Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Module 01
Lecture 35
Problem solving session

Okay, so as I told you we will do one problem very simple problem very very simple it is nothing to do with what we have done with this complicated equations, for complicated equations for the problems to be done I have actually asked you sent you last night the assignment so that is why particularly the problems given in Smith the solved examples please go through it first go through the solved examples and then try to solve them the problems which I have given, okay then I tell you definitely if you are able to do on your own as a group one or two also you can do together, okay two three but not only one doing and other people just sitting all three discussing and doing will be very good do it then it will boost your confidence like anything that means not only this design if you are able to this design even distillation column design, observer design all these things will look very trivial if you are able to take up this design to even the mechanical design part.

Mechanical design part means you calculate what is the total amount of catalyst then you have to think how do you put this total amount of catalyst, what should be the diameter, what should be the height and how do you put them support because when it is a packed bed you have to support the packing on something that is a distributor plate otherwise if you simply take without any holes a plate and then support it you cannot put anything no the gases cannot go inside no perforated plate, perforated plate design is also very important which you have never told you in during distillation design, okay that is why I told you know I think my example all our Indian movies the where we stop, where we stop? After marriage, (())(1:51) you know marriage there must be a marriage all people laughing that is the last scene in every movie they do not know that real problem start only after marriage, okay.

Similarly here finding out ten plates is not much for distillation column how do you put these ten plates, okay what is the geometry of these ten plates? So that is the problem how do you fix these plates to shell how many problems much more difficult you know marriage problems you can

solve but this problems you cannot solve so easily, okay because your counselors and all that for marriage but I think here distillation column design only you have to do, with a degree if you go to that is what I am telling you know you cannot go to consultant if you have a chemical engineering degree, right? Where do you go, right? Someone can go if he does not have a chemical engineering degree he can go to consultant no problem at all, okay good.

So that is why it will really help you in understanding if you are able to solve and if you have time please try that two dimensional model also where finite difference method is used, it will be very good, good but for that you have to spend some time, right? But unfortunately I have given this time non-catalytic reactor design if I could have given the actual catalytic reactor design as a project does techniques you could have learnt but this is totally your imagination so that is why this non-catalytic reactor what I have given that is infiltration is totally you have to imagine everything only thing what I have given is how much waste is to be (())(3:24), that is all, okay.

So you have to choose the system you have to find out what is the carbon content and you have to say no please do not give that you know because this (())(3:35) can be land field (())(3:37) not necessary in two lines our design is over you are not allowed to do that it is a non-catalytic reactor you have to design it and the reason also why you cannot do that is now a days there is no place for land field, particular in Andhra there is no place because every politician has taken thousands of acres. So I think there is no place to put even this waste solid waste, okay in Tamil Nadu also no they are not because I told you no all Indians are brothers and sisters so they are ministers here also they have brothers and sisters so these people also have occupied but anyway technical solution you have to give not simply land field, okay good.

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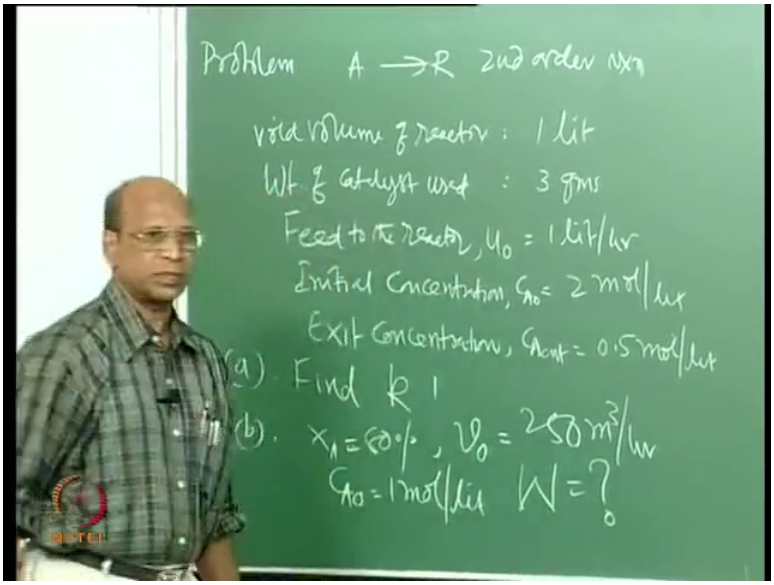

