Chemical Reaction Engineering

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Lecture No. # 32

Case Study - Ammonia Synthesis

Friends, let us continue our discussion on design of reactors for ammonia synthesis; and we will try to look at some of the design aspects, considering even the non-isothermal reactor design. So, where we stopped in the last session was looking at these balances for ammonia synthesis namely, the mass and energy balances; and realizing that this is a fixed bed reactor, so we have the energy and mass balance, which look something like this.

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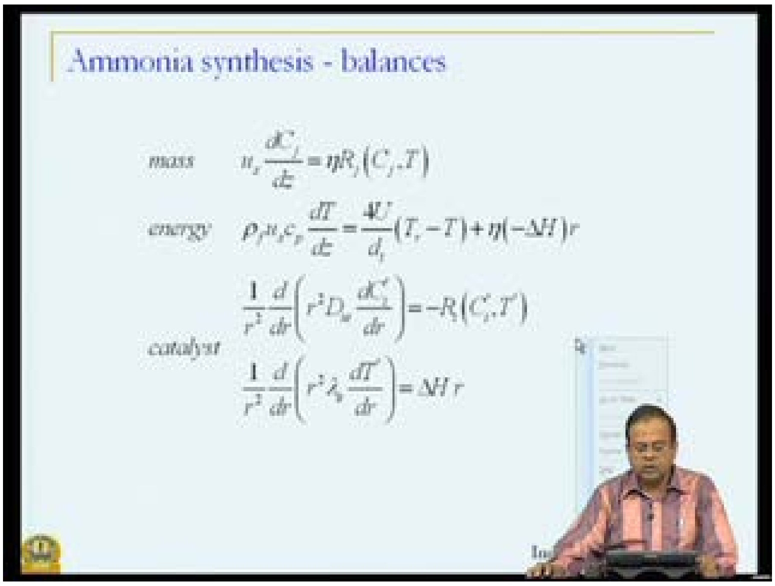

Ammonia synthesis - balances

mass $u_s \frac{dC_j}{dz} = \eta R_j(C_j, T)$

energy $\rho_f u_s c_p \frac{dT}{dz} = \frac{4U}{d_t}(T_s - T) + \eta(-\Delta H)r$

catalyst

$\frac{1}{r^2}\frac{d}{dr}\left(r^2 D_e \frac{dC_j'}{dr}\right) = -R(C_j', T')$

$\frac{1}{r^2}\frac{d}{dr}\left(r^2 \lambda_e \frac{dT'}{dr}\right) = \Delta H\, r$

We also discussed that, we need to introduce the idea of effectiveness factor, because this is a catalytic reaction, so there may be some mass transport limitation, associated with the performance of the catalyst. Now what we are going to do is for sake of discussion, we will neglect these diffusional limitations at the present moment, because I want to illustrate the idea of how non-isothermal reactors reactors are operated and so on. So, let us let us for time being, just focus on assuming this effectiveness factor value is unity, it does not change qualitatively any any design design aspect; so before we now go to the actual reactor design and look at various operations, let us go back to the case, where we had earlier considered that what happens when you have a reaction, which is reversible and which is exothermic in nature.

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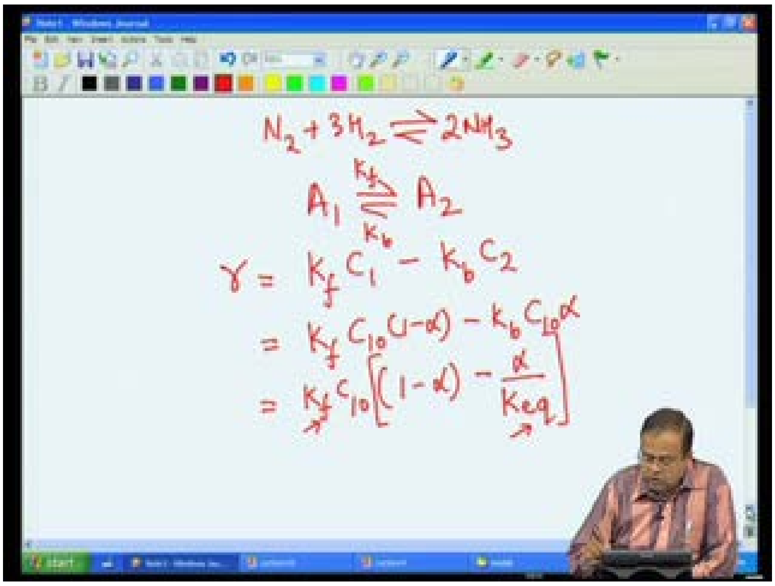

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$A_1 \underset{K_b}{\overset{K_f}{\rightleftharpoons}} A_2$$

$$\begin{aligned} r &= K_f C_1 - K_b C_2 \\ &= K_f C_{10}(1-\alpha) - K_b C_{10}\alpha \\ &= \underset{\nearrow}{K_f} C_{10}\left[(1-\alpha) - \frac{\alpha}{\underset{\nearrow}{K_{eq}}}\right] \end{aligned}$$

So our ammonia synthesis reaction for example, the reaction which we have is characterized by two features; one - it is a reversible reaction, number two - it is a exothermic reaction. So we know that equilibrium extent of reaction decreases as we increase the temperature, but this is not the only thing temperature is not the only thing that is changing in the rector, our extent of reaction or reactant concentrations in turn are also also change. So, to look at the behavior of such reacting system, let us go back and we have discussed this, but I was repeat it; let us say that we have a exothermic reaction A 1 going to A 1 going to A 2, so rate of these reaction for example, let us write this as forward rate constant and this as backward rate constant; so rate of these reaction is K f into C 1 minus K b into C 2.

