

**Chemical Engineering.**  
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**Lecture-49.**

**Nonisothermal mixed flow reactors continued (multiple steady-states) part II.**

Professor: What was the central issue with mixed flow reactor, in nonisothermal? Asking question is very bad. Talking straightaway is the best I think. Yah, Anupriya, what was the problem, why you were so much worried about this fellow?

Student: (0:34).

Professor: So what happens? Feedback is always happy, what happens, what are the issues?

Student: There are multiple steady states.

Professor: Yah, I mean why should I worry if there are multiple steady states?

Student: Because you will be either getting exceeding temperature or you will be getting lower conversion.

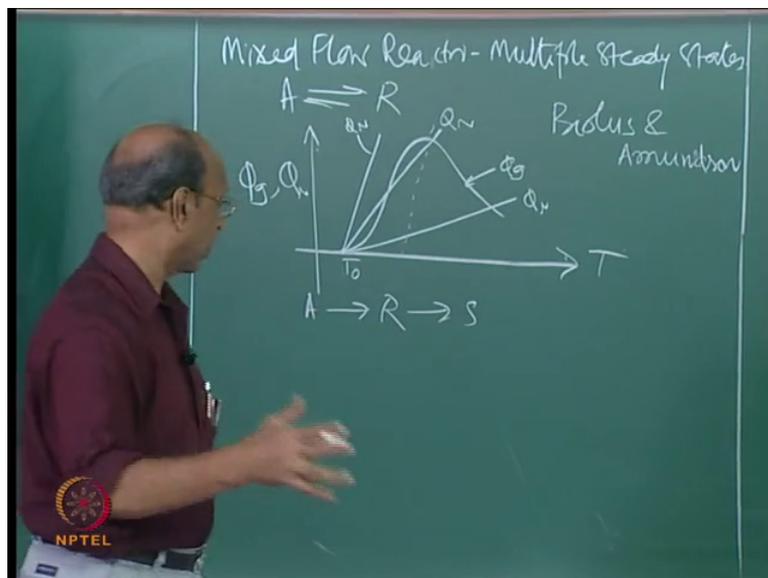
Professor: Yah, particularly unfortunately when you have calculated from energy balance, a temperature, which is in that middle point, okay, and also you have conditions corresponding to a line which goes through that 3 points and unfortunately what you have is only middle point without knowing, so then you may be thinking that that is the temperature maybe around 70 degrees-80 degrees but suddenly it may shoot up to 150 or 200 degrees where everything will be burnt. Okay, so that is the reason why immediately after design is done for mixed flow reactor, nonisothermal design, then you have to check really whether these steady states, you know the particularly the temperature whether it is correct temperature or not.

If it is not correct temperature and definitely when you are, you have to operate only at that point, that middle point because if you go above, some explosion may be occurring, if you come below, there may not be reaction at all. So you have to operate only at that point, what you have to do, how you have to go for control and have an excellent control and if it is going away, see earlier on its own, is one temperature increase is there, 1 degree centigrade, so then it was coming back on its own. You know, under steady-state condition and even if there is one point less and 1 degree less, less than the operating temperature, maybe 100, 99, again it will go back to that particular temperature.

But this unsteady state temperature is dangerous. If it moves up, then it goes to the next steady-state maybe 200 kilometres, no not kilometres, 200 degrees away. So then you will have problems. Similarly when you come down, then it may go to that you know what is called the extinguishing point. That means the entire reaction may get extinguished. That means particularly in the case of combustion that is called extinguishing. Like you know Bunsen burner when I told you, when you put too much gas, why it is switching off on its own, was that the amount of gas is more and the temperature that is, the heat that is available the flame is not sufficient, so that means the, all the gas should be heated to that temperature.

But when you suddenly increase the flow rate, you have more amount of cold fluid, cold feed, where there is no, there is no, temperature cannot sustain on its own. Right, that is why it will get extinguished, so stop. Okay, so that is why if you have, I think very low means anyways will not catch fire, those are the 2 extremes. So I also gave you some practical examples what you see everyday, you know matchstick and all that, so that that will make some interest in you, okay, I mean, the daily things what we see also we can see in the actual reactors, right.

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And all that we have discussed is only for simply irreversible reactions that are going to R. So what kind of these graphs you get, if I have for example reversible exothermic reaction of this type, what kind of QC curve you get by the way for this kind of situation? You are not at all expanding you are brain I say. You are interested in submitting assignments in the Moodle, all that is there but I think you know no mood in the class, yah, absolutely, you do not have any

mood in the class, I think you are only working in Moodle, Moodle, Moodle. Can you expect, I think you know the S shaped curve can justify now.

