Chemical Reaction Engineering 2 (Heterogeneous Reactors)

Professor K. Krishnaiah.
Department of Chemical Engineering.
Indian Institute of Technology, Madras.

Lecture-22.

Interface Effectiveness Factor and Generalised nonisothermal Effectiveness Factor for External Mass Transfer Step.

Professor: So we have been discussing about this interface effectiveness factor or the effectiveness factor based on our mass transfer steps. And the 1st one what we have taken was the film control, diffusion also is very fast, diffusion through the pores also is very fast. So if only film is controlling, how do you develop the effectiveness factors. And for that we give the name as interface effectiveness factor, interface effectiveness factors, okay, this is continued. We have already done, derived one equation yesterday for first-order reaction, okay.

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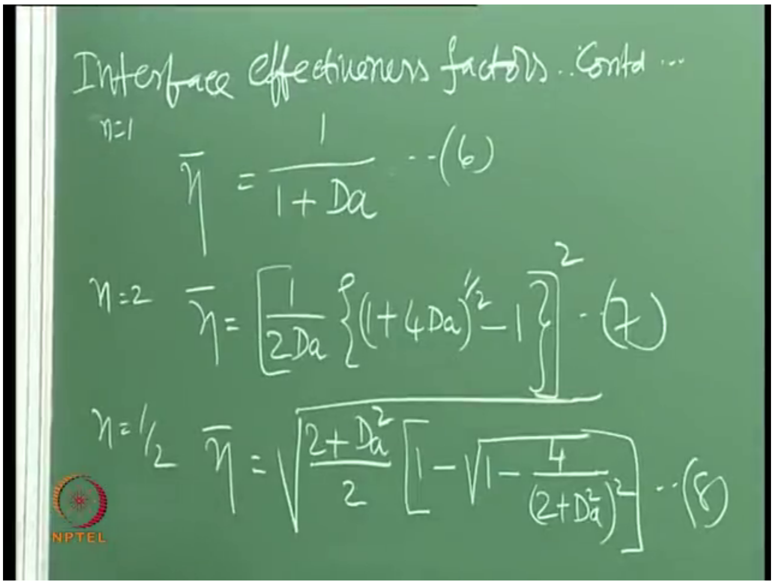

Interface effectiveness factors ..Contd ...

n=1 $\bar{\eta} = \frac{1}{1+Da}$ ..(6)

n=2 $\bar{\eta} = \left[\frac{1}{2Da}\left\{(1+4Da)^{1/2}-1\right\}\right]^2$ ·(7)

n=1/2 $\bar{\eta} = \sqrt{\frac{2+Da^2}{2}\left[1-\sqrt{1-\frac{4}{(2+Da^2)^2}}\right]}$ ..(8)

So that equation was ETA bar for n equal to1, first-order equal to1 by 1+ DA, we DA is the Dam Kohler number, okay, good. And for second-order you are going to derive, I will give the final expression as Eta bar equal to, of course Eta bar is also R by R actual by R observed, okay, that is also that eta bar. So then ETA bar equal to 1 by 2 DA Dam Kohler number, then I have 1 plus 4 DA, okay, to the power of half minus1 and this whole thing squared. So if this number was, what is that, equation number, this is 6 and this is 7.

So you can also derive this one for half order, so for half order you have ETA bar equal to 2+ DA square by 2, then we have 1 miners square root of 1 - 4 by 2+ DA square, again this is whole square, yah, this is yours. And here everything this under square, this is the equation 8. now please let me check, this I am coming from notes. 2 Plus DA square by2 correct, 1 minus square root of 1- 4 by 2+ DA square whole square, all this, yah and the entire thing is under, please check this. And now I have lots of simple simple problems for my separate tests, okay. One day I can give you this 1st n equal to, n equal to half, next day I will give you n equal to minus1, okay, so many things.

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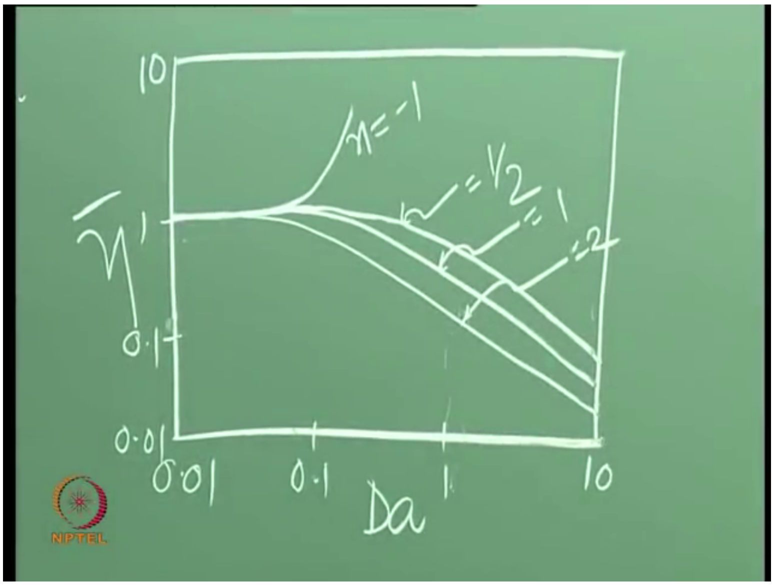

