Thermal Processing of Foods
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Lecture No. 7
Kinetics of Reactions

Good morning all, today we are going to see the topic of kinetics of reaction.

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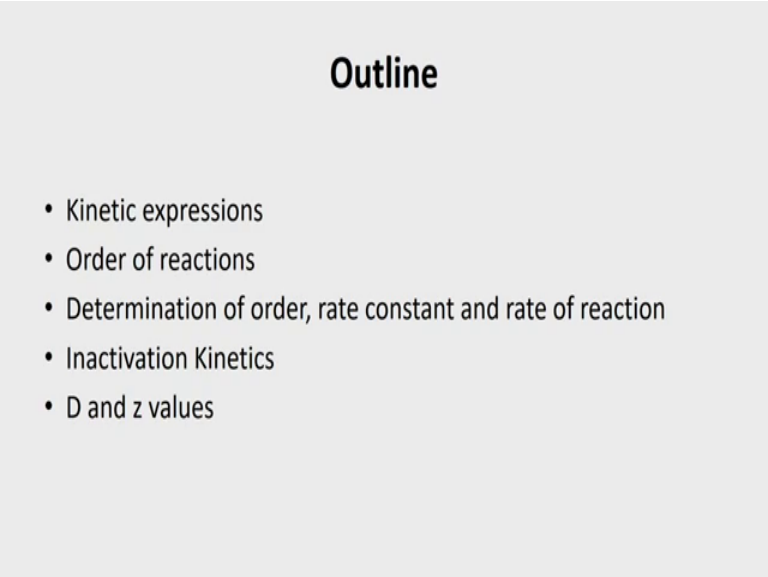

In this topic, today we are going to cover kinetic expressions, order of reactions, determination of order, rate constant and rate of reaction, inactivation kinetics, D and z values.

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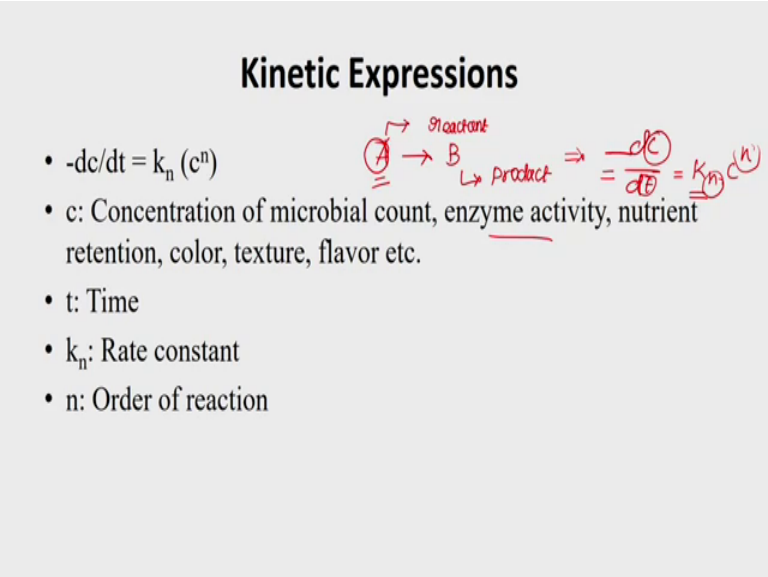

So the first one we are going to talk about kinetic expressions. So normally any reaction, for example, if A gives B, so this A is nothing but a reactant and B is nothing but a product. So how do I represent the concentration of reacting species with respect to time, so that is nothing but kinetic expressions.

Here which is nothing but dc upon dt so this c is nothing but concentration of the reacting species. So this minus sign is for, when the reaction happens the reactant A is getting depleted over the time. So which is equivalent to kn and c power n. So what is this k, this k is nothing but a rate constant and this n is nothing but a order of reaction. So in general so this n is nothing but the order of reaction.

So this c is nothing but the concentration of the reactant to the power n. n is nothing but a order of reaction. So the course what we are dealing with here is the thermal processing of food. So in the thermal processing the one of the main process is nothing but sterilization which is nothing but a cleaning of microorganisms using a temperature. So this c talks about concentration of microbial count for example, initially I have particular microbial count so over the time at particular temperature how the microbial count is getting reduced.