I cannot keep on telling the same thing you know grinding, grinding, grinding, finally you know like shrinking core model what will, the particle may disappear. You may disappear out sometime because of my grinding, okay. But I think nothing is happening, no reaction, absolute calm, before storm. Okay, I think, absolutely no idea no? Okay, can you justify why S shaped curve you get for A going to R? I explained also. That is what is S shaped, I am asking what is the reason. What is the reason, physics I say, all the time I think the semester is about to be overcome I am talking about physics, physics, physics, you are talking about chemistry, chemistry, chemistry, okay. Your chemistry with other teachers and all that.

(( ))(5:17) but at very high temperatures...

Initial increase means it should increase heat. See, we have S shaped curve, what is the justification for S shaped curve? Unfortunately if you apply to some college, where you want to join for Ph.D. and all that, then this kind of question is asked, what you will do? They would ask you to derive, they will simply ask you to explain how. Yah, Abhishek is telling give me chance, yah.

Student: Initially when the temperature is low.

Professor: Initially temperature is low, concentration is high, but rate of reaction still low.

Student: Yah, the concentration and temperature shoots below that, the rate of reaction shoots up...

Professor: You have already gone to shooting temperature. I am talking about S shaped, where it goes like this.

Student: After the initial part, 2<sup>nd</sup> part.

Professor: Initial part what happens, temperature is low, even though concentration is high, rate of reaction is low, heat generation is low, temperature increase is low, how many lows? Okay, and then after some time the concentration even though it is low, temperature will pick up, so now when it is started raising very steeply, then you have the right combination of temperature as well as concentration even though concentration is low, temperature is picking

up. But finally temperature is very high, but what is not picking up, concentration. That is why it has to get flattened.

Again remember I say. How many years I have to tell you same thing, yah but I think all of you have a wonderful technique that the moment you cross the door, I think you forget everything whatever is discussed. Is it (7:08) or some kind of curse? That no one should remember after the class is over. I think I do not know, this is what is happening. Okay, anyway, it is unfair to ask you because I think my time is going. Okay, so for A going to R, this kind of QG will be like this. The downtrend is not there for irreversible reaction, irreversible reaction. Why should there be that downtrend? Because of the backward reaction, okay. Because of the backward reaction, so now when it goes, reaches a maximum, that means rate is reaching a maximum.

So that means series will be maximum, then rate decreases, you have also seen, you know that, our graphs, okay. That is why you get this kind of shape for A going to R, you know reversible reaction. Okay. And even if it is second-order  $A + B \rightarrow R + S$  also, shaped same. Good, and here...

Student: Temperature, the concentration of R is more and concentration and temperature, both are same.

Professor: Concentration of R is more, what is the relationship between concentration and R?

Student: Concentration and temperature, both are high.

Professor: How concentration is more? 1<sup>st</sup> of all it is minus  $r_A$ , how concentration is more?

Student: Sir, reversible reaction I am talking about.

Professor: Reversible reaction, that is R, CR is more, so?

Student: After reaching the maximum point...

Professor: Which rate you are talking? Reversible but what rate? Minus  $r_A$ , okay, the difference between forward reaction and backward reaction is minus  $r_A$ . Minus  $r_A$  equal to  $K_1 C_A$  minus  $K_2 C_R$ , what is  $K_2 C_R$ , it is the backward reaction. What is  $K_1 C_A$ , is the forward reaction. So what is overall reaction? Again we are going to LKG. Yah, R, that R only we are talking, it reaches maximum. His doubt is that you know concentration of CR increasing, why should it fall, it will naturally fall.

But temperature is increasing, he had released is only decreasing, temperature is increasing, right, temperature is increasing, okay. But only heat release will be less, it reaches maximum and then from there it comes down, right, yah. So that is what. So now when I want to draw QR lines are here, by the way where I have to operate on this line? Here, okay, right. So when I start for example, I may have a situation where, I may have, okay, this, this or maybe I think I have drawn it, okay, so maybe I will draw this, which one you choose? Because all of them,  $T_0$  is same, this  $T_0$  is same.

So depending on slope, UA and also you have Sigma of, that equation is same. So because this is QR lines, this QG line, this is QR line, QR, but different slopes. So normally we will try to choose this, why, because conversion will be maximum corresponding to this QG, QR, okay. But you know why I am telling this one is that here it is inevitable for you to have control, yah, that will give multiple steady-states. But if I go here, safe, no problem, but still the concentration is, the conversion is very well. So that is the reason when you have this kind of situation, you try to go here and then, but this is again very very low, the other one is not I think.

So here somewhere, otherwise what you can do is, you can now draw a line like this. So that means you are deliberately changing T,  $T_0$ , right, so and also the slope, slope means FA, Sigma of FI, CPI plus FUA, so all those variables you have to try to manipulate. And  $T_0$  also you have to push it, right. But when you are trying to push  $T_0$ , that is why, so many beautiful things are there in reactor design, so much brain is required for doing, you know reactor design. So where I told this one is, that when  $T_0$  is moved, we do not know whether it will be economical or not, that means before entering the reactor you have to increase the temperature of the fuel.

