Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Lecture-23.
Generalised nonisothermal Effectiveness Factor for External Mass Transfer Step Continued.

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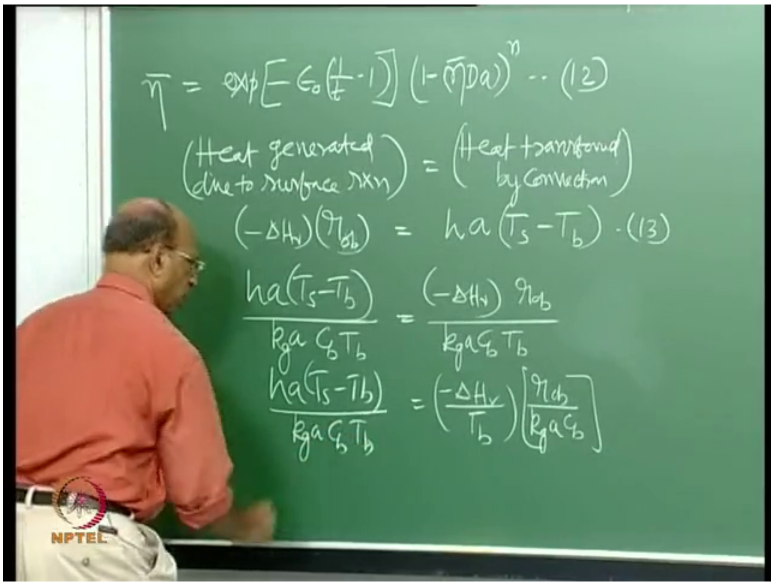

$$\bar{\eta} = \exp\left[-\epsilon_0\left(\frac{1}{t}-1\right)\right](1-\bar{\eta}Da)^n \cdots (12)$$

$$\begin{pmatrix}\text{Heat generated}\\ \text{due to surface rxn}\end{pmatrix} = \begin{pmatrix}\text{Heat transferred}\\ \text{by convection}\end{pmatrix}$$

$$(-\Delta H_r)(r_{ob}) = ha(T_s - T_b) \cdot (13)$$

$$\frac{ha(T_s-T_b)}{k_g a C_b T_b} = \frac{(-\Delta H_r)\, r_{ob}}{k_g a C_b T_b}$$

$$\frac{ha(T_s-T_b)}{k_g a C_b T_b} = \left(\frac{-\Delta H_r}{T_b}\right)\left[\frac{r_{ob}}{k_g a C_b}\right]$$

Professor: In the last class we have been deriving generalised isothermal, generalised nonisothermal effectiveness factor for external mass transfer control steps alone, right, external mass transfer control steps alone. What was the last equation we have written was this Eta bar equal to exponential, yah, this multiplied by 1 minus Eta bar DA to the power of n, Eta bar DA as a one group, Eta bar, what was the, 12, equation 12. Then we thought we have to still develop write this expression in terms of observables because this T is TS by TB where TS is still not known to me, so that also we have to write.

And in terms of observable and for that what you have to write is the energy balance around the particle. So the energy balance around the particle, I think, let me give this in continuation, otherwise you may not know what is happening in between. Yah, equation 12 cannot be used to calculate effectiveness factor since small t equal to TS by TB is not known, you. To get surface temperature TS, we can write the energy balance at steady state as heat generated due to surface reaction, this is equal to heat transferred by convection. Sometimes radiation, negative effects of which we are neglecting, okay. Only by convection we are taking.

So now if I write heat generated by reaction is, we know Delta HR into rate of reaction, okay, that RB, this is equal to Rob, observe, not B, B means bulk, we will say yah observed, Rob. Yah this is equal to heat, so by convection, that is ha TS minus TB. If it is and endothermic reaction, that will be the reverse. And that is also taken care of by this sign, minus Dell H, so that is okay, no problem there. So this is equation 13, yah. Equation 13 but now you have to be careful about these units. This a is again metres square, metal cube of the catalyst, right.

So that is why heat transfer coefficient will not have straightforward units, you have to be more careful there. Indeed their mission I may guess, I may give consistent units but the consistent units will be different because of A. And also Delta HR can be expressed as calories per gram sometimes, calories per moles also sometimes. So unless you know again that conversion and all that, you will make mistakes. So that is why you have to be more careful, good. So now you can use this equation and then start writing that, if I have, okay, if I divide this 1 by Kg B, I will write H here, TS minus T b divided by, I am just bringing this side, Kg a Cb Tb.

I will divide the side this, so than this and also we have to divide minus Delta HR Rob divided by Kg a Cb Tb, right. So now we can also write this one as minus Delta H TB, this is also minus Delta HR Tb as one term, the other term is rob by Kg a Cb. You know what this term is, this is observable, this is Eta bar DA. Okay. This equation, okay, let me also right here, this HA TS Tb by Kg a Cb Tb, okay, good.

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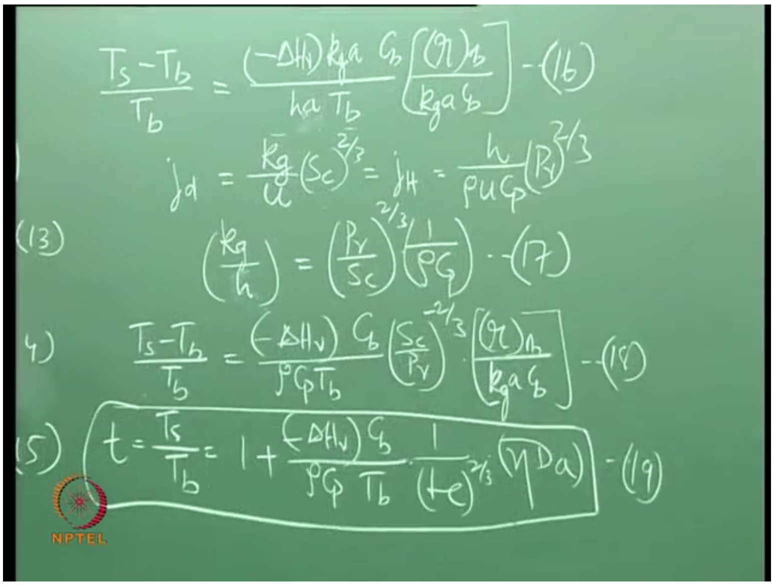

