Chemical Reaction Engineering 2 (Heterogeneous Reactors)

Professor K. Krishnaiah

Department of Chemical Engineering

Indian Institute of Technology, Madras

Lecture 27

Non-isothermal intraphase effectiveness factor

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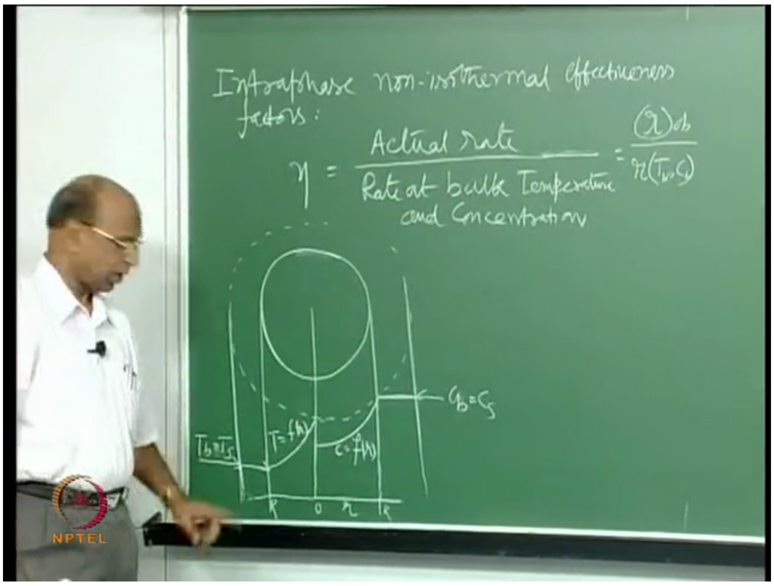

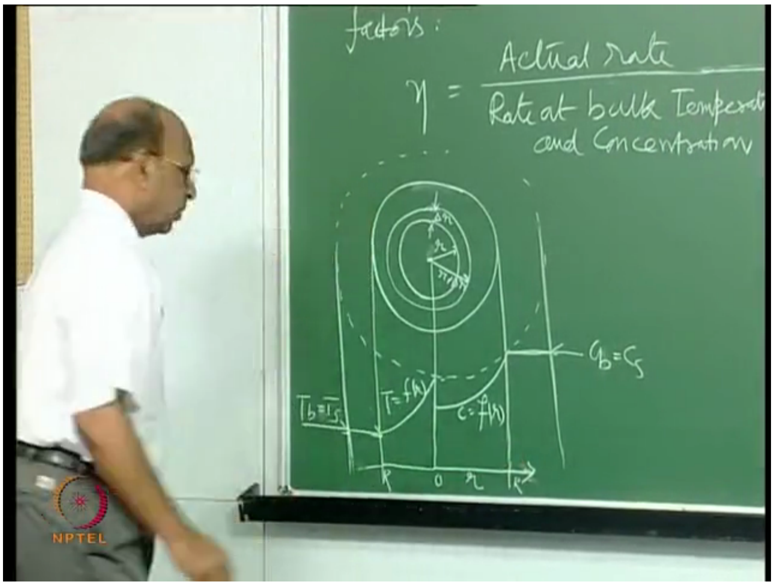

Okay we will start now ya intraphase non-isothermal effectiveness factors, okay and we have done something similar to this in the interphase effectiveness factors non-isothermal, right. What was the definition there, general definition for effectiveness factor? Eta, ya Eta equal to actual rate ya by bulk T temperature okay temperature and concentration temperature and concentration, right.

So this may be r ob now this r function of temperature and concentration, okay ofcourse clearly we can also write okay here comma b b at bulk temperature and concentration, good okay. So as usual we will start single particle and film is there but it has become nice now it is not affecting anything, okay this is C b also equal to C s this is C s and from here concentration decreases, right this is T b also equal to T s T s, so if I take a exothermic reaction this may be something like this. So here T is a function of r and here C is a function of R, this is r capital R, this is small r, this is 0, this is capital R, good.

So if you look at the definition you have to get now actual rate where actual rate is a function of this concentration and this temperature at that point or at this point. For example if I take at this point there is a concentration and also correspondingly there is a temperature, right. So the rate now depends on because this is also non-isothermal this is also a function of T b and this one r ob is also a function of T and C at any point inside the particle.

So what you have to get information is the rate at every point so that means if I know the profile I can get the rate at every point, right and also I mean with temperature and concentration. Now we have to develop equations how to do that ya so this is a thickness of delta r thickness of delta r and here I have small r, this one is r plus delta r, right and now you just imagine because it is mass transfer mass transfer is from outside mass transfer is going in this direction, okay and it is an exothermic reaction so heat is coming in the opposite direction, so coordinate system you have to be careful in the sense that when you are writing conductivity equation, what is conductivity equation? (())(5:01) what is the equation, 2 equal to minus k e dt by dr like Fick’s law okay good.

So that equation only we are going to use again here like De D effective because D effective is not the diffusivity of gas-gas normally we imagine for binary system D effective diffusivity I am talking because now these two gases are now diffusing through the pores and pores also will have some kind of influence on the molecules molecular diffusion like exactly when you are going through narrow gate in your OAT, okay you can calculate what is the diffusion coefficient there when you are going for (())(5:50) movies, okay.

So similarly here also when you have small pores and then large amount of gas is sent there A and B so because otherwise A may be going inside, B may be forming there and then again coming out binary diffusion. So under these conditions that is the effective diffusivity because of these pores and pores are not uniform some may be small, some may be larger, some may be lengthier all that.

