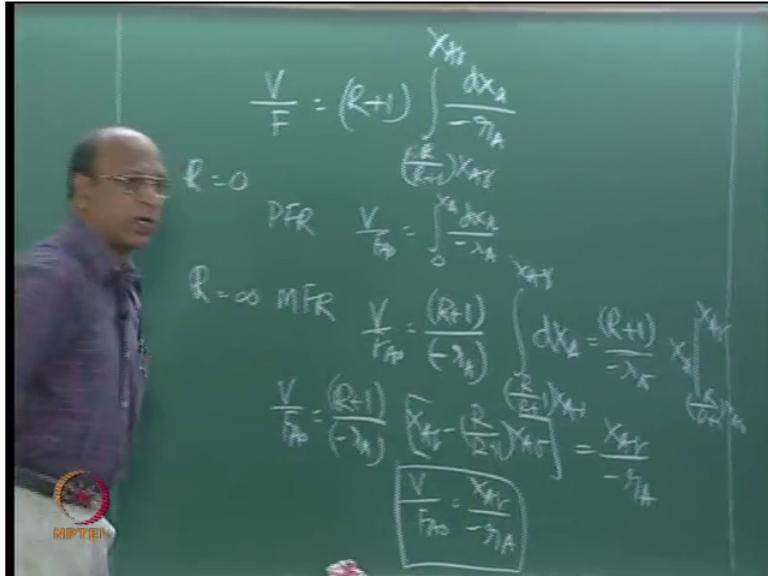


**Chemical Engineering.**  
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**Lecture-37.**  
**Multiple Reactions Part VI.**

(Refer Slide Time: 0:22)



Professor: Okay, Yah, answer, before Van de Vusse reaction, okay. So what is the problem? As R tends to 0, V by F equal to R + 1 integral X AF, yah, this is the 1<sup>st</sup> one, you have to write it correctly, okay. Then you have to show as R equal to 0, this goes to PFR, right, straightforward. V by F A 0 equal to 0 to XA, d XA by minus RA, okay, good. Yah, so as R tends to infinity, MFR, okay. So within the time given, there is one of the simplest derivations what you can have here is using the physical concept. When I divide by R, why should I divide by R? divide by R means, where do I divide? Which when I divide by R? Which denominator?

You cannot do that, this you cannot take it to infinity, okay. That will help it, so the simplest concept is that when R equal to infinity, what is rate throughout? Rate, rate, same. Okay, that means is it constant? Throughout the reactor? Correct no, so when it is constant, you pull out that, here V by F not equal to, R1, R + 1 divided by minus RA. Now integrate, what is there to be integrated? This is R by R plus 1 XAF dXA. So dXA equal to XA, right, so now this will be R + 1 minus RA so this is XA, so this equal to, why not, yah why not, that is what I am asking.

Yah, you have to integrate, if it is changing with conversion, changing inside the reactor. It is not changing, it is about the rate because it is come in a in an ideal CS TR, you have only one rate, right. So that rate is constant in a plugged flow reactor but you have  $R$  equal to infinity. Every, this, what I also explain to you, when you are discussing about  $(\infty)(3:13)$  equal to infinity, so  $R$  everywhere is same, that is by throughout the reaction to have one rate which means it is MFR. Now mathematically also you can prove that. Now if I write this  $V$  by  $F_N$   $R$ ,  $R + 1$  minus  $R_A$ , this is substituting lower limit, upper limit,  $X_{AF}$  minus  $R$  by  $R$  plus  $1$   $X_{AF}$ .

Yah, how much is that?

Student:  $X_{AF}$ .

Professor: This is  $X_{AF}$  by minus, so what is the equation now,  $V$  by  $F_{A0}$  equal to  $X_{AF}$  by minus  $R_A$ . That is what is MFR equation. This is wonderful, again, this is wonderful, okay. Because this is, what is the physics we have discussed when you are really talking about recycled reactor,  $R$  equal to infinity means what? It does not mean that you are thinking back, everything back and then you know what happens, if you eat more and more and more and more and do not know, your stomach will explode, okay. Same thing there, I think you know, you are not, there must be outlet, there is outlet nearby drop by drop for the mixed flow, recycled reactor where I have infinite  $R$ .

Only small amount, 1 ML is taken out, I also gave that example, 10 metre cubed is recycled. That means throughout the reactor I have almost the same rate. So that is why you can take it when they do it. This is wonderful problem but you know the marks allotment for the 1<sup>st</sup> one it is 0, and for the other one. Yah, yah, people will laugh if I ask you to put  $R$  equal to 0 here,  $R$  equal to 0 there and you are only, you know M tech, MS, Ph.d., okay. Minus L KG also will do that. That is memory, there is already in the hard disk, you are not doing anything. You are not doing anything, it is there in the hard disk.