$$\frac{T_s - T_b}{T_b} = \frac{(-\Delta H_r)\, k_g a\, C_b}{h a\, T_b}\left[\frac{(r)_{ob}}{k_g a\, C_b}\right] \quad \text{--(16)}$$

$$j_d = \frac{k_g}{u}(S_c)^{2/3} = j_H = \frac{h}{\rho u C_p}(P_r)^{2/3}$$

(13)

$$\left(\frac{k_g}{h}\right) = \left(\frac{P_r}{S_c}\right)^{2/3}\left(\frac{1}{\rho C_p}\right) \quad \text{--(17)}$$

4)

$$\frac{T_s - T_b}{T_b} = \frac{(-\Delta H_r)\, C_b}{\rho C_p T_b}\left(\frac{S_c}{P_r}\right)^{-2/3}\cdot\left[\frac{(r)_{ob}}{k_g a\, C_b}\right] \quad \text{--(18)}$$

5)

$$\boxed{t = \frac{T_s}{T_b} = 1 + \frac{(-\Delta H_r)\, C_b}{\rho C_p\, T_b}\cdot\frac{1}{(t_e)^{2/3}}(\eta D_a)} \quad \text{-(19)}$$

So if I write, if I just take only, I think I will go here TS minus TB by TB equal to, this I am just leaving, for those things I am taking that side. So then you will have here minus Delta HR, okay, Kg a Cb divided by HA TB into Rob divided by Kg a Cb, so this is another term for us, yah. So some more also can be, I mean this is enough for us but still we can use some more simplification taking Kg and HA together. There is a number also which relates, Prandlt number and Schmidt number, Lewis number, yah good. So we will also try to write that because it should be as simple as possible for us for use.

So that is why I will really appreciate Carberry as the way he has done, it is really wonderful. So you understood the idea no, this is equation number 14, this also will put 15, yah. Okay. So then that will be 16, for the whole idea now is whether we can use some other thing for Kg a or HA, A, A will get cancelled, so we will have simply Kg by H, okay, so that is the term you will have. And now for that we have to use the relationship JD, too much to ask you for the definition of JD. JD represents the mass transfer, JD factor, okay. And JH represents? Heat transfer.

And JD equal to JH, of course for the analogy wise, JD equal to JH equal to F by2, that analogy we are using. So but JD is Kg by U, U is the velocity and Schmidt to the power of 2 by 3. Which is also equal to JH, now JH definition is H by rho U CP into Prandlt to the power of 2 by 3. Okay. JD equal to JH, good. now this can be also written now as Kg, we are taking only these 2, this and then this, so if I take those 2, then Kg by H equal to, we have Prandltby Smith or to the power of 2 by 3 into 1 by Rho CP, this is another term. Okay.

Yah, so this equation we will say is 17. now we can substitute this in equation 16, because Kg by H, Kg by H, A, A will get cancelled, right. Kg by H, then what you get, TS by TB by Tb, TS minus TB by TB, you will get as minus Delta HR Cb Rho CP Tb Schmidt by Prandlt of -2 by 3 yah into, into Rob divided by Kg a Cb, correct. Or something missing? You will get it no? This is nice, we also have now okay I will also write this one as simply TS by TB equal to, okay, before that t equal to small t equal to TS by TB, this is 1 plus minus Delta HR Cb divided by rho CP by TB, this is one group and this is 1 by Lewis to the power of, Le is Lewis number into Eta bar DA, so this is the equation.

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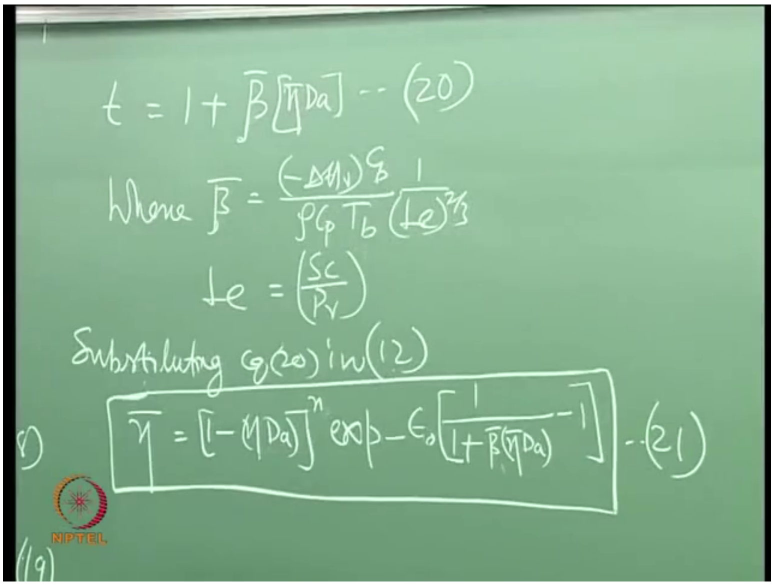

$$t = 1 + \bar{\beta}[\bar{\eta} Da] \quad \cdots (20)$$

Where $\bar{\beta} = \dfrac{(-\Delta H_r) C_b}{\rho C_p T_b} \dfrac{1}{(Le)^{2/3}}$

$Le = \left(\dfrac{Sc}{Pr}\right)$

Substituting eq(20) in (12)

$$\boxed{\bar{\eta} = [1 - (\bar{\eta} Da)]^n \exp - \epsilon_0 \left[\frac{1}{1 + \bar{\beta}(\bar{\eta} Da)} - 1\right]} \quad \cdots (21)$$

This is equation 19, that is what is TS. So we will write this entire thing as simply t equal to 1+ very beautiful form, okay, beta bar, that is supposed to be beta, yah, beta bar Eta bar DA, very simplified. So this is equation number 20, where beta bar equal to minus Delta HR Cb divided by rho CP TB into 1 by Lewis to the power of 2 by 3. Yah, where of course Lewis number Lewis equal to Schmidt by Prandlt number. This is a number which relates heat and mass transfer, right, that you know. Good. So this is the one, now we have to substitute equation 20 in here, in equation 12. Okay.