So everything taken into effect as De D effective and that is what what we use in Fick's law okay j equal to De minus De dC A by dr, okay ya. Similarly here even the temperature we do the same we have now effective thermal conductivity, why it is not the normal conductivity of the solid, normal thermal conductivity of the solid is easy to find out there are no pores nothing but this is a catalyst particle with pores.

So when the heat is transferred, heat will see some wide age then some connection with solids, some other wide age, some connection with solid so I think again it is random it is not uniform (())(6:59) or uniform (())(7:01) throughout so that is why again thermal conductivity has also has lot of work separately people doing only on thermal conductivity in packed beds, thermal conductivity in all other systems again it depends on hydrodynamics and all that, okay so that is why ke, De are very very important parameters in all heterogeneous systems ke is thermal effective thermal conductivity, De is effective diffusivity, okay they are not the normal one which we easily take, right which we easily get from the tables and that is why lot of research has been done on that to give some values, good.

So when I write the mass balance and heat balance I will give you the finally the differential equations, okay that means what is entering here for mass 4 Pi r square tell me quickly I do not write that I will just tell you, for mass first of all 4 Pi r square totally rate you know what is mass mass that is entering rate that means moles per time 4 Pi r square minus De that is all at r equal to r plus delta r and here at r and similarly when heat is coming out you have to take the corresponding symbols again 4 Pi r square ke into dt by dr this is now minus this time because it is moving towards the this along the coordinate so again at r and r plus delta r take all these things you know as delta r tending to 0 then you will get the familiar equations which you already know.

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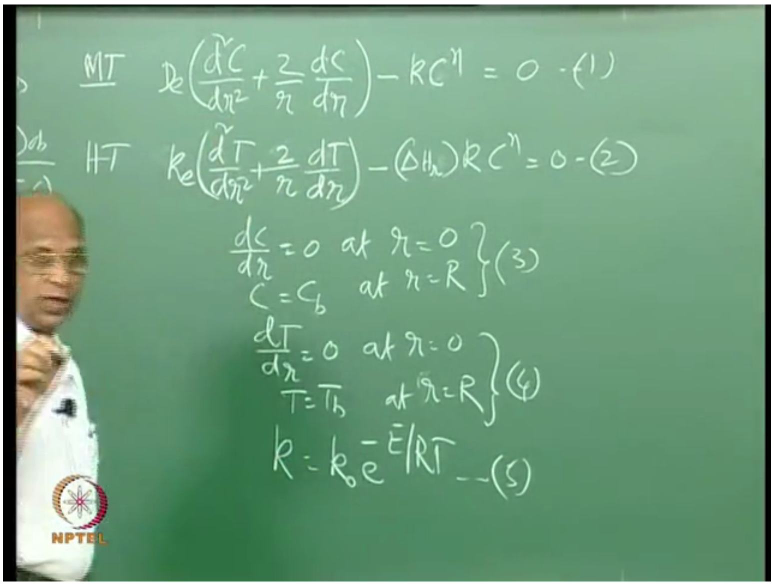

For mass transfer these are the things you would have used many times these equations De d square C by dr square dc by dr minus k C to the power of n if I take nth order reaction equal to 0 and similarly for heat transfer or energy balance I have k e this is the beauty of transport phenomena 2 by r minus I have delta h r into rate of reaction k C to the power of n equal to 0 oh here thank you thank you dT by dr very good that is why always you know fresh classes are very important because you will be fresh you will catch mistake, otherwise I think after 2 classes gone going to sleeping mode, okay good this is heat of reaction.

So now these are the two equations which we have I mean we have to solve both are second order differential equations then you need 4 boundary conditions, what are the boundary conditions here? dc by dr equal to 0 at r equal to 0 this is one and C equal to C b which is also equal to C s, okay at r equal to capital R. Similarly dT by dr equal to 0 at r equal to 0 and T equal to T b at r equal to capital R, good so this is equation 3, this is equation 4, good.

Can you solve that equation first concentration, concentration equation is it easy to solve for n equal to 1 if you can solve, okay and this one second equation from their concentration second see first equation first equation you can solve for C, you cannot solve anyone of them independently so you need some link in between, okay correct no because this is here I have that is what I told you know this Arrhenius fellow hidden somewhere, okay if you do not notice that fellow will kill you, right.

So this k is nothing but k 0 e power minus E by RT so that is there so that is why you cannot solve both of them so you have to solve them simultaneously, right. So now again observe that two equations can you link them what is the linking factor there k C to the power of n. So if I solve from this equation k C to the power of n or rate this is nothing but rate, okay then if I can substitute here then I have a relationship between temperature and concentration, okay.