So you have to use a different heat exchanger, some other heating system. So all these things, overall picture is all these things you have to take into picture and then find out whether simply at a lower temperature  $T_0$ , is it economical, operating here or drawing something like this may be economical because the slope is very very steep there. Okay, slope is, slope is very very steep. When I want to change the slope, what are the conditions I have, feed rate, correct no, Sigma, Sigma FI CPI is nothing but feed rate only,  $F_0$ . So that means  $F_0$  should be very large. When you have  $F_0$  very large, what will happen to the overall reactor size?

Volumes should increase because the residence time will be decreasing, okay, because again, if you are not using nothing but volumetric flow rate into C a 0 no. So that is why, so many

things, so many connections, particularly nonisothermal design when you are doing all these problems will come. Those are the issues you have to appreciate, at least you should know what are the problems. If you are able to find out what are the problems, there solutions can find out later. That is all the time I have been telling, what are the issues, what are the problems. Do you know the problem in the design of mixed flow reactor or plugged flow reactor?

Plugged flow reactor, this problem will not come, very happy. Why Swami? I told you, I told in the class, not only you, everyone. Yesterday I told why this multiple steady states will not exist in a PFR, do you remember? Yah, what is the reason?

Student: Any regulation of heat in plugged flow will be...

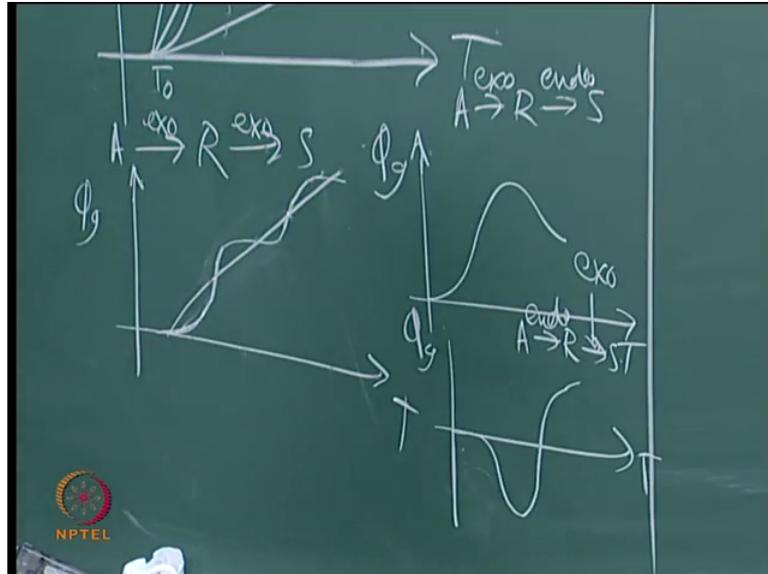
Professor: Yah will be simply washed out. Okay, there is no communication backward, that increase in temperature or, heat, accumulation and all that will be simply washed off. If there is the temperature rise, it will just move away. But the problem there is, another problem is parameter sensitivity. Right, that means at a particular point, particularly that is very dangerous would temperature, that  $T_0$ , feed temperature. When feed temperature is increased slowly come at one point it shoots up. You cannot control anything in the reactor. This information I am not able to give you more, except words only.

So I think Biolus and Amundson there is a paper, Biolus and Amundson, I think, yah Biolus and Amundson. Under Amundson if you will search, a lot of information you will get. So they are actually they have varied various  $T_0$ s, feed temperature, and showed at what temperature, at what feed template it shoots up. Like you have shown that figure no, that kind of figures can see. Okay, and another of my questions, plugged flow, yesterday I think it skipped from my mind to ask you. If I have recycled reactor, will you have multiple steady states? See, extending, extending brain I say.

You should question me. Yes, because there is feedback. Okay, you see how much beautiful information is there in your brain, if you want to bring it out. Yes Swami, Swami started laughing now. Yes, subject is laughable or, okay, good. Fine. So this is one thing and the process is same to find out you know steady-state and all that, writing and energy balance, material balance and then drawing the line or solving both the questions and then trying to find out, okay, good. That is the one, so I may also have a reaction something like this. So

that as well as there have also not done, I think after seeing you I have to do more and more, okay, because you are silently absorbing, I do not know how much you are absorbing.