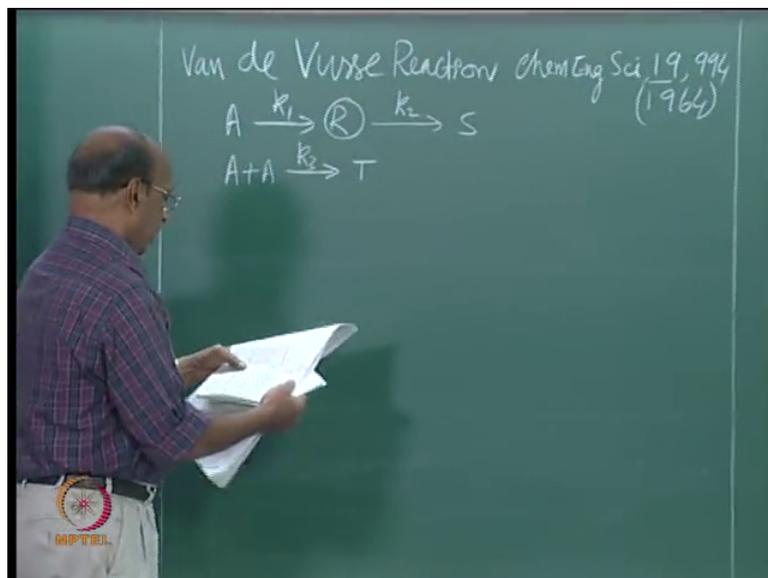
Student:  $(\infty)(5:41)$

Professor: Okay, so that is why, I think Mark cannot be simply equally divided I say. It cannot be fully divided, or do not have, they could not have come here without hard disk. Maybe you know megabytes maybe, storing place will be less or more, but for that you have not made it on own I say, only God made it and gave it to you. Okay, good, so that is what. What is

wrong? There is no funny way, whatever I will give will be 1, we are 9, it will be one Mark and 9 Marks for remembrance, okay. 5-5 is too much. 2, otherwise 2, that is all, 2 or 8, 2 or 8.

No, no, I think, you know, people will really laugh at it, when you want to substitute here 0 and 0 and you see that give marks, you give me marks. Okay, anyway, marks does not matter. So I am going to conduct many, so this you may write down, you have not got sufficient mass here, okay, so then we will see at the end how you can see the marks, marks is not the criteria. But you see again once more I want to remind you the beautiful concept. Now you do not forget so easily, right. At this point of time do not forget now so easily about this proof why recycled reactor R equal to infinity is a mixed flow reactor.

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You are not very happy, 5 marks you want. Okay, Mark we will see later, okay, good. So we will come to now this Van de Vusse reaction. So now tell me, this one also, the other day also we have written here. Not tell me, because you have to think, Gopi, anything you are saying? This one you could not see, who, okay, you know the answer now? Okay, good. You do not want to know, that is all. Surprisingly what I did earlier was, yesterday I gave one example, I gave the solution and next day morning again same thing repeated, same question paper, okay.

Yah, still I think only 4-5 people come out of again maybe at that time 60 were not there, maybe 4-5 or something was there. Only 4-5 wrote that, that is what is the use of hard disk. Okay, because not able to store that also. Not able to store that, so that is why I try all tricks you do to make you think and then to make you remember. Remembering also is important,

okay. At least main concepts, not everything, main concepts, okay. So now you tell me what is the real problem here, why this reaction should be discussed at all? What is the conflict? So you think and then tell me.

Avinash? What is the  $(\tau)$ (8:50) in this equation? Why do you have to discuss that equation as a great equation?  $R$  is the desired one, that round is the desired one.

Student: That is parallel and series.

Professor: So?

Student: There is a contradiction sir.

Professor: So the problem is easily solved because you have a rule. When you have a 2<sup>nd</sup> order and first-order, what is the rule? And there in parallel or series?

Student: Parallel.  $(\tau)$ (9:29).

Professor: Think I say, think, think because parallel with respect to  $A$ , so parallel with respect to  $A$ , then what is the rule? And one is first-order and one is 2<sup>nd</sup> order. So that  $A$  is going to  $R$  or  $2A$  is going to  $P$ , yah, what is the rule? You have to keep high concentrations or you have to keep low concentrations?