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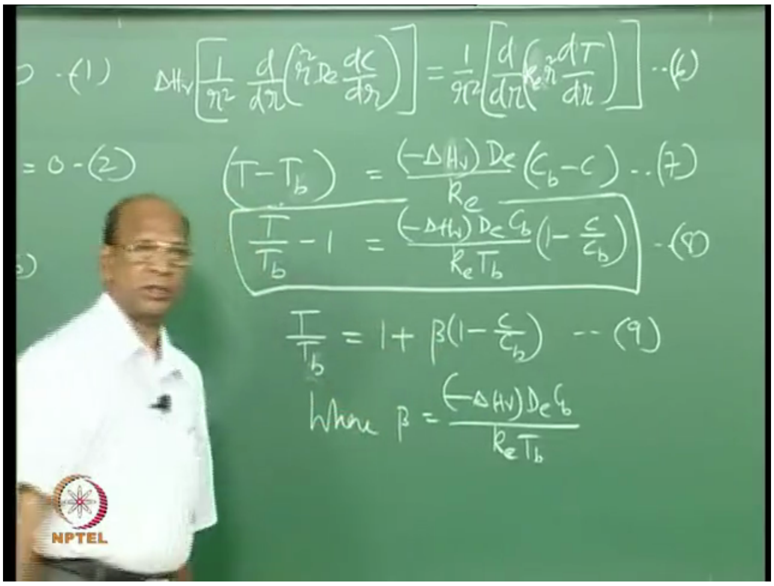


$$-(1) \quad \Delta H_v\left[\frac{1}{r^2}\frac{d}{dr}\left(r^2 De \frac{dC}{dr}\right)\right] = \frac{1}{r^2}\left[\frac{d}{dr}\left(k_e r^2 \frac{dT}{dr}\right)\right] \;..(6)$$

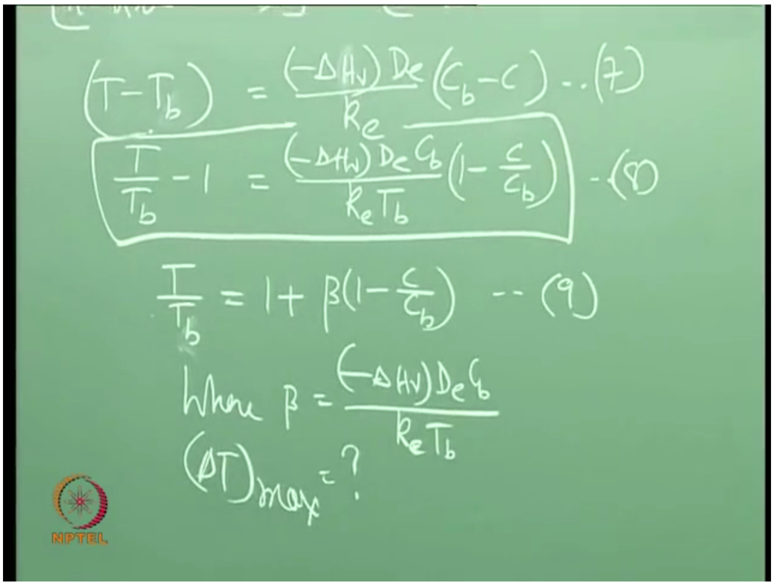
$$= 0 - (2)$$

$$(T - T_b) = \frac{(-\Delta H_v) De}{K_e}(C_b - C) \;..(7)$$

$$\boxed{\frac{T}{T_b} - 1 = \frac{(-\Delta H_v) De\, C_b}{K_e T_b}\left(1 - \frac{C}{C_b}\right)} \;-(8)$$

$$\frac{T}{T_b} = 1 + \beta\left(1 - \frac{C}{C_b}\right) \;--(9)$$

$$\text{Where } \beta = \frac{(-\Delta H_v) De\, C_b}{K_e T_b}$$



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$$\text{Where } \beta = \frac{(-\Delta H_v) De\, C_b}{K_e T_b}$$

$$(\Delta T)_{max} = ?$$

So that relationship you will get if you write this in terms of this also can be written in the short form no in this form like 1 by r square remember 1 by r square short form this is expansion form d by dr of r square De by dC by dr, okay that form only. So this form equal to that and if I also substitute this form this will be delta H r all this correct I am just substituting that form here and I have this equation, this is equal to again 1 by r square d by (dt) no dr k e dt by dr correct no by r square oh ya ya right k e r square right so this is the another equation now, okay.

Using these two this equation this is now 5, 6 can you tell me the relation between concentration and twice you have to integrate that and then you will get the relationship between ya someone did already very simple ya Anurag you do whatever you want to tell me between what is T and C relationship no it is not like management no you do what you are telling is it can be solved solve by taking some constant and all that what I am asking you you solve telling to solve is difficult I mean that is only my job to tell that you know you solve I need not even know and you can always take that and that assumption you have to do otherwise you cannot solve, diffusivity and thermal conductivity are independent of temperature and concentration also, okay diffusivity sometimes can depend on, those are the questions you ask me know sir how can we solve sir unless you tell this, okay good I will leave it to you.

So if you solve that what you get is T minus T s equal to minus delta H r De by k e into C b minus C s, okay I mean you may have some confusion with signs and all that that you can always get it when you actually solve, okay good you try later gotted (())(17:09) you will get it first differentiation and also you have to use the boundary conditions same boundary conditions and then you will get this equation, this gives me wonderful relationship between concentration and temperature.

So what I do now is you go to this equation k I have here this k fellow has this Arrhenius this T so this T I am going to substitute there here, right k k has T and that T is substituted from this equation anyway ya C b and C s at any point okay this is evaluated at any point now this is C, C b equal to C s, right okay good so that is the one and you solve those two equations, okay.

So now we have equation 1, 2 and 7 with the boundary conditions you have to solve the concentration profile, temperature profile and then integrate for the average rate correct no average rate that is the actual rate you will get and then ofcourse you have that as actual rate that divided by bulk rate will give you effectiveness factor, we do not have a solution for that, so only people have given the results in terms of empirical correlations, okay.