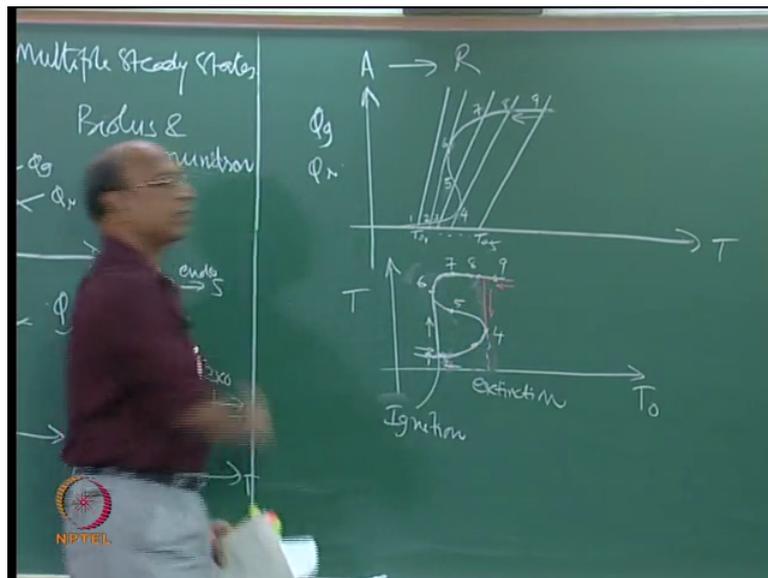
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So this K going to R, R going to S, very nice funny graphs you will get, okay. QG and temperature, right, if both are exothermic reactions, exo exo, Swami you guess? They are irreversible reactions, right. They are irreversible, yah, excellent, good guess, okay or in other words snake. Like this, yah, like this it goes, okay, this is like snake no. Okay, so now in this case, how many steady-states you have? This also, lowest one. 1, 2, 3, 4, okay, yah, I think this also, 5. Yah, 5. And as usual this will be unsteady state and intermediate, this will be unsteady state.

Anyway, that is there for information. And I can also give you, this is exothermic and this is endothermic, just for information only what you are, differentiate, you know how many beautiful things are there in reaction engineering, I just want to show it to you. Okay, this is A going to R, R going to S but this is exo and this is endo, yah, very good, beautiful. So it goes like this, falls. Good, so now next one. We have QG and T, but here we have A going to R, R going to S but the 1<sup>st</sup> one is endo and this is XO, yes, that is why I have drawn this also. It goes below, comes out like this. So if you like snakes, I you will get a lot of snakes in this multiple steady states. Okay, good.

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Yah, there is another thing also which we have to just discuss about ignition and, ignition and, yah, extinction. Taxation and ignition points, okay. So those points we will discuss for A going to R, normal S shaped curve. Okay, so for normal S shaped curve, QG versus T and of course also QR is there, both are there. Let me draw like this curve, okay, so I may have a line like this, that we know already or I may also has, this is just touching here, this is 1, this is 0.1, this is 0.2 and this one below, you are experts in this now, this is 3, this is 4, this is 5, okay.

Now next logically it may be like this, so this is 3, oh sorry, sorry, okay, so this point is put as 4, that I will give you, this is 5, this is 5, this is 6, this is 7, yah, so this is 8, then this of course we know, this is 9. So meaning of this is if you keep  $T_0$  changing, what other various stages, you know the entire curve moves? Okay, how the reactor moves or how the conditions inside the reactor moves? Right, so that means we are starting here, this one you know, 0.1 and this is 2, 3, 4, 5, 6, 7, 8, 9, okay. Good. So now if I plot them, again this is just, yah T versus  $T_0$ . For example this one is  $T_0 1$   $T_0 2$ ,  $T_0 3$ ,  $T_0 4$ ,  $T_0 5$ , like that. Right.

$T_0 1$  to  $T_0 5$ , so  $T_0$  is the variable here. That means decide to find out what will be T,  $T_s$  in the reactor when I vary  $T_0$ , okay. Okay, you will get, yah, so when you travel here, this point will be there, this is 1, then it is moving slowly, slowly increasing, choosy is increasing, that means temperature is increasing, this is also temperature is increasing, here also we have another temperature, so all that I can show simply as like this, okay, this is 0.1, this maybe 0.2, 0.3 and then it goes like this, goes like this, okay. So this point is 0.4, here you will have some back 0.5, this will be 0.6, this is too much, I have turned it too much.

Yah, so here it is 0.6, this will be 0.6, then of course here you will have 0.7 point slightly away, 0.8, then here is 0.9, okay. So, I think this point also slightly I have to draw. Okay. So this is 0.1, 0.2, this is 3<sup>rd</sup> point, so like that. So what will happen is, to the kind of hysteresis, when you are moving from 1 to 2, right from 1 to 2, 1 is here and then suddenly may go to label 6 without travelling all that distance. Okay, so that means it may straight go like this, right.

And then, that means this is the one, it may go like this. So this point is called ignition point, that means suddenly I have temperature here, and next temperature is very high, it is not next small temperature, next small temperature, that means it is not going through all, you know that increment temperatures, the way we are imagining it. Right, so suddenly when I have these 2 points and next steady-state for this is this, okay. So it may touch instead of going to 3, 4, and 5. When I am increasing  $T_0$  slowly. Right, so from this temperature it may go like this, good, so that is one way.

