations thats all these 2, 2 and 7 okay and I have 3 variables of course I can also write this in terms of writing those 2 equations FA nought.

I am writing this one delta XA equal to minus RA, A delta Z that is one this is may be in terms of difference delta than I am writing this one as 8 and 9th equation is this sigma Fi CPi delta T, this one I am writing delta T, plus pie U D delta Z, this we will leave it as T minus TC minus because this is outside temperature FA nought okay minus delta HR FA nought delta XA equal to zero please check I think whether I have written something wrong or not. So 8 and 9 are the equations what we have to use good yeah. So what is the procedure to solve that?

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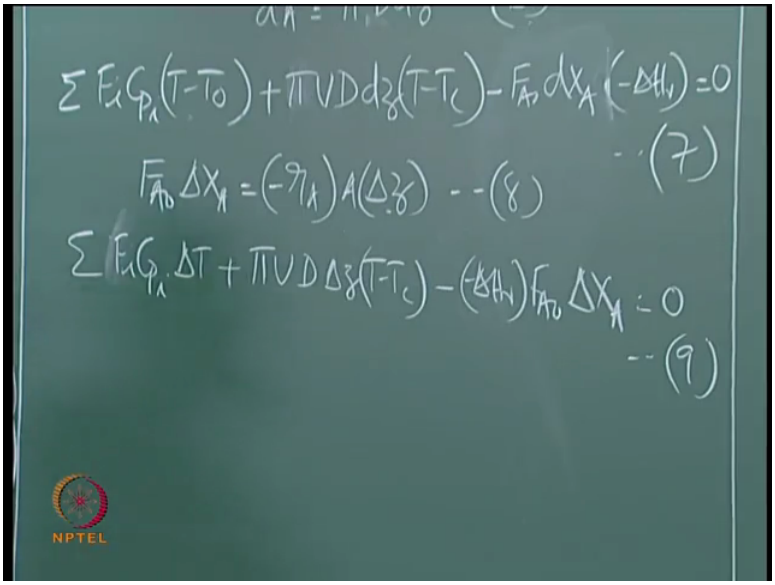

Because I have these 2 equations right the this equation will give me the relationship between X versus T and this equation will give me don't give me by actually I have here temperature, conversion as well as length. All three are there in this where as here only 2 that is temperature and conversion because minus RA is not there. Right minus RA contains T and X both correct no?

And also Z because of this balance DV minus RA into DV so that is what you have to remember these are the basic things which you have to remember if you remember those you know the basics then automatically whatever problem is given to you. You will automatically try to solve that because you know the procedure thats why I was telling you 50 percent you know problem is solved if you know the problem clearly what is the problem?

Here my problem is I have equations and three unknowns how do I solve that? And I know that energy balance gives me only relationship between conversion and temperature. Okay good yes so the procedure is exactly same as yeah what you have given in a for batch reactor so first one what is that step? To solve this.

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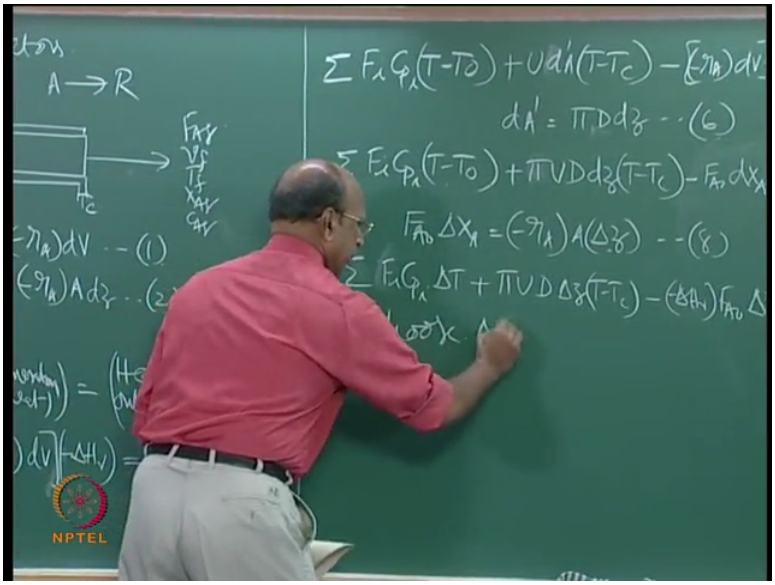

Choose yeah delta XA may be for example point 1 or point nought 5 okay or if you are very very (())(25:05) person I think more accurate and more sophisticated more what you call I think not sincere but I think there is one word yeah if you want to be very very accurate then you have to go for delta XA equal to point nought nought one that will take you two years okay yeah I mean because every step you only want to calculate.