Student:  $(\tau)$ (9:57).

Professor: That you remember, good, that is excellent, right. So you have to keep, because  $R$  is designed on, that is lower order, you have to keep the concentration is lowest possible. Then which reactor is better for us?

Student:  $(\tau)$ (10:13).

Professor: CSTR  $(\tau)$ (10:15), okay. Then what is the conflict in the 2<sup>nd</sup> one? There will be conflict no, I can use MFR and then go to sleep ? Yah, again  $R$  is going to  $S$  but our idea is to maximise  $R$ . So then what is the conflict now? No, let us just assume 1<sup>st</sup> isothermal. Sukanya? What is the conflict now? You solved that parallel conflict, is there any other conflict now?

Student: If we have increased  $R$ , we have to increase  $A$  but...

Professor: Yah, why we should increase  $A$  if I want to increase  $R$ ?

Student: ( ) (10:59).

Professor: Why should I increase R, A for R, what is the problem? Your answer is right but the explanation how will you give? Please think I say. Please think, please think, please think.

Student: ( ) (11:23).

Professor: Yah, it is there. But what is the conflict, I mean what is there, is there any conflict, happily I can now take MFR and then go to sleep. What is the other conflict, is there any other conflict 1<sup>st</sup> of all? I am not saying there is concert, I am only just trying to think you come in and make you think. Why? Why, why, give me the reason? different positions on...?

Student: ( ) (11:55).

Professor: For what reactions?

Student: Series.

Professor: Yes, that point only I just want to get from you. The 1<sup>st</sup> one is a A going to R, R going to S and R is the desired product. So actually it will tell me that use PFR. You will have to keep the concentration as high as possible, that is why use PFR. Now there is a side reaction for that A and then it is higher-order than the other, you know, the main series reaction, it is a parallel reaction, now this one says that no, no, do not go to PFR, go to, yah, sorry, mixed flow, to give the consideration as low as possible, right. Now there is a conflict, which one is the better one?

How do you, do you use 1<sup>st</sup> PFR or do you use 1<sup>st</sup> MFR, or what do you really do? That means you can extend, you are taking a little bit, you have one extreme PFR, another extreme MFR, right, but maybe somewhere in between you have controlled mixing. Controlled mixing means R equal to 1, you have, you have some kind of control over mixing, right. R equal to 10, you may have some kind of mixing, that is the reason why this kind of reactions wherever we had the conflict between, one says that use plugged flow, the other says that use mixed flow.

But in between their maybe some conditions, where recycled reactor is the best. And also unfortunately we cannot make it as a rule. You know, the statement, use always R, recycle ratio for this kind of reaction is not a rule because it cannot satisfy, right. So that is why only straightforward reactions like A going R, R going to S, yes, I have to use plugged flow

reactor, high concentrations. Otherwise if I have 2 parallel reactions without R I mean without R going to S, I have only A and A plus B going to T, that means I have no parallel reactions, one second-order, another one is first-order, I know the rules clearly.

But when you combine this, you have the conflict, okay, now 1<sup>st</sup> reaction says that you can go to PFR, 2<sup>nd</sup> direction says that, no, no, no, MFR is better, that means you have 2 also suppress this, then only you will have more formation of R and then you have to also see how do you suppress this next. Right, so but in general if I do not have this, this will give me maximum, okay, if I have only series, series reaction. So now you can see the recycled reactor is also useful in such cases where there is a conflict and if you do not know which reactor to be used because this says mixed flow, the bottom one parallel, that series alone if you take PFR.

And in somewhere in between, probably you have to use that also depends on K1 values, K2 value, K3 values. That also depends on K1, K2, K3 values, why it depends? This thing is little bit of more thinking, you know, deeper, you have to scratch. You know like that Inception movie, 1<sup>st</sup> dream and then dream within a dream, then dream again within a dream, 3<sup>rd</sup> layer. So now you are only scratching the 1<sup>st</sup> layer, now scratch the 2<sup>nd</sup> layer.

Student: ( ) (15:15).

Professor: What is that?

Student: ( ) (15:22).

Professor: Yah, that is what, I think you know, that is why it depends on K values, now you can just imagine, like I say that I have K1 equal to 100 and whereas K2 equal to, K3 equal to 0.01, which reactor is the best? Obviously PFR, right. But on the other hand if I have K1 is 0.1 and K3 is 100, you see, we should not think that is going to, totally revolutionise the yield, no. The overall will be definitely much much less but within that you will get more of R. That is why someone had these doubts, I think after the class people were asking me. Sir by maintaining this alone, how do you get more, no, within that the overall rate falls.