Beta bar, is it observable? All those parameters we know, okay, so that is why now if this t is replaced by 1+ beta bar Eta bar DA, okay, Eta bar DA, then we have equation 12, everything is observable, beautiful, good. So substitute in equation 20 in 12, equation 20 in 12, what you get is Eta bar equal to 1 minus Eta bar DA, okay to the power of n exponential minus Epsilon 0, yah, Epsilon 0, 1 by 1 plus beta bar Eta bar DA -1, this again, yah so this is equation. This is equation, equation 21. Beautiful derivation, I like the derivation, the reason is that you know whatever we studied in heat and mass transfer, everything is used here, for Kg, KH, Lewis number, all the things.

You know independently you might have used here and there but here in this derivation, so beautifully done, so that you know I have this measurement Rob divided by Kg A Cb, then we have beta bar, again we know all these parameters. And that is all, what else, we have Epsilon 0, which is nothing but your Arhenius number where it is Epsilon by R TB, TB is the bulk temperature, that also I know. So then I can calculate what is eta. Whether it is first-order reaction, second-order reaction, whatever order reaction. Good. So I think we will plot those things later and then for discussion. Because just writing equation is not enough, you have to plot and try to understand.

By the way how many parameters we have here? Eta bar and DA will be Y axis and X axis, Eta bar and this is observable, right. Then I have Epsilon 0 as one parameter, Eta bar is another parameter, 2 parameters. What Kartik? Looking clueless.

Student: n is a parameter.

Professor: Yah, n also is a parameter, 3 parameters, n also is a parameter. So now we have to plot, you know this what is simulation I say. When you have derived the equation, then you have to see what are the parameters and then try to, of course dependent, independent, these 2 we have to 1st take, then all other parameters you have to vary and see how the effectiveness factor is changing with other parameters. So that means 1st we have to vary eta keeping beta, beta bar an Epsilon 0 constant. Then you have to keep eta constant, sorry M constant and then very, of course n an Epsilon 0 constant, maybe beta bar varied, okay.

And of course you keep eta, sorry n and beta bar, set an Epsilon varied, okay. So these are the graph which will do and before that we can also very nicely use this information, particularly equation 20. Yah equation 20 can it be, beta can it be negative or positive? Can it be negative?

Student: Yah.

Professor: Yes, it can be negative, it can be positive. Then it means exothermic, negative means endothermic, please remember that. So that also has come into picture. Good. So and equation 20 will give me the relationship between concentration gradient and temperature gradient. Can you just look into that and tell? Is it really possible? Equation 20, small t is TS by TB, okay. So if I bring 1 this site, I will have TS minus TB by TB, good. Yah, so that is the temperature gradient, so the other thing side must be I should have concentration gradient. Find out, where do you get that, if you look into your notes you will get that, it is not at all difficult.

Student: It is CS minus Cb by…

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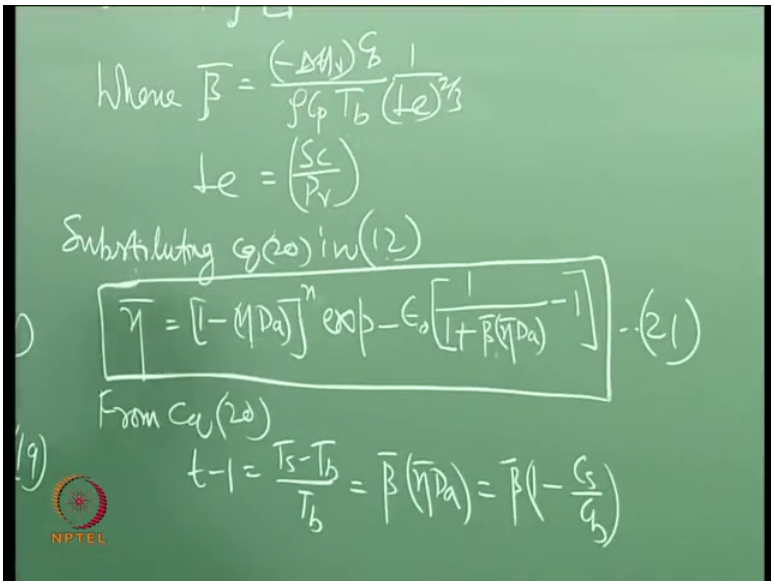

Where $\bar{\beta} = \frac{(-\Delta H_r) C_b}{\rho C_p T_b} \frac{1}{(Le)^{2/3}}$

$Le = \left(\frac{Sc}{Pr}\right)$

Substituting eq (20) in (12)

$$\boxed{\bar{\eta} = [1-(\bar{\eta} Da)]^n \exp - \epsilon_0 \left[\frac{1}{1+\bar{\beta}(\bar{\eta} Da)} - 1\right]} \quad \text{..(21)}$$

From eq (20)

$$t-1 = \frac{T_s - T_b}{T_b} = \bar{\beta}(\bar{\eta} Da) = \bar{\beta}\left(1-\frac{C_s}{C_b}\right)$$

Professor: Yah, so here we have t minus1 which are nothing but TS minus TB equal to sorry beta bar Eta bar DA where Eta bar DA the thing but 1 minus, yes, beta bar 1 minus CS by Cb, beta bar, right. So if I know this parameter beta bar, then I can also calculate what will be the increase in temperature, right. And why we are doing that, I think there is a reason for that. Okay, so beta bar values we know and for, okay we have to also find out what is the maximum temperature that is possible, TS minus DB Max. Maximum temperature difference or temperature gradient possible. And you get that from that equation?