Minus1 you try what kind of equation you will get, boost. So then when you develop these equations, then if you would try to plot that and see how the effectiveness factors are varying with Dam Kohler number. I have here ETA bar, here I have DA, right and this DA on log scale is very from 0.01, 0.1, 1, 10, log scale. And this side also it is log scale, to 0.01, 0.1, 1, 10, good, okay. So now if I plot this, for example n equal to1 which we understood 1st, so for n equal to1 we will get like this and then going like this, this is for n equal to1, we will draw that.

So for n equal to 2 it will be like this, for n equal to half it will be like this and it is nice to see for, this is just a qualitative graph, not exact, it may not be to the scale. So this is for n equal to minus1, this equal to half, this is for 1 and this is for 2, okay. So what is the use of this graph? We develop equations and we draw graphs, then we should know why we are drawing graphs, do not that we do not have any work but I think you know there is a meaning, you can also have a lot of conclusions from the graph. Engineers and scientists always you lots of graph because one picture can speak thousand words, that is the reason, okay.

Yah so how to use this one? Swami any idea? What is the use of this graph? Where did you do your M tech? You are MS or Ph.D.

Student: MS.

Professor: Okay, what did you do your B tech? BVRIT, where? If you draw, did you teachers say anytime to draw on the board and try to explain? Just asking, what kind of, can you remember at least one graph? Well difficult question. That is why memory memory memory, because of the computers all files are temporarily stored and 1 semester is the maximum time. After one semester all temporary files deleted, next semester ready for storing files.

Student: Clean slate.

Professor: Yes clean slate. (())(7:08) so that maximum driving force you will have. Okay, Harunal, why do we draw graphs 1st of all?

Student: We want to see the variation in the progress of the reaction.

Professor: How do you see the progress of the reaction in this graph?

Student: How conversion it is…

Professor: How…?

Student: How conversion…

Professor: Again my question, where is the conversion here in this graph? This is (())(7:37) factor versus Dam Kohler number. What information will get from this graph? I think all these things are necessary I say, that is why I have to take you know every semester 100 classes because I am trying to tell everything, that is my bad lack, that is the problem. How do you know from here there is mass transfer control or not?

Low Dam Kohler number, eta is close to 1. Yah, low Dam Kohler number somewhere here, he will have, that do all, all the order also you will have effectiveness factors equal to almost 1, okay. And then as Dam Kohler number is increasing, what is the meaning of Dam Kohler number increasing? KGa is decreasing, that is in the denominator no and also please remember that DA is not universal definition for 1st author, you know K by K Ga we have written yesterday for first-order. So that is the 1st one in this case, but here the definition changes, here the definition changes.

The reason we have general expression for nth order, okay, yah. So that is the one and that is interpretation from the graph. But what is the use of the graph apart from interpretation? I can now find out what is effectiveness factor for my catalyst. What information I require? For finding out, okay, to find out how effective my catalyst is, what information I need to have? Dam Kohler number, how do you get Dam Kohler number?

Student: By kinetic.

Professor: Kinetic, that means intrinsic rate I should know and also KG a I should know. Do you have any questions for KG a? Lots, that depends on what kind of reactor you using, okay, for KG days. And K is intrinsic rate constant, right but anyway, somehow when you go DA which is nothing but K by KG A, CB to the power of n minus1, okay, for general nth order, so then I will 1st know what is DA and then I will go year, for certain order point, maybe 0.2 or 0.3, okay, is effectiveness factor. Similarly when I go at 1 and then see that maybe approximately this is not exact to the scale, so that is why again you go here and then you will get almost 1.

So then that will give an idea just by calculate Dam Kohler number whether you have any, another factor, the catalyst will be effective or not or using the entire surface area for catalyst or not, okay. So that is the use of all effectiveness factor versus Dam Kohler number and if you go to diffusion through pores, there are 2 parameters, 1 parameter comes there like DA. What is the parameter called? You have done already, so that is why Thiele modulus, okay. So now Thiele modulus you are supposed to calculate and once you know Thiele modulus, then the graph will easily allow me to check whether I have effective catalyst or non-effective catalysts, right. Good, so that is the reason why we have the information on this.

But there is a catch here, DA is having intrinsic rate constant and you can never get any information on interesting rate constant. Why? In heterogeneous system always whatever you, whether you like or not, definitely there will be some slight effect of mass transfer. So that means that K is not exactly K but it is upper end K, in the presence of mass transfer. Okay, so how do I now get this coordinate without any mass transfer effects and most importantly how do you get that Y axis, x-axis in terms of observables. That means, observables means measurables, in terms of measurables, how do you get this coordinate? Because here K is not observable, it is not measurable so easily, okay.