So this is called, this corresponding state is called ignition, that means suddenly this catching fire. Right, okay, similarly what will happen if I come down? Would that means from this side,  $T_0$  5 to, yah,  $T_0$  5 to  $T_0$  5,  $T_0$  1 to  $T_0$  5. So when I am coming down here like this, yah this is fine, okay and at this point you can see, I am coming here, from here to table 4. So that is what it straight falls, it should be straight line, it is not curved, it is not slightly slanted, maybe, yah, here, this goes, maybe this also I have to remove, yah. So this is the point when I am coming from this side and this is the point when I am going this side.

So this point what do you think? This is ignition point, see here, you are coming from this side and then you have 9, anyway high-temperature, then I have 8 and suddenly from here to 4. So the reaction can extinguish, can get extinguished. So this is extinction point on this line. That is why normally it is shown that, there is a kind of hysteresis what we have. So it goes like this and when you are coming, you are coming like this. Correct no, when you are going, you are going like this, when you are increasing temperature, feed but when you are decreasing feed, then you are coming like this.

So you have this one overall, right. So this is only just for your information and of course, problems can be given on this nicely but I think in the examination, probably I will not give on this one, the reason is it takes time, you have to plot that and then carefully look at those points and anyways you can currently calculate and draw it, definitely you will get all those points, right. That is why it will take time, so maybe one problem or 5 problems I have to

give, you either do one problem or 5 problems, okay, good. So this is what I just want to tell you about this, some more things about multiple steady states, mixed flow reactor.

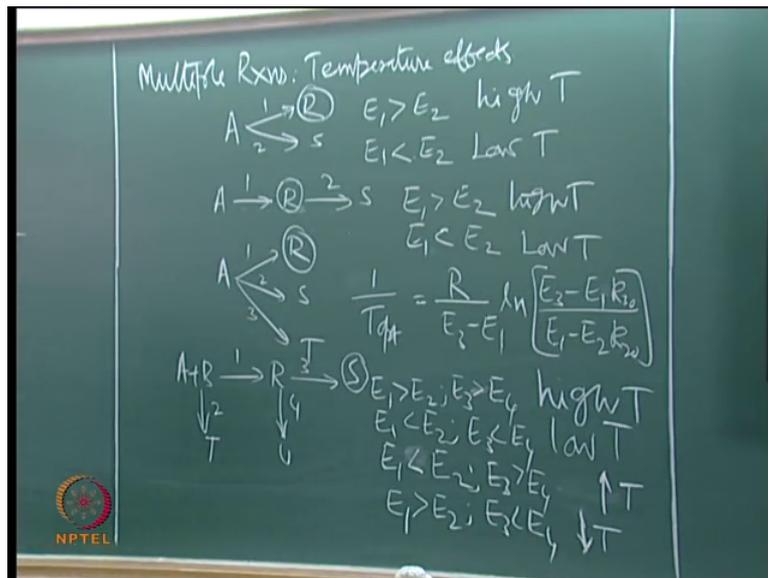
So as I told you, there is a lot of information available, actually there is a book called control of chemical reactors by JM Douglas. I remember correctly, JM Douglas, no, not Douglas, anyway, I think, I have forgotten now. So that is also another book, only on control of reactors. In fact you know in M tech we had earlier, some kind of history, M tech we had earlier 6 streams, 6 streams were there. Right, we had biochemical engineering, environmental engineering, polymer engineering, chemical reaction in your thing, transport phenomena and control. 6 are covered, yah.

So I think at that time, again maybe 3 for the M tech input, right. So in every branch, every same, only 5, 5, 5 but some streams I think is used to get only 1 or 2, like that. So at that time in chemical reaction measuring stream, all these courses were there. We had separate reactor theory course, chemical and catalytic reaction engineering course and then on catalytic reaction engineering course separately and then, stability of chemical reactors, that was another course and one more, eating only these 5 courses. And the remaining thing anyway you protect, transport phenomena and reactor theory was common to everyone.

Reactor theory was common to everyone but those who were there in the reaction engineering stream, they have to take the remaining 4 extra, that is chemical and catalytic reaction engineering, non-catalytic relation engineering, stability of reactors and one more course, all these courses. Okay, good, yah, so at that time we used to teach all that. Now we have also forgotten because I think streams are removed and now a brain also is becoming you know blood, it is not sharp. Because when you teach also, we also remember. In fact the most beneficiary of teaching is the teacher.

Okay, yah, not the students, unfortunately, okay, good. So I think with this I think have covered all this, anything else, only, one or 2 things now. Just left out. That is a normal multiple reactors, how do you get the maximum, this be postponed at the time, we discussed, if you have activation energy for one reactor is more than the activation energy of another reactors, what do you do? How do you operate the reactor? Okay, so that information I told you that when you are discussing nonisothermal reactors, we will just discuss that.