Student: TS is 0. TS is 0.

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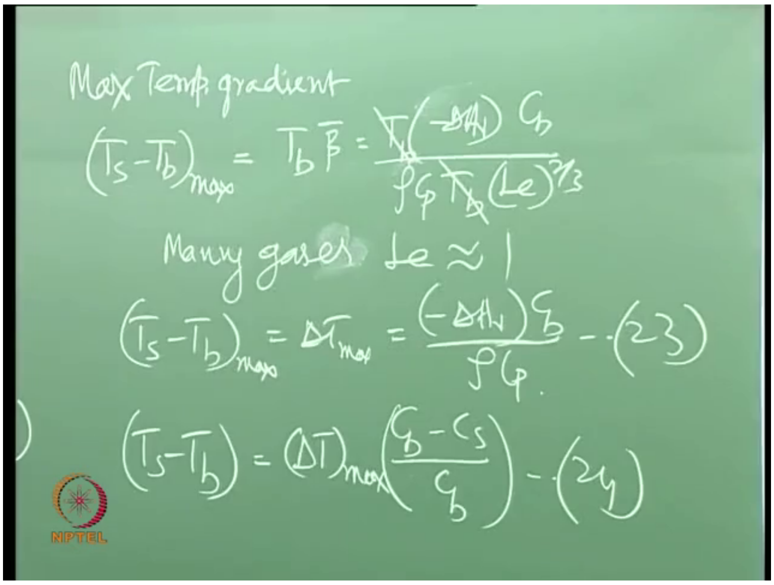

Max Temp gradient

$$(T_s - T_b)_{max} = T_b \bar{\beta} = \frac{\cancel{T_b}(-\Delta H_r) C_b}{\rho C_p \cancel{T_b} (Le)^{2/3}}$$

Many gases $Le \approx 1$

$$(T_s-T_b)_{max} = \Delta T_{max} = \frac{(-\Delta H_r) C_b}{\rho C_p} \quad \text{..(23)}$$

$$(T_s - T_b) = (\Delta T)_{max} \left(\frac{C_b - C_s}{C_b}\right) \quad \text{..(24)}$$

Professor: TS is 0, okay. So you will get the maximum temperature when TS equal to 0, maximum temperature gradient when your CS equal to 0. Then what we have here is this equation if I take, this equation, yah then we have TS minus TB Max equal to, this TB I will take this side, TB into beta bar, right. Okay, so beta bar we can substitute now, beta bar equal to TB, beta bar is minus Delta HR Cb divided by rho CP TB Lewis to the power of 2 by 3. So TB, TB we can cancel out and for many gas phase, for many gases, okay, gases, Lewis number is approximately 1.

For many gases, that means Prandlt number and Schmidt number is same, almost same, okay. So now you will have equation TS minus Tb max which we call delta T Max equal to, what do we get, yah minus Delta HR Cb by rho CP. So this is equation, this equation number I have to give 22, this is 23, yah. So now I can write this equation, equation 22 as TS minus TB equal to Delta T Max of Cb CS by Cb. So this is equation 24, okay, simply I substitute here, that is all. So what is the use of that equation 24, do we have any use of equation 23? Apart from nicely writing equation, is there any use of that? Of equation 23, is there any use of that?

Student: To control the reaction.

Professor: To control the reaction.

Student: Temperature and all. (())(21:38).

Professor: Sorry?

Student: It will give a relationship between concentration and temperature.

Professor: Yah, that is the equation but what is the use of that?

Student: We can always control the bulk concentration.

Professor: How can we control the bulk concentration? But controlling the bulk concentration what do you do?

Student: We can maintain the required temperature difference.

Professor: What is the required temperature?

Student: TS minus TB, so upper limit temperature…

Professor: How much I have to maintain?

Student: Which is within the operating conditions?

Professor: What are the operating conditions?

Student: (())(22:16).

Professor: Yah, this is what finally you are slowly going, okay, good. You know there are what are called hot spots? now what is physical be in hot spots? Why should we know hot spots? Yah, not only explosion, there are many other things, you know catalyst may get spoiled, okay, so that is why we have to a Priory itself we have to calculate whether this temperature is dangerous to either catalyst or the accumulation will take place, or the explosion may take place. So that is when the beginning itself you can have an idea how to calculate, in what is the temperature, maximum you will get.

So then you should definitely, you should not cross, if there is a dangerous line like, let us say 500, the difference, and maybe around 500 your explosion may stop, the reactants may explode or the catalyst may get damaged because of thermal sintering, all these things we will know and when you get this estimation, then we know that okay, now we should be safely around 450 we can apply. Otherwise always more the temperature, more the rate of reaction, you will be very happy, okay. But this will give you an idea how to calculate the thermal sintering or explosions of the other reactants or the products.

That is why every step what you have done is not waste of time, okay. So most of the time we will be happy to derive the equations but afterwards we do not know what to do. Where do we actually use, so that is the reason why I am kind to explain all that, so this is the overall picture of this derivation of non-isothermal effectiveness factor for external mass transfer control roles. We have taken only taken only one step. Right, that one step alone is the mass transfer controlling step, the rate of reaction as well as the comment that the diffusion, there is no diffusion here because mostly nonporous.