But thats why reasonably as engineers you have to take that steps such that you will not get inaccurate results but stills you will not get okay I mean you will get accurate results okay so those that is the balance and that balance no one can tell you that balance should be only with you okay I mean as teachers we only just tell but finally you have to walk through the door. Okay dialogue from matrix okay yeah you have to walk through that so choose delta X for example point 1.

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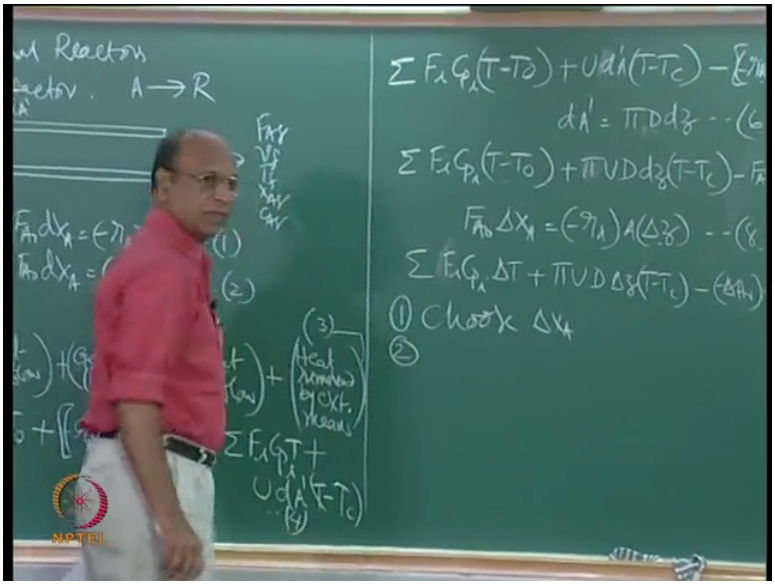

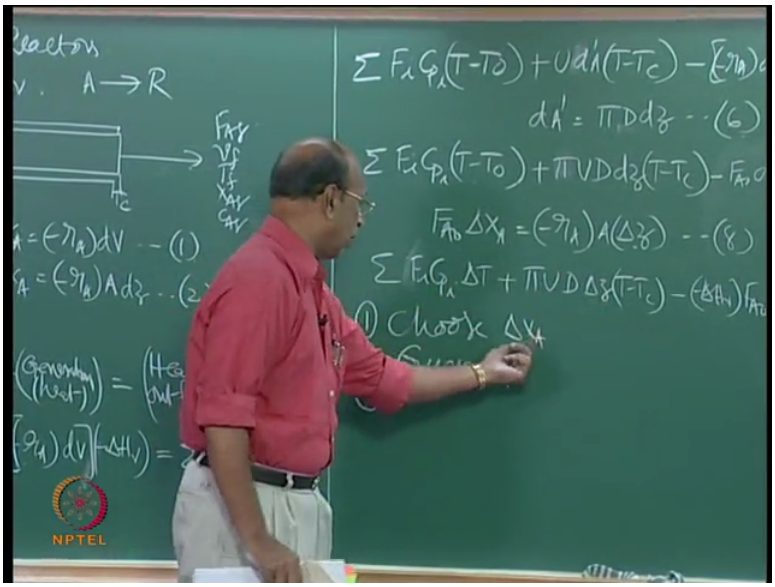

And then next tell me I think the procedure you should know by this time.

Student: (())(26:13)

Professor: Now guess value for delta T that means in this increase I think you know physics also if you want to remember okay now I have chosen delta X as 10 percent conversion so now your guess will be okay for 10 percent increase in conversion what should have been the temperature increase that is what that is what will be the guess value. Right so now guess delta T.

That is how I think you know initially we started with 100 degree centigrade and let me say that you know you may have okay hundred and ten (())(26:48) temperature degree okay that T so now once you know that then we have to yeah 3.

Student: (())(26:59)

Professor: calculate now I know T X and then calculate yeah okay I will only calculate T from here no no no delta Z is also there sorry dZ is also is. Yeah dZ is also is, now I will calculate dZ from here sorry I think I told you wrongly that means I was telling that this will give me the only temperature and conversion that is only for adiabatic system. Not for non isothermal system, I think why no one I think all of you are sleeping definitely.

So this delta Z is there you should have told me no sir delta Z is there how can you say that it gives you only temperature and conversion. Temperature and conversion only comes for adiabatic system.

Student: (())(27:45)

Professor: How did you know?