What we will do normally is that we take very fine powder and then send the gas over the powder and we assume that we do not have any mass transfer limitations. And fine powder means it is a vague statement, okay. What is fine powder for you?

Student: Talcum powder.

Professor: Talcum powder is fine powder but I think you know scientifically in terms of size, you have to tell no.

Student: Microns.

Professor: Microns or micron or what? Yah, you should have some of these things you know observables in your mind. I told you know what is the length of the chalk piece, oh, 50 microns you cannot apply you know talcum powder at all, skin will come off. normally you take like this and then pore no, yah, so then skin will come off for 50 microns. It should be very very fine, less than 10, 1 micron preferably. Really, yah, 50 microns if you want to see, come to our lab and then we have a lot of sand, we are with 50 microns. 50 microns, 100 microns, 200 microns, 500 microns we have will show it to you if you do not believe. And you can check that with your talcum powder, okay.

So talcum powder, yah, that is why when you say that fine powder, it does not really mean anything to us, okay. And you cannot go to 0.1 micron, 0.5 micron more you know another 1000 off the micron know that if you go, particles also will run off, like dust particles. Dust particles are also only 1 micron, 5 micron, 10 microns and like that. Dust particles if you see on the scooter or cycle or car whatever you have, you can see no harm much is accumulating also, they can try to find out. So that is why whatever you do, you cannot avoid mass transfer when you are taking particles.

That is why Carberry has a very beautiful idea, let me express this that x-axis in terms of observable or measurable experimentally. Experimentally we are supposed to do good measurements, correct measurements and then use that coordinate to calculate what will be the Eta bar. The next task is to relate one of observable to Eta bar, it is something a question like this but here you will have observable at the parameter and you can calculate now what is Eta bar. Okay, that is what what we will do now. You know the problem now no? Why we cannot use, same problem, same problem you have with pore diffusion.

Thiele modulus is not observable, is remembered for first-order Thiele modulus, because you have done some courses already. What is the equation for Thiele modulus? Pie equal to, normally many people use pie as Thiele modulus.

Student: Tan inverse.

Professor: What inverse? Pie, I am asking pie, not effectiveness factor. You are telling effectiveness factor equal to1 by tan h pie as the 4 single pore, okay. I am not talking about that, I am talking about, try to recall your memory what you have written in the examination, right.

Student: MCP by KL.

Professor: MCP is heat transfer. What is MCP in your language? It is not specific heat and mass and all that? What is MCP? Because everyone will of their own notation. You do not remember?

Student: L root K by D.

Professor: What is L? You said L into? Land, yah, that is right, yah L into?

Student: Root K by D.

Professor: Yes, for first-order recall that L is your pages of the particle, R into square root of K by D. Again K is intrinsic rate constant, yah. Why Anurag you do not sleep normally in nights, you sleep, then again I think always you will I am hearing from the class. One thing may be terribly boring to you, okay, yah yah, yah, I think that looks because body reactions you cannot stop no, okay. Here, body reactions you cannot stop most of the time. Okay, anyway, so destroy root of K by D, again there also gave intrinsic rate value cannot, intrinsic rate constant value cannot measure it easily.

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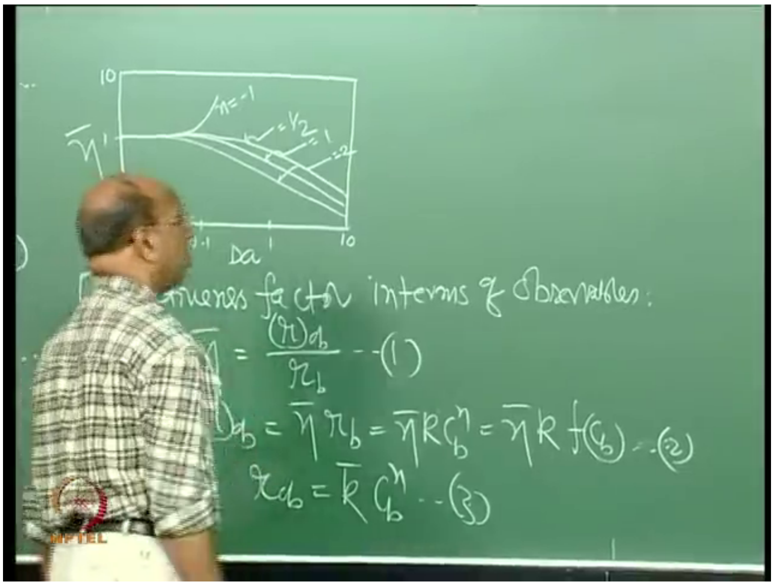