So this problem simple problem I will try to do anyway please take this problem, I will dictate I do not have to write the whole thing, a second order reaction A going R, you have calculators with you no? A second order reaction problem A going to R this is second order reaction e studied the second order reaction A going R e studied in recycle reactor (())(4:58) in a recycle reactor, good in a recycle reactor with large recycle ratio and the follow data are recorded, so void volume of the reactor 1 liter weight of the catalyst used 3 grams feed to the reactor is let us say u not equal to 1 liter per hour initial concentration Ca not is 2 moles per liter and Ca out exit concentration Ca out equal to 0.5 moles per liter, okay.

So then the problem is a, find k that is 1 calculate k value, okay other one is b how much catalyst is required in a packed bed reactor or 80 percent conversion of a packed bed reactor for 80 percent conversion of 250 meter cube per hour of feed of concentration 1 mole per liter no recycle is used full stop there no recycle is used, the other one is part c repeat part b if the reactor is packed with one part catalyst, two four parts inert solid this addition inerts helps maintain isothermal conditions and reduce possible hotspots, okay.

So the other data which I have to give you is Xa equal to 80 percent and v not equal to 250 meter cube per hour and Ca not equal to 1 mole per liter you have to find out what is W, right? Okay. So now you have the calculators, right? With you most of you it is a second order reaction please see that I think you know and recycle reactor, okay.

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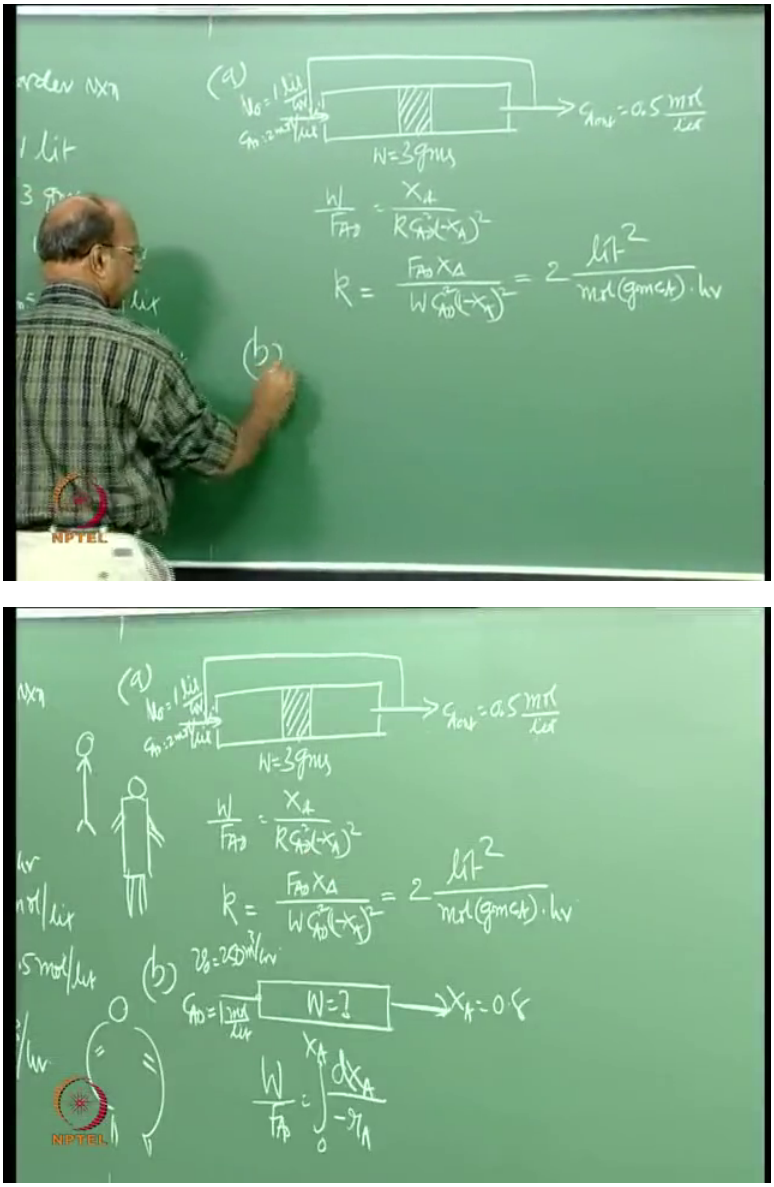