Student: Expression

Professor: Expression is known to you. But RA content is temperature and conversion what conversion and what temperature? Thats what you are trying to find out. What conversion and what temperature? Okay now understood or that is the good question all of you I told you know all Indians are brothers and sisters but only one brother and one sister may ask in the class.

Okay so that is why I think you know most of you may be having the same doubt so RA is written in terms of K nought, E power minus E by RT if it is first order reaction then CA nought into one minus XA right so it has T it has X. But I don't know what is in this element in my small delta that strip you know delta Z what is the T and what is that means theoretically what I should have is at every cross section I should have the R and corresponding X so once I know that then I can plot 1 by minus RA versus XA area under the curve will give me the volume.

Okay but here I don't know I have to find out that R right but I don't have to draw your graph here and then I can yeah so what if I know T and X I can calculate that delta Z write you can

also guess for example for this delta X right what will be the length. Right may be 5 centimetres right so then calculate delta T, delta T means, delta T is nothing by the T nought minus T minus T nought, so that T I am able to find out here.

So that is why I have been telling you unless you take this one as smaller and smaller that R will not be accurate okay because Ramkrishna asked that question do I know at least R zero that means entry R zero.

Student: (())(29:49)

Professor: Entry R zero what is the equation just imagine what is the equation.

Student: (())(29:55)

Professor: R equal to

Student: (())(29:57)

Professor: Yeah T for minus E by RT CA nought right.

Student: Temperature

Professor: Temperature is known and conversion also that means R nought I know. But only thing is this point R corresponding to that one point you know may be if I call that one RA 1 that I don't know so that is why you can imagine this as a smaller strip and then find out if you what you have to do is if you are imagining slightly bigger strip like point one also may be bigger strip if the reaction is very first particularly right. Point 1 so that is why then you may have yeah so here I have R nought here I have RA 1.

Some people more accurate people will say that average of that 2 I will take understood no? Not understood? Started sleeping no? Okay this is R nought,this is RA 1, RA nought RA 1, but actually there is a distance what I need is for each and every cross section so if I make this one as smaller as possible then that will be very close to RA 1 and then because there is a reaction there will be depending on you don't know whether increasing or decreasing.

Because temperature increases and they concentration decreases that affecter will be there and initially anyway R increases so that one I have to take. That is why when you take slightly bigger strip for example delta XA equal to point 1 strip. Then I can take this is RA 1, this is RA nought now in between the average of those 2, arithmetic average simply if this is

let us say 10 and this is now 20 as an example. So in this strip the average rate is 15. Okay so that is the kind of things you have to slowly start doing that okay.

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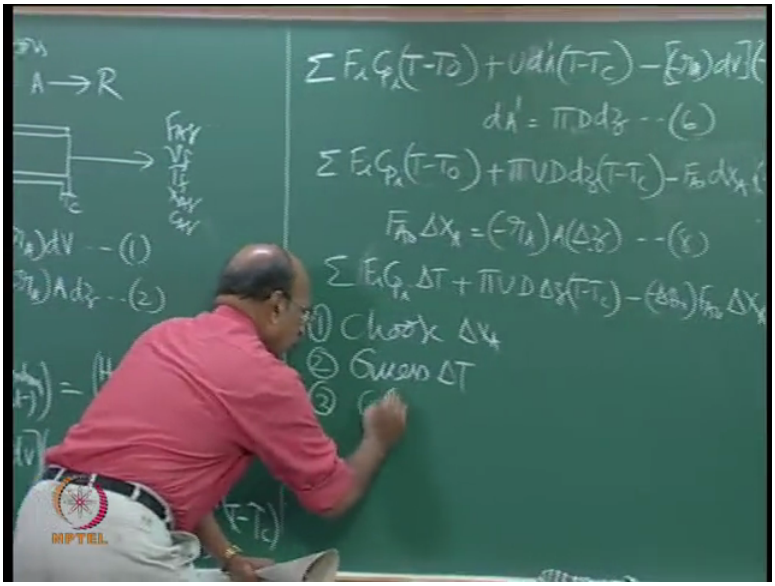