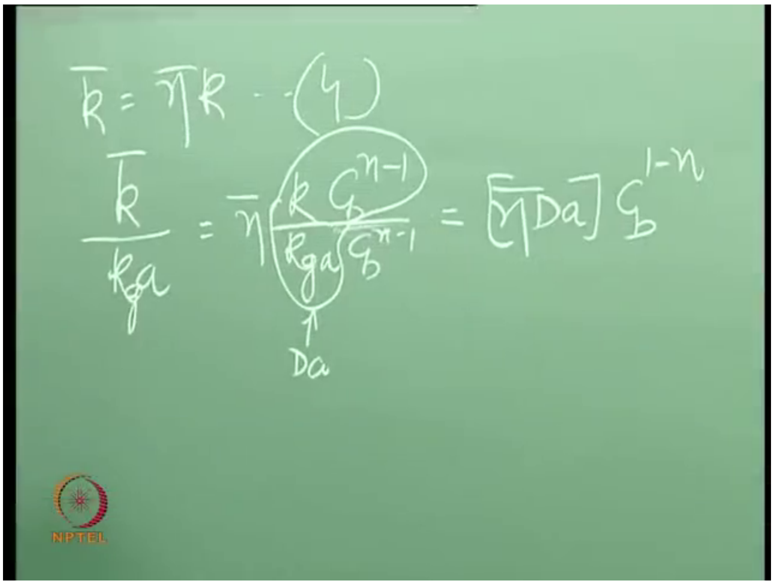

So that is why there also we have to do something else to find out what is effectiveness factor. So here also we have to do the same thing, so this is, this one was done by beautifully by Carberry. So that is why some people call or including me I call this Carberry observable, okay. So Carberry's observable if you write, that is effectiveness factor, effectiveness factor in terms of observables, observables. Okay, so we have an equation Eta bar equal to R ob, that is actual rate observed or actual rate and R B, RB is red based on bulk conditions. We are talking about isothermal conditions only here, okay but later on I will tell you how we can also change to non-isothermal conditions.

But observable will not change, yah Eta bar equal to ROB by RB and we also know that from this equation if I call this, okay let me to this one as separate equation. So I have ROB equal to Eta bar RB, RB is the general rate. So we can also have this one as Eta bar K CB to the power of n for nth order reaction, RB. Or in general this also we can have Eta bar K function of CB. It need not be always see CB to the power of n but it can be any form. So this is equation 1, no, equation 2, okay. Good. So what we got here is this, this, in this equation Rob, Rob is equal to, this Eta bar K, we call as K bar CB to the power of n. So this is a equation 3 where K bar equal to Eta bar K.

Okay, so now what I do is I will just try to manipulate, this is equation 4, so K bar by KG A, I just divide and I have here Eta bar, this will be now because I divided KGa at this side, here also I have to divide by KGa and also CB to the power of n minus1, also I divide by CB to the power of n minus1, yah. So I have something here, you know what is this group? Dam Kohler number, right. So now, yah this is Dam Kohler number, so this equation now can be written as Eta bar DA, correct, this will put as one thing, Eta bar DA and the other side we have CB to the power of 1 minus n, I have just taken it up.

Okay, so this K bar we will substitute in this equation, K bar, this is equation, this is 5. So K bar we have from 5, you tell me, substitute equation 5 in 3, and tell me what you get. Substitute equation 5 in 3, what do you get, Rob equal to, so much time…

Student: (())(21:00) into KG a.

Professor: Into KG a, okay. So Rob you get as, Prabhu once more? Eta bar Dam Kohler number as one group into CB into KG a. So this is equation, so now Eta bar DA, this is the question number 6, Eta bar DA as a group I will write now Rob by CB KG a. So this is equation 7 and this is an observable, that is an observable. Why that is an observable? Rachit…?

Student: (())(21:59).

Professor: Which K?

Student: There is no K.

Professor: Why it is observable I am asking.

Student: All things are measurable.

Professor: Yes, all things are measurable because most of the time for KG a we have lots of correlations, whatever type of reactors you take, whatever conditions retain and then CB measurable, Rob is measurable, you are measuring the rate, R observed is measurable. And that is why this group is called the Carberry’s observable quantity and this if I now Eta bar DA versus eta, if I am able to develop equation, Eta bar DA versus eta, eta is the effectiveness factor. Eta bar DA is nothing but Rob CB KG a. So in other words I have to plot Rob divided by CB KG a versus eta and then I measure this, go to lab, measures this Rob CB KG a and then I can now either calculate or go to the graph and then find out what will be the effectiveness factor.

now I am sure my effectiveness factor is correct. Earlier I had always suspicion that how accurate my assumption here for intrinsic rate, intrinsic constant. Right. So that is the problem, so that is why this has been beautifully solved by Carberry to say that yes. You have now dissolves available and use this available to calculate effectiveness factor for your catalyst. This idea I think he got only from the, I do not know whether you heard of criteria called Weisz-Prater criteria? Weisz-Prater, Weisz-Prater, again some more grandfathers in chemical engineering.

Yah that Weisz-Prater criteria is used for diffusion through pores, okay. That also we will do that. This this will be very similar to that, this criteria also authors of the rebel also, that is also an observable. In fact there using Weisz-Prater criteria you can even find out what should be the diameter of the particle which you to design. That will come under catalyst design apart from scientific design of finding out active sites and time to impose, put some active sites deliberately whenever you want and that is surface science. Apart from that the microscopical design, that means design of the particle maybe, should it be 1 inch or 1 centimetre 1 millimetre, okay.