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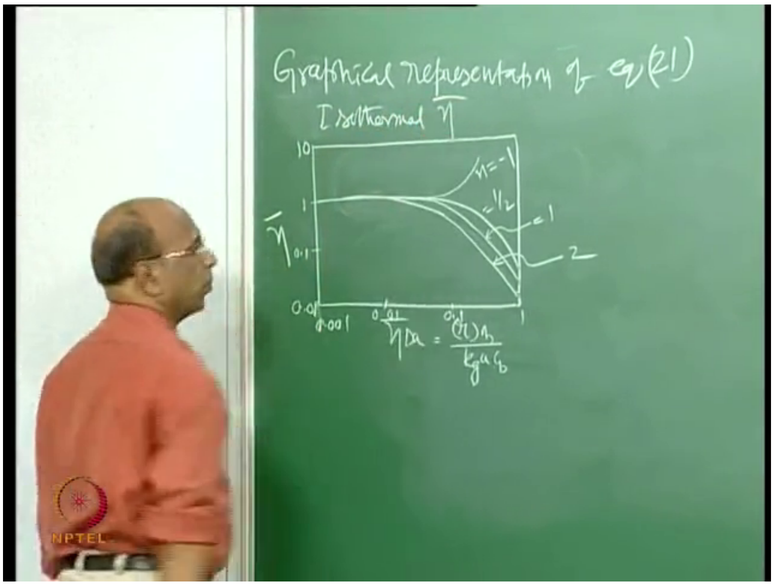

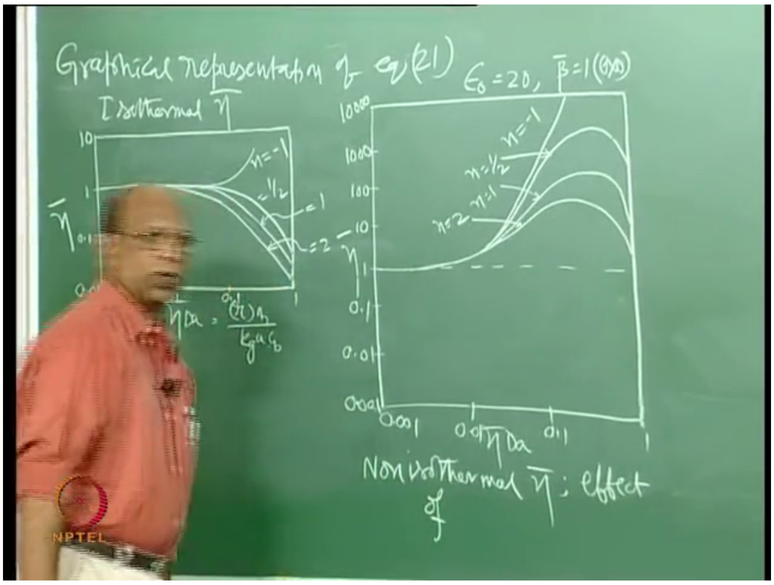

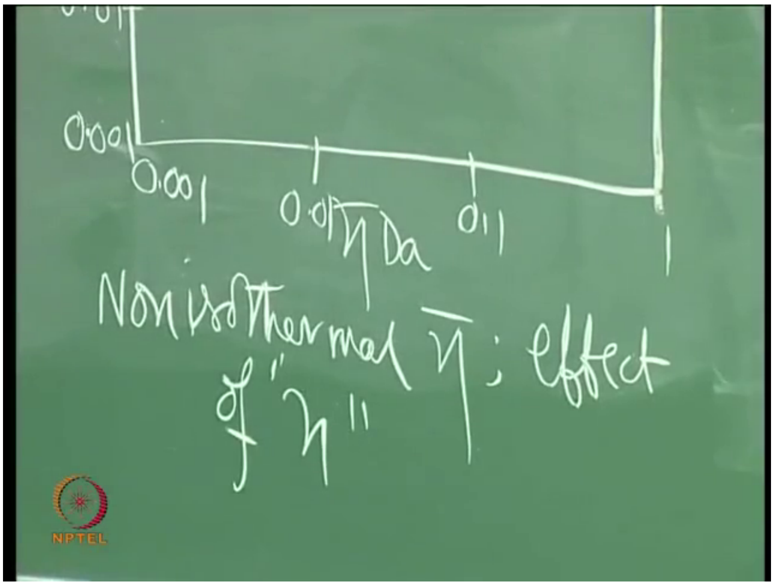

Even if there is diffusion, diffusion also very very possible. That means all surface area is freely available for you, okay, good. So now let us plot this graph and then try to interpret any extra information you get from all this. Equation 21 we are now trying to plot. Hopefully I do not need the other side. Graphical representation of equation 21. So the 1st graph what we plot, yah, is Eta bar versus Eta bar DA, Eta bar DA is Rob Kg a Cb this reminded 1. So here we will start with log scale 0.1, 1, 10, this side you cannot have more than 1, so it starts with 0.001, then I have 0.01, 0.1 and 1.

Yah, so this is the coordinates, so then we have, yah, 1st isothermal we will take is, so isothermal means this will not be there no. Okay, isothermal, so if you plot isothermal, okay, exact qualitative graph only. Yah, so then I also have, this is n equal to minus1, this is half, this one equal to1, this one equal to 2. Okay, very easy to plot this on Excel, right. So the only thing that changes here is n and this is isothermal, isothermal, I will write Eta bar, effectiveness factor, good. So let me also plot the other one, the one, so this is again Eta bar, then we will have, this is Eta bar DA, I do not have to repeat everytime Rob.

So this is same again 0.001, yah, 0.01, 0.1 and 1. This side I have 0.001 this is 0.001, 0.01, 0.1, this is 1, 10, 100, 1000. Okay, yah, you can also go to 10,000. That is Eta bar. So the parameters which will fix it is that we have Epsilon 0 equal to, Arhenius number equal to 20. And beta bar equal to 1+1, that means exothermic reaction, this one. Let us see how do you plot. So this goes, it is very nice to plot, in the room also if you can plot this. It goes like this, goes like this, it goes like this. So here the parameter is n equal to minus1, n equal to half and n equal to1, then we also have something like this for n equal to 2.

