Chemical Reaction Engineering

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Lecture - 14

External Mass Transfer

Good morning. So, in the last lecture we looked at how to in corporately external mass transfer.

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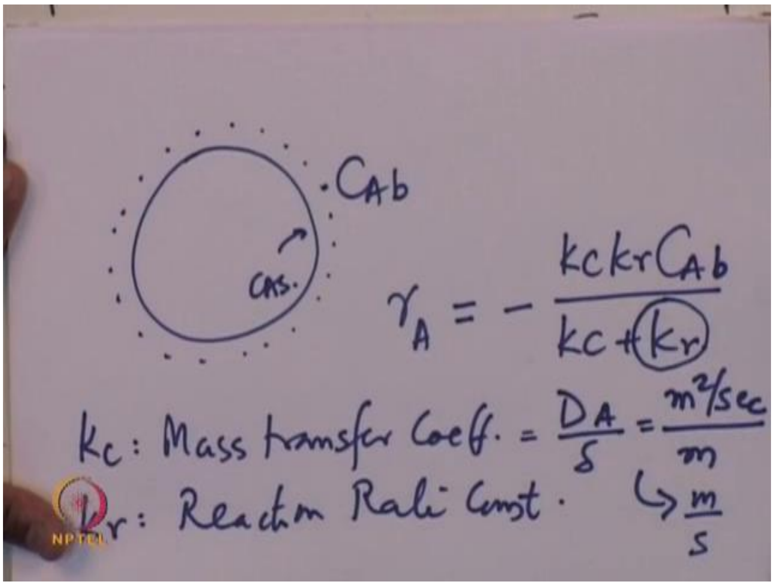

$\cdot C_{Ab}$

C_{AS}.

$$r_A = -\frac{k_c k_r C_{Ab}}{k_c + \boxed{k_r}}$$

k_c : Mass transfer Coeff. $= \frac{D_A}{\delta} = \frac{m^2/sec}{m}$

k_r : Reaction Rate Const. $\hookrightarrow \frac{m}{s}$

We talking about a particle, a chattels particle around are that is the fill around it, other this a rounds a chattels particle. Which is hypnotically fill and the concentration very easy in side of a fill; outside of fill the concentration is a bulb concentration at the surface the concentration is CAS and inside a particle of course, we have the reaction taking place, you may have effectiveness factor being significantly around, being substantially lower than 1 or it can be equal to 1 depending on what is a pole structure and on that, but we are not worry in much about that, we have were in about external mass transfer.

So; in that case, is the overall rate can be given as if you have a reaction which is first order then rA is equal to minus KCKr CA divided by KC plus Kr. Let me, quickly tell you what we mean by KC is the mass transfer coefficient and Kr is reaction rate constant and of course, we talking about bulk concentration it should be BCA, B there, because everything we are expressing in terms of the bulk concentration in that is a main purpose are motivation behind deriving this equation.

Now again like, if you right expression in this particular of form the elects of KC and Kr should be same. So, the mass transfer unit, you remember it DA divided by delta, what is the unit of DA. DA is say meters square per second or centimeters square per second, delta is meters of a unit of mass transfer meters per second. It is meter per second; now, a the Kr that is rate constant, K of A in the first order reaction, it should be, in this particular case, which will have the same unit as that of a the mass transfer coefficient. Now, the Kr here is the rate per unit external surface area, rate per unit external surface area.

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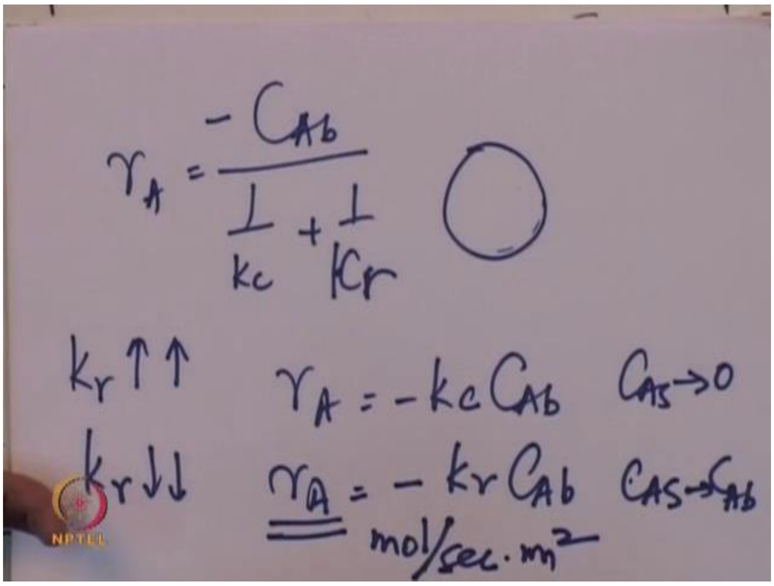

$$r_A = \frac{-C_{Ab}}{\frac{1}{k_c} + \frac{1}{K_r}}$$

$k_r \uparrow\uparrow$ $r_A = -k_c C_{Ab}$ $C_{As} \to 0$

$k_r \downarrow\downarrow$ $\underline{\underline{r_A}} = -k_r C_{Ab}$ $C_{As} \to C_{Ab}$

$mol/sec \cdot m^2$

So, if it is the volumetric rate constant, the unit is cycle involves whereas, in the case of in this particular case, we have the unit give which is equal to case KC. Now, let us go here and the of course, we further try to interpret this by saying that rA is equal to CAB divided by 1 by KC. But 1 by Kr and this is in negative sign here, because we talking about the rate of reaction for A. Now, depending on the relative magnitudes of these constraints, reaction is either external mass transfer or reaction control. So, if Kr is very large, then rA is equal to KC CAB were CAS is almost 0, if Kr is very small, then it is governed by the reaction. The oral rate is governed by the reaction it is going to we like this.

In this case, CAS is equal to CAB. The rate is the expressed in units moles per second meter square; very important this and meter square is the is a construction area externals surface and not the internal surface. Otherwise remember that if you talking about different surface area for internal mass transfer, internal diffusion some time we express or rate constraint. In terms of internal surface area, which is significantly large substantially large compare to the external surface area, but right now these are you unit of fluxes that is moles per meter square per cycle. So, let us go head now and try understand is external mass transfer in more detail. Now, a external mass transfer, suppose external mass transfer is important.