So what we have here is a recycle reactor something like this this is the catalyst 3 grams we have put it goes small amount is taken that is recycle, okay so I can close also this, this is W 3 grams and of course the feed is given u0 velocity is given as 1 liter, no v0 not u0 volumetric flow rate v0, v0 is 1 liter per hour and Ca not equal to 2 moles per liter anything else is given, that is all Ca out here equal to 0.5 moles per liter, good.

So what is the problem now? See this is typical Levenspiel problem I am just indirectly trying to tell you you know examinations, right? All typical Levenspiel problems starting from second first semester first chapter does not have any problems then onwards he give some clue in the

beginning and he have to get some information from the first part and then use that first part in the second part to calculate something else, okay.

So first of all he is asking you k and data given recycle reactor is given so now what equation use to calculate this is ideal plug flow because nothing is told about non-idealities, right? Simply ideal plug flow and this is how most of his problems are formulated because this is what is happening most of the time in industry if you are developing a new process in the laboratory you conduct some experiment, get the kinetic data use that kinetic data to finally scale up the industrial process, okay.

And here to avoid complications we are simply taking plug flow, isothermal there is no temperature variation and all that. So the simplest problems we are trying to attempt so that you know slowly you can graduate if the complications are increasing later, okay but currently it is only the simplest problem isothermal plug flow and it is recycle reactor with large recycle ratio, what is the meaning of that? What is the equation used to calculate k, it is second order reaction please remember, (())(11:53) you do not have anything no calculator nothing but you do not need calculator also I think it is calculations are very simple very very simply there are not that difficult W by Fa not equal to Xa by minus ra which is nothing but kca not 1 minus Xa correct no this is the equation, substitute the actual units and then try to find out I say substitute the actual units there Fa not is moles per hour liter or gram excellent that is the work miter square mole gram catalyst hour and if you write 2 I will not give you I think not even half mark there negative marks only will be given (())(13:31) if you just write only 2 you got it correctly liter square.

So that is the one actually, so this will be after substitution of all I will simply writing here 2 liter square mole gram catalyst per hour, so I just want to tell you you know because this is a peculiar unit you would have never imagined that this kind of units will be there for k values because we always know for second order someone was telling no mole liter hour that is what what you remember that is L kg long time back over, okay.

So for heterogeneous system you can have anything any units, okay good please write you got it Kaviya? Anand Kumar? No, okay. So what is the next one? Next one we have this is a, in b we have the packed bed, okay you have to find out packed bed where you v not given as 250 meter cubed per hour v not Ca not equal to 1 mole per liter, okay and Xa equal to 0.8 question is what

is W, now this is a packed bed, what is the equation used? But what is the other side, again W by Fa not equal to integral now you say you integrate and tell me W by Fa not equal to 0 to Xa dxa by minus ra it is second order reaction, anyone?

Ranita anything? Your handwriting is so beautiful I say I want to see she writes very clearly, (()) (16:27) for 250 grams, correct is substitute all that also got same thing, how much you got? 500 into 10 raise to into 10 to the power of 3 grams 500 kgs, correct no? But what do you mean by too high how much you expect? How much you expect I say it is industrial reactor 250 times 250 meter cube so that is why it is more only, thousand kgs you do not get 500 kg only check weather k value 2 see, and the problem is that you know you think that you are right and you go to hostel and tell that he gives always less marks, okay not only you I mean all I told you know all Indians are brothers and sisters there is no change, right?