So one more step before going to that graph is this this also can be written if I divide by okay sorry T b we are using consistently T b, T b equal to T s, okay so this is equation now if I can solve also this T minus T b minus 1 equal to minus delta H r De I also have C b k e T b into 1 minus C by C b this is another equation, equation 8 where this also can be written as T by T s T T b (())(20:04) I am writing equal to 1 plus beta C b this is equation 9 where beta equal to minus delta H r all this De C b k e T b anything missing there, k e T b ya correct you see like your beta bar here also we have beta, good.

And again this nice equation simply relates temperature and concentration, we can also find out what is the maximum temperature that is possible here where C equal to 0, okay C equal to 0 then you will have when this is 0 you will have T by T b equal to 1 plus beta, okay so that is what is the maximum delta, ofcourse if you bring this this side then you will have the maximum thing I think that I am not doing that, okay I just leave it to you your imagination but now I think I can also ask you what is the maximum temperature that is why you have to make a note and then find out okay delta max everything I have to write I say become LKG all the time okay good.

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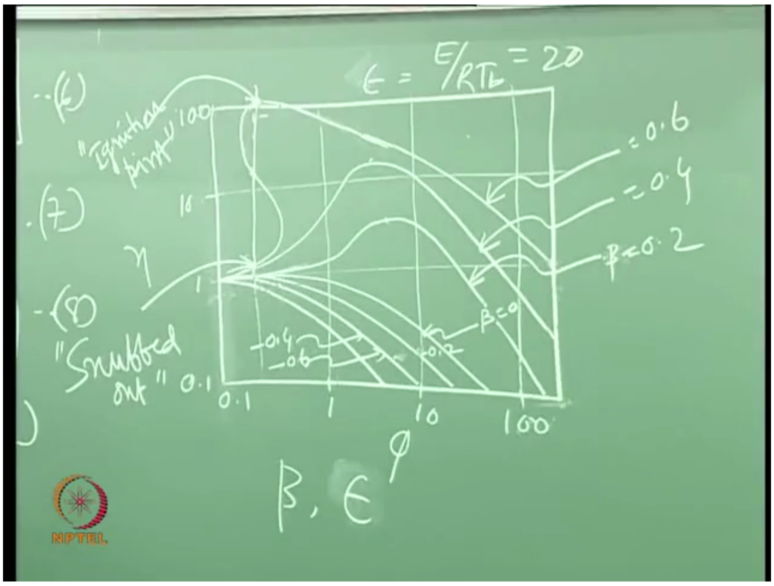

So now we will use this information and try to plot because we have to finally say what is the effectiveness factor and how many parameters I have here, what are the basic things which we have to plot? We have to plot Phi versus Phi versus Eta only right ya Eta versus Phi, what are the parameters now from this thing what will be the parameters dimensionless you know already one there beta, another one because Arrhenius fellow is there epsilon epsilon Arrhenius number so these two Arrhenius number is one parameter and beta is another parameter, okay.

So now let us plot this for gamma, gamma is the no no not gamma epsilon we are epsilon no, epsilon equal to E by RT b okay epsilon equal to E by RT b and ofcourse beta we will try to plot there so I can start here from 0.1, okay 1, 10, 10, 100, okay so this side I may have 0.1, 1, 10, 100 so okay approximately ya so that okay. So beta equal to 0 means where is beta here beta equal to 0 means isothermal, okay that means delta H r equal to 0 ya or very very very small approximately 0 delta H r, okay.

So that we will plot first that is nothing but isothermal, right beta equal to 0 which you are already familiar with isothermal so you may get 0.1 right ya something like this and first simple things beta negative beta negative means again you know endothermic beta negative is endothermic so I may have this may be point minus 0.2 like this, right so this is beta equal to 0 equal to (0.2 minus) minus 0.2 this is okay minus 0.4, minus 0.6, good so now the exciting things exciting things are beta positive that is 0.2 ya they will not cross anyway.

So this is this is beta okay let me write again beta equal to 0.2, 0.4, 0.6, okay top one is slightly awkward I think it has to go till top and then slightly come down, okay anyway just analytically the to show the trend, good. So what can you predict ya this is this particular thing is for 20 so if you draw this curves for 10 you will have slightly different, okay straight foreword things first, endothermic reaction always you have less than 1 endothermic and ofcourse beta equal to 0 is isothermal we know already we know how to draw that and as the beta is increasing then you will have you have even more than 1, more than 10, more than 100 effectiveness factors.

So what is the meaning that means this rate is even 100 times more than the bulk rate ya any explanation you know it is possible but any explanation, high temperature, heat of reaction because of exothermicity the temperature may increase there but you should have a combination of why it is going to 100 and all that write combination of temperature as well as concentration, if you do not have concentration again even though if I have temperature there is no use, right sufficient concentration that may be happening somewhere down because temperatures may be high but here you have mass transfer resistance Phi large, Phi large means mass transfer resistance, right.

So that is why you may not have and then that may be falling there, good. So the things what you have to identify here is there is a maximum for this curves when you go for exothermic and where you will have to be really careful because these peaks may destroy your catalyst because thermals entering may come into picture, okay or the particle itself may break, right all these things the thermal integration, okay of the particles may not be there so it may break so all these things may happen so that is why we should have an idea of this temperature as well as the concentrations concentration no problem particularly temperatures we should have an idea and that will come automatically when you are solving this, this, this to get the actual rates, good.