Definitely if I am not going to use plugged flow A going to R, R going to S, and then if I use mixed flow, the overall yield definitely falls. But within that again, if I am able to maintain concentration of A as low as possible, that is mixed flow reactor, then I will have you know definitely more R than compared to T. T formation I have to suppress. So that is why the conflict in all these reactions is this particular one. That means which reactor is the best one?

Is it only one reactor or many reactors? How do you do that? You have to write equations, you have to solve them and you have to write equations in 2 fashions, like one is, design equation like this, other one is time independent equations.

What are time independent equations? What you have done, what you have done many times till now. Like for example  $dCR$  by  $dCA$  or  $dCR$  by  $dCS$ , you know just for comparison, I am just telling you. But most of the time,  $dCR$  by  $dCA$  can be used because when you are talking about yield, so those are time independent equations, but still they are differential equations. Right, so you have to use and you have to be expert in learning in the solutions of differential equations. Now let us write the differential equation for this and see what will happen, can we do something.

I am not giving the final solution but I think only few tips for you. So that you know, I just want to post because you have many things to do, okay. I cannot alone spend time on this alone but I have to expose you to those problems at least, right. And a simple problem I can always give in the examination because of the time I have to blackmail you with the exam, that is the problem. Otherwise immediately you delete all the files regarding multiple reactions, right. So that is why our deletion activity is very very fast. The moment you know that this is not coming in the examination, simply switch of the, that part of the brain, right.

So that is why, that is why we have to, you have to expose you to some equations where I think you know the overall problem, you know, that is what what we see in MS, Ph.d. and also M tech and all that. When you are doing project, if you understand what is the problem you have to solve, 50 percent is already solved. Most of us would know what is the problem to be solved 1<sup>st</sup>. That clarity is not there, the moment you have the clarity, okay, in this particular problem I want to only look at this point, right, that means you have the clarity. What exactly, you know, that is not that easy to find out which point you are going to concentrate, it is not that easy, the way I am telling you.

You should have tremendous amount of background information on that particular problem definition, then only you will know what is missing, what is not wishing and what is that you have to do very very clearly. Okay, because all of you are going to do the projects, that is why I am always trying to tell, whenever there is an opportunity. You understood no, I think particularly Ph.d. scholars, MS scholars, who have been given already the problem, did you understand your problems 1<sup>st</sup>?

The moment you understand your problem, you have got 50 percent of the solution, it is very easy now to tackle. Okay, when compared to not knowing the problem at all and my experience with many backers, many students in this Institute as Dean academic research is that. Because those people who are taking more time, more time you know like, I am not telling everyone, then maybe special cases like you know the problem was still you cannot do because problem itself is very very difficult to solve, it is not easy to solve, right.

But in most of the times, when I talked to the students, the problem they tell me, sir, the guide did not define the problem, I do not believe the student, 100 percent, that also is there, because guide also would have given very clear problem but this fellow would not have understood. Because human mind, you know, they never think twice to lie, to escape some situations. That is our defence mechanism, okay, okay, our defence mechanism to escape for life is either lie or run or jump, whatever you want to, you have to do it. So here in life and death question, when dean asks, okay, why you are taking more time, then blame someone, not blame yourself.

If you blame yourself only, you are starting thinking about your problem because even here in examination also, you write the examination, if you are not doing well, who is the 1<sup>st</sup> one to be blame, the teacher, the question paper, yah. Question paper and God for the, God for who created this question paper is the teacher, so that is why I think teacher is blamed, okay. But on the top, on the other hand if you just link on your own, okay, what did I do yesterday? Okay, how much I have prepared. Right in any subject, yah, then blame goes to you and that will improve for some people, for some people.

Again you know for some other people, okay, I think okay, I have not prepared well but I have not prepared well because in my family there is a problem, okay, my friend is not well, and yesterday my friend's girlfriend did not call him, he is worried. Okay, no, no I saw paper I think you know yesterday, yesterday paper there was a suicide because the girlfriend did not call this boy and then he hanged himself somewhere, Kanpur or somewhere, I think, not IIT but some other place.