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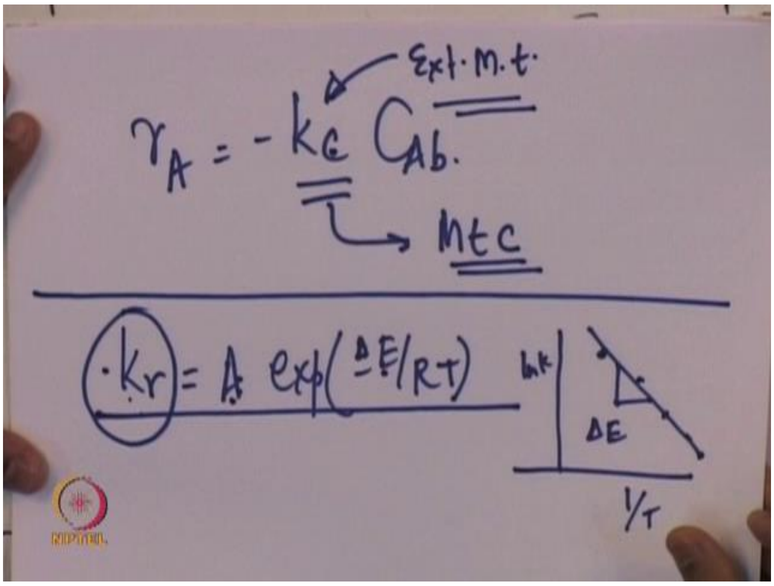

Now, it is the rate given by this particular expression. Now, this is a very simple expression where KC is very important is mass transfer coefficient how do we get it. This expression looks quite similar to first order to rate equation reaction is intrinsically kinetically controlled; adsorption is negligible, desorption is negligible at all other absorption coefficients are smaller. So, the denominator is unit r is equal to minus K CA.

So, again the expression looks at similar, but meaning is quite different now this K CA here in this expression is different from the Kr from, the Kr. Now, Kr we know Kr is a rate constraints which is of course, a frequency factor as a same unit has depth of Kr. So, it is per unit external surface, this we also the per unit external surface area. Then exponential minus E by RT; now, it is very easy, it is we know, how to calculate this how we know, determine this through the experiments in the about laboratory. I do experiments at different temperatures at get float for 1 by t verses LNK and this float this slow will give me delta E or E other and then you have a in the same the during E of course, is semi lock float LNK verses 1 by T.

So, you know out to get Kr, you know how to get a delta E by performing experiment different temperature is in laboratory and get the value of Kr. So, for in normal reaction which is controlled by intrinsic kinetics, I do not have, any problem it is designing a reactor. Now, if it is the external mass transfer, which is play in a important role. How do I design a reactor that is a question. So, first of all, you need to know the external mass transfer coefficient, under the conditions that we are doing the reaction.

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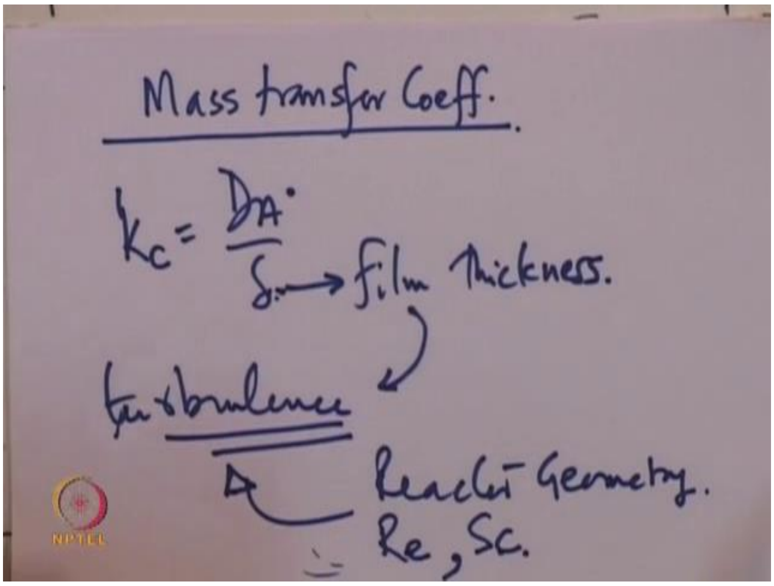

Mass transfer Coeff.

$$k_c = \frac{D_A}{\delta} \rightarrow \text{film thickness.}$$

turbulence

Reactor Geometry.

Re, Sc.

Now, let us spend some time on the external mass transfer coefficient, because that is seems to be the important parameters here; mass transfer coefficient. Like depends on which parameters as know, always remember this relationship easy to know what kC is dependent on as an set depends on the diffusion coefficient. And if depends on delta that is film thickness and this film thickness is in turned if a function of say, turbulence or how well is a mixing. What is the flow pattern decide all this, is this in turned decided by the Reactor Geometry, flow pattern is a decide by the Reactor Geometry actual flow rates.

So, in term a dimensionally is numbers which is that dimensionally number is important in this case, it is a Reynold number. NRE or RE and another number, which a something do with the property is like, viscosity, than density, then diffusion coefficient, this dimensional number in mass transfer, which is call is met number. So, the mass transfer coefficient depends on this parameter, these particular factors, in met number Reynolds number and react the Geometry. So, there are correlations for masses coefficient.

So, so what people do, normally rate performs experiments, then the different conditions. They know that, mass transfer coefficient is going be function of Reynolds number, is going to be function of met number. What it do is that performance experiment in the laboratory at different values of Reynold number, different values big number under otherwise similar condition get of a function reality, get the dependents and that is the correlation for the given reaction Geometry.

So, I have tubular reactors. So, if reactor this is the correlation for the mass transfer coefficient. I have fluids made reaction this is the correlation for the mass transfer, in the every correlation you would see these 2 numbers, but that correlation is specific to the reactor of interest. Now, let us make Biology, because you have probably learned E transfer before mass transfer. So, we know this something less in number in E transfer. Something 1 a lesson number, how to define this? These as a something, do a convectional E transfer coefficient

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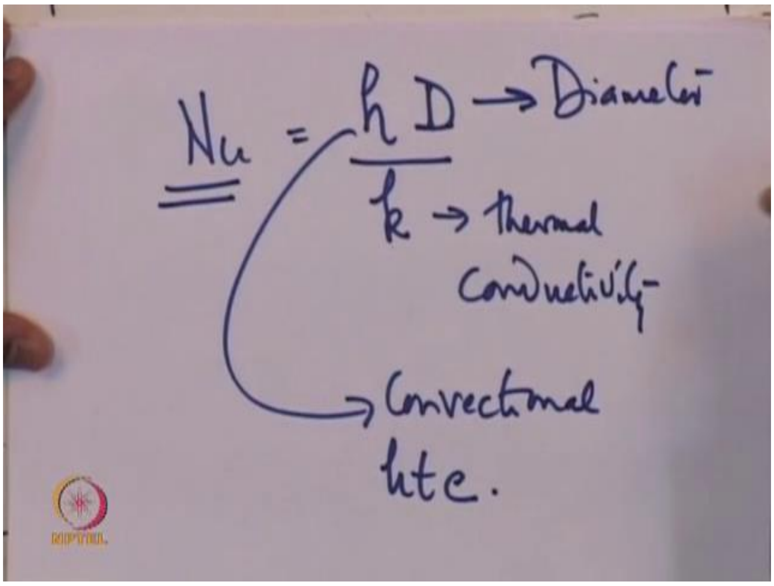

So, it is nothing but h with the E transfer coefficient, h then sum D; now D, is the characteristic dimension, it can the diameter the cube, by k. Now, do not the confuse this k with rate constant, again it argue what E transfer. So, this is nothing but the thermal conductivity and this D is not diffusion coefficient, this is diameter or some dimension. This is the conventional E transfer coefficient and this is the illustration number give which this is given by this particular ratio of product of a h in D to k. So, lesson number tells 0 about the E transfer coefficient.