Another striking thing here is that at some Phi values that is what is the exciting thing there that is what is the beauty there and lot of papers are there on that particular aspect alone, how this multiplicity what we call okay or unstable steady states, unstable temperatures, or stable temperatures, multiplicity in temperatures so all this general words are used for this phenomena and then they found that surprisingly it is very very narrow region there under those Phi's only you will get this kind of behaviour that means particle will be operating at three temperatures at a particular Phi like CSTR we have done last semester, okay CSTR under certain conditions will have three temperatures one will be unstable, the remaining two will be stable even here it exactly same thing, this is stable temperature, what do you mean by stable temperature? What we have done here is just nothing but solving heat removal and heat generation it is the balance between heat removal and heat generation, okay.

So whenever you have both are equal then you will have only one point, right. So under these conditions here I have one point like that and when I am slightly coming in this direction and then suddenly here suddenly it may fall to this or from there suddenly it may fall to this that is not a problem but problem is if I am operating on this at this point if there is any slight change in the temperatures due to many conditions even mass transfer conditions also will change the rate so that rate will change automatically the temperature because rate is directly connected with the exothermicity of the reaction.

So any kind of instabilities in the parameters will either go from here to here or here to here okay so this point is the reaction (())(31:29) extension of the reaction almost that means you are coming from 100 to almost 1 or 2 here when you are coming in this direction or when you are going from this direction then you have from here to here suddenly jumping to very high temperatures I mean effectiveness factors that is due to only high temperatures and all this is possible for beta equal to large values just look at beta and then find out is there really something wrong with that beta? What is the meaning of beta large there?

Delta H r must be large very good, k is low, so what is the meaning of that k is low? Delta H r is large, k is low means it is a very bad combination ya it is always like heart attack and sugar, diabetic and heart attack together, okay it is a deadly combination. So you have large amount of heat in the particle but it is not able to conduct out, if it is able to dissipate it out no problem, it will quickly come to one of those steady state conditions, okay. that is the reason why we have and I think no book has given nice explanation except Aris book, Aris goes into very very deep into this concepts as well as mathematics more.

So he says that this curve is possible only when I have a catalyst with you know the problem is when you are tracking one particular curve, okay the parameters are related, right Phi also contains k correct no Phi contains k and also here here I have k e, De here also I have E all these parameters ofcourse T b will not change E will not change this is not a problem but there is a beta keeping beta alone constant and varying Phi is not easy, why? De is there, in Phi you have De you know, in beta also you have De, right so that is why.

That is why what he says is imagine a situation where catalyst particle with deactivation, deactivation simply reduces the temperature without effecting all other things, okay I mean rate of reaction, it is getting simply deactivated because some active sides are not slowly getting blocked but keeping the particle integrity as it is so diffusivity must be same. So under those conditions when you are moving from this to this, initially you have low effectiveness factors why because mass transfer is again wake him up I think you are very much interested in subject that is why I think for you it is like a song, okay and the moment you come to the class I am going to my matrix close over, okay that can happen with a beautiful song like mothers did, good.

So when you have it at this point at this point here then I have low effectiveness factors almost one or two, right that is because of high effectiveness factor sorry high kilo modulus and then you are moving in this direction because anyway when you are moving in this direction towards reaction control regime this is mass transfer regime controlled regime and this is reaction control regime we are moving to that side so that means the rate of reaction must increase because more and more mass transfer coming right here less mass transfer, here when you move this side more mass transfer.

So slowly you are coming like this and this is increasing and at this point suddenly either it may fall suddenly here, okay so that means the reaction which is going on till here suddenly snuffed out I think that is a term you uses or reaction got extincted extension of reaction and the other side it seems that is not easy to to imagine but if you are able to imagine that that means moving this side that means from reaction regime to mass transfer controlling regime, okay.

When you are moving in this direction after some small changes in Phi suddenly you may jump from this to this which we calls as ignition point ignition point, okay good this is very nice because whenever you have see always whenever you have increasing and decreasing trend there is no thrill, there is no kick if you plot x versus y may be it is increasing and in other case it is decreasing, always increasing, decreasing no kick but kicks will come whenever you have it reaches maximum and falls, okay or when it reaches minimum and again increases suddenly.

So then there is some phenomena which is changing its gear somewhere due to some reasons and then you have to find out those reasons. So that is why as research scholars you should be looking for those kicks instead of asking for smooth variations like x is increasing, y is increasing, okay x should increase and y should increase the way you never expected that is why we have a journal called (())(37:26) journal, okay then you have ofcourse journal of fluid mechanics and all that.

If you have normal way x versus y when you plot, when it is going smoothly up they will never publish the paper, okay. So they publish happily those papers when you have a graph this is y, this is x so it goes like this, goes like this, goes like this, goes like this very good (())(37:50) paper because you do not know what is happening here, okay. So this goes suddenly sometime what happens it comes back again goes forward and again goes down, goes up so this kind of complicated phenomena if you are able to explain reasonably so these are the complications so that is why you are getting this kind of behaviour, immediately acceptance letter will come your paper has been accepted because no one could understood, okay so that is why I think we are publishing leave it, good.

So that is the kind of kicks you have to really see for when you are doing your P.Hd, okay so that is why observe do not try to have only smooth curves and straight lines, smooth curves and straight lines nothing will happen, okay no kicks will be there, good. So this is about non-isothermal effectiveness factor and and what you have learnt here is (())(38:43) ofcourse there are many things there is a criteria where this particular zone can be avoided there are equations available, okay depending on beta and epsilon, if you know beta and epsilon sorry because many books use gamma gamma as minus C by RT.