We now express C 1 and C 2 in terms of extent of reaction, which are obviously related to each other; so C 10 into 1 minus alpha minus let us assume that there is no b A 2 present in the beginning, so this will be simple C 1 into alpha; or in other words we will have reaction rate, which is if I take K f and K C 10 out will be 1 minus alpha minus alpha by K equilibrium, because K equilibrium is nothing but the ratio of K f by K b we have seen all this; so we know that this is a function of temperature, this is a function of temperature.

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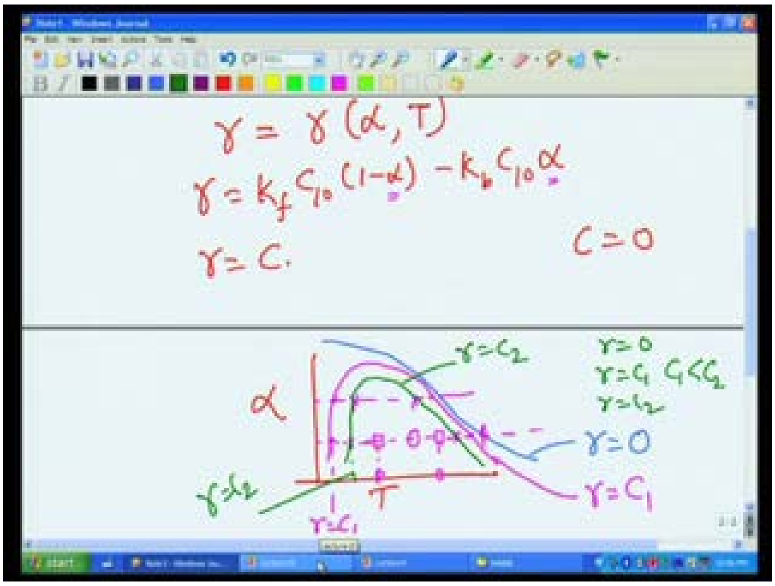

$$r = r(\alpha, T)$$

$$r = k_f C_{10}(1-\alpha) - k_b C_{10}\alpha$$

$$r = C. \qquad C = 0$$

So, let us try to look at what will happen to our rate of reaction; or in general, I can write my rate of reaction as a function of progress of reaction alpha and temperature in the reactor reactor T. Now let me let me rewrite this, and we had discussed this earlier that at the beginning, that is when alpha is 0 and we have certain temperature T, what will happen to the what will happen to the rate of the rate of the reaction; alpha is 0; so the rate will be governed by the first term over here. Now here, there are two different different factors, which which determine the determine the rate; for example, if we say that we will look at these expression in the following manner.

Let us say that we look at this variation of rate in the domain of alpha and and temperature; so let us say that we want to look at how these rate will change in the phase plane of temperature and alpha; so in this phase plane - two-dimensional plane, we are going to plot the contours, such that the rate of reaction is is constant; so first constant, so we are going plot contours of r equal to constant constant C; and the first constant that we can plot is when C is 0, that means we have achieved our equilibrium, and that contours I will represent it by this blue line over here, so for these blue line rate is 0, that is my that is my contours.

Now let me try to draw contours for different values of this constant C 1; but before we do that let us try to qualitatively understand, how this rate will rate will vary; since, rate is a function of both alpha and T, we will for sake of argument, say that we are looking at what will happen to the rate, as I change my temperature while maintaining alpha alpha constant. So let us say that I pick some value of alpha, I pick some value of of alpha, and fix it, and vary this temperature, and see what what will happen to the rate of this rate of this reaction so in this expression over here, I have fixed alpha value, and I am just going to change temperature.

Now we know that at low temperatures, reaction rate at the start of the reaction, let us say where chosen alpha value, which is small, so let us say we are somewhere in the beginning phase of the reaction; and if temperature is low, and the the reaction is is is just started, the rate constant k f will have a small value, the contribution due to second term over here will be small, because we are just at the beginning, so there is not much A 2 in the system; so let us say that we have some point over here, for which my rate has a value C 1, a low value. Now I go on increasing the temperature, so you expect that the rate of reaction will increased; indeed if we travel along this line - horizontal line, compared to this point, the rate at this particular temperature will be slightly slightly higher; the rate at some other temperature will be even even higher; so dot represents lower reaction rate, star or cross little higher, square little higher; now will these rate keep on increasing indefinitely?

I know that at this intersection point, my rate is 0; so if I have started with a low value of rate, and if I am increasing these rate, at some point of time, the rate much start decreasing so that it goes to a 0 value; once again I am looking at what will be my value of rate, if I fix a value of alpha, so this horizontal line and keep changing the changing the temperature, so at low temperatures, I will have some rate, which is of a low value, as I increase temperature, the rate will will increase; primarily, because the rate constant k f is increasing, the contribution due to reverse reaction is still very small and therefore, the net reason is increasing the value of the rate; and so if I keep further increasing; but I also know that at this intersection point the rate is 0; so these rate from a lower value will start increasing, and then at some point, it will reach a maximum value reach a maximum value, and then I will have another point over here, which has the same rate, it will start decreasing; so this rate value will be same as the rate value at this particular temperature, so at this two temperatures, rate values are are same.

Then once again I will have this point, where this, at this temperature, the rate is same as the rate at this temperature; so we have increasing rate, and then decreasing rate, and it will it will go to 0 at this particular point. Now I can repeat the same exercise for a different value of alpha, and once again I will find that I will have some temperature, at which rate is same as this, and once again the same argument; or in other words, I will have… If I now join these points for example, what are the contours of constant rate; I am just joining the point, on which the rate value is constant.