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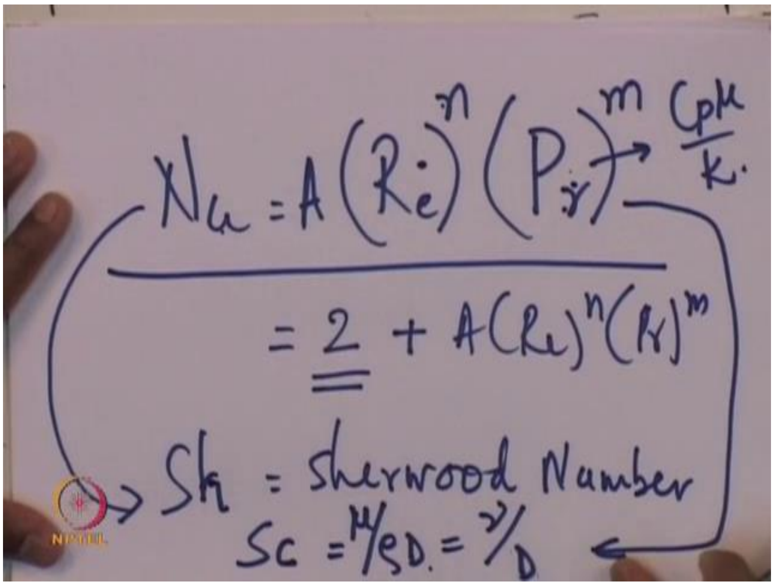

$N_u = A(R_e)^n (P_r)^m \rightarrow \frac{C_p\mu}{k}$

$= \underline{\underline{2}} + A(R_e)^n (P_r)^m$

S_h = Sherwood Number

$S_c = \mu/\rho D = \nu/D$

This lesson number is related to again 2 numbers. Is roll number and is a numarilistic pringle number the of course, this is not; this product will seen that, for there is something a range to n sum m and is some constant E. So, this is correlation. So, in the remains the correlation in this particular form. Now, from reactor to reactor; from Geometries to Geometries; these constraints wet very, but the otherwise, the terms are same terms are same. Now, you may ask me question that is suppose is medium in the know flow.

So, Reynolds number which is function of velocity 0. So; does it mean that, this is know E transfer saying place, does it mean that, E transfer coefficient is 0; that is not true because have a stagnant medium say water, I am heating from 1 side it is know get transfer right. So, for very lower values of result number or a for stagnant medium, you have a relationship given by 2 plus A in to Re ratio NPRS to m. So, this is the number 2; it so happens that, at very low value of result number lesson number become equal to. Now, for mass transfer you have see this analogy heat momentum and mass. So, this dimension less numbers see there is always of counterpart for 1 number E transferred to another number mass transfer.

So, which is the counterpart for lesson number, in mass transfer the counterpart A is number of called Sherwood number very important, what is the counterpart Re, no is no counterpart Re is then mass of are also. What is Pr is, CP m by k, were k is thermal conductivity CP is specificate m is the risk are city. For Pr there is a counter part in mass transfer, which is nothing but you already mentioned rate that is met number, which is given by mue by D; the D were is not the defusality, D is defusality and m is viscosity.

So, mue by row convey sometimes new denoted at this. New divided by D; I hope it is clear. So, there is analogy for analogies number in mass Sherwood number. For Pr this analogies number, in mass transfer that is met number.

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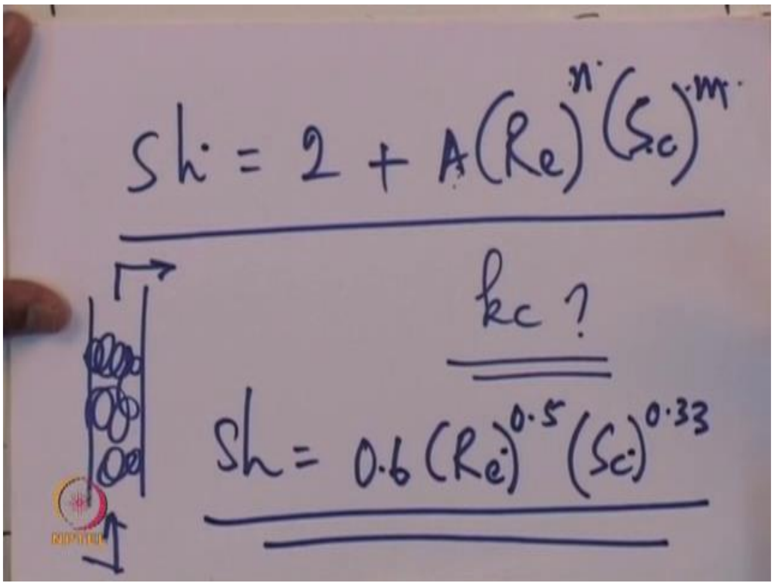

$$Sh = 2 + A(Re)^{n}(Sc)^{m}$$

k_c ?

$$Sh = 0.6(Re)^{0.5}(Sc)^{0.33}$$

So, like this correlation I will have similar correlation in mass transfer given as Sherwood number is equal to 2 plus A in to Reynolds number is to n and scribe numbers is to m. So, I got we relationship and this is the relationship that I want. This is some think that I only used to estimate of to calculate the value of kc, because that is what is required from a reacted is like in these constant, there is known own given the geometry.

So, what are will do for example, I want to designing fix base reactors, which is pack with the cattles and it is gas of flow it what other liquid going inside. All perform experiments the weld plan weld designing experiment to estimate on get of values of

Sherwood number for different values of relondness met number. At once have these again, estimate the value of dislike. What I do for, normal collects at determine rate constant, at determine activation energy, at determine frequency factor from the liberated rate. So, I would similar thing here, I am generating liberate data by do the experiment different condition is, that is at different value of role number and swit number. I getting the value of Sherwood number, at only to do a experiment and the reactive condition can be non-reactive also.

So, simple examples I will take naphthalene in a balls, naphthalene as a trend lines to sub line you can I just pass a gas at this at temperature. I will see, what happens hoe much naphthalene gets we priced, what is the rate at visit get we priced, that is depends on the mass can for. So, the many possibilities you can get up value of mass transfer coefficient. So, need not be the reaction active experiments or an experiment conducted and reactive conditions. It can be experiment for just mass transfer of a from solid to liquid or solid to gas. So, doing such experiments determine the values of, but doing some such experiment determine the value of this AN and m and get of final correlation the fix bed reactor. And not this fix bate can be flute as base.