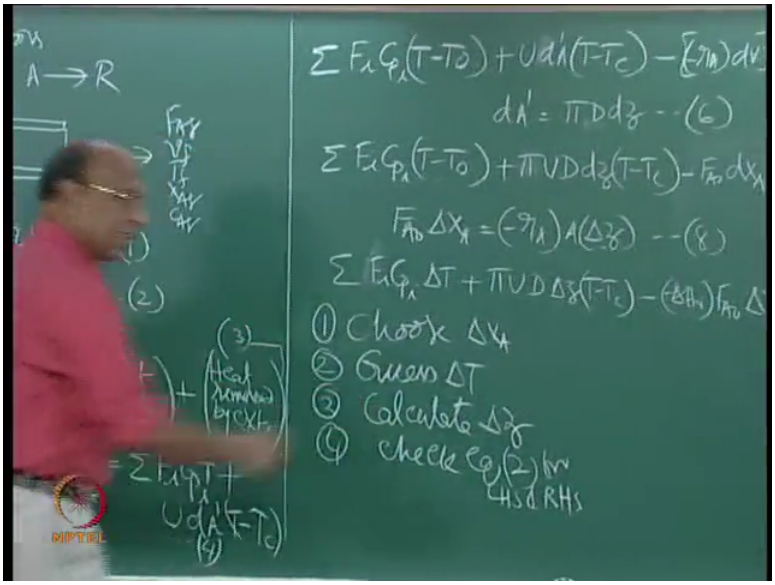

Now calculate, now tell me calculate.

Student: (())(31:51)

Professor: Manikanta? Z excellent yeah delta Z anyway Z equal to zero in the beginning.

Student: Sir, T also we don't know na?

Professor: T I am guessing it, see 100 I have guess, I mean 100 is T nought 110 I guessed right so that means delta T is 10 degrees, delta T only 10 degrees raised so T nought plus that

delta T will give me T at this point. Right so that means at this point at this point, at this point I have T XA and also I know Z, because Z I am calculating T I am guessing and I have choosen my delta XA as point 1 for all three I know that means I can now calculate what will be the rate at this point. Right okay good.

Now how do I know that this is correct or not now check this in this equation. That is the fourth step you know yeah yeah what do you write there for the fourth step.

Student: check equation,

Professor: Calculate. Not calculate I think check probably, check equation 2.

Student: (())(33:19)

Professor: Here I have written 2 yeah.

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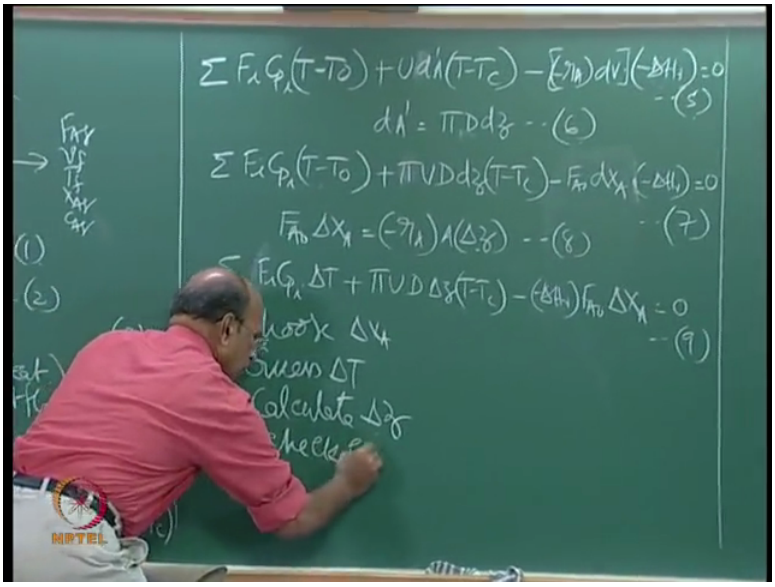

Check equation 2. Okay if LHS is not equal to RHS yeah check equation for LHS and RHS. I mean checking means only checking RHS LHS but still I am writing there okay so now if you are not able to get LHS equal to RHS then.

Student: (())(33:51)

Professor: Yeah, now 5

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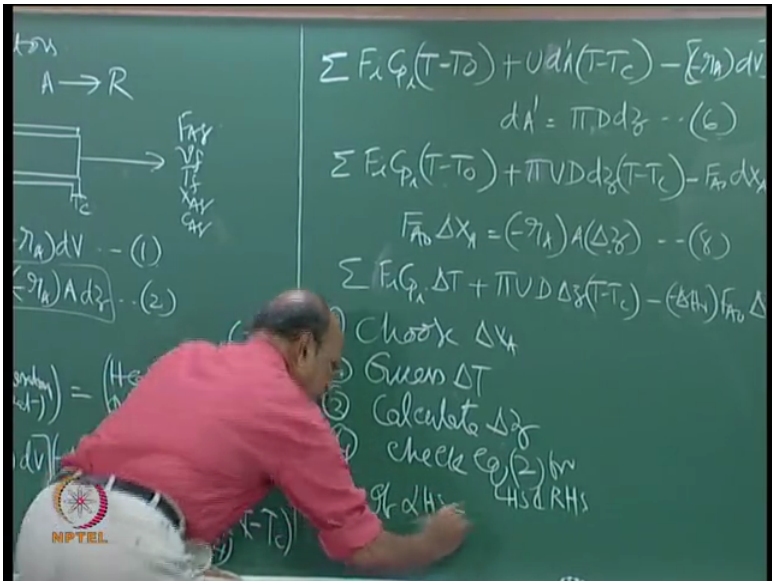