So let me say that I will now join all the points, where rate value is C 1, and that value, that contour will now pass through all these dots, and look something like this so that r is equal to C 1 over here; if I do it for a different value, let us say I do if for this particular value, where r is equal to C 2, so if I join all those points, my contours will look something like this; what is my my characteristic; my equilibrium line is r is equal to 0, another contour r equal to C 1, another contour r equal to C 2; so r equal to C 1, C 2, my different contours; and C 1 is less than less than C 2 and so on; so this is how my contours will contours will look like. So what is the what is the characteristic; so let us let us actually look at, how these contours contours in reality look like.

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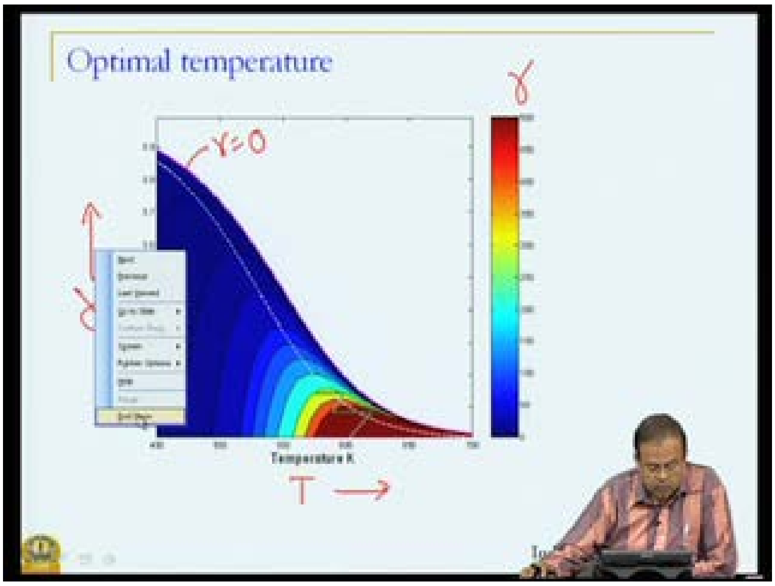

Optimal temperature

So if I if I plot those by talking the appropriate value, what we are looking here is the temperature on this axis, and extent alpha, so whatever we qualitatively qualitatively discussed, we are looking it pictorially, by saying that this different colors represent different values of rate, so this is a this is a value of rate from a low value, which is dark blue to a brown or red, which is a high value of rate; and this particular violet line is r is equal to r is equal to 0.

So what is happening? By taking the same logic as as as before, if I say at this value of alpha which is 0.1, if I if I if I just draw this line what will happen; as I as I as I mentioned earlier, rate will start with a low value go on increasing, you know the rate is increasing, because the color index is changing in this particular manner; so rate is increasing, increasing, increasing reaching a maximum value, and then again it will start decreasing, before it goes to A 0 value. So in other words our contours are of this particular particular nature as we as we explain explain before. So now what will happen what will happen to my to my reactor, so let me erase all this things; so let us let us go back and look at this reaction rate further.

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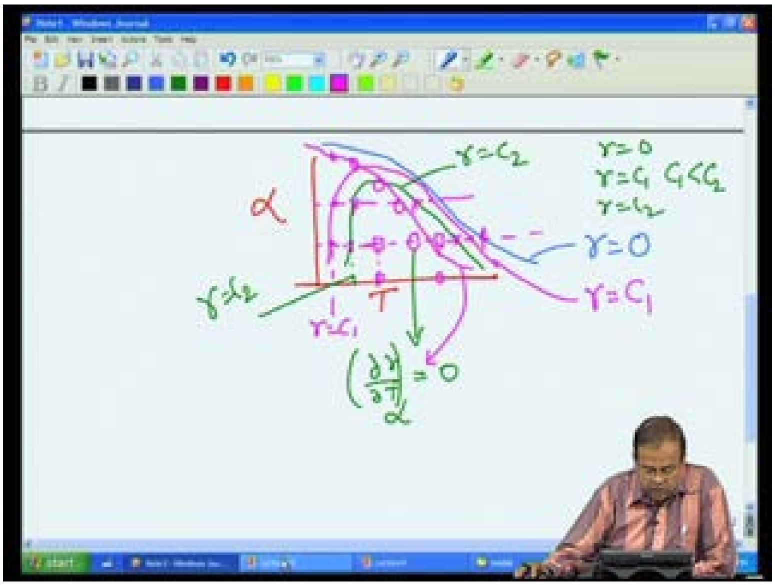

So what we are saying what we are saying is the rate value is increasing, increasing, increasing reaching a maximum value, then decreasing, decreasing further right; so let us try to look at, what is the characteristic of this particular point; at this point, what is happening; alpha is constant and with temperature, the rate value is increasing, reaching a maximum value, and then decreasing. So if we were to express this characteristic of this point in a mathematical term, what is happening with respect to temperature; the rate has a maximum value, and rate as a function having a maximum value at temperature T has a characteristic that del r del T the gradient must be 0; why not total derivative; why partial derivative; because we are keeping alpha constant.

So at a constant value of alpha, derivate of this rate expression, this rate expression over here, with respect to temperature reaches 0 value, and this is what will characterize the rate being maximum. Now I can identify identify all such points for example, at a different value of alpha, let us say this is that point, at different another different value, this is those points; I can identify all those points, and then I if I join, I will get another trajectory, whose characteristic is del r del T at a constant value of alpha is 0.