And sometimes it may be the enzyme activity. So enzyme activity is also related to the food processing. So when I am going to kill about the particular cell concentration at particular time at

particular temperature. So how my enzyme activity of the food is getting changed, so the same may be enzyme activity as well and sometime it talks about the nutrient retention. So when I am going to heat the food for a particular time to kill microorganisms so how much of nutrient is retented in particular time at particular temperature that that concentration also I would be interested. And sometimes it is colour, sometimes it is texture, flavor, etc. So this t is nothing but a time and kn is nothing but rate constant where n is the order of reaction.

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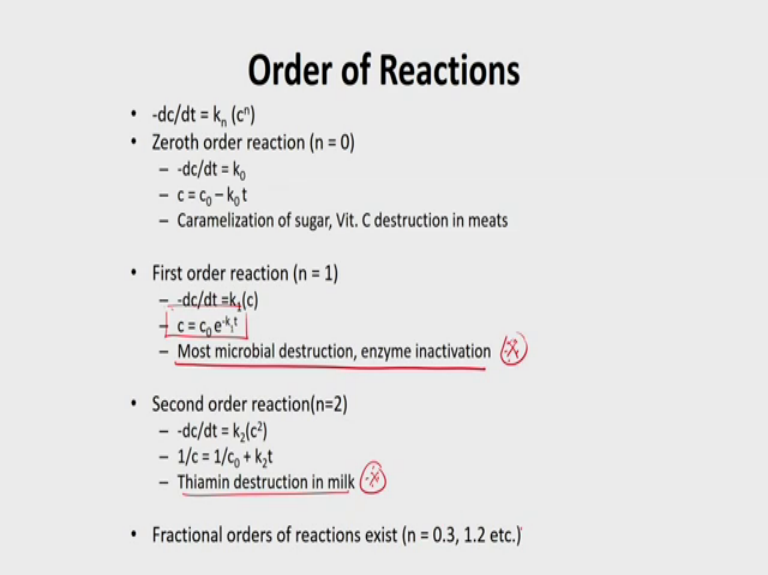

So we have already told about the kinetic expressions which is nothing but minus dc upon dt equal kn c power n. So based on the n, whether it is 0 or 1 or 2, the reactions are categorized into zeroth order reaction, first order reaction, second order reactions sometimes fractional orders of reaction also exist, for example n equal to 0.3, n equal to 0.2 1.2, etc. So how are we going to derive such a kinetic expression for different orders of reaction that we are going to see in next slides.

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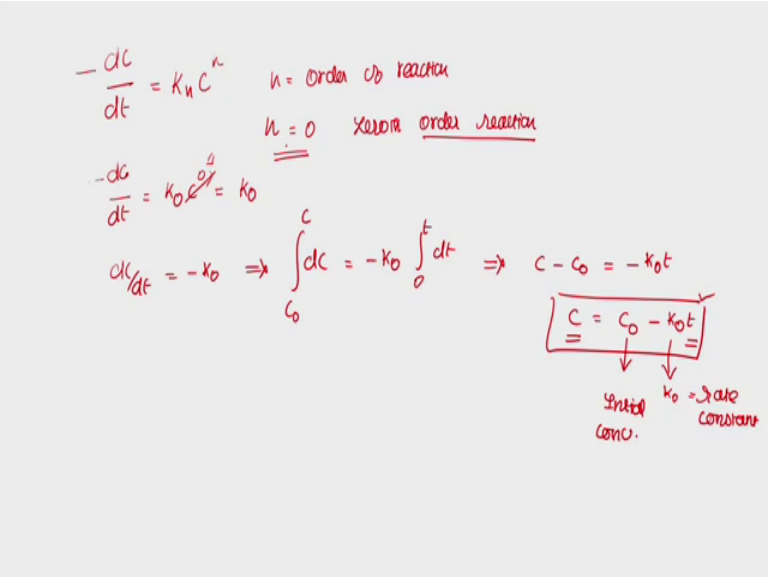

So my general kinetic expression goes like minus dc dt which is equal to kn c power n. So this n is nothing but order of reaction. So if I know order of the reaction priori so for example my n is equal to 0. So that means it is zeroth order reaction. So how do I write kinetic expression dc upon dt which is nothing but k naught c power 0, so which is nothing but k naught.

So now I integrate over initial concentration c naught and final concentration c over the time zeroth minute to t th minute. So this is nothing but 1 so this is k naught so here dc dt is nothing but minus k naught so which implies dc is nothing but minus k naught 0 to t dt, the same way my concentration goes from initial concentration c naught tofinal concentration c. So this becomes c minus c naught which is nothing but minus k naught into t.