As usual I am dangerous, I can also ask you to plot this in the examination all. Really, why not. Okay, and then interpret, what this happening. Good, so this is n equal to, Dubai equal to1, so that means what you can say about this non-isothermal, non-isothermal Eta bar, okay, what is the effect? Effect of, this is what what you do in your research also, effect of what, what is that reassuring effect? Effect of order of reaction, it is effect of n, order of reaction. Good, so now you have many more graphs like this. We have now shown for that non-isothermal equation 21, effect of n, then we have to show effect of beta and then we have to show effect of Epsilon, good, okay.

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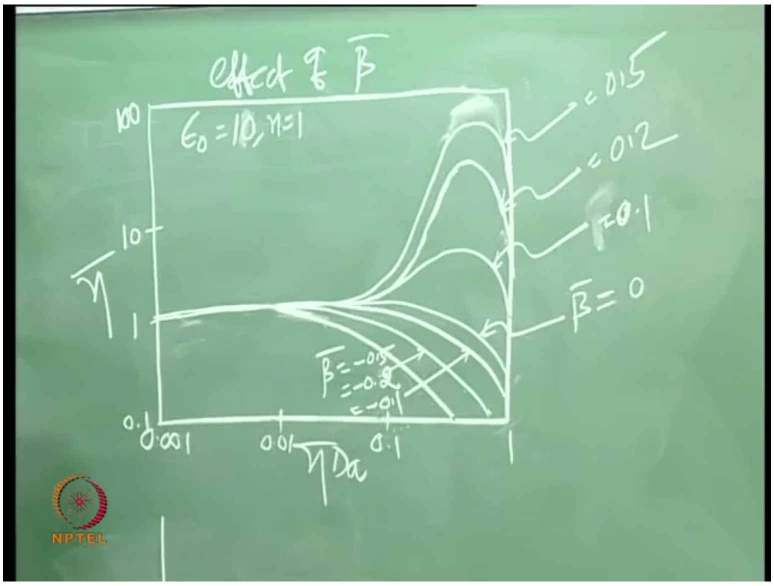

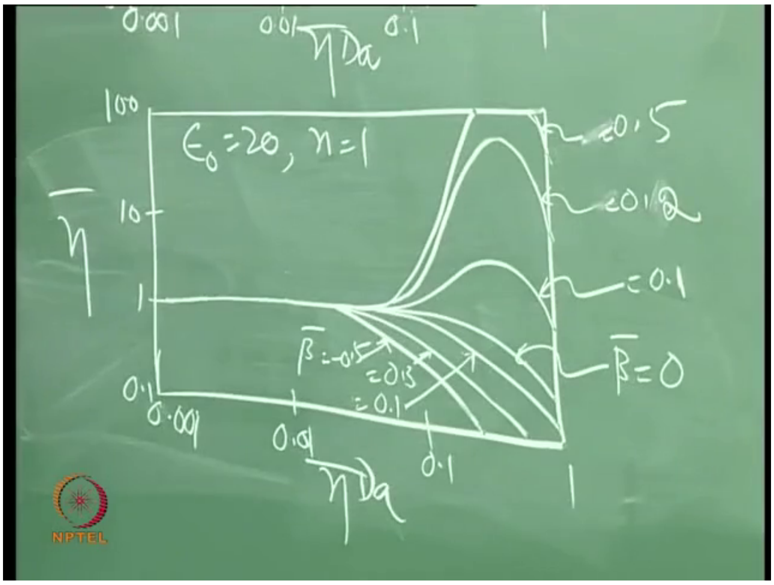

That will do, so then all these are nonisothermal graphs. This is Eta bar, Eta bar DA. So this side it is say 0.001, then we have 0.01, 0.1, 1. So here is this is 0.1, 1 and 10. So the parameters what we fix here is Epsilon 0 equal to 10, n equal to1, 1st order, so then we have beaten as the parameter. So when we have beta as the parameter, yah, so I will give these parameter values later. Here we have, so this is beta bar equal to -0.5, this one. So this one equal to -0.2, this one -0.1, okay. Good. So the, you, so I think (())(34:25). Okay, so this is beta bar equal to 0, this is beta bar, okay equal to 0.1, this is beta bar equal to 0.2, this is beta bar equal to 0.5.

Okay. Good. This will be a single line. Okay, anyway you going to plot all this on the computer, okay, usually the computer, okay. So this one is effect of beta bar, we will again have, you Epsilon equal to 20, I have not written to scale here, maybe I should not touch it there, okay. So exactly similar graph we will have 0.001, 0.01, 0.1, 1. This is Eta bar 0.1, 1, 10, 100. So if I plot here also we will have, yah. So, yah, so this is beta bar equal to 0, 0.1, 0.2, 0.5, yah. So similarly this side I have beta bar equal to -0.5, is something wrong there, 0.3, 0.1., Okay.

Yah, parameters I will write here. Epsilon 0 equal to 20, right and n equal to1. So what is the difference between this graph in this graph? This is for Epsilon equal to 20, so that is why, here approximately, qualitatively this is going to almost around maybe around 70-80 and here it is crossing even 100, actual values when you are plotting you know. So this will tell is that always the effectiveness actors when I have Epsilon 0 equal to 20, you will have higher effectiveness, effectiveness factor. Effectiveness actors value will be more if you take Epsilon 0 equal to 20 when compared to this.

These are the same parameters and beta negative means endothermic and positive means exothermic. Okay, now let us just see from this picture onwards, what the product from this? You know that, as Eta bar is increasing, Eta bar DA is increasing, Eta bar decreases, Eta bar DA. Or otherwise we will call that as Carberry number, as Carberry number is increasing, we will have here Eta bar falling. Why?

Student: Eta bar (())(39:01).