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Quickly I will go through, that is multiple reactions, temperature effects, okay, yah. So if I have A going to R and A going to S, this is desired, what symbol. So here, this is 1 and 2 reactions, I have a case where  $E_1$  greater than  $E_2$  and other case is  $E_1$  less than  $E_2$ , how do you operate this, how do you operate this? You have that rule already with you? Yah, then  $E_1$  is greater than  $E_2$ , use high-temperature in the reactor so that this will be forming more and more and that is what what you wanted, that is the day that product. So that is what, so here, I have high T, high-temperature.

And here no T, good, very simple. So this is only just to remind you all this again. So now I have here, this is the desired product, right and I have 1 and 2, again you have case here,  $E_1$  greater than  $E_2$  and  $E_1$  less than  $E_2$ , yah, what is the now condition., If I use high-temperature, okay, so this will be, yah, so this will be forming more, when you go to temperature scheme after some time you have to go to low temperature. But straightaway, okay, if I have this one more, definitely I have to use low temperatures. So that is why we write here simply, here also high T and also low T.

But when I ask temperature scheme, then you have to say that, okay, initially use high-temperature and then later you go to low temperatures, okay, good. So that is the one and when I have this one, A going to R, R going to come all 3, I have R, S and T, this is the desired product, yah. This one, I will just nicely leave it for you, this is 1, 2, 3, this is the desired product. I will give you some kind of equation,  $1/T_{opt}$  equal to, optimum temperature. Here you cannot use only one temperature, some are optimum temperature, sorry, you can use one temperature but that has to depend on  $E_1$ ,  $E_2$  and  $E_3$ .

If this one is less and these 2 are more, okay, activation energies, all this may be low, this may be high, this may be low, all combinations are there, okay. But even then with all these combinations you will get a nice equation, you please derive this equation. I want to derive that, it is very simple. Only thing is you have to write equation for maximum, what is that it is rate there, maximum, yield, not conversion, not rate, okay. Both does not, both the not have any meaning here, it is yield. You write an equation for yield and differentiate with respect to temperature, then you will get this T out, okay. So that equation is  $R$  by  $E_3$  minus  $E_1$ , log of  $E_3$  minus  $E_1$ ,  $E_1 K_{30}$ , this 30 is  $(\Delta H)_{30}$  effect for the 3<sup>rd</sup> reaction, okay, good.

So divided by  $E_1$  minus  $E_2$   $K_{20}$ , so that is the equation, yah. Sorry, logical, logical doubt, that  $R$  is the gas constant, okay, good, so that is one. And the last one which I want to tell you is a famous reaction, what is that, Denby reaction. Okay, good. So when I go to Denby reaction, it may be, you can write here  $A + B$  going to, okay,  $R$  going to  $S$ , this is going to  $T$ , this is going to  $U$ ,  $R, S, T, U$ , okay. So now because this one is 1, 2, 3, 4, okay, I am in various combinations are possible. The 1<sup>st</sup> combination is  $E_1$  greater than  $E_2$  and  $E_3$  greater than  $E_4$ . What is the temperature scheme now? Yah, Pooja?

Oh, desired product, very good question, yah. You see, this one is desired, very good question. Not  $R$ , he we have  $S$  is desired. I will ask you here, I will tell here  $S$  and I will ask in the examination  $R$ . Okay, in between.

$(\Delta H)_{30}$ .

Yah, so that means uniformly we have high-temperature, that is right, okay, good. So then you have  $E_1$  less than  $E_2$ , reverse of this and  $E_3$  less than  $E_4$ , this is low temperature. Right, so I have there another case,  $E_1$  less than  $E_2$ ,  $E_1$  less than  $E_2$  and  $E_3$  greater than  $E_4$ . Yah, initially low temperature and then slowly increase the temperature, I am happy I say, I think at least your experts of this temperature scheme. Okay, activation energies, somehow I think you like activation energy, all of you are able to answer this, okay.

This is increasing temperature, how do I write? Okay, correct no, I look increasing temperature, okay, good. So then, other one is, of course, reverse of this,  $E_1$  greater than  $E_2$  and  $E_3$  less than  $E_4$ , this is decreasing temperature. Or maybe he is I have to put here increasing temperature is, increasing temperature. Okay, good, actually those of good symbols, when you are doing Ph.D. work or MS work or project work, it is better always, if you have 4, 5 variables, okay. And the dependent variable you have to see, how it is getting, it

is increasing or decreasing. So write like this, okay, if Delta P as an example, because we easily understand Delta P.

So Delta P is increasing with velocity, okay so we write Delta P increasing with velocity, Delta P increasing U, right. So like that, with viscosity what happens, with density what happens, density of fluid, diameter of the pipe, what happens. That will give you very clear picture for your either equation development or correlation development, if you write like this, all the parameters. Because all of you have to do some projects, definitely, okay, good. So with this I think, very happy, nonisothermal eye cover this you are much more than earlier, there is why always, Rahul is scolding me that you are partial to this.