So if you know beta and epsilon and calculating using these two there are some criteria like Weisz-Prater criteria where they have found that to avoid this what should be the value of beta and epsilon or combination of beta, epsilon, okay nice information so that you do not have to operate here, operate somewhere here which is more stable and better, okay highest you are getting so temperature I mean the effectiveness factors are very high, catalyst particle is very very active so you operate under those conditions and your reactor volume will be automatically very very small reactor volume because rate of reaction is very high always in the design V by FA not equal to dx by minus RA the (())(39:52) denominator so that is what is the chemical engineers dream, how do I increase my RA at the bottom so that I will get maximum ya minimum volume for given conversion or maximum conversion for a given volume, okay so that is the criteria excellent good.

So the next one which I would like to do is the combination of internal and interphase and intraphase combination of internal and external effectiveness factor, okay so that we will do good I think you have I enjoy always but I do not know whether you enjoyed or not, okay Abhinav you are enjoying anyway, okay you are always in your wonder world what is that who is that girl name Alice in wonderland, okay. So that is why I think you always enjoy enjoys on wonder world.

In Germany you know German professors they will have this board one part and another part another board. So you know when professor completes first time ofcourse till that point so when he is writing here his students will come then and wipe it out this side, okay and when again he comes here and then goes that side he fills up so like that and their classes are one and half hour classes most of the classes, okay (())(41:19) German professor German professor really fantastic, okay.

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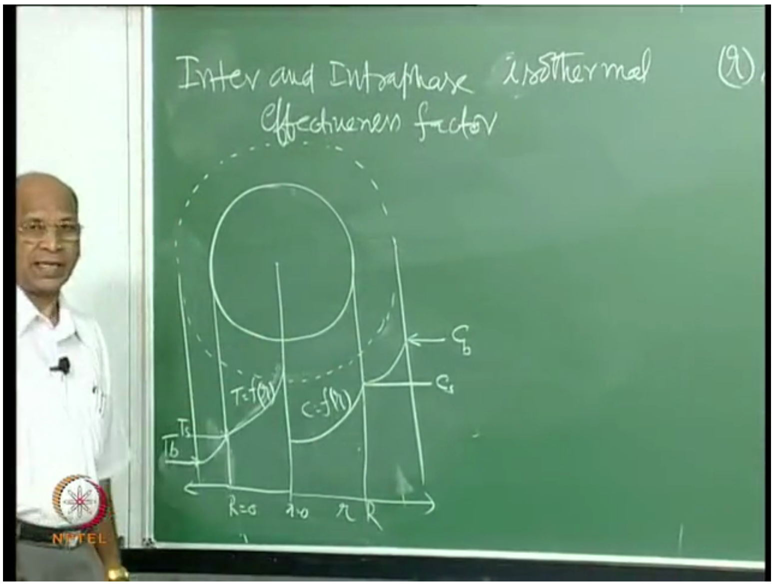

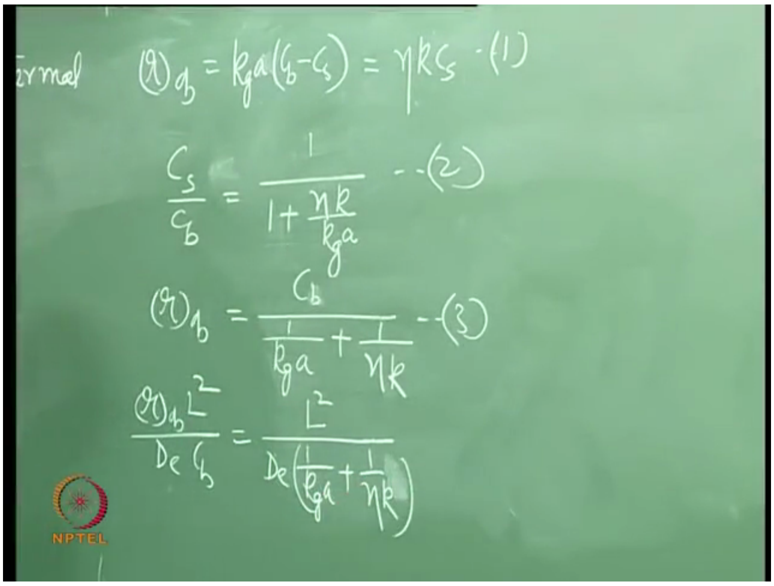
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(9) $q_b = k_g a(C_b - C_s) = \eta k C_s$ ·(1)

$$\frac{C_s}{C_b} = \frac{1}{1+\frac{\eta k}{k_g a}} \quad \text{--(2)}$$

$$(r)_b = \frac{C_b}{\frac{1}{k_g a}+\frac{1}{\eta k}} \quad \text{--(3)}$$

$$\frac{(r)_b L^2}{D_e C_b} = \frac{L^2}{D_e\left(\frac{1}{k_g a}+\frac{1}{\eta k}\right)}$$

So this is inter and so we have now is combination now we are talking about inter and intraphase isothermal effectiveness factor and we also have combination of inter and intraphase non-isothermal effectiveness factor that we are not touching right now, otherwise you know earlier we use to have one course separately on catalytic reactions only on catalytic reactions so that is why we used to do all that there I use to do when we had a stream in M Tech where chemical reaction engineering stream I think that is 87, 88, 90 that time some 10 years also it was there.

At that time we had 5 courses in reaction engineering that non-catalytic reaction also was separate course, reactor theory was common for everyone and there was also a course called chemical reactor design for process plants only design reactor design (())(42:21) problem was you know operating problems we did not have sufficient students not reaction engineering, reaction engineering transport phenomena transport phenomena is another another stream so these two on process control this two always use to have there were other things like enrolment engineering, biochemical engineering, polymer engineering so always those three were empty that means only one or two.