So whatever you write I have to give the marks or not the correct answer, 500 kgs per meter cube, okay. Now you tell me how do I put this 500 kg per meter cube? After marriage? No marriage (())(18:15), okay so 500 kgs we got the catalyst so how do I now choose my dimensions for the reactor you should have some dimensions no some diameter and some height if it is a cylindrical, can you also use square cross section and some height? No, why? In the corners corners are always bad even if you have sharp corners better come out of that, okay we also have sharp corners so we want only rounded personality but I think round reactors we cannot use because we use difficult there so that is why cylindrical reactors we use, okay which represents us I think I told you no last semester all human beings can be classified into three groups, first group is straight lines, in the class I think Renita is straight line y equal to mx plus c, okay only one dimension you have other dimensions not there, right? Very tall and lean people I say, okay where 1 dimension is seen earlier in very old movies there used to be in Telgu there used to be an actor Ramana Reddy excellent representation of 1 dimensional model you know single straight line, okay.

So they look almost something like this you know that is the straight line, okay and other category is cylinders these are normal, okay all of us and other category is somewhere legs somewhere hands, not (())(20:15) I used to see always this spherical coordinates with that you know that Adnan Sami or someone was there, he is I think now he reduced I think maybe 250 kgs, 120 kgs execrated multiplied by 2, okay so 250 kgs I think you know always you can see

now you can start looking in the road when you are moving you can see most of times straight lines, cylinders, spheres. Now in India this spherical coordinates are increasing all of us starts here like this, third category because they take almost highly nutritious food so that is why, third category means spheres only that is what I am telling if you take too much fat and all that you become like that, okay.

So earlier it is not much maybe 50, 60 years back straight lines where there but I think spherical coordinates are not that much for human beings but now a days it is very happy you know to have that kind of coordinates what I say you see most of the young boys and girls it is not missions I think you know I tell you in our society the problem is that when we were born for each parent minimum it is 7 or 8, okay children, right? Not only starvation attention is not there I think mother also do not remember to which kid she has fed, okay.

So but on the average everyone is equal sometime they will get some food, okay but nowadays it is 0.5 or 1 children 0.5 children also are there, okay 1 children but now everything and also now most of the time now all the parents are very well (())(22:15) that means they have sufficient money and all that because mother and father both of them are working so so many things are happening both of them are well educated so now everything they want to give to the kids, if there is a burger immediately advertised in TV they will run through that shop buy and then put in his mouth or her mouth, okay Krishna sweets advertisement, go buy 10 kgs of Mysore pak put in his mouth or her mouth.

So what will happen? After some time he thinks that my god I have to take every day 10 kgs sweets that boy you know kid he does not know many things and also any advertisement in beautiful cloths like jeans pant that fellow will be 1 inch and you know so they will design I think 0.4 inch jeans pant, so mother father will run to that jeans shop you know it is express mall and what are other malls in there some other malls are there no, love style or many places, so they go buy and then even he is weeping he will put or parents will put and anyway cor and all that that is the same arrogance which has come to the society. So that is why if he comes to class 1 he thinks that he must be the first everything he should get right or wrong whether he writes wrongly like you are telling no 200 or 100 whatever you write I have to give the marks because parents are giving everything, okay.

So like that whatever exams you write like that school education will be over and you feel that you know you are the top and this how the society is moving because this arrogance has come because of the parents who have now only 1 or 0.5 children we have not mentioned the particle size for example, okay there are so many assumptions, okay what are the assumption particle size is not given 3 kgs is told there what size, not known, okay but will it be different size or same size we have to use?

(())(24:19) you have taken some data using 3 grams and the 3 grams also will have some size definitely is it the same size of different size you use, exactly same size you have to use what will happen if I do not use same size I will use something different you do not know whether there maybe mass transfer effects if you take large particles mass transfer effects, okay and if you take very small particles pressure drop effect because again you have to put in the packed bed no so all that so that is why there are so many assumptions here which we normally do not tell we will just give as an academician this is the problem I have not told even packed bed I mean packed bed behaving as plug flow, okay.

So there are so many things which we have to really use if you go to reality, reality is your industrial reactor where I have to put this 250 kgs 500 kgs where first of all you have to question what is the particle size, right? So the same size only you have to use which used here because otherwise your kinetics will be different your k value may be different, okay because intuition of diffusional problems all that may come, right? So that is the one, then what is the diameter you put? You have some thumb rules I am just want you to recall your memory we have some thumb rules already.