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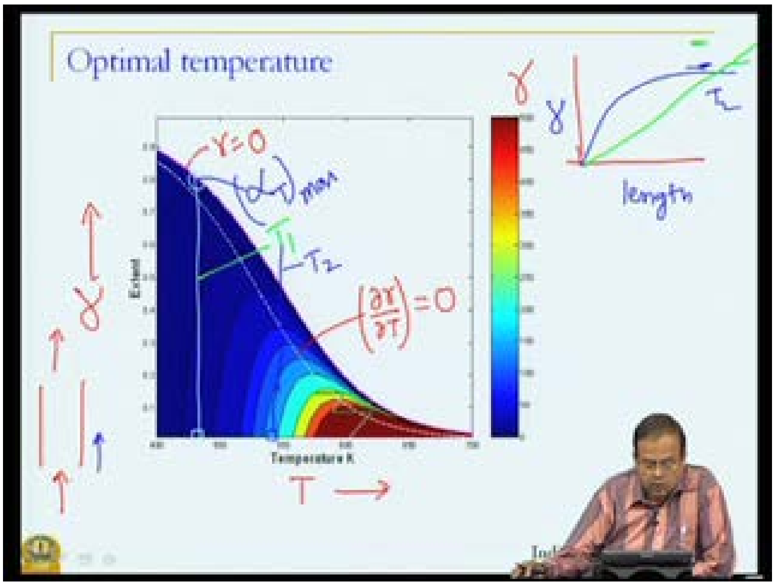

Optimal temperature

And this is how this is how that trajectory will look like; the white line that you see in this has a has a characteristic that on this particular line, del r del T equal to equal to 0. So this is how that how that how that reactor reactor… How that rate will will change? Qualitatively we discussed it for a reaction A 1 going A 2, but you can take my word that for reaction n 2 plus 2 3 h 2 given 2 n h 3 a same reversible exothermic reaction, the behavior will be exactly exactly identical.

Now let us say that we have our packed bed reactor, we are passing ammonia nitrogen and hydrogen from one end, and taking out ammonia from other end along with unreacted nitrogen and hydrogen; now let us try to look at in the same phase plane, how how would be how would be carryout reaction or when we carryout a reaction, what would happen? Now we talked about we talked about two different kinds of reactor operations; isothermal reactor and adiabatic adiabatic reactor; but let us let us let us try to try to look at to begin with what happens when you have an isothermal isothermal reactor.

So let us say that I have an isothermal reactor and I am going to maintain the temperature constant; now to visualize what is what will happen in the reactor, we can what is changing in the reactor as as the reaction takes place; there are two thing that can change; extent of reaction alpha and temperature. So what we are saying for isothermal reactor, temperature is fixed; so if temperature is fixed, let us say I fixed that temperature value over here, at this particular value; so if temperature value is fixed, that means I am looking at a vertical operation, which will progress along this vertical vertical line, because my temperature is fixed; and typically what happens to the extent of reaction - at the beginning it is 0, and extent of reaction will progressively progressively increase, extent only increases we saw that that extent of reaction is a positive quantity, and it can increase and eventually reach a saturation value, which could be maximum extent of the of the reaction. What is that maximum extent for this particular reaction carried out at this temperature - it is this point, because sorry not that point.

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It is this particular point, when r is equal to 0, because we cannot have we cannot have our extent higher than that; so now let us say that we now try to visualize, what will happen to the extent of reaction along the length of this along the length this reactor; so if I if I travel along with this along with this length length or distance from the inlet, what will happen to the extent, and I will plot that over here, so length versus extent of reaction alpha temperature is constant.

What is my limiting value; let us say that my limiting value is alpha at some temperature T max; and that value is this value over here, this value over here; so what will happen to my extent of reaction; starting with a 0 value, notice what is happening to what is happening extent is always always increasing, but at what rate is it increasing; notice the color change I -i hope you can see it, but if I suppose, if I take the temperature point over here, then you will be able to see it more clearly. Suppose if I am going isothermal reactor at this particular temperature, you see by color you can make out the reaction rate is reaction rate is decreasing; so the reaction rate is maximum at alpha equal to 0, and then it is progressively progressively decreasing.

So what will happen - my alpha will change and go to a saturation saturation value; why is that, because I have maintain the temperature I have maintain the temperature for which for which my my equilibrium constant is this particular value let us say, and so I cannot whatever length of reactor I take, I cannot increase my equilibrium conversion higher than a my my conversion higher or my extent of reaction higher than the equilibrium extent of reaction. So this is the limit, and the rate is maximum at the at the beginning, and will go on go on increasing in this particular manner.

Suppose this was at temperature T 2; T 2 then what will happen at temperature T 1; let me see, if you can see, suppose this is my temperature temperature T 1, I think I need to use a different color, because we are not able to see much, so let us say this is my temperature T 1, this particular point; so what will happen at temperature T 1? At temperature T 1 my equilibrium conversion is conversion is conversion is higher, but the rate is low compared to this temperature, so I will take enormously long time to reach that saturation, if at all if at all I I reach it; or in other words, let me plot it.