Why 1 millimetre, 1 centimetre, 1 inch. The reason is that we should not have any mass transfer limitation for the particle. What will happen if you have mass transfer limitation? Your surface area is not completely utilised, so that is the reason why you have to design his particles, okay. Without any mass transfer limitations, most of the times that should be only reaction that is controlling, mass transfer should not control the reaction. Okay, it is like for us also always you know we would like to have as much food as possible. Whether you work or not that is reaction, okay but this is the basic criteria.

Even if you are late by one hour for lunch, sir lunch, sir lunch, sir lunch, every student starts looking at his watch, okay. That is the mass transfer is the basic requirement, so that is why we would not keep you angry at all, always feed them and try to extract maximum work. That is not possible, at least feeding is done all the time. Okay, good, so similarly like that only we should design our particles such that the particle should not get angry. Always there must be sufficient amount of mass that is available, the concentrations, then of course depending on temperatures and all that it can happily react. Good.

Yah, so now let us relate this observable in terms of effectiveness factor. Okay, so that is what is the next one, okay, please write this, otherwise I think you may forget. Eta bar is an observable, if Eta bar DA is related to Eta bar analytically, I have Eta bar DA is related to Eta bar, Eta bar DA as one group always. Eta bar DA is nothing but observable, good. So is Eta bar DA in the bracket you write is related to Eta bar analytic in the, it would be useful to know about the catalyst, to know about the catalyst. Let us do this in a more general form taking non-isothermal effectiveness, taking nonisothermal effectiveness, nonisothermal effects, not effectiveness, taking nonisothermal defects, okay.

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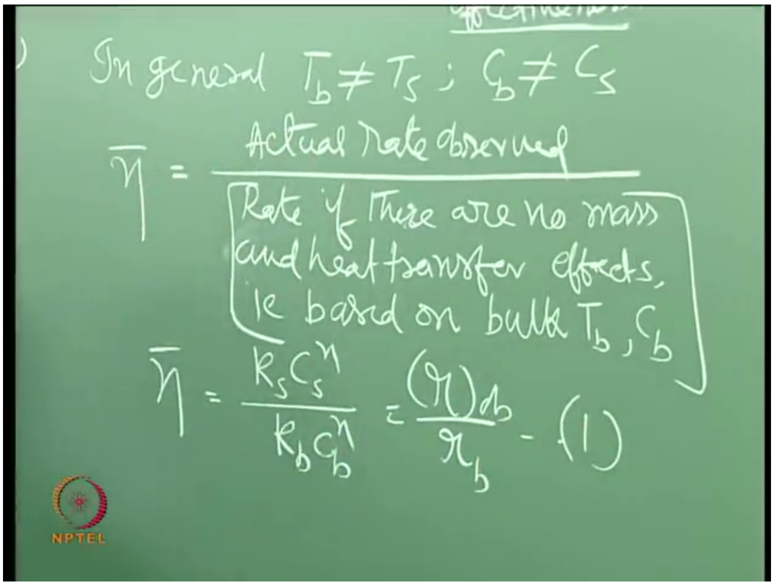
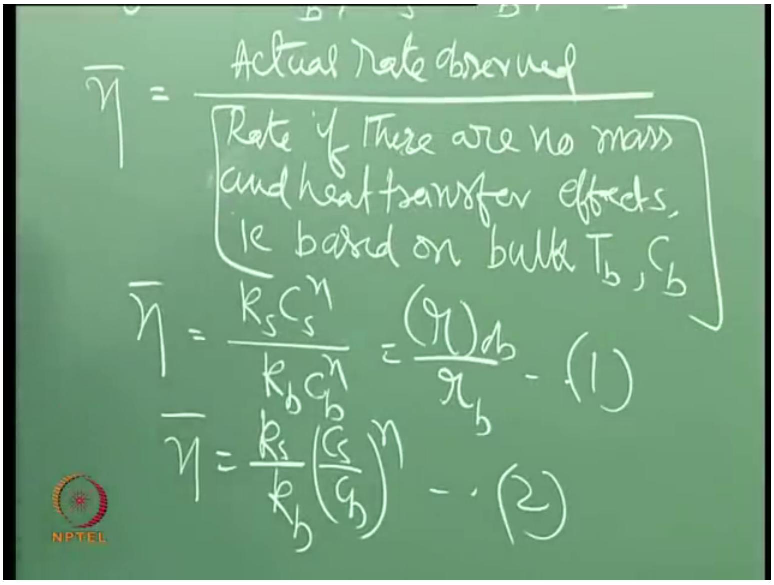