So, have a certain correlations; so typically for fix bed reactor, this value if you doing at a very large of relatively have a velocity, then this factor becomes very high compare to this, so then the neglect these 2. So, I made write this as say 0.6 in just a typical value for a fix bed reactor with cylindrical or other with a circular cross section 0.5 SC as to 0.33. So, this is the correlations. So, this is a correlation for Sherwood number or in other words, this is correlations from which and determine value of masses coefficient. How we determine, I can calculate the in order number for given reynocity, I can calculate the Smith number, I know deception go we sent I know, characteristics dimension. So, I know, the masses coefficients. If I know the Sherwood number, how would the define Sherwood number by the indents I did not tell that.

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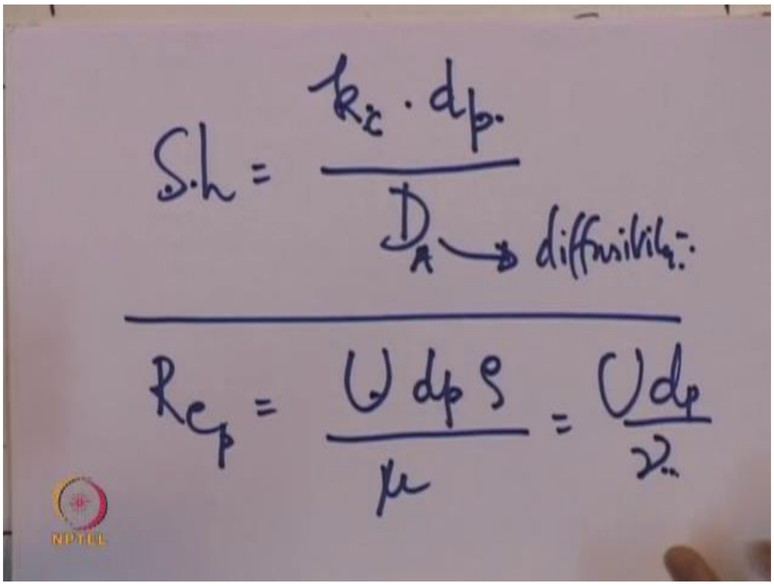

$$Sh = \frac{k_c \cdot d_p}{D_A} \rightarrow \text{diffusivity}$$

$$Re_p = \frac{U d_p \rho}{\mu} = \frac{U d_p}{\nu}$$

So; it Sherwood number is, something similar to lesson number. So, here instead of convey withdrawn position, I have a mass transfer coefficient KC, into some characteristics dimension, if it is a fix bed reactor with spherical cartelist particles. When it is dp divided by instead of conductivity now have diffusivity. Now, this is diffusivity or do not get confused with diameter, I have I will use this diameter, while defining lesson number, but now it is diffusivity. So, many variable and not many alphabets that is why, is you have same alphabets coming again and again, Sherwood number.

So, once as value of Sherwood number, from the correlation I know, the diffusivity let me denoted as a DA for component A; I know, the partying diameter again get you value of kc, now let see KC depends on what. So, as a set before let it is a something got the flow pattern are decided by the react the geometry and velocity. So, let say I have a cylindrical reactor, a fix bed reactor how a determine. So, which are parameters of factors, a variable in other that, I can play with to manipulated value of kc. So, for rate concentration for the reaction, I change a temperature, because I know then if I increased temperature k increases.

Now, here which are the parameters that again play with, I already told you Reynold number and Smith number. Now, Smith number is what this all property of components at I am using, I cannot really change them off course, for the gas face diffusivity is and miss causatives are functions are temperature the very, but off course not significant even see that later. So, which is the main parameter that again plays with, the Reynold number and Reynold number, in this case the Reynold number let we call define is U that is velocity beat as for second dp is a particle Reynold number.

So, let me write it that d are e p particle Reynold number, dp raw divided by mu or Udp divided by nu can a malty we cause it is. This is how, I am defining Reynold number. In word defines on dv raw mue instead of d. Now, have a dp here that, as a particle Reynold number because I am taking particle radios or diameter as characteristics dimension here to define Reynold number, we that is the mos that is, the most appropriate dimension here as per as a mass coefficient concerned; because, I am talking about, mass coefficient around the chatelatic particle and not for the mass transfer world to the fluid in side of fluid for the wall, then your particle. So now, just particle diameter that is more important

So, this is Reynold number. So, this U is something, that going to decide a value of Sh and hence kc, why because Sh is the strong functional Reynold number. You already seeing that Re these 2.5 and what else, in all this again there is another parameter that dis again and again which I can play with is dp. So, that dp here, is a dp here. So, let us put everything to get there, and see how the mass coefficient where is we dp and you together.

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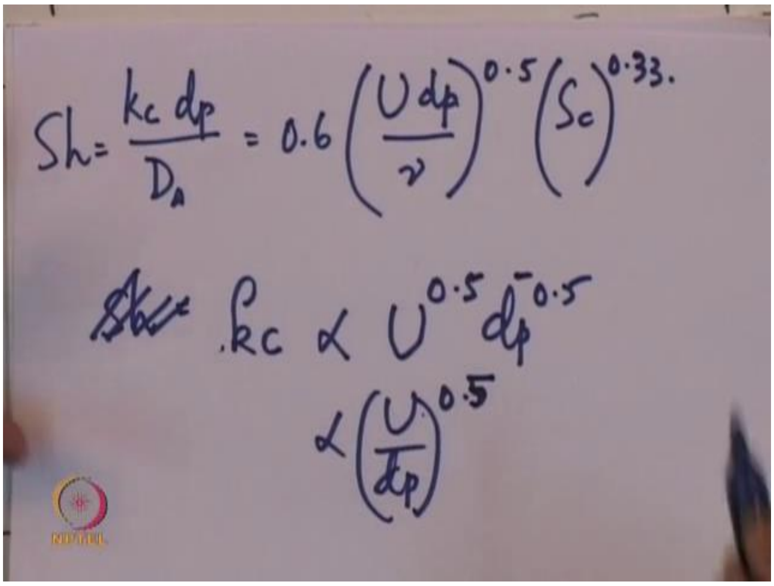

$$Sh = \frac{k_c d_p}{D_A} = 0.6 \left(\frac{U d_p}{\nu}\right)^{0.5} \left(S_c\right)^{0.33}.$$

~~Sh~~ $k_c \propto U^{0.5} d_p^{-0.5}$

$$\propto \left(\frac{U}{d_p}\right)^{0.5}$$

So, Sh residual to kc in to what, dp divided by Da is residual to 0.6 Reynold number, U dp nu there is to 0.5, that in to smith number there is to 0.33. So, how a dependency now, this diameter is is coming here also, here also. Since let me write kc is proportional to U as to 0.5 and the d p here, dp as to 0.5. On the other words, U by dp there as to 0.5; in its minus point 5 because d p comes here. So, this is the relationship of a proportionality that I see. Kc is proportional to U by dp is to 0.5 off course, remember this is for fix bed reactor cylindrical geometry and circular cross section it may slightly very year end an, but then I am just showing you the importance of these parameters as per as external mass transfer is concerned.