Okay, I read yesterday, yesterday or day before yesterday, you know in the paper. So that kind of stupid reasons always you can find, okay. So that is why all these things I have to tell you also whenever there is an opportunity to change your mind, I tell you teaching is not only just making you understand the subject what what you are teaching, changing the mind also is teaching. That is much more important. If you are able to click at that point, mind, and here,

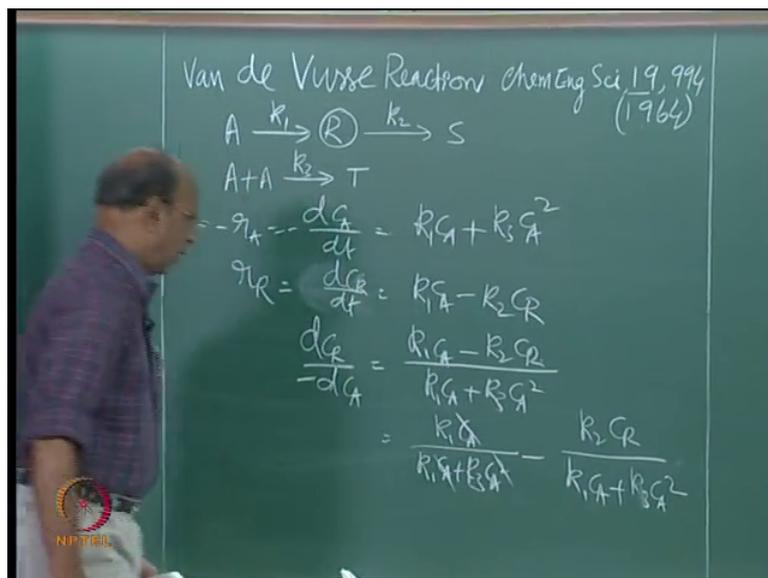
that is why I told you, if I become Leonardo Dicaprio, I will like to enter all your brains and change them, Inception, okay.

That, I mean not possible for me right now, otherwise if I am a matrix hero Nero, then put CDs in everyone, CRE CDs inside your brains, load CRE. But that is not possible now, so, at present on this planet only way to learn the subject is hard work, sweat, always sweat, that is why you know, so it is in quotation, Gopi... Yah? Anyone else, you know that quotation, Thomas Edison quotation?

Student: ( ) (22:58).

Professor: There is another one, equivalent one? None of you know that, really? Yah, Shahid, one percent inspiration and 99 percent perspiration. Perspiration means what, sweating, that is what I am doing right now, okay, yah, that is what.

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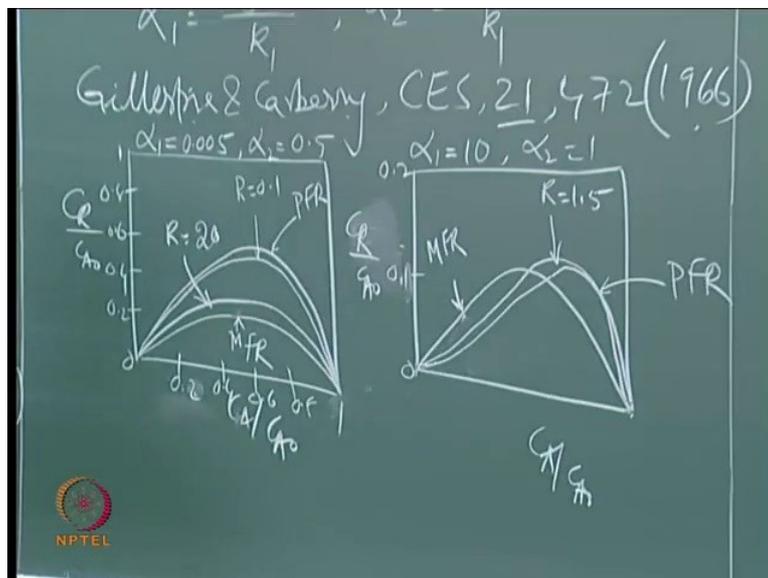
So work, you know the inspiration and also the concept is very small but to understand that, you have to work, work, work. Okay, now let us write these equations. Okay, so now minus RA how do I write, minus RA equal to dCA by dT, again minus is there, catch me if I am making mistakes, yah. It is forming in both the , it is the composing A, minus RA, then, you see temporarily you went out of your mind, out of class, not mind. You are just looking at that, tell me now. K1 CA plus