In general $T_b \neq T_s$; $C_b \neq C_s$

$$\bar{\eta} = \frac{\text{Actual rate observed}}{\left[\begin{array}{l}\text{Rate if there are no mass}\\ \text{and heat transfer effects,}\\ \text{ie based on bulk } T_b, C_b\end{array}\right]}$$

$$\bar{\eta} = \frac{k_s C_s^n}{k_b C_b^n} = \frac{(r)_{ob}}{r_b} \quad - (1)$$



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$$\bar{\eta} = \frac{k_s C_s^n}{k_b C_b^n} = \frac{(r)_{ob}}{r_b} - (1)$$

$$\bar{\eta} = \frac{k_s}{k_b}\left(\frac{C_s}{C_b}\right)^n \quad -\cdot (2)$$

So now we have another title here, generalised nonisothermal effectiveness, nonisothermal, , because you are talking only about film, external effectiveness, yah, this is a month. Okay, good, so let me do that, in general you have for any reaction T B is not difficult to TS and CB is not equal to CS, what is the meaning? Yah, always there may be some limitations, yah, so then Eta bar in this case is defined, when you have nonisothermal conditions as actual rate observed, let me also write that divided by rate if there is no, if there are no, if there are no mass transfer, okay I am also writing mass and heat transfer effects or limitations.

That is based on, that is rate based on bulk Tb / Cb, that is based on bulk Tb, CB. Good, so this Eta bar can be written as KS, CS to the power of n, divided by KB CB to the power of n, yah, of course in normal term this will be Rob by RB. So this is equation number 1, okay, this is equation number 1, then I will go here, remove all this. This derivation again is popularised by Carberry. What is the spelling of Carberry? As if you know I am just telling?

Student: Carberry.

Professor: Car plus berry, car plus berry, berries you know? What are the spelling for car, what is for berry, berry, okay, Carberry, okay, he is very good. Very good chemical reaction engineer, excellent, this derivation you will see how beautifully he has used all basic fundamentals that were described in chemical engineering, in terms of transport, wonderful, excellent derivation, really enjoy it doing. Okay, yah, this equation, that equation, maybe I will write the same thing, Eta bar, just writing in a slightly different way, this is KS by Kb, CS by CB whole to the power of n. You know idea is that this group separately we will find out and this group separately we will find out, okay.

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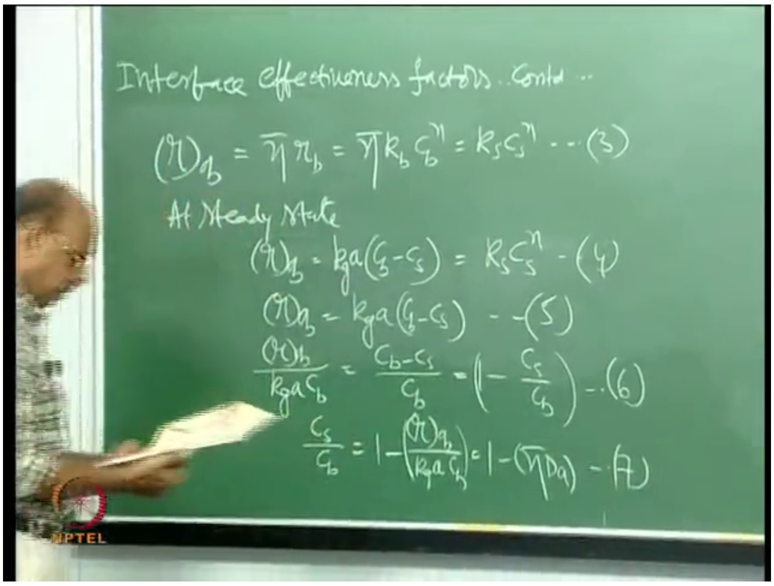

Interface effectiveness factors .. Contd ..

$$(r)_{ob} = \bar{\eta}\, r_b = \bar{\eta}\, k_b C_b^n = k_s C_s^n \cdots (3)$$

At steady state

$$(r)_{ob} = k_g a (C_b - C_s) = k_s C_s^n - (4)$$

$$(r)_{ob} = k_g a (C_b - C_s) \; - - (5)$$

$$\frac{(r)_{ob}}{k_g a C_b} = \frac{C_b - C_s}{C_b} = \left(1 - \frac{C_s}{C_b}\right) - \cdot (6)$$

$$\frac{C_s}{C_b} = 1 - \left(\frac{(r)_{ob}}{k_g a C_b}\right) = 1 - (\bar{\eta} Da) - \cdot (7)$$

That is the reason why same equation is written in terms of this and ks by KB equal to1 if I have isothermal case. Okay. Right, that is why we are going to use that equation, equation 2. And yah, this is again just to write, same thing I will be writing many times, just for, what simple algebra. So this is nothing but Eta bar K be CB to the power of n. Also which is also equal to KS CS to the power of n, this is equation number 3. Okay, so now we have, again we have you know either a wire, nonporous wire or you may have particle, nonporous particle.