So if the diameter is let us say 6 mm particles which we have used so then minimum diameter should be how much? Yesterday we have some criteria no r by dp less than 4 what will happen? Why, that means you have uniform distribution, okay. So you should maintain that much, okay good but the problem now is if you take only that diameter and pack 500 kgs length will be bigger it will go to the top to the moon, okay so that is why as an engineer you have to balance because I have taken the data using this kind of condition particles and diameters particle size, temperatures, flows and all that, can I maintain the same kind of conditions and reduce the height also, right? Otherwise pumping cost and all that will be per unit length no delta p all that.

So that is why most of this design problems are having open ended solutions, if you are a very good engineer you design it, wonderful it is like architect constructing the house no if he is a good architect you can see the beauty of the house if it is a lousy fellow we can also see the lousiness of the house. So that is why simply leaving here 500 kgs and then finding out, okay somehow you put because we never tell you how to put in fact, right? Starting with the distillation even for heat exchanges, right? We normally give you in the class find out what is the total area you say 10 meter square, how do you put this 10 meter square, what is the diameter of the tube? And how do you arrange these tubes, okay. So all these are the problems which you have to note down somewhere, right? So that is why packed bed reactor even though we have used simply this is the packed bed reactor nicely all academicians are responsible for this also because never tell the we also live in only real imaginary world not in the real world, okay.

So if I am able to really give you what is this size how it should be I mean I am giving you the general thumb rules, what should be the minimum length because here we have plug flow diameter we told at least minimum length how much you have to maintain so that you will have plug flow almost L by d greater than almost plug flow if you do if you use that much that means if you are using 6 mm particles, okay 190 means 200 you take, right? 200 into 6 1.2 meters that is minimum height if you are able to go beyond that you are happily going for plug flow but the problem is if you have more and more lengthy reactor then you have the pressure drop more and more and you cannot afford that because whatever you are gaining the what is that if you get more money, more money also will go pumping, so that is the reason why you have to really balance, good okay.

So these are the things what we have and another one next one c because I know you are hearing as if it is (())(29:20) or something like that, okay but unless you write somewhere you will not remember afterwards all the questions what I raised what should be the height, what should be the diameter you know in fact how do you design the distributor plate you need one distributor plate at the bottom and one distributor plate at the top here, here you should have one distributor plate here you should have another distributor plate and the another question is, Kaviya would you put this packed bed horizontally or vertically? Prabhuv why are (())(29:50) he says like this and I will also ask if you say horizontal why horizontal, why? Correct (())(30:05) that is why usually all reactors are, if I put horizontally it is very good I say I do not have to pump at all,

right? Pumping cost is very very low if I put horizontally, what may be the contact I think it is going no.

You see simple things I say very very simple things where do you want to put all reactors as Prabhuv said only vertical, why cannot put horizontal? Not only that I can also tell, actually mixing is bad for reactor no why do you need mixing you cannot have mixing, contracting between what and what by putting horizontal what will happen in reactor how the contact is less, there is no phase no only one phase you know for example gas, what will happen if I have for example distillation column horizontal distillation column instead of vertical I will put horizontal because it is two phase very clearly seen that liquid is at the bottom, gas is at the top and then the contact is only where interface.

So that means you are not able to generates bubbles generate large amount of surface area and contact the liquid, something like that can you also think when you put horizontal packed bed, it is after all catalyst, okay and you are packing you cannot have exactly there will be slightly some gap between the top wall channeling, channeling is the main reason because when you put horizontally the particles try to consolidate themselves and then you will have definitely something or other on the top more wide edge, so when you have more edge more and more gas will try to go at the top because less resistance, okay.

So that is the reason why most of the time in all, I think as Prabhuv said you know most of the time we use all columns vertical only in chemical engineering we do not know x direction all chemical engineers know only y direction distillation column same thing absorption column same thing all extraction columns all mass transfer heat exchangers by the way, why? Why cannot we put vertical? We cannot put vertical, why horizontal? That is right question is right most of the time they are, surface area you are putting all the tubes no all these surface area is given by the number of tubes inside outside you have a shell, that will be correct answer, why it does not matter? Why it does not matter it depends on what, even then temperature gradient depends on what is the contact between liquid and solid tubes, it does not matter if you are able to fill up the entire shell and also entire tube if definitely matters if you have two phase flow again in heat exchangers particularly when they have steam generation condensers and all that you have to go vertical condensers, horizontal condensers, no okay.