There is go had. Now, let me do experimenting laboratory. So, now I know, which is a factor that is affective and making more in fact on mass transfer coefficient, for reaction. Intrinsic reaction is a temperature where as in this particular case it is U by dp, it is U by dp. So, I do experiments in the laboratory for a fix bed reactor.

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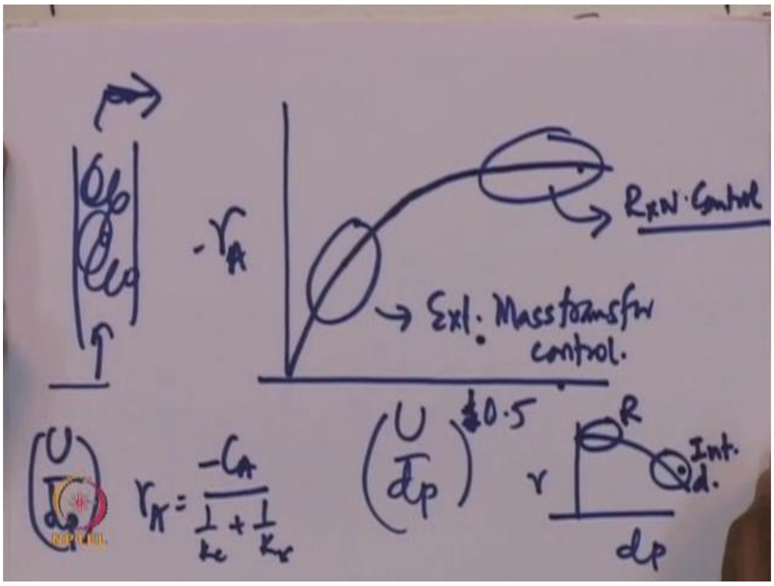

A different values of U by dp h A U h A dp I a do it. And I flow, this grasp by getting the rate under otherwise similar conditions now, you by ask me like it may be re along all than again the same principle probably are you just take small length of the characterless. So, for their I need to plan experiments very well. So, that I do not bring in other effects. So, under otherwise similar conditions, if I perform experiments for different values of U by dp there is to there is half.

And determine the rate says rA or minus rA other what about want you see, can be predicate the nature of this graph, it will come down like this. So, were we go like this remain constant or it will go up come down. What can we say, if I have very small value of u by dp what did means either is the mass transfer coefficient is very small. I have a reaction taking place now, I am talking about reaction that is taking place on the characterless, inside or outside is characterless is responsible for the reaction. I am doing the experiment here say cyclohexene dehydration, cumin decomposition Intel Venice dehydration whatever.

So, many reactions possible I am doing those reactions and I am determining the rate now, this value of U by dp is very small means; if I want to compare intrinsic reaction rate and mass transfer, which is going to governorate it is the external mass transfer that is go to governorate. Why because, the value of external mass transfer is very small. Remember r A residual to minus Ca for a first out of reaction 1 by kc plus upon 1 by kr. So, in kc is very small, this is go to the 1 because this is very large, this is want to be 0 comp or other negligible compare to this. And the reaction will become mass transfer controlled or go on increasing U by dp what will happened.

The value of kc will increase, the rate will increase because kc will calm and numerator as I go on increase the value of U by dp, kc linking the rate will increased. So, is would be like this, I go on increase the now, look at in the nature, in look at a trade. What is happening here, it is going it is attaining saturation here, it is not increasing it for the after certain value if U by dp. And do not see, cerise in the rate can you say why or can you explain why, it is all because of, the fact that after some value of U by dp the kc become so large that now, the reactions controlled by kr.

So, it is crossing the value because U by dp are not of fatting kr remember that, kr is a fitted by the temperature. So, if I change you, by dp only kc is changing and because of which, I am in their increasing rate, but after some time this case becomes. So, large that it will overtake kr and kr starts controlling. So, in this region I have external mass transfer control and in this region, I have reaction control. So, this is have it is gone to be. So, you it is quite similar to what we have looked at before as well like, for inter particle diffusion. Remember that, you have 2 regions, if you flow dp versus r and you see that this in this range you have inter particle. And this is you have reaction, is a reaction control. In this case, you have a inter particle diffusion control.

So, something similar; the dr seeing here, here it is reaction control; here it is a mass transfer control. The you may ask with creation is a inter particle is it is here. Now, we are just clubbing all those other in facts in this, remember this graph only tells me that, if I here, the reaction is not control the external mass transfer, it is controlled by other reaction or internal diffusion option these option whatever. So, I have already told you while doing this analysis and clubbing all those in facts, I am putting together all those in facts in this reaction term. And external mass transits treated separately now for a first taller reaction, then we like what will happen if I have some effectiveness factor.

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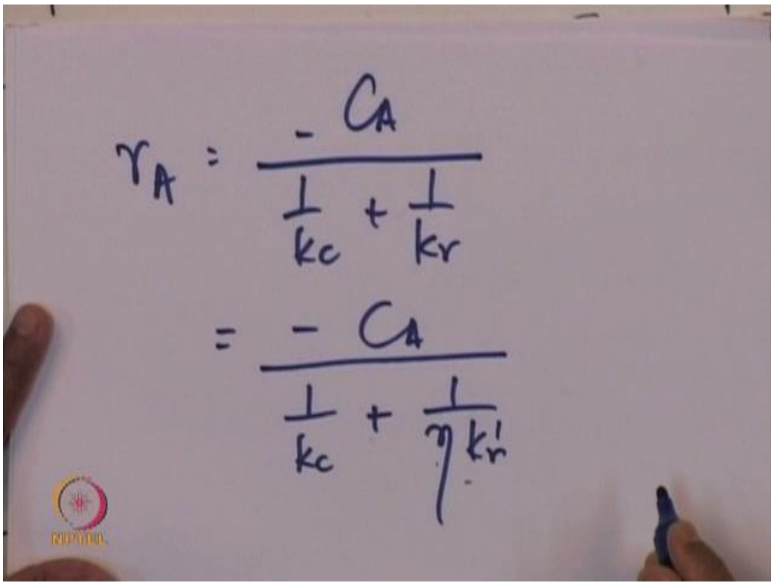

$$r_A = \frac{-C_A}{\frac{1}{k_c} + \frac{1}{k_r}}$$

$$= \frac{-C_A}{\frac{1}{k_c} + \frac{1}{\eta k_r'}}$$

So, it is very simple, what will I do is this. The rate of the reaction is CA 1 by kc plus 1 by kr. Now, if amounting carbureted effectiveness factor also, what will I do? I do not need to do anything much, I need to just do this why, is already seen in definition of eta. Now, we this what have done is effect. So, now, I made call this is kr daze, you this is intrinsic, when the molecules are need the catalytic sight and this is taking care of the poor diffusion effects, this means the eta value.

While; appears see, against that the where look the where the happening the equation. Why it has a appearing is the product and not like this separately 1 by eta or something like that. Why, because diffusion anti degradants they going parlor, were as reaction and mass transfer there is series. So, when there is series then you see the effects as to separate terms in then parlor, you see the product. This is how, you should read equations this is how you should read or interpret the final equation that you gets in know, point in by hearting this equation.