So for that particle at steady-state, please remember only film is controlling, that 1st picture you have to say, okay, will it will be controlling. At steady-state you have Rob, rate observed equal to this equation already you know KG a CB minus CS, yah, so this is equation, equation for, this already, okay, at steady-state this must be also equal to rate of reaction on the KS CS to the power of n, this is equation 4, because at steady-state we are equating, this is okay, Rob, the sequel to this, right. Okay, good, so it is again Rob, I am separating only this, KG a, CB minus CS, this is equation 5.

I will simply divide this problem by KG a CB, yah equal to CB minus CS by CB which can also be written as 1 minus CS by CB. I think you know, all this I could have done in one or 2 steps but writing more steps, so this is equal to 6. Okay, now probably you would seen this, okay, already we find some pattern, CS by be there. So now I can write, I can right now CS by CB equal to 1 minus Rob by KG a CB which is also equal to, dissolve one group, 1 minus Eta bar DA, correct. Yah. Good. Right, okay, so now if I substitute CS by CB there, what do I get?

Substituting equation 7 in 2, substituting equation 7 in 2, what do I get? Eta bar equal to, yah, KS by K be into 1 minus Eta bar DA this is one group to the power of n, yah. So this is the nonisothermal effectiveness factor, yah, for isothermal case, KS equal to Kb, then Eta bar is equal to 1 minus Eta bar DA to the power of n. n and eta should not look same, eta and more tip, this is also eta, Eta bar DA, okay. So that means the, now you can see very easily, now I can calculate this one power n equal to1, n equal to 2, n equal to half, okay, same thing what we have done. But that equation is different, this equation is different.

And here I am very sure, what is Eta bar DA, which measure, right. So measuring the sense you know, I have all these parameters. You can also plot this graph now as Eta bar versus, okay, Eta bar versus Eta bar DA or Eta bar versus Rob divided by CB KG a. I am now more confident for isothermal case, we have a relationship now, Eta bar in terms of observables. Observables are nothing but your rate observed CB measurable, KG a measurable, all applications, good. So now how do I extend this or this will plot later for n equal to1, n equal to 2, n equal to half and all that, this equation, plotting, Eta bar versus observables. Good.

So that will do later but now here K s, what is the equation in terms of temperature? Arhenius equation, okay. Again we have the problem, in Arhenius equation that K is supposed to be intrinsic reaction date constant. Okay. So now we have to somehow eliminate that, you know the temperature, that K means when I say that Arhenius equation K equal to K0 or KS equal to K0, E power minus…?

Student: (())(37:46).

Professor: What is that T?

Student: Temperature.

Professor: Which temperature??

Student: (())(37:54).

Professor: Where is the operating condition?

Student: At which reaction is taking place.

Professor: Where?

Student: On the surface.

Professor: On the surface, it is not T, it is TS. Okay, K S is K0 into E power minus E by ati S. But again that TS is not measurable for us, right. Like CS is not measurable, TS also is not measurable. So that is the reason why I cannot use this equation straight, so I have to do something else. That again I have to make everything in terms observables, everything in terms of measurable. That I think is beautifully done by Carberry, okay. So what we will do now here is this Ks by K b, we will try to substitute for nonisothermal okay and we have an equation for you know KS by, if I write KS by KB in terms of Arhenius equation.

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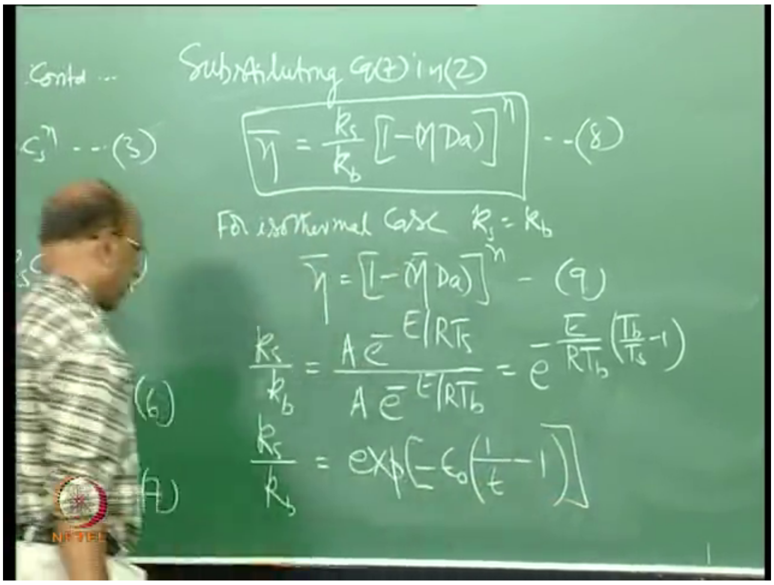

So that equations can be, yah this is equation 9, KS by K b, okay, this can be written as let me into E power minus E by RTS divided by A, A will not change, E power minus E, E also will not change , R also will not change, only TB , TS, right. So this equation can return as E power minus E by R Tb, okay, E by R TB and 1 survival idea, this is TB T is minus1,, okay, that is fine, okay, good. So of course same thing we can write K B in terms of some dimensionless numbers, that is exponential Epsilon 0, 1 by t, minus1, of course, if you want I can also put another bracket there. Where Epsilon 0 equal to, you have come across that number.