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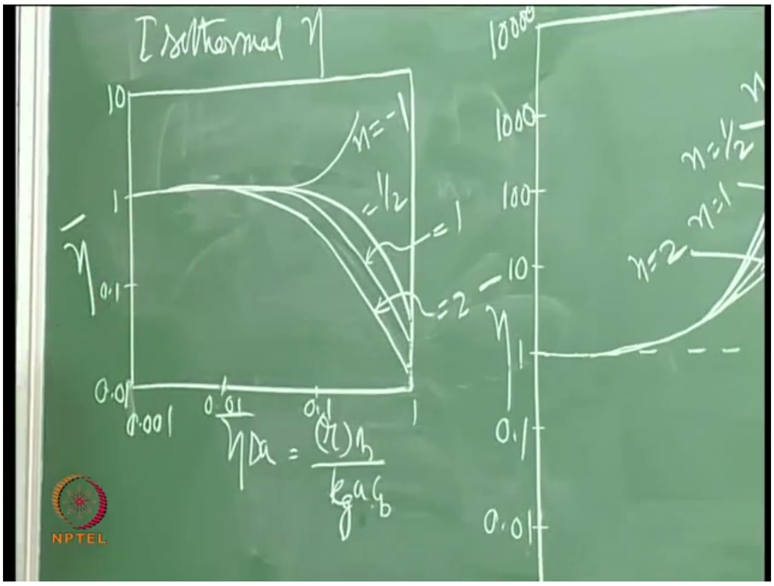


Professor: Exponential? What exponential relation? You tell me the physics of this one. Is it correct when Eta bar, I mean this observable Carberry number is increasing, this is, effectiveness actor is decreasing. Which one controlling? Kg a is increasing means, yah it is increasing means kg a is decreasing. That means past password decreases, so that is why effectiveness actor, that means there is no sufficient amount of mass going to the particle for reaction. That means, okay, here are almost everything same? Which one is controlling here? There is sufficient amount of mass after but reaction is controlling and because amount of massage for the same throughout the particle, okay, so that is why all the surface area is occupied, so then I have effectiveness factor equal to almost 1.

So then as you increase this, then Kg a is decreasing, right, so that means all the surface area is not available, effectiveness actor is falling, that is another observation. These all what you write on your research also, after simulation or after doing some experiments when you plot the, against the parameters, this is what what you have to discuss, okay, thoroughly. And then when you take n equal to1, 2, minus1 and all that, what can you say? 1st of all n is negative always gives effectiveness actor more than 1, correct, 1 or more. Why? This is why is very difficult, everytime you have to say why.

Student: (())(40:53).

Professor: Yeah, that is the beauty in negative (())(40:55). So as a reaction, as the concentration is decreasing, rate of reaction is increasing. That is why always, it is a very nice funny reaction. Okay, so all positive orders, as order is increasing, he will have less and less effectiveness actor. Can you tell me what is the reason?

Student: Can you repeat?

Professor: Concentration, how do you say concentration is negative…? It is true, because the concentration is decreasing, correct no, when you come this side, the concentration is decreasing on the surface. So when you have squared and cubed reactions like that, definitely will have that effect more for the rate of reaction. So that is why it is decreasing with number. All the observations, here also the same thing, but here what is the striking thing, here all the effectiveness actors are greater than 1. Why? n or greater. Exothermic reaction.

So that means the templates in the particle or on the particle is higher for rate of reaction is definitely higher and then you have more and more rate there because the temperature is higher. So that is why you are getting that all the things. now with order again, same thing, the 2nd order you will have less effectiveness active, first-order, half order and negative. That is why it can even go to calculation wise even 10,000, effectiveness actor, when you are calculating you know that. Good. But if these are the parameters and also we have to tell here, that here Epsilon 0 what you have taken is high-value.

See the parameters also is very funny, always with things that you have to change from 0 to infinity, were parameters, it is not so. Like you see here, one particular thing, what is the maximum value of beta what you have taken, 0.5, it cannot be 100. Because physical parameters will not be there in that definition of beta bar here. For many systems you will never get that kind of very large values like 100, 200, 300. It will be only around 1, 0.5, 0.7, 0.8, like that. These are the real physical parameters for many reactions that were taken and plotted.

Otherwise if you do not understand those with its, then what you, varies from 0 to infinity. So 0 to infinity will get very funny funny readings, so that is why one has to be careful when you are choosing these parameters. And effectiveness factors also, it is not thousands, okay, maximum, most of the times it is less than 100. Epsilon 0 100 means very very very very high reaction. That means energy is very high, any small change in temperature will be very very sensitive, okay, small change in temperature you will have, the reaction is very very temperature sensitive.

So all these things which you have learnt already also we can use that for discussion here. Right and when you compare this and this, always, another thing, beta bar when it is negative, always you will have reactions, I mean the effectiveness factor less than 1. That is also there, why, why Anand Kumar? Why for endothermic reactions always you have effectiveness factor less than one?

Student: Always Delta T (())(44:27).

Professor: Always Delta T, what is the temperature on the… You have endothermic reaction, what is the temperature on the surface, is it less than TB or more than TB? So naturally you will be having low rate of reactions, so we will have that, okay. Good. So this is what, this is what is that we can discuss and then of course here and here the difference is that this will give you little bit low effectiveness factor and this will give you a little bit high effectiveness factor because here Epsilon 0 equal to 20.

So tomorrow if I give a surprise test and ask you to draw these graphs qualitatively and then give the explanation, you have to give all these. But I can give no, what is wrong in that? Okay, it is a qualitative, you have to just see and then that a lot these graphs and explain each and every graph. Okay, on this graph from 4-5 points, on this graph from 4-5 points, okay, inside this is a very good training for research also. This is what you do in your projects, whether you simulate or whether you to experiments available to both, you have to write only on the graph like the discussion what we have done till now. Okay. Good.

With this I think is effectiveness actors are, our external effectiveness actor what we call, interface effectiveness actor. So the discussion on that is over but only thing is there are one or 2 points which you have to think. What are the practical applications of these? Either any practical application for this equation, that means where I can use and calculate, is there any practical application? What you know? What kind of particles we are talking here? Most of the times we are talking about nonporous particles, okay, so is there any reaction bad nonporous particles are used as catalysts, in all those places it is useful.