So then we thought it one point of time let us merge all M Tech so that they will not learn anything so we combined master of all (())(42:52) so I think that is what what we did. So inter and intraphase isothermal effectiveness factor ya so first one I think as usual we will start with the diagram these diagrams are very good I say good I have become expert in drawing particles on the on the board and this film also you never see this kind of film anywhere in reality, okay.

So this is the one in fact this is very good habit of drawing the profiles for whatever problem you take, okay so this is r equal to 0, capital R, small r equal to 0, this is r good. So in the film now we have to show the profiles this is C b, C s and C, good ya and this side if I have exothermic reaction T b, T s and you may have at this this is T s not linear in shape also exactly we do not know this is this is T s good isothermal I am just plotting the whole thing there, okay you are right here you can always assume that T b equal to T s equal to T, right this is the whole thing these are the profiles what we are taking now that is right you are correct isothermal only we are taking right now, good.

So when you are talking about isothermal this is general profile it is not that I am now solving this problem using these profiles only these things, good okay. So we already have an equation for I think I will write here so we have r ob equal to and steady state conditions this mass transfer through the film must be equal to diffusion at the surface, right that is what how you have done for intraphase effectiveness factor.

So then you have k g a k g a C b minus C s, here I have Eta bar k not Eta bar Eta this is logical for me, right. So this Eta this Eta I know already that is internal intraphase effectiveness factor so this is the intrinsic rate that multiplied by this will give me the rate on the surface, okay now film is coming into picture now that film is because of this gradient C b minus C s, right.

So what is the procedure eliminating C s and finding out what is r ob this is r s where the rate is based on the all the surface area ofcourse, right external surface area only but this Eta will take care of those gradient inside this one I do not know whether you have understood this or not, okay Eta when I multiply okay if Eta equal to 1 then it will be straight line there is no effect of intraphase mass transfer no resistance so like that.

So because when Eta equal to 0.5 for example you may have this kind of profile so that will take care of that. So then we have this is equation 1 solving this you will get these two C s equal to or C s by C b equal to I have 1 by 1 plus Eta k by k g a please check this this is step 2 quickly try or it is common sense correct good. So then I have r ob equal to (C o) C b divided by 1 by k g a plus 1 by Eta k, okay. So this equation 3 we will try to arrange this in terms of an observable, okay.

How do we do that? This is r ob L square that means I am dividing this by L square and dividing by De C b, okay or otherwise ofcourse I can bring that C b this side, okay this side L square by De and C b also okay let me and the same thing we also do here if we substitute that then I will have L square De 1 by k g a just it is a manipulation that is all nothing new no equation is new and only mathematical jugglery here and there to get some beautiful information so 1 by Eta k, 1 by Eta k, correct.

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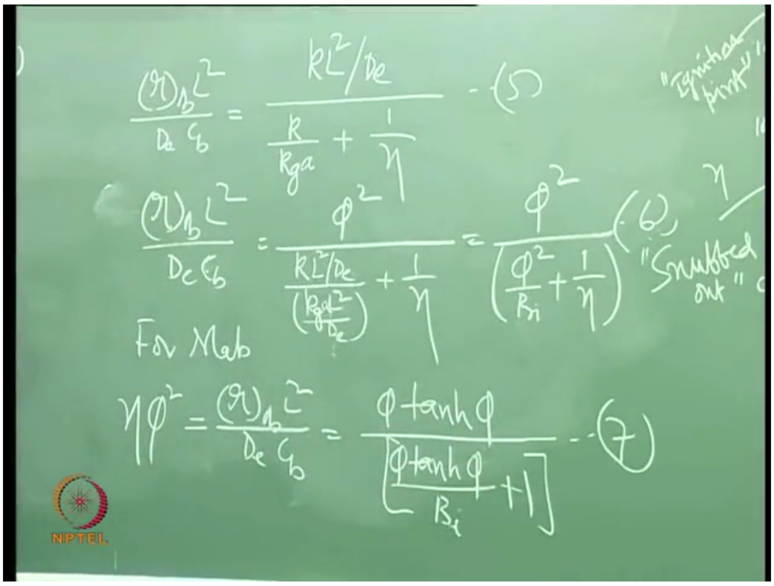


$$\frac{(r)_{ob} L^2}{D_e C_b} = \frac{kL^2/D_e}{\frac{k}{k_g a} + \frac{1}{\eta}} \quad \text{---} (5)$$

$$\frac{(r)_{ob} L^2}{D_e C_b} = \frac{\phi^2}{\frac{kL^2/D_e}{\left(\frac{k_g a L^2}{D_e}\right)} + \frac{1}{\eta}} = \frac{\phi^2}{\left(\frac{\phi^2}{B_i} + \frac{1}{\eta}\right)} \quad \text{---} (6)$$