You are 1<sup>st</sup> of all very lenient to this batch, okay, plus you are also telling them more, okay, maybe I think this is my last thing, so that is why I have to tell more, otherwise I do not know where I have put later. Okay, good, so this is the one, but I tell you, everything will be happy in the class but the moment you cross the door, nothing will be happy for you. And next class is much worse, next class you come, all looking happily bland faces. Fresh CD, okay, which I think you can put any memory there but what is the use, fresh CD, nothing is there inside. So that is what is happening everytime every class. So now I think this is closed now and now we have what is left is residence time distributions, right, yah.

Without writing there I will introduce you to residence time distributions, then we will write in the next class, right. Residence time distribution, we discussed about ideal reactors, we also discussed about, when we were discussing about ideal reactors, residence time distribution. Okay, Merit, what is the residence time distribution for plugged flow?

Student: 0.

Professor: Why it is 0?

Student: Because (0)(40:37).

Professor: What do you mean back accumulation, where is the question of circulation? You are talking about steady-state reactors, use correct words, there is another thing. Always you will lose marks the moment you use wrong words without knowing without thinking in the interviews. If you do not know, you keep quiet, that is much better. But if you are trying to say something which you have not understood or you do not have any mini for that and

simply say some word, people will definitely get you, not only Merit, everyone. So that is why, where is a combination in PFR we are talking?

Student: ( ) (41:13).

Professor: Yah, that you tell, residential distribution equal to 0 because every particle will spend exactly 10 seconds, what kind of stupid question you are asking. Because where is the distribution there, because each and every particle will exactly spend 10 seconds means 10 seconds. If it is 11 seconds or 9 seconds only, distribution comes. Okay, Swami, just behind him, what is the residence time distribution for mixed flow?

Student: ( ) (41:39).

Professor: Straightaway infinity. Infinity is a point, did not distribution. You see again catching points. If you say only distribution, it will start from somewhere and end somewhere I say. 0?

Student: 0 to infinity.

Professor: Ideal reactor, you are talking about was ideal reactors, it is too ideal, okay, yah. It is 0 to infinity, right. Now I think we will go to Pooja. Pooja what is the residence time distribution for batch factor?

Student: Sir same as PFR.

Professor: What is that? Same as PFR, that means have to go to PFR research.

Student: 0.

Professor: Why 0?

Student: Sir because it is the same time we ( ) (42:26).

Professor: Yah, here it is by definition but there by force because you are not a loving anything to go out, anything to enter in batch reactor, you are closing the doors, like you know in batch systems, whether you like the class or not, 50 minutes you cannot go out. So all of you have exactly the same residence time here, what is residence time distribution for this class?

Student: 50 minutes.

Professor: Residence time distribution? 0. Mentally not working, physically or there. Mentally you may not listen to me even one would also, okay, throughout the class, you will be sitting here, you may be in your own matrix, correct no. How can I check, unfortunately I am not Neo to check and then cross, okay, you are out of the matrix or inside the matrix. So that is why I think in batch reactor also it is 0. Batch reactor normally we do not take into picture when you are talking about RTD, particularly when it is flow only. Because when it is flow, it got, its own choice to go out or coming, okay, for the particles.

Whereas in batch system, where is the choice, your closing the doors. That is why all residence time distribution is focused only on flow systems. Okay, and white is 0 for mixed flow? Sorry for plugged flow, why the 0 to infinity for mixed flow, why? Because you just take the value but now I am asking why.

Student: (0)(43:57).

Professor: By definition we defined our PFR such that there is no distribution of particles and each and every particle has to spend exactly same time. What is the best example?

Student: Conveyor belt.

Professor: Conveyor belt, please remember that. I think other than conveyor belt, you do not have anything, any reactor. Only conveyor belt will take all the particles exactly because again once they enter, they cannot walk, they will there, that particle, it does not have legs no, so that is why I think it will be taken and then at the end whatever you fix, 10 minutes, 20 minutes, like that it will come. For example of 1 conveyor belt reactor? Coal combustion, mainly this Coal combustion, because coal has always plugged flow, coal particles.

That means if I have uniform size of the particles and at the end of 10 minutes, each and every particle would have burned same way, executive same way, right. But in reality that is not that, that relatively will see in the next semester, okay, good. This is the one, now this ideal residence time distribution will be spoiled by non-ideal parameters. What is the statement? Ideal distribution that is 0 distribution for PFR, 0 to infinite distribution for, yah, for mixed flow, CST R will be spoiled by non-ideal parameters like axial mixing, dead zones, yah, recirculations, by passing, these are, most of the time these only 4-5. Okay.