So you see these are very very simple things but we never bother to give some attention towards that, okay. So that is why I think equipment design is one of the wonderful subjects for example all these things will come there no, this is process design in fact what we calculate to 500 kgs and then just leave it that is the process, okay using that equations and all that this is the amount I got but equipment we design only we tell me how do I put this 500 grams or 10 meter square area for example heat exchanger, okay or 10 plates or 20 plates how do I put it, okay and what kind of plates I think you also know no that in distillation itself we use cu plates, bubble caps and cu plates with down comers what is the difference between cu plates with down comer and cu plates without down comer, remember Prabhuv?

Anytime, where when we will weep where will weeping occur in which plate cu plate or why weeping should occur, you are not supposed to operate in that regime that is why flow regime maps are given to you you are not supposed to operate in the where you have the weeping of the liquid, correct no? That is not operational regime and you cannot also go for flooding regime where you have too much vapor phase and two less liquid phase and it is not allowing liquid to come down, that also you cannot operate you should not.

So when do you choose what also is very important when do you choose for example cu plate with down comer the best thing is cu plate only, why? Because in each cu each perforation will definitely develop one bubble, so that bubble will contact the liquid which is just above the plate now in cu plates what happens is the liquid and gas both of them have to come through the same cu's, right? So through some cu's gas will go, through some cu's liquid will go, right?

So that is the reason why you have very quick flooding and there is no good contact because if you take 2 meter diameter 2 diameter also can be the diameter of distillation columns. So one corner you will have only liquid coming down another corner only gas going up you will not have uniform distribution of exact distribution of gas bubbles generating throughout that is why what compromise is, okay let us allow the liquid to go through down comer and allow only gas through the cu's where you have each and every bubble forming then that will contact but anyway above that you know there is a flow here and then comes out and the bubbles are going and then contacting a liquid one of the best designs then you have other one that is packed beds, packed bed distillation for example when do you use packed bed distillation, when do you use plate distillation plate column distillation.

So so many things are there even heat exchangers when do you use coil type heat exchangers, when do you use simple shell and tube, okay and plate type heat exchangers are also available plates, one plate, next plate, next plate goes like this and within the plates you will have again another volume available for flow, so many wonderful design there is no limit for chemical engineering thinking you think that all the things are over in chemical engineering limitation is only your brain not the subject in fact in any subject this is the limitation not the subject itself, okay good.

So these are all the things but now we are not discussed see no, let us discuss 11 o clock, okay see repeat part b if the reactor is packed with one path catalyst what will happen will the conversion change, why? Pressure drop forget pressure drop we are not even talking here, that is all only weight of the catalyst, sorry weight of the total amount of solid will increase but it is not going to change the conversions, right? And because you are sending the same thing and only thing why we are doing that is for maintaining isothermal conditions this is what I mentioned also some time earlier to maintain some isothermal conditions people always but if you are volume is so precious why should I use 5 times larger than you know the active catalyst alone if that is more important then I think you have to look at only one part of catalyst and then try to leave with that but if volume is not the constraint for us then you can go for more volume maintaining isothermal conditions isothermal is easy to design and no temperature controls and all that.

So that is the reason why but everything is again academics finally you have to do this this this this and compare which one has the best system, and what is your objective function? Cost, finally cost everything is money, okay but without doing anything we want money you know that is what is nowadays our trend I should not do anything but I should get crores and crores of rupees, okay with that attitude we cannot design anything but I think you have to know all this do everything and then try to find out which gives you the minimum cost of production then you can sell with some profit and you will get some profit after the design, okay.

So I thought I will start fluidized bed I think we will stop here, okay. So now I think I have thoroughly done packed beds but the thoroughness will come to you provided you work hard, okay please spend some time and all of you are not taking 100 courses, okay and it is varying from 1 to maximum 3 or 4, correct no? 4, so that is why it is not too much load because we have

24 hours per day we cannot ask more than that, so then I think definitely you can spend some time in learning this, okay Savita, good. So I think we will stop here and then meet on Monday with fluidized beds, thank you.