If LHS is not equal to RHS now go to step two. And repeat yeah, go to aww this is difficult step 2 and repeat. Okay go to step 2 okay what is the sixth one. Thats all 5? What you have written there last time? Rahul?

Student: (())(34:29)

Professor: Thats all. Repeat 2 to 5. Good, so that is the one so really it will be very very good when you do this kind of trial and error because you need patience that will also make you learn patience okay because problem with present generation is (())(34:57) we have patience with you there is no patience and you also need all the results instantaneous have you, yeah instantaneous thats what I think you know you time concept you don't have the moment you think you should be happening that only happens in old mythology.

And all that where god wants to appear means (())(35:19) he will come there. Disappear means again (())(35:21) he goes out okay good we will stop here this is over then I have to talk about something about adiabatic reactors and of course next is CSTR, okay.

Student: (())(35:31) So if I fix delta Z there are only 2 equations to solve and 2 unknown try to solve simultaneously

Professor: yeah, How for what delta Z?

Student: (())(35:46)

Professor: But how do you know that is correct.

Student: Study the variation of conversion and temperature along the length.

Professor: No but delta Z also should vary no?

Student: Delta Z I am fixing and (())(35:57) again another I am taking.

Professor: Same thing only what we are doing. That's what same thing only whether you choose delta T or delta Z doesn't matter or here also deltaX this what in the last class also that is the good question again this is also I was telling you choosing delta X is not the ultimate. Okay I chose because that is convenient for me to have 10 percent conversion.

What he says is let me take delta Z here thats what you telling no? You can take delta Z and correspondingly in that length what is the conversion that is also logical. What is the temperature? Right you can also do that right so that is why I mean X I have chosen because most of the time we talk about X delta Z also can be chosen in fact anything even delta T also you can take chose these what also mention in the batch reactor.

Student: 0 to X.

Professor: 0 to X only,

Student: Delta Z means 0 to Z?

Professor: 0 to Z. Thats why I have written here from the beginning here here here you have to go beginning to any cross section yeah beginning , because T nought I know if I take somewhere here I don't know what is T entering and what is T leaving that is the reason T nought here. And Z nought also I know 0 so like that it is easy for me. X is 0 so 0 you know very well so thats why we taught from that point. What is that? Manikanta?

Student: Delta X is with there point 1 we have taken how many (())(37:16)

Professor: Not guess, if your guess is not wrong may be guess is not right then what again change, okay delta Z you can guess I mean like for example 10 centimetres what should be the conversion.

Student: Sir, while putting there XA and beta (())(37:16) equation is 2. What is the head of (())(37:16)

Professor: Minus RA initial minus RA I know X equal to 0 there T nought and then what is the other one thats all. Only T and X in the or right so at this point I am calculating all that

here from this steps so I know now T I know X, I can calculate R here yeah that is what your question no? How do you know RA? RA contains what? T and XA so now by guessing 1XA and I am calculating okay delta Z anyway I am also sorry choosing XA guessing this.

And then calculating this and then checking there once the check is right then I know what is X that is what I have written here somewhere yeah what is T what is X? What is Z? All three I know at this point so unless you do one problem you don't enjoy that I say, one problem you have to do it.

Student: Sir you can take, that delta X and delta Z big than this problem this inaccurate this method gives inaccurate results?

Professor: Yes,

Student: As small means that the smaller thing is accurate.

Professor: More accurate that means every cross section you are touching almost if you are able to go that level.

Student: Accurate is differential equation I have taken strip into delta Z and delta T.

Professor: Thats what difference method.

Student: Thats why you should take as small as possible.

Professor: Yes, okay and if you want some problems which have been solved, the problems have been solved by smith in 13^{th} chapter I don't know if 13^{th} chapter is heterogeneous systems. But procedure is same. There (())(39:09) is the plug flow reactor. Okay so along the length you would go so 13^{th} chapter if someone is interested you can just go and see, next semester anyway they have to be interested but the same procedure okay.