So, much in this like we understand it very well; you would be able to write it properly, but off course remember this is for the first reaction. So, we have. So, we know what is mass transfer coefficient, we know how it changes with velocity and a particle diameter and how doing know that, reaction is controlled by mass transfer register or by intrinsic reaction. So, know once we know that reaction is controlled by mass transfer coefficient offer in external mass transfer, then how do we design a reactor.

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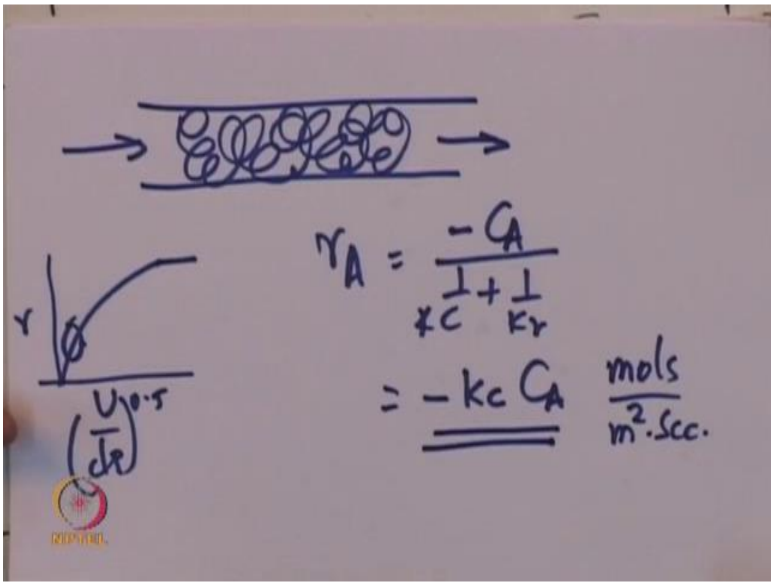

So, let us look at that; I have a fix bed reactor which is fact with the catalytic I want to determine the length of high required or weight of the catalytic required to achieve certain can once up and this is are problem finally, it this every reactor engineer reaction engineer should think of reactor design this is final objective, all we are doing is to somehow, to be able to design this particular reactor that we have in neither.

So, if I am in this particular region U by dp there is to 0.5 r and here, then how do you design the reactor; what is a rate equation rA residual to minus k CA divided by 1 plus k c plus 1, 1 by kc plus 1 by kr and kr is very large compare to kc. So, it is going to be minus k c CA know; what is a unit by the way, what is a unit of react here, the unit of react here, may be using that the unit is moles per meter square second here. Now, I want to design the reactor. So, let me write the mass balance these particular terms look quite similar to the reaction term of off course that you take care of the units.

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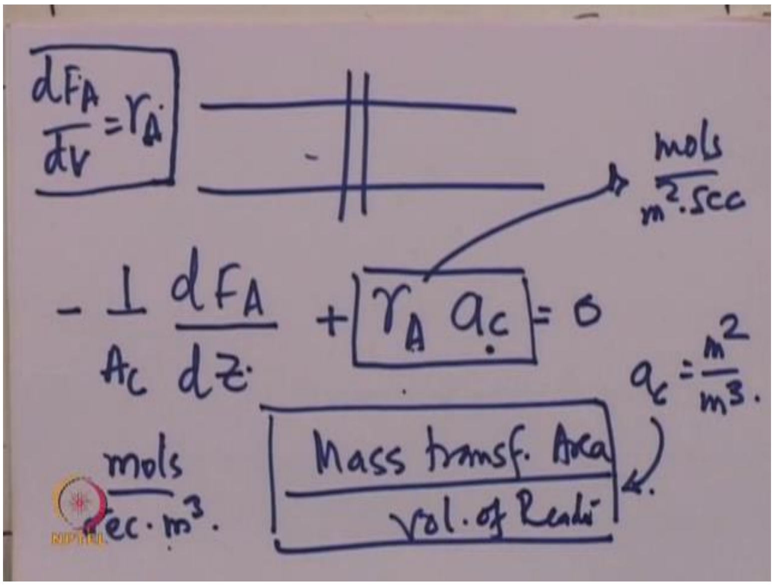

So, let me take the defalcation balance it is like my normal plug flow reactor, what is a equation for the plug flow reactor it is going to be take the balance coming in, going out and delta becoming almost 0. What I have is d FA by dz divided by AC that is cross sectional area plus rA into ac, electric made define all these terms residual to 0. At it would be very clear for see, in normal plug flow reacts is like d FA by a dv minus rA is residual to 0. See remember like, per normal plug flow reactor d FA by dV residual to rA, which is what, we have when using reaction engineering part 1. The difference here it is a same equation except to fact that instead of rA I have rA into ac. Why, because unit of rA here, is per unit area and here it is per unit to volume know look at is you needs here, FA is moles per second, this has you meter cube.

So, it is same as this. So, rA also the unit moles per second meter cube. So, this fellow this particular term will also have the same unit moles per meter cube second, but you already said that Ra has unit moles per meter squares second. I want I am multiplying it by ac to bring it to this unit. So, what is unit of ac, ac has a unit meter square per meter cube. So, how a defines the ac? ac is the mass transfer area per unit volume of what, volume this volume of the contractor, volume of the reactor. So, this volume is volume of reactor. So, how much mass transfer area an providing per unit volume of the reactor that becomes very important.

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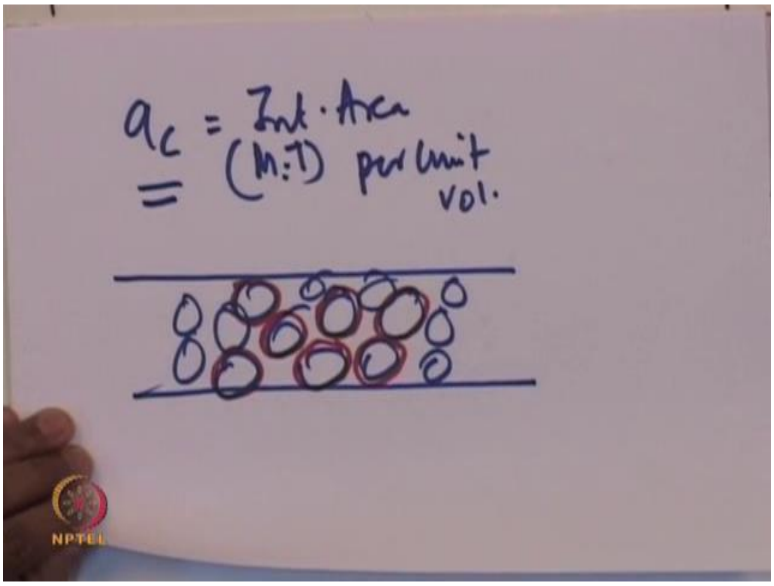

So, ac now let us talk about, ac; ac is interfacial area or mass transfer area m T area are the. So, in the reactor I have these particles, which area, I am talking about this area which is add a external surface. So, it is easy know, I know how many particles I have, diameters I know why, dagger for a fix bed. So, from that I can calculate this. So, it is nothing but a property of the reactor and the packing that I am using, the catalytic packing that I am using.