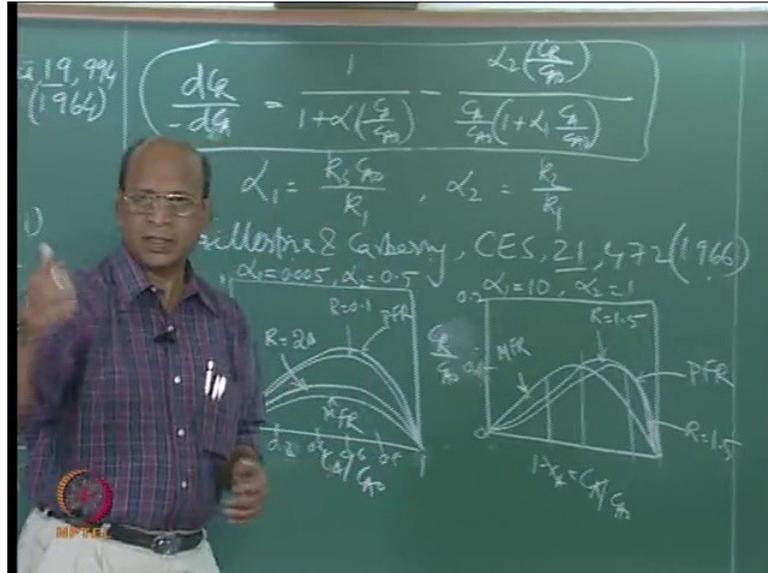
Student: ( ) (24:03).

Professor:  $K_3 CA^2$ , because it is second-order reaction. Okay, now RR, this also of course I can write my next here, okay, R, R, this is like series reaction, okay,  $K_1, dCR \text{ by } dT$  equal to  $K_1 CA - K_2 CR$ . Of course CS also I can write but let us, correct no, it is normal series reaction I say. That is why you know when you have too much information also you get confused, that is what exactly Google is doing us. That, one click, 1,000,000,025 in 1 seconds, all those sites will come. Now you try to find out in 1,000,000 sites, what is there, okay, Mar Gaya, I think you know that is why too much information, so confused, right.

So that is why I told you know, remember that centipede, yah, that is what what you are doing. That is what what you are doing when you are opening Google also, because so many sites, you do not know what to do with them, okay. Okay, good, okay. So now I think these 2 are just sufficient for us, now let me write  $dCR \text{ by } dT - dCA \text{ by } dT = 0$ , yah, I think I am writing the final equation but only thing is you have to divide 1 the other and adjust. If there is a common factor you can remove, that means for example if I am dividing, yah,  $dCR \text{ by } dT$ , let me write the 1<sup>st</sup>.  $K_1 CA - K_2 CR$  whole thing divided by  $K_1 CA + K_3 CA^2$ , okay.

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This also can be written as 2 terms, that is  $K_1 C_A$ ,  $K_3 C_A$  square minus  $K_2 C_R$  by  $K_1 C_A$  plus  $K_3 C_A$  square. So here only I am telling, common thing you can cancel out, right. So now you will have your  $K_1$  by  $K_1$  plus  $K_3 C_A$ . Now this equation, this is 1, 2, 3, 4, this equation can be written as  $dC_R$  by  $dC_A$ , minus, equal to  $1$  by  $1 + \alpha_1 C_A$  by  $C_{A0}$  minus  $\alpha_2 C_R$  by  $C_{A0}$  divided by, okay,  $C_A$  by  $C_{A0} + \alpha_1 C_A$  by  $C_{A0}$ , you can try this. I think you know, this is only just algebraic jugglery, where  $\alpha_1$  is, now,  $\alpha_1$  is  $K_3 C_{A0}$  by  $K_1$ , right. And  $\alpha_2$ , this you can guess,  $K_2$  by  $K_1$ .

Now the greatness of Van de Vusse at that time in 64, happened because he could solve this problem. This is a differential equation, we made this one into a dimensionless group, this is a dimensionless group because  $K_3$  is a second-order constant, right,  $K_3$ . And you know the units, units is concentration inverse multiplied by concentration and time inverse, this is also time inverse, both will get cancelled, first-order. So that is why this is dimensionless, this is also  $K_1$ ,  $K_1$ ,  $K_2$ , both are first-order, both are inverse time, so it is only homogenous reaction is no, constant density.

So that is why they get, these are the dimensionless quantities and this is a differential equation which you have to solve. And the solutions are given in this journal and there are also some more solutions by our Carberry, I am saying our Carberry as if he is our grandfather, yah, maybe, okay. So he also, he and his students, I think his Ph.d. students, Gillespie and Carberry, anything I have to also give the nations but anyway, I think, Gillespie and Carberry, this also in CES, now I think you know, I do not have to write chemical engineering science separately, CES means chemical engineering science.