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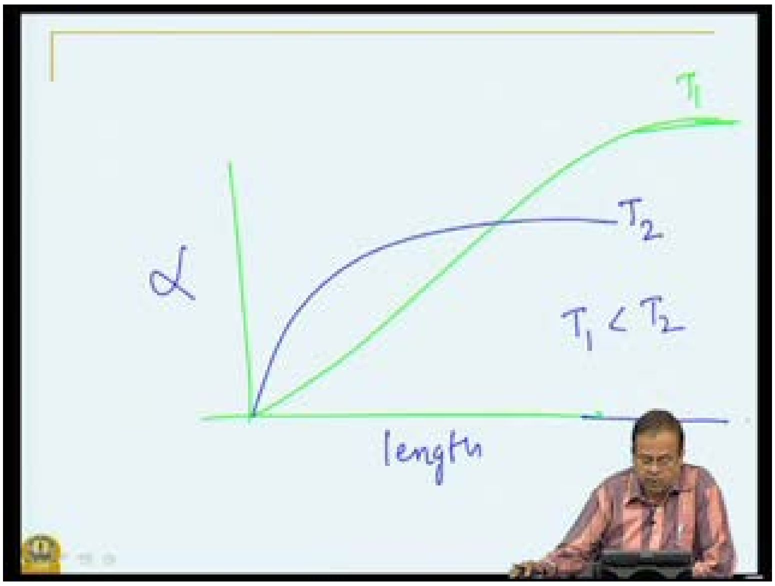

This will be at temperature T 1, and at some other temperature temperature T 2, a lower value, but lower equilibrium conversion; so this is my length of reactor, this is my extent of reaction, reaction alpha; what is T 1 and T 2? T 1 is less than T 2 that is what you expect in a in a exothermic reaction, reversible exothermic reaction. So the point is if you carryout these reaction in an isothermal reactor; you will reach saturation and no matter what you do with your reactor, if you increase the length of reactor, you will not get higher and higher higher conversion; so that is that is how that is how we we have determined our isothermal reactor behavior.

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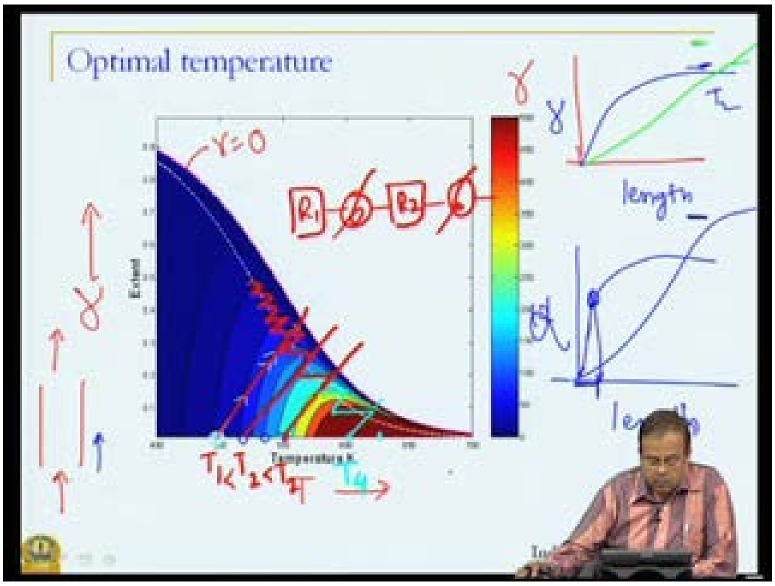
Optimal temperature

Let us look at try to look at what will happen what will happen if my reactor is operated in an adiabatic manner, and for an adiabatic reactor, let us see how this reactor reactor performance performance will look like; so my adiabatic adiabatic reactor; let me erase this also; let me keep that. So let us say that we are going to operate an adiabatic reactor, and try to look at length versus versus extent of reaction alpha

Now what is a characteristic of adiabatic reaction? We had seen earlier that for an adiabatic reactor, assuming that if the all the thermal properties, heat of reaction is independent of temperature, alpha and temperature has a linear relationship; so let us say that we we we have let us try to take (( )) let us say that we are trying to trying to look at how these reactor performance will be if we if we carry out an adiabatic adiabatic reaction; so I am going to I am going to carry out an adiabatic reaction, let us say by starting at this temperature 500, and what is my adiabatic line? My adiabatic line is a is a straight line; I should along a straight line with certain certain slope, isothermal line is a vertical line, but this is line with certain certain slope, so this is my isothermal operation, this is my adiabatic operation.

So now, what will happen, what will happen to the extent of reaction, as we as we change the length of a reactor; so again, we start from this particular point, we start from this particular point, and then we see that as we are increasing the… as as the reaction is progressing, what is happening to the temperature? Temperature is increasing, because this adiabatic reactor, no heat removable; exothermic reaction, so it adds to the energy of the system; and the energy released by the reaction adds to the energy content of the system, and the temperature keeps on keeps on increasing.

So what will happen, as temperature increases; let us travel along this adiabatic line, reaction rate having certain value, the rate is increasing; look at the color color slide, rate is increasing as we are traveling in this direction; however there comes a point, where we see that the rate is once again decreasing, you see the change in color eventually, reaching a zero value; so what happens; what happens to my adiabatic reactor now; extent is extent is is is is increasing as as before, so if I plot the extent of reaction versus length of reactor, starting with 0 value initially, I will have rate which is some value, but then it will increase, unlike this the rate here will increase initially as my temperature is increasing, as I I am traveling along the length of the reactor, it will increase reach reach a maximum value maximum value over here, and then start decreasing, so and once again, I will reach a saturation saturation value.

Now, the same as initial temperature isothermal, I would have got a higher conversion, but in a longer time, because the rates are lower, you can see the colors scheme; the rate along these vertical line are in general lower, so even though we are getting higher equilibrium conversion, those are obtained with a lower rate; whereas along the adiabatic line, the rates are progressively increasing at least compared to what would happen with isothermal line, so rates are increasing, but then again you go and hit a saturation, and that to a lower value of (( )); so you hit a saturation, but much faster at a lower value, but much quicker compared to an isothermal isothermal operation.