So, it is something that is given to you, all it is need to found out depending on what is given and what is found out. So, for a given real extant of conversion, I can get a value of ac, that is required or for ac given I can calculate the conversion. So, it is quite similar to what we did for reacted design, again go back 2 year reaction engineering part 1, for the given volume I calculate conversion or for given conversion I calculate volume or later what we date was like, when was late was express per unit weight of the gat list. I said, if you have conversion given you can calculate the weight of the catalytic required or the weight of the catalytic given you calculate the conversion.

Now here, in this problem I am calculating the area required for the mass transfer. For the given the merger or for the given area, I can calculate the conversion of this area depends on what, area depend of amount of cartels of I am taking it depend on the particle dammed a and voltage. Because it is per unit volume the reactor, this is the meaning of the interracially area per unit volume interfacial area per unit volume nothing else is, the important here, because the inter reaction the rate of the reaction is governed by the external mass transfer. So, it does not depend on the post structure, it does not depend on the activity of the catalyst; I already decide already conclude, but do experiment that it is governed by external mass.

So, nothing to do temperature of course, like the temperature is solidly may can impact and, but cat telic activity post structure, poor volume, tortuosity, absorption coefficient none of them are making impact on the rate, it is the external mass transfer. So, which are the parameters, then remember the equation for the mass transfer coefficient sherwood number. So, Reynolds number and mid number for the given properties diffusivity and density, it is the velocity and the particle diameter.

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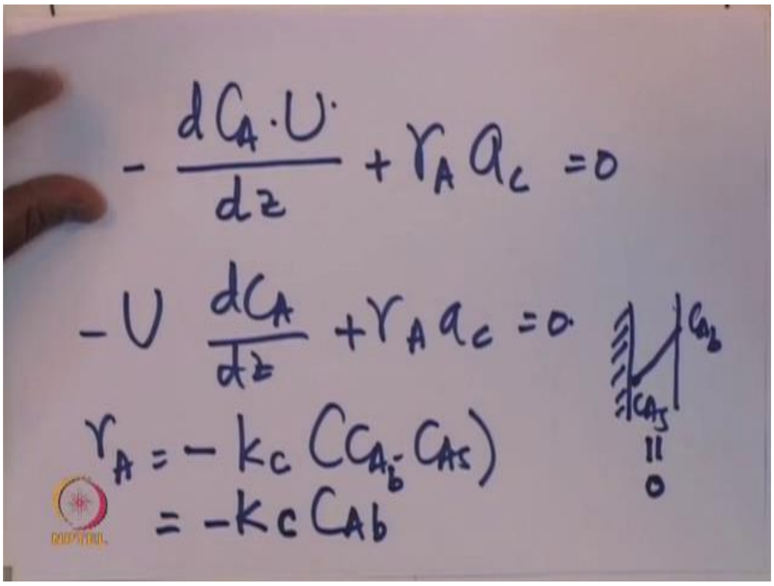

$$-\frac{dC_A \cdot U}{dz} + r_A a_c = 0$$

$$-U\frac{dC_A}{dz} + r_A a_c = 0$$

$$r_A = -k_c\left(C_{Ab} - C_{As}\right)$$

$$= -k_c C_{Ab}$$

So, ac is a very important parameter here and when if you look at the equation you have this; which is similar to normal flug flow equation, only difference is, I have this correction we are terms of ac. And because of I am expressing per unit area. So, next go head and derive this further every FA can be converted to concentration, this can be return as, say if a will be multiplication of flow rate and concentration. So, it is this can be as d CA into U divided by are d by dZ into U; you is the velocity, it would be volumetric flow rate, but since area is there volumetric flow rate divided by area is velocity, plus rA into ac is equal to 0. You can have a separate rotation for rA, because of area defining, right know it is per unit area as long as you and you remember units of Ra that that of d use in order to very much about that. So, here I am multiplying it by ac means, it is per unit area.

So, I can take U out of the derivatives if it is constant. Now, you know when it is constant in this temperate drop, velocities not changing as we go from in let out late, temperatures is not changing as. So, the normal condition so many assumptions are there, but if I am allow to do that, then I take you out d CA by dz plus rA ac is equal to 0. As a suppose, I substitute for r A now, what is rA is equal to minus kc into CA minus CAS. Remember, an CA B minus CA B clarity CAS. Linear, difference between these to an if it is external mass transfer control; you know proximately this is equal to 0. So, since CA B is very large compare to CA S this become 0. So, I can say this, I can simply for this further rate.

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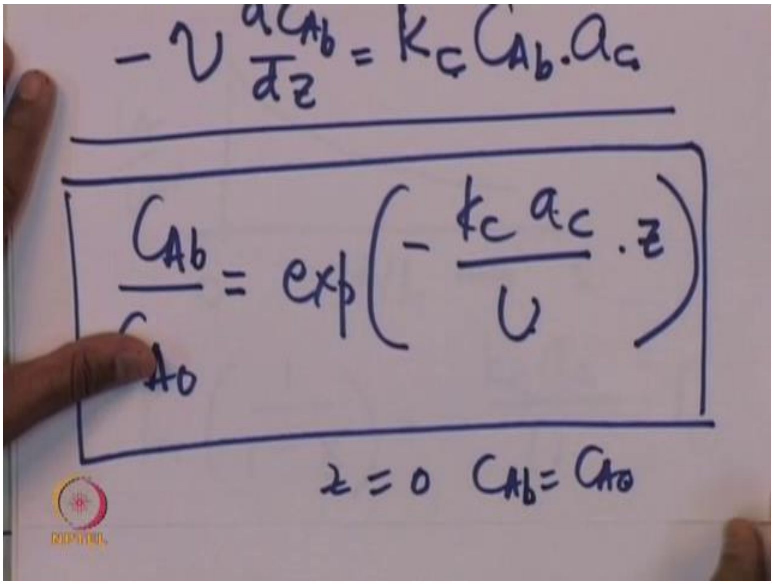

$$-U\frac{dC_{Ab}}{dz} = k_c C_{Ab}.a_c$$

$$\boxed{\frac{C_{Ab}}{C_{A0}} = \exp\left(-\frac{k_c a_c}{U}.z\right)}$$

$z = 0 \quad C_{Ab} = C_{A0}$

So; let us substitute for a what I get here is, minus U d cA by d z is equal to kc, kc other is the mass of a coefficient, CAb or CA b here and then ac, go I am working terms of bulk concentrations. So, working also I should have return CA b, let me do that CA b bulk concentration. CA b here, every were you can next CA b, it is a bulk concentration that I am working way. So, this is the very important familiar equation, we know as z increases this CA b goes down, on this looks take a normal rate equation for a first order reaction, only difference is there is intrinsic rate constant. Now, I have a mass of coefficient multiplied by interaction area per unit volume.