And this language also you have to use because if there is a new article in CES you have to tell, okay. So the moment I think, if I hear that kind of discussion in our department, I will be really very happy. 1<sup>st</sup> of all you know what is the meaning of CES and tech and also I know that you see in that latest journal and now you are informing your friends. But how many of you have seen CES journals? Very good, how many of you have read out of that? Seeing and reading are different, seeing is different and reading is different. You have done? Why you have done?

Student: Some articles on ( ) (29:48).

Professor: Okay, good, so CES and, no, no, I have to believe, why are they laughing? Not good no? Just, so 21 is the volume, 472 is the page number, this is how we write, 1966, okay. So they have produced some graph, actually Van de Vusse solved this problem for only 2 extremes like, I think recycle, recycled reactor he has not attempted but he is only told that under what conditions plugged flow is better and under what conditions mixed flow is better, okay, that is Van de Vusse contribution.

But later these people have told that okay now because there is a conflict between 2 extremes, intermediate mixing will be better, now you see the actual use of recycle reactor is only to control mixing, not to increase conversion, that is the 1<sup>st</sup> answer which we gave earlier. Forget about that, delete that file, okay, that particular file where you stored the information that, you know recycle factories always used for high conversion, no, it is not used for high conversions. You will never get high conversions, right, but high yields you can get. High conversion is we are comparing to ideal reactors, okay, yah, so that is why, you have to now remember that recycle is used to increase the yield in case of complicated reactions and what is the other use?

To control the temperature. If it is highly exothermic reaction, you know again, see, even though many times I have found myself common sense is not common, it is really uncommon, okay. But we will see very simply, oh, common sense. And also we use another word, oh it is very obvious. So what I have found is after 60 years of my life is that obvious is not obvious, common sense is not common. That is why I repeat many many simple things, many simple things, okay. So that is the reason why I think I also repeat many times, good. So what these people have done was there used recycle reactor and then showed that under some conditions the recycle ratio is very good, recycle reactor is very good.

Those things I have will just try to plot. Very complicated equations are there and you know, these all chemical engineering science papers, journals, we have online in IIT Madras. So that is why you do not have to go anywhere, no physical movement, sit in your room click, science direct, go to chemical engineering science, see those numbers, you will see those points. Okay, whether you read it or not, just go through and then appreciate the kind of mathematics that are involved, okay. Then if you are interested, automatically you will try to solve, okay.

So now what we, what they are plotted here was this is from Carberry,  $CA_0$  and this side I have  $CA$  by  $CA_0$ , most of the multiple reaction graph will be something like that, not  $\tau$  in reactor design you have  $K\tau$  or  $K_1\tau$  or that kind of things, right. If it is second-order,  $K\tau CA_0$ , that is the dam Kohler number. But most of these multiple reaction we have this kind of graph where this is the desired product, this is conversion, like,  $1 - \alpha_1$ ,  $1 - \alpha_2$  conversion, okay, good. So I will just give 2 examples, I mean 2 cases where  $\alpha_1 = 0.005$  and  $\alpha_2 = 0.5$ .

There are many graph but I have to then one graph, 2 graphs for you just to compare. So this is also the same thing,  $CR$  by  $CA_0$ ,  $CA$  by  $CA_0$ . And here  $\alpha_1 = 10$ , here  $\alpha_2 = 1$ , okay, good. So now, oh my God, timeout, okay, so this is varying between 0 to 1, maybe 0.2, 0.4, 0.6, 0.8, this is 0.2, 0.4, 0.6 and 0.8. And here also I have, this is the advantage of using dimensionless numbers, you get 0 to 1 here, 0 to 1 here. 0.4, 0.6, 0.8 and 1. Conversion is from 0 to 1 anyway, yah.

But here the graph which I want to show here is that, this is PFR, very near to that there is another line  $R = 0.1$ , then afterwards we have, it may not be exactly to scale but to illustrate the point it is okay, MFR, and I have another line here where  $R = 20$ . Excellent, so another one I just want to draw here. So I have some MFR lying, okay, here also have put 0 to, actually I want to show here  $CR$  by  $CA_0$ , this is 0.1, this is 0.2. Okay, that means maximum, here at least I could go to 0.6 and here it is only maximum 0.1 and 0.2, okay, but your graph will be only in between this.

So here if I take alone MFR, it will be approximately something like this, okay, this MFR, no, let me write later, okay, MFR, yah. So now if I have ideal PFR, you will have like this, this is PFR, if I have recycle ratio of 1.5 you will be somewhere in between, goes to maximum here and then takes a turn. So this is  $R = 1.5$  from that, okay, good, so what do you predict from these 2 graphs? Nothing? No, I think from graph you can predict really lot. So that

means unless you understand, this graph means when you are drawing this graph, you have to than these 2,  $\alpha_1$ , because those are the parameters, okay.