Yah, so example which I have been telling already? Yah, ammonia is oxidised to nO for nitric acid production, okay. One example, practical example you can take, NH3 is oxidised to NO, NO is nitrous oxide, nitrous, nitric oxide over platinum catalyst, wire meshes, that is one and you also have another reaction, synthesis of very dangerous, hydrogen cyanide. Any cyanide is dangerous, good…

Student: Explosive.

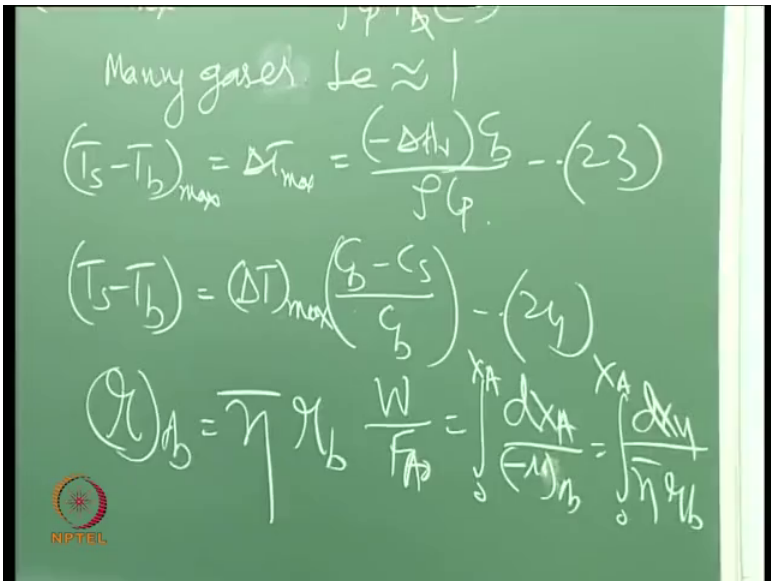
Professor: Not explosive, poisonous. HCn, hydrogen cyanide, synthesis of hydrogen cyanide from nH3, O2 oxygen, and CH4 over platinum wire again, over platinum wires, wiremesh. Just repeat, synthesis of hydrogen cyanide from nH3, that means reactants nH3, oxigen and methane, CH4 and catalyst is platinum wire, mesh. Okay, next one is, 3rd one is methanol oxidation to formaldehyde over nonporous silver. This is the reason why we teach you chemical technology, in chemical technology, all these equations are supposed to come. Okay. Yah, so then the 4th one is very famous one where all of you know but you may not get the point now.

For coarse you have that catalytic converter. In catalytic converters also similar questions are used, why? Wiremesh is not put in catalytic converter, to the monolith supply was so drawn earlier I think, it is the monolith where you have, it is a cylinder like this, okay, then you have, those are again platinum coated and you will have some other, it is actually mixed catalyst. So there will be many, because you do not have only CO, CO is, CO2 to CO2 it has to go, then all other hydrocarbons also they should be decomposed to hydrogen and all that. So that is the reason why it is mixed catalyst.

And now see, if I look at one box here, okay, so then you have the reaction taking place on the surface. It is just a sheet, one sheet, another sheet, another sheet, like that. So all the action is happening only on the surface, it is not for us. So then you have only film control, only film is there. So now under film control you have again same thing, same equations. So that is why 4th one is in automotive exhaust catalytic muffler, in automotive, exhaust catalytic muffler muffler, the oxidation of CO and hydrocarbons, oxidation of CO, carbon monoxide and hydrocarbons at high temperature occurs on the external surface of catalyst, on the external surface of catalyst.

These are the examples, that means what you have done is not waste but I think you know still it is useful for us just to tell you that all this analysis is a wonderful analysis. Because whenever you have this kind of mass transfer controlling, a lone film controlling, this is the analysis what you have to do to find out the effectiveness of catalyst. As I told you what is the use of this effectiveness? In the beginning I also mentioned that. 1st of all you have an idea whether I have an effective catalyst or not. 2nd is if I want to use that Rob, Rob, and if someone gives me R intrinsic, R based on bulk, that means there is no masterful effect.

(Refer Slide Time: 51:12)



Many gases Le ≈ 1

$$(T_s - T_b)_{max} = \Delta T_{max} = \frac{(-\Delta H_r) C_b}{\rho C_p} \quad \text{--(23)}$$

$$(T_s - T_b) = (\Delta T)_{max} \left(\frac{C_b - C_s}{C_b} \right) \quad \text{--(24)}$$

$$(r)_{ob} = \bar{\eta}\, r_b \qquad \frac{W}{F_{A0}} = \int_0^{X_A} \frac{dX_A}{(-r_A)_{ob}} = \int_0^{X_A} \frac{dX_A}{\bar{\eta}\, r_b}$$

So then I can simply write Rob Eta bar RB. And if you using this information to design a packet bed catalytic reactor, then we have W by FA0 equal to 0 to XA dXA by minus 1 A, minus Rob, which is nothing but Eta bar, Eta bar RB. It is simply nothing but Eta bar RB. So now Eta bar equation you have to substitute here if it is isothermal, if it is non-isothermal, you have to substitute this equation and you need here, this is a mass balance equation, you have the temperature balance also, that will tell you. Because finally this has to be converted, everything in terms of XA for the integration, right. Even though I have nonisothermal, it is temperature change, okay.

So that is why to convert that we have all the relationship like including constipation, this equation within 2 which relates concentration and temperature, all that information you have to use here to integrate this expression. And Eta bar if it is nonisothermal, he will have help because you have this equation, okay. So that is the reason why you have not done anything useless, everything is practically useful if you want to design. If you do not want to design and go to IT, no problem. Okay, yah, so good, we will stop here and then tomorrho we will start the normal, diffusion 2nd step. If diffusion is controlling through the post, how do you know, again develop effectiveness factors and then both combined how do you develop, okay.