So clearly, both isothermal operation alone or adiabatic operation alone are not not sufficient, because they would not give you the maximum maximum conversion or desired conversion that that you want. So how do we how do we run these reactors, then what what what we are what we are seeing here now, this is a different white line than before, so what is happening along this, is along the adiabatic line along the adiabatic line the point where the rate is maximum are all joints; so you can start at different temperatures, and travel along these adiabatic lines, and see where the rate is reaching maximum, and you join those join those points.

So now, if you were to design this reactor, if you were to design this reactor, first of all what does what does it mean that you will reach saturation; first of all, strictly mathematically speaking, as you approach the equilibrium conversion, the rate of reaction goes to 0; so the rate of increase in conversion will also go to 0, that means conversion - equilibrium conversion mathematically speaking can be obtained only with a reactor, which is infinitely long that is one point, but that is that is that besides the point.

What is happening as we are traveling along this adiabatic line? Initially, at least the temperature is increasing, so rate of reaction is increasing, but if you cross this particular point, let us say that that point was point was over here; so if you cross if you cross this particular length of reactor, if you have a reactor length, which is higher than this, you are actually utilizing it in an in a efficient manner, because rate of reaction is reaction is lower, so what should you do instead of that? This is what is precisely done in the in the reactor reactor design.

So before we go to that, I also want to point out the following factor; see suppose suppose we start with this temperature T 1, then we will travel along this line, suppose I start with temperature T 2, I will travel along this line, temperature T 3 over here, I will travel along along this line, what are the characteristic of this three different temperatures and three different lines - temperature T 1 is smaller than T 2 is smaller than T 3, but in terms of rates, the rate along this T 3, adiabatic line starting with T 3, you look at again, just keep looking at the color scheme, the rate here is much higher compared to rate along this particular line, that is this what I am saying is rate, if we start with temperature temperature T 3 is much higher than rate that you would get if you start along temperature T 2, if you start along temperature temperature T 1 right, but the equilibrium conversion is conversion is low.

If we start with temperature T 3, so that gives us an clue, as to how we should run these run these reactors. Now what is that what is that clue or what is that what is that idea? See in the starting of the reaction, you are not worried about equilibrium, because you are far away from equilibrium, so you could afford to start a reaction at a higher temperature, because equilibrium is still far away; so one way of doing this would be suppose that we start these reaction reaction at a high temperature, and let me let me choose that high temperature over here.

So, suppose if I start my reaction over here, I think it is not very visible, so let us use another color; suppose I start my reaction over here, I am away from equilibrium, so I can run it or let me start it over here, so I can run it along adiabatic reactor; so if I run it along adiabatic reactor, I will have increasing temperatures, but if I continue along with this path, I am going to hit equilibrium. So I will stop my reaction or I will consider, I will I will temporarily halt my reaction.

Now, so I will start with let us say temperature T 4; I start with my temperature T 4, run it for some time, and then stop it; and stop it and do what? I reduce the temperature, so let us say that I have I have run my reaction for for certain certain amount of time, and then I reduce my temperature, if I reduce my temperature without doing anything to the reactants, I will travel along this horizontal line. So what will I have? I will have same conversion, but lower temperature now; and I will once again start my start my adiabatic operation, so once again I will travel along a straight line, and I will reach some point. I repeat this operation, so that I go back, stop the reaction, cool it let me change the color now, because we are in a different region; so again I go and I will keep on doing this behavior, such that I will have higher and higher conversion.

So what is the idea that that that we are using? We are now using some way of generating a temperature profile, which will follow this dotted line, because if you follow this dotted line strictly, you will get the maximum reaction rate; so in a in a batch reactor or in a in a fixed bed reactor, your temperature should have ideally changed along these white line, because that is where the reaction rate is maximum, but that is difficult to achieve. So I am going to achieve this by various different ways, one of the way for example, I can I can think of this is that that I will I will start, I will run my adiabatic reactor, so what will be my my operation look like; I will have let us say a reactor R 1 corresponding to this, then and heat exchanger to remove the heat, followed by another reactor R 2 second segment, again another heat exchanger cooling, again another reactor and continue this series.

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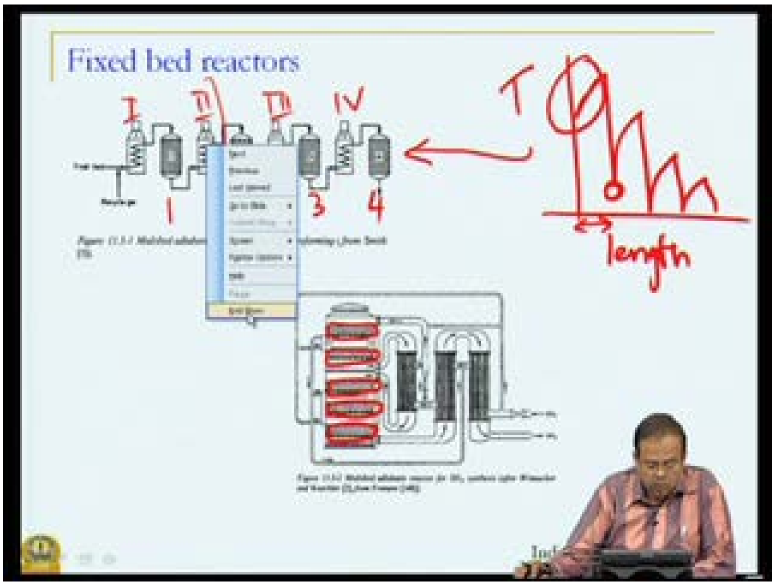

Fixed bed reactors

So in other words, let me let us go back over here; in other words, I will have this arrangement; what am I what am I doing here? This is my heat exchanger followed by followed by reactor, so 1, 2, 3, 1, 2, 3, 4 that we that you see here, are the reactors and roman I, II, III, IV are my heat exchangers. So what what am I what am I doing? I am I am sending, I am preheating my reactor to high temperature, why - because we just now saw that initially better to start with a higher temperature, so I am preheating it at higher temperature, sending it to reactor one, so this is my reactor one, then cooling it down in this heater, so that is my heater, this particular operation or cooler so heat exchanger unit h 1 let us say, and then keep doing this operation in a sequential sequential manner.