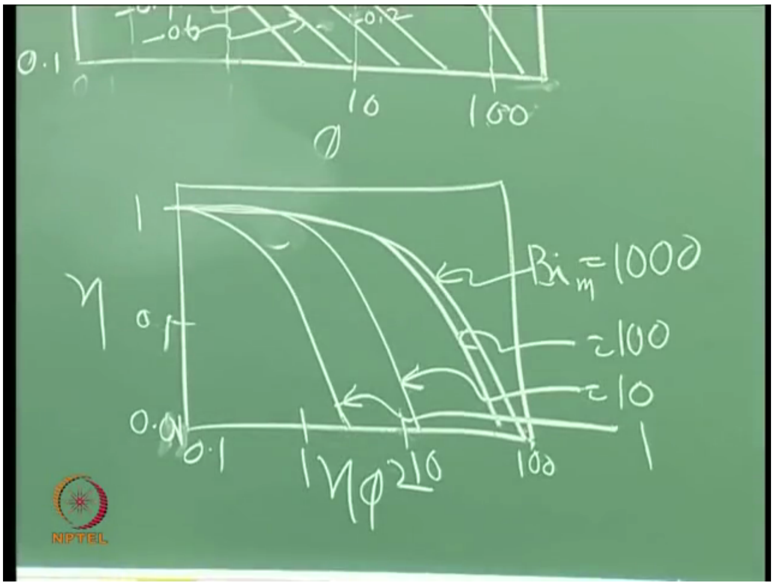
For Slab

$$\eta\phi^2 = \frac{(r)_{ob} L^2}{D_e C_b} = \frac{\phi \tanh\phi}{\left[\frac{\phi \tanh\phi}{B_i} + 1\right]} \quad \text{---} (7)$$

"Ignition point"

"Snuffed out"

η



So now this equation can also be written in terms of r ob that is an observable this is an observable De C b which is which can be written as k L square by De again manipulation there k by k g a plus 1 by Eta, okay and this I know already k L square by De what is that? Phi square, okay so that is the one. Now this particular part I have to also just manipulate, okay De C b this will be Phi square divided by I have here again k L square by De here alone I am doing that again k L square by De and I can also arrange that k g a L square by De plus 1 by Eta just again I have divided by L square by De, L square by De but remember oh no here remember k g a, what is k g a?

So what is that a specific surface area per unit volume yesterday we have seen V by S x is what?

Student is answering: R by 3.

So that is also a characteristic dimension for us, so that is why that L and this L can be cancelled. So now I have k L by De k g a L by De what is that number, Sherwood number will come only when you have single phase, okay this is Biot number Biot number Biot number will come when you have more than one phase, okay good. So that is why we can write this one again Phi square by Phi square by Biot number plus 1 by Eta, okay good.

Now Eta let us say for slab what is Eta for slab? Tan is Phi by Phi, okay we can substitute that and then try to simplify that what do you get for slab for slab Eta equal to Tan h Phi by Phi, did you get this r ob L square by De C b equal to Phi Tan h Phi divided by Phi Tan h Phi by Biot number plus 1 is this number is gone total, so this is 4, 5, 6, 7 could you get that Rinita? Substituting Tan h Phi by Phi, 1 by Eta so Phi will go up and then you get something cancelled and you will end up with that equation, okay good that is nice everything is nice, okay.

So this is you remember this is Eta r ob L square De by C b only 24 hours gone I say Eta Phi square only yesterday only we have discussed about that that is Eta Phi square. So Eta Phi square equal to this observable equal to this, okay and when you plot this this is what you get, okay this is Eta Phi square which is nothing but your observable, this is Eta, this is again isothermal so maximum is 1, this side you will have 0.1, 100, somewhere here 10, somewhere here 1, 1, 10.

So when I plot now beta is the parameter not beta what is that Biot number Biot number is the parameter so then you will have, okay it is fine so this is Biot number equal to Biot number mass you know heat also has Biot number heat Biot number also is there so that is why we put this one as for mass. So this is equal to 1000, this is equal to 100, this is equal to 10, this equal to 1, excellent take Sandeep back sufficient send back you have either you draw that quickly drawing is very good because you will have one more experience you know by drawing it that is why I did not give this first and how do you use this Eta Phi square is observable, our idea is to find out the overall effectiveness factor, okay I measure the rate, I know the dimension, I know De correlations and C b so now I will go here read and then get the corresponding overall effectiveness factor, okay.

So for that if both are controlling so this is the one what we have to learn and this is very simple now because I do not have to explain that much and one more thing you have to observe is that you know 100 and 1000 almost there is not much any difference. So what do you conclude? Mass transfer ya right controlling when it is all together, it is reaction controlling mass transfer is not controlling so that is why when you design a particle you have this information on mass transfer coefficient and all that diffusivity you calculate Biot once you calculate Biot number if it is 1000, 500 like that then you say external mass transfer is not coming into picture at all.

So then you concentrate on internal intraphase effectiveness factor you know how nicely one can do k g a is known I have correlations, De is known I have correlations but you have to find out at what temperature pressure and all conditions and then calculate what is Biot number, if Biot number is generally 500 and 1000 safely ignore external mass transfer, okay good. I think when Narsimha Reddy was telling this is Sherwood number Sherwood number will not give you that kind of information this is only within one phase Sherwood number. So here Biot number will give me which is between two phases, okay diffusivity is inside and k g is within the particle I mean in the film surrounding the particle the film so it combines those two film and then intraphase so that is the reason why Biot number is more useful for Heterogeneous systems and Sherwood number and all that is normally for single fluids that is you have all the correlations, okay.

And ofcourse there is no way you can also call this one as the Sherwood number 2 but you should know what is that diffusivity coefficient and what is the mass transfer coefficient, the Sherwood number what does that give you Narsimha Reddy Sherwood number what is the information you will get from there? k g divided by what is that D which diffusivity, mass diffusivity it is within the same phase binary diffusivity so that will give you a ratio of convective transport by all that within the phase, whereas here between the phases so that is the difference between this and that, okay good and the moment you cross the door anyway you will not remember anything, okay but anyway examination is coming.