Where Epsilon 0 equal to, you what did you say?

Student: E by RTb…

Professor: E by RTb, be bold, Arhenius?

Student: Arhenius constant.

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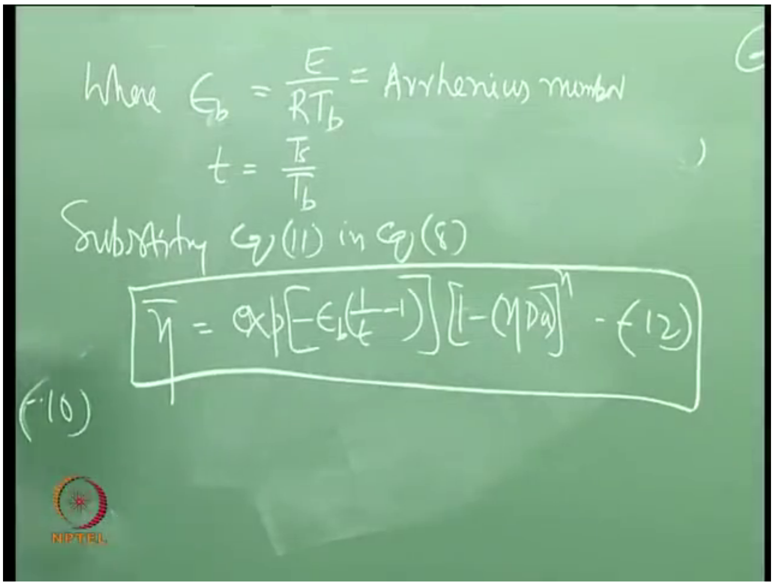

Where $\epsilon_b = \frac{E}{RT_b}$ = Arrhenius number

$t = \frac{T_s}{T_b}$

Substituting eq (11) in eq (8)

$$\boxed{\bar{\eta} = \exp\left[-\epsilon_b\left(\frac{1}{t}-1\right)\right]\left[1-(\bar{\eta} D_a)\right]^n} \quad -(12)$$

-(10)

Professor: Arhenius number, that is Arhenius number. And t equal to t equal to TS by TB. So numbers if I put, this is 10, this is 11 and of course those 2, no numbers there. So now, this Ks by equation 11 I can substitute in equation 8, okay. So substituting equation 11 in equation 8, now you will have Eta bar exponential minus Epsilon or Epsilon 0, okay. I think Epsilon 0, I can put Epsilon B, why, based on Tb, okay. So Epsilon B, 1 by T minus1, this equation and okay, this multiplied by 1 minus Eta bar DA, or to the power of n. So this is equation number 12, okay. Is it useful now?

This is observable, this is Arhenius number, observables, do I know a Priory what is Arhenius number, yes you know, definitely you know. So observable and T, not available. So that is why now you have to go to feed and mass balance around the palette and then right to relate that in terms of measurable. Really, wonderfully done, I think that I cannot do now because I think you have, you run for that class, even though I have time, you do not have time. Okay. So what we do here is that the particle you taken the steady-state conditions like we have written, yah steady-state condition.

Now this is the mass balance, now we use heat balance. What is the heat balance there? What is the heat balance?

Student: (())(43:25).

Professor: Yes where is convection and where is conduction?

Student: In the particle there is conduction and outside it is convection.

Professor: Yah, are you taking a porous particle by the way? So why pores and all that? The amount of heat generated by the equation on the surface must be equal to…

Student: (())(43:54).

Professor: Yah, heat supplied to the surface, if it is endothermic or heat brought out from the surface if it is exothermic. So this particle will be hot if it is exothermic but outside temperature is less, so naturally it flows in this direction. And if it is endothermic reaction Hb, sorry TB will be higher, and other milk, on the surface you will have less temperature, so is it flows in the other way. So always, exothermic is exiting, we will take exothermic reaction, okay, good. I think that we will do, that balance and now we will get in terms of heat transfer coefficient and heat of reaction and all that.

So you will have another parameter called beta in terms of observable. And everything can be expected terms of TB, like CB we have expressed. So that is how you finally get Eta bar, this equation, everything in terms of observable. That means for Ts by TB, you have to write an equation in terms of observable. It is a wonderful design, everything you know, your have heard of what is JH, JD factors and all that? Those things also become her, yah. Do you know what is the relationship between JD and JH?

Yah, simplest thing they have come I think you know that is under certain conditions, what she said is right, JD is equal to JH. But under some other conditions JD equal to 0.7 JH or so, okay. But anyway we take JD and JH and I may giving the examination JD equal to 0.7 JH, okay. Good, particularly for if you take only packet bed reactor, you may have JD good to JH, 0.7 JH, okay. You see all these criterions you have already learned in transport phenomena, momentum transfer and all that, okay. So that is why I think all the things we are beautifully going to use to solve this problem, okay. Now you run, thank you.