So what what would I have got now; I would have got if you look at temperature against the length of the reactor, I started with some high temperature that temperature went up, because of adiabatic operation; then I had cooler, so temperature came down, again went up, again came down, again went up, came down and so on. So an optimal optimal design problem for example, would be what should be the length of this segment length of these reactor and to what level should I should I bring down my my temperature.

So this can be achieved in a simple simple operation operation like this or we can achieve it in an more complicated complicated operation, which actually this is this is a example from sulphur dioxide oxidation to trioxide to in the manufacturing of sulphuric acid, essentially a reversible exothermic reaction, so what we have here is bed of reactors, so this is my reactor with four different beds; and these are my heat exchangers; so what I am doing is actually, passing the reactor through the bed, passing the reactor through the bed, taking it to the heat exchanger, again passing it through the bed to another set of heat exchangers. So what what we are able to able to achieve by doing all this is is get the best of both kinetics as well as as well as thermodynamics. Let us let us recap what what we we we saw so far.

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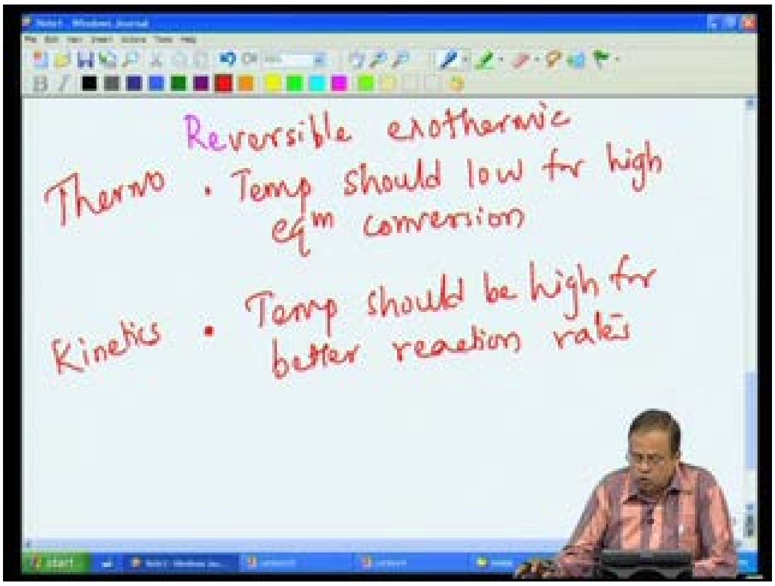

Reversible exothermic

Thermo • Temp should low for high eq^m conversion

Kinetics • Temp should be high for better reaction rates

So what what we have is a reversible exothermic reaction; my thermodynamics tells me that temperature should be low for high equilibrium conversions, my kinetics tells me… So this is thermo, my kinetics tells me that temperature should be high for better reaction rates, so this is my kinetics. Obviously we we have to strike a balance, because we want high reaction rates as well as high equilibrium conversions; so how do we try to strike these balance, we tried to strike these balance by saying that ideally in the beginning of the reaction, thermodynamics is far from my mind, because we are far away from equilibrium, so why bother about thermodynamics.

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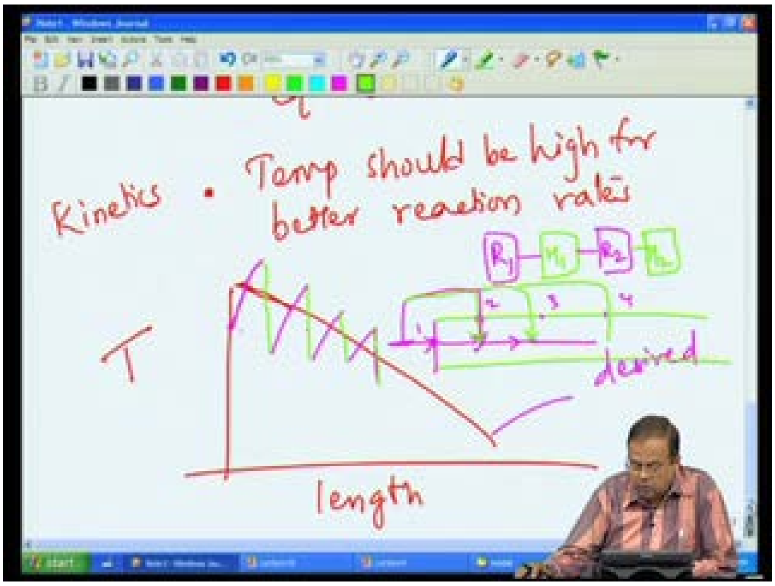

So if you if you look at plug flow reactor or fix bed reactor for example, as a length and if I say now, if I will see how my temperature is to be manipulated; at the beginning stages I am far away from equilibrium, so I should focus on achieving the best kinetics; and how can I do that by having as high temperature as possible, but as my reaction proceeds, if I keep that high temperature or if I keep the reactor at high temperature, I know, I am going to stumble upon my thermodynamic limit; so what should I do? I should lower that temperature and keep on lowering this temperature, so that I get best of both the words, how? By focusing on better kinetics over here, and by focusing on better equilibrium conversion or better thermodynamics over over here.