So, I can solve this equation an analytically, CA by CA 0 is equal to exponential minus kc ac divided by U into z. This is how the concentration there is of course, you have, the you need on condition. What is condition at z is equal to 0 CA is equal to CA0. Why use this condition, this difference equation is the od ordinary differential equation. And get this profile of concentration along z rustler known. Once I start my experiment or reactor. So, this is quite similar to got be before, for a first on the reaction in the plug area actor; only difference that it should be remember is that meaning of concentrate that mathematically that looks similar.

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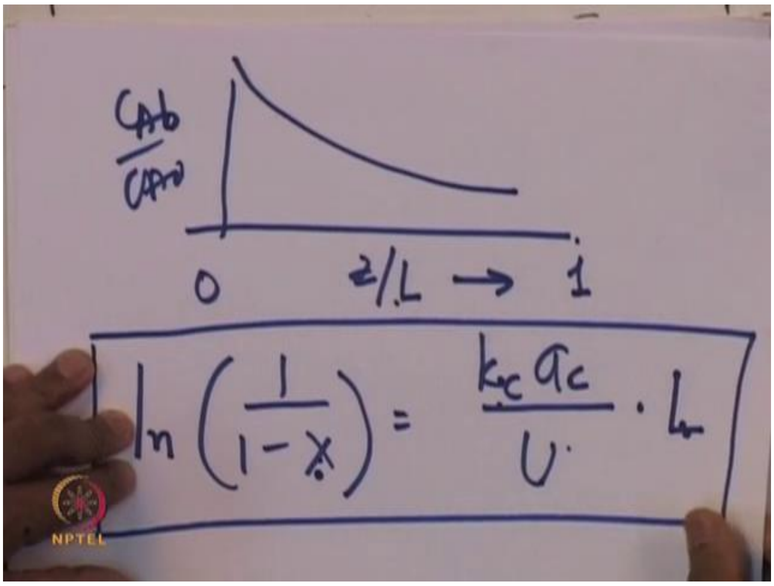

So, I the length increase from 0 to L. What is L? L is a length of the reactor CA by CA0 goes like this, a typical plug flow type behavior. I convert disquisition to conversion form and you know, how to do that, 1 on 1 minus x is equal to kc ac divide divided by U into l; that means, the given length, what is conversion. So, substitute L for z in that equation, what is CA, CA is equal to CA0 minus CA0 is to 1 minus x. Again b here, but it is like you know, the meaning of it is CA b is equal to CA0 clear. So, I get of the relationship between length in conversion, I need to know kc, I need to AC, I need to know U, velocity or this kc will again an spread enough time how will get this kc, will be obtain from the correlations Sherwood number.

So, you have this co-relations given, maybe we can solves from problem later, but before that late sleekly an look at 1 nice example, given in before that like, let talk about every time poor cattles, but then if you remember first or second lecture of catalytic in donation to catalyst, as at a different types of cattails part from poor there is some noncore catalyst all. So, were you can have a gauge you can have a plate or you can have mono late. Were coefficient is not important that, reaction takes, reaction is so fast. All you do not need many catalytic pgs or atom, for the reaction to catalyze the reaction.

So, I can this take a gauge, you are gauge all I can take a foil, over is the reaction will take place say Alco hold your gauge Ammonia to Nitric oxide reaction is instant any gas, but then the computation it inter reaction mass transfer, because once the reactor, which is the catalytic site reaction takes place. So, most for time these reactions are governed by mass transferred, there governed by mass transfer. So, identified area mass transfer how much area mass transfer your providing an that is good enough that tells about read of mass transfer, if is your increase the mass transfer rate or oral rate because rate is governed by mass transfer. You can increase the area available or you can increase the Reynold number and you may get the higher rate. So, this one example or a case studied that is given in books which is quit with quite good.

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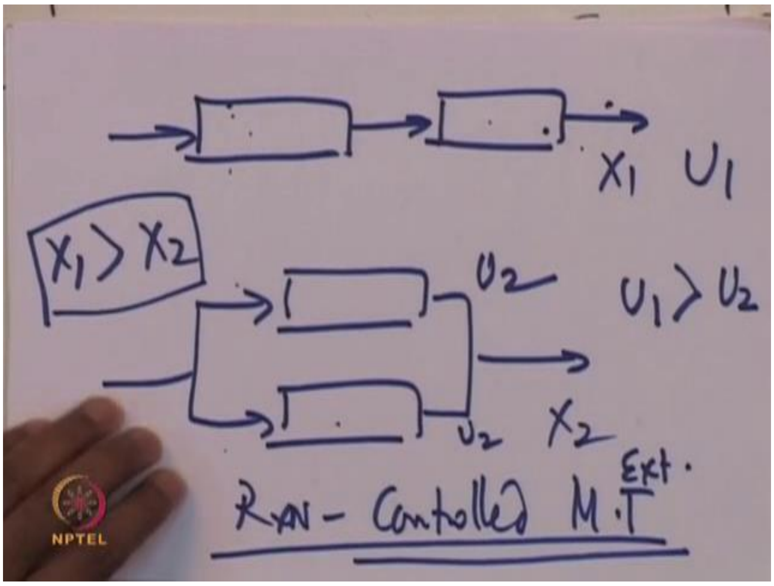

So, otherwise just these discuss that, now you have 2 reactors physics base reactors. I want put them is series and I will realized certain conversion here. I will realize certain conversion here. Now, instead of using this reactors in series, I am use in parlor, what are you going to similar parlor means, I would splinters feed in to 2 parts equally an it is reactors are also equal length lets us zoom that, and I do this.

So, the conversion here x1 conversion here x2 are they going to same, are they going to different. If at all x1 is higher than x2 or x1 is more than x2 with it to see that; now, with already seen, in reaction part 1 that for normal reaction which 1 governed by intrinsic connects, this does not matter. First order the reaction this does not matter, irrespective of parlor put in they put them is series of parlor you get same conversion, but now the reaction a s controlled by mass transfer, external mass transfer. If that is the case, there while will see a difference. While will see a different, look at this high very large flow rate here, I am using the same reactor of this dimension like the velocity here.

So, U1 and the velocity here, say again the velocity are where we same here, then let me call there will U2, U1 and U2 which is greater U1 is greater than U2. And it the reactions controlled by mass transfer of the same volume now, which is provided for the same feet it is likely that, this combination is going to give me higher rate complete to this or higher conversion complete this. So, x1 is equal to be greater than x2 you can prove that. So, x1 is likely to be a greater than x2; so do it as homework.

Let seen what happens; look at the equations for the right on the equation is the for flow reactor of whatever like you are not plug flow, you are tube the reactor just now, if derive that. You know, we just react this know, this is the equation that we have derived for this equation, you right it for every react, the react 1, reactor 2 some them of and similar thing and do it for these 2. And see what happens, you realize that because the velocities higher here, then here, for the every reactor here individual reactor the mass transfer coefficient is large, the Reynolds number is large. The reaction rate here, is higher are compare to this 2. So, this going to give you better conversion and this. So, we continue this discussion later and will solves some examples.

Thank you.