Those are the parameters,  $\alpha_1$  equal to 0.005, what is  $\alpha_1$ ?  $K_3$ , that means what? That, that means parallel reaction is there but  $K_3$  by this  $K_3$   $CA_0$  by  $K_1$ , is it small one  $K_3$  or is it larger one? Small one, so that means what is the rule? Because that is ignorable for example, PFR, now you see, when I have PFR, PFR giving me maximum, then the next one what is  $R$  equal to 0.1? Very near to PFR, very near to PFR. So that is why it is almost, you will also is almost like PFR yield. And then definitely we are going to get low MFR yield because rule says that use high concentration but MFR is just low concentration, so yield reduces definitely.

And also you can see the yield is only around 0.3, 0.4 here and whereas here it is around 0.6. That is what is the meaning of maintaining low concentrations, high concentrations, okay. Always you cannot get 90 percent yield everytime, but whatever yield you get, using these rules you will have more of the desired products. The overall yield itself maybe 5 percent, out of that 5 percent you may get 4 percent as desired one, the another 1 percent maybe only undesired one. Okay, so that is what is the meaning of that, okay, good. This is very clear because rule tells me that you have A going to R, R going to S series, PFR is the best and this follows as it is.

All that you have shown in this paper, in this paper, right, good. So now the other one is here,  $\alpha_1$  equal to 10 and  $\alpha_2$  equal to 1, what is the meaning now? Yah, that means the side reaction, unwanted reaction has more rate, that means more  $K_3$ , okay. So what is our rule says, use CS TR, okay, we have used CST R. That is why it is giving more yield, now see the overall yield itself has reduced, it is around 0.1. If I take here and this also is conversion, this is actually  $1 - X_A$ . So at this point I may have 60 percent conversion.

That 60 percent conversion, please remember, 60 percent will not be here, plotting  $1 - X_A$ . 60 percent conversion, maximum limit is 0.1 in a mixed flow reactor because we know that at low concentrations you will not have that kind of high rates. So the overall yield is suppressed a little bit but out of that if you look again, MFR gives me 0.1 and which is PFR, yah, this takes a turn here, this crosses actually, yah, this also I have to write  $R$  equal to 1.5, okay, good.

So PFR gives only till here, PFR there is no use. So that means only at low conversions, if you use, definitely PFR will give you more conversion. More, you know, here, less conversions. Because you were starting here,  $X$  equal to 1 here and  $X$  equal to 0 here, no, the other way.  $1 - X$  and talking no, yah, so that is the reason why at low conversions if you go, that means high  $CA$  by  $CA_0$  values, PFR will give you definitely more yield. So now you have to choose, okay, is it better to go for that kind of low yields, that means low conversions, low conversions and then use PFR and then use a separate mass transfer equipment to again increase the concentration of the product which you want.

See how many open-ended problems are there in chemical engineering? And unfortunately these are not the only reaction, like these thousands of reactions others, multiple reaction. So everytime you have to go to the corresponding, I mean corresponding reaction, find out the basic rules, if they are not following, then you have to choose, writing these equations, then solving them and finally plotting and then deciding which reactor is the best. And if I want only conversion between this and this, recycle ratio is the best. If I am maintaining my conversion only between this, recycle reactor will give me the highest yield.

Now how do we decide that which one is better, which one is better how do we decide is only by economic analysis at the end. Now, okay, I will tell this, conversion is only 20 percent, now I use mass transfer equipment and what is the cost for masses for equipment, what is the cost for this very percent conversion, what is your overall cost, whether I am making profit or not. The other one what I said you know, attainable region I have been telling you, attainable region, there is a website towards South America, South Africa, South African website.

So what they did was, you see, what is the maximum attainable region, maximum attainable region is they take for example all this and then they take this and then from here they take this. Okay, that is one, that means till here it is MFR which is giving, this is what is the maximum attainable region, understood no. So this is concentration if I am able to maintain MFR, I will get maximum, then beyond that I should be able to maintain recycle ratio, then I will take PFR.

So that is the maximum attainable region. It is not that simple the way I have told you but you know there are some rules how to follow, you know depending on its gradient and all that, there are many things. But this is the simplest one which I can give you, what you mean by that attainable region. Now this guideline is the attainable region, that is what is the attainable region. So beyond this, for example, here you will get anything, here also you can never get

anything. Okay. Anything means yield wise and telling, okay. Tomorrow I will start temperature effects.