Now in an in an typical typical fix bed reactor; manipulating temperature along the length of the reactor is is extremely difficult. So how can we how can we overcome this problem? So let me let me say that this is what I want to I want to I want to achieve; so how can we how can we overcome this overcome this problem. We can overcome this problem by by by saying, so this is my ideal ideal trajectory; so how will I how will I be able to overcome this problem that I would not be able to do all this in a single single shot.

So one way of overcoming this problem is I will use series of reactors and heat exchange equipment, and what will I try to do? So this is my optimal, so let say that this is my desired temperature profile, but how will I try to achieve it? I will try to achieve it by one way is I start my reactor at high temperature, let it increased; and then using heat exchanger, I bring it down; so my reactor operation operation would look like R 1, followed by heat exchange unit H 1, then once again another reactor adiabatic reactor, so R 2 followed by H 2 and and so on. So this is this is one possibility right, and I can keep on doing this as long depending on my design criteria; so that is that is that is one way of doing it.

There is another way of doing it also; not suppose, so this would require that we have small reactors, but many of such reactors along with my heat exchange units in series; suppose I have only one reactor, a big reactor, then how can I achieve the same same same strategy, I can achieved it by doing the following. Let us say that I have a big reactor, big reactor so what will I do? I will run it as an adiabatic reactor, so I will send in my feed over here, some some feed over here, then what will happen if I run it as adiabatic, let say the temperature starts increasing temperature starts increasing like this over here.

Then, in order to bring down the temperature, instead of using an heat exchanger, I can actually actually use the cold feed at a different location; so my feed locations are no longer just the inlet point and the exit point, but I have inlet point 1, 1, 2, 3, 4 and so on; so if I introduce a cold feed, which mixes with this hot stream, what will happen; the temperature will come down of course, in this case, the conversion will also change, but but that is a small detail; so temperature will come down. So let it again run in an exothermic manner, and let us add another cold feed, so these are all my cold feeds; so I have my temperature going up another cold feed and and and so on. So that is another another possibility.

There is yet another reactor design; so this is reactor design 1, reactor design 2 and let us look at yet another another another possibility, and this is along the following following line. Now if you look at look at what we want? We want high temperature at the beginning of the reactant and cooler temperatures as the as the reactants passed through the through the reactor. Now if you look at the reaction, again I will repeat, so exothermic reaction, for which I want high temperature at the beginning of the reactor;

high temperature means that I have to supply lot of energy, so lot of energy has to be supplied to preheat these reactor, but as the reaction is going to take place, it is going to generate energy, and I know that I have to cool; if I if I look at this temperature profile that I want, I know that along the length of the reactor I need cooling, because my reaction is generating lot of lot of heat.

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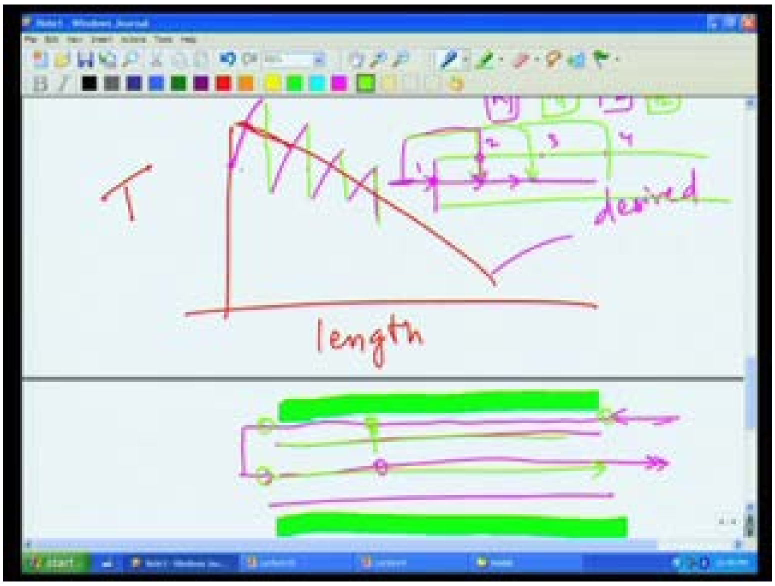

So why not combine these two processes in an beneficial manner, what are these two processes; I need to preheat my reactant to a high temperature and once the reactants enters the reactor, so let us say that I have my I have my reactor and let us say this is my inlet - conventional inlet, but instead of that, let us let us try to look at now in a different different manner; let us say that my reactor is actually… Reactant is is actually surrounded by a shell, so this is my this is my reactant.

So what I am going to do what I am going to going to going to do is that if I have to send my reactants in a reactor in this particular particular manner and my products are coming out like this I am going to actually send my cold reactants in this shell so that the reactants before entering into the reactor goes through this shell; now what happens as they go through this shell, what is happening eventually as the reaction proceeds along this this line, what will happen? This reactants, which are generating energy over here, will come in contact with or rather will come in contact with, will come in contact with the cold reactant, so energy will flow from here to here, there by cooling the reactant stream and heating the preheating the reactant stream.

So what will happen in the shell? In the shell temperature will increasing from this point to this point, and in the reactor temperature will decrease from the inlet to the exit. A clever way of combining both the requirements that is of preheating the reactant as well as cooling the cooling the reactant as reaction takes place. This is what is called as auto thermal reaction, and we will look at the design of such auto thermal processes in our next season, thank you.