So that is why we have to now find out the residence time distribution for normal reactor, real reactor, not ideal reactor and then to find and then to find out non-ideality would have created

this kind of distribution. It is like you know many people are going to hospitals nowadays, you know everyone is sick, right. So they go there, you go there, then they give a test, maybe blood test, because they cannot find out what is wrong with your body. So by taking blood test, they will know, okay, this parameter is not well, so probably this is the cause, that is what exactly what you are going to also do.

That, otherwise, you have not come to that stage, maybe you will come very quickly, you know this diabetes stage. Because now it seems in India diabetes comes around 20-25, earlier it was 60, okay. Because the kind of food what you take is wonderful food, so that is the reason why I think diabetes is pre-poned. I think, really, I think in Andhra it seems as a diabetic capital of the world. Because those are the people, they take this much rice and that rice has only sugar, nothing else. Okay, yah, so that is the reason, I am not joking, I am correct, it is Andhra, Andhra is the capital of the world for diabetes.

That is 3 times or 4 times? Okay, 4<sup>th</sup> time they take snacks, again made of rice only. Okay, so that is why, that is very bad, that is why North India it is slightly less because we did slightly better than twice as far as diabetes is concerned. They will also get a little bit later and also, the problem is early morning breakfast is 100 sweets. Correct no, for example Bengal. , 99, then how many? Oh, breakfast no sweet? For lunch, every day. Then what you take for breakfast?

Student: Parathas, Rotis.

Professor: Parathas and Rotis in everyday meal? Okay, but I think which they take, I think in Rajasthan, all sweets in the morning, Gujarat. Yah, Gujarat, yah we are great in that, somewhere some non-ideality will be there, always, yah. So there is why particular when sugar patients go there, they will give glucose into your mouth, correct no, empty stomach you have to go and then they take the blood test and afterwards they will pour 5 ml or 10 ml into your mouth and then after 1 hour or half an hour or also maybe one a or 2 hours, 1.5 hours, 2 hours, 2.5 hours, they take the sample.

What they are doing, they are exactly doing tracer tests. That is what, we also inject tracer and at the outlet we try to calculate, we try to collect sample. Then depending on the tracer, I mean, this sugar concentration, glucose concentration, then I will find out for healthy body there is a curve, ideal reactor. Correct no, for healthy body, how the sugar will be absorbed by the body, there is a curve. So for non-healthy body, it can go anywhere, for healthy body there

is only one curve. For non-healthy body there are thousands of girls, so correct no, because you may have some kind of problem, I may have some kind of problem, okay.

So that is why they try to check and then try to find out whether they have, the healthy body or wrong body. So if they have that one, then sugar, then they will correct you and all that, that is different, that is what exactly we are going to find out here. Because we know the ideal reactor, you know response, the graph. But only thing is now we have to develop an equation also for ideal reactors and then compare always, with that curve what is experimentally curve. Okay, so this is what is your overall picture and unfortunately, I have to take more time, I have to spend more time maybe next class.

And this residence time distribution, normally we talk only for one phase, what we have talked to till now is only for homogenous reactors. Right, but if I have 2 phases like coal combustion, I have coal particles solid and also air entry for combustion. Now I have to find out how coal is entering and leaving and how air is entering and leaving. Same thing for temple catalytic reactions. Catalyst is in the packet bed and air is, sorry, the reactants are entering, getting converted and products are coming out. Now find out what is happening the catalyst but fortunately here catalyst is batch, it is not moving. So RTD for catalyst will not come, correct no.

But if I take moving bed, I can use moving bed catalytic reactors. So the particles also are moving, maybe cocurrent going up or maybe countercurrent, solids coming, gas going up. Now I have to find out, gas is moving in plugged flow, particles are coming down in plugged flow of gas is moving in mixed flow, only 2 flows ideally, right. Our solids are coming in mixed flow, you have to find out, little bit extension, slurry reactors. So when you have slurry reactors, you have 3 phases. What are the 3 phases? Gas, liquid and solid.

Solid is the, I mean if you take the example of hydrogenation of vegetable oils, what is the catalyst, what is the gas? Hydrogen. And what is the liquid? Unsaturated oil. Okay, now you have many possibilities. I can take for example oil as batch, solids also is batch and gas only public. So when these 2 are bad, I do not have to worry much about it. Okay. But I have to worry about bubbles whether they are going in plugged flow or whether they are going in mixed flow. That means all the bubbles are spending exactly same time or some bubbles are coming very quickly, some bubbles are coming very late, then you have 0 to infinity residence time distribution. Like a story am trying to tell.

So now what will happen if I have liquid also moving, liquid also continuously coming, continuously going out. Now that will be in mixed flow or whether it is really a mixed flow or not, we have to check. So that is why for multiple reactions, for every phase you have to check whether it is mixed flow or plugged flow. So these are the techniques we are trying to develop in the next few classes.