So c is nothing but c naught minus k naught into t. So at any particular time I will be able to calculate my concentration when order of reaction is nothing but a zeroth order. I would require t time and rate constant k naught, k naught here is rate constant, so this is nothing but my initial concentration of the microorganism or nutrient or enzyme activity anything. So I would be able to tell what is my c at time equal to t if my order is zeroth order.

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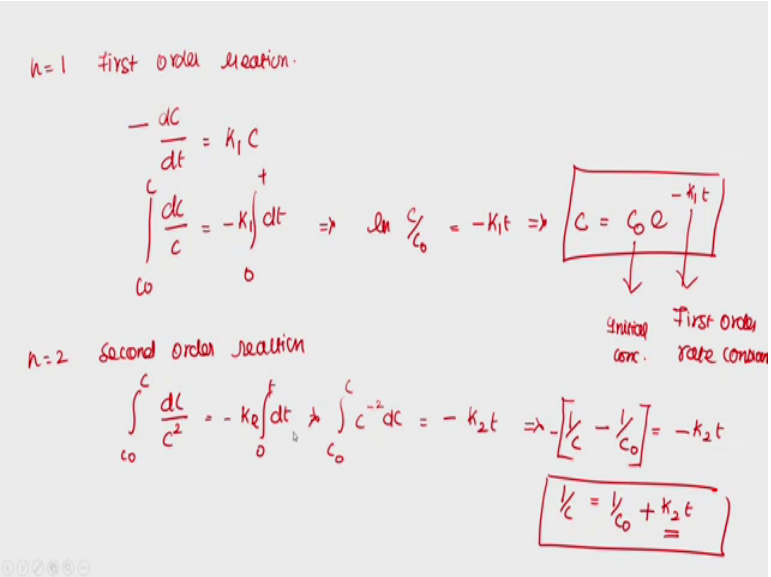

So if my order is a first order, my n equal to 1 that is nothing but a first order, first order reaction. So here I would be able to write dc upon dt which is nothing but k1 c power 1 which is nothing but c. So dc upon c which is nothing but minus k1 dt, so I will integrate over initial concentration to final concentration, initial minute to time t th minute. So, which is nothing but lon c upon c naught which is nothing but minus k1 t. So if you want to calculate the concentration at any point of time c naught e power minus k1 t.

So if I want to calculate at particular time t, what is my concentration so from the initial concentration and from first order rate constant so this is nothing but first order rate constant. So this is my initial concentration. The same thing for n equal to 2, n equal to 2, it is nothing but a second order reaction, so c naught to c, so dc upon c square which is nothing but minus k2 0 to t dt, so which is nothing but integral c naught to c c power minus 2 dc. So here I am assuming some of you are from science background as well.

So I am going into detail so if you are from engineering background you have already taken the course of the some chemical reaction engineering this would be simple. So this is nothing but 1 upon minus c. 1 upon minus c naught which is nothing but minus k2 t so this is nothing but minus 2 plus 1 minus 2 plus 1, this will become a minus. So you would be having 1 upon c is

nothing but 1 upon c is nothing but 1 upon c naught minus k2 t. So this is second order rate constant so at particular time t so I will be able to tell what it is my concentration.

So this is what here we have done for example, this is plus so this is 1 minus c goes there and this 1 upon c so this will come here it must be plus. 1 upon c is nothing but 1 upon c naught plus k2 t. So this is where here given at zeroth order reaction your c is nothing but c naught minus k naught t. So we have derived here c equal to c naught minus k naught t and for first order reaction so it is nothing but c equals to c naught e power minus k1 t and for second order reaction it is nothing but 1 upon c, 1 upon c naught plus k2 t. So that is what we derived here.

So what are all the examples for zeroth order reaction. This is caramelization of sugar and vitamin C destruction in meats. So these follow zeroth order reaction so most of the microbial destruction and enzyme inactivation. So this is important because we are going to discuss extensively about this in this course. So for microbial destruction, so what are all the kinetic expression, so these both follows first order reaction.

So we would be talking extensively about c equal to c naught e power minus k1 t and second order reaction it is nothing but 1 upon c 1 upon c naught plus k2 t. This is thiamin destruction in milk. So when we will be talking about milk pasteurization. So this is important. And fractional orders also would be possible. So we are not going to go in detail about that. So now what we have done here is if I known my order of reaction a priori, so I will be able to calculate my concentration at any point of time t but if I don't know order of reaction a priori, so how would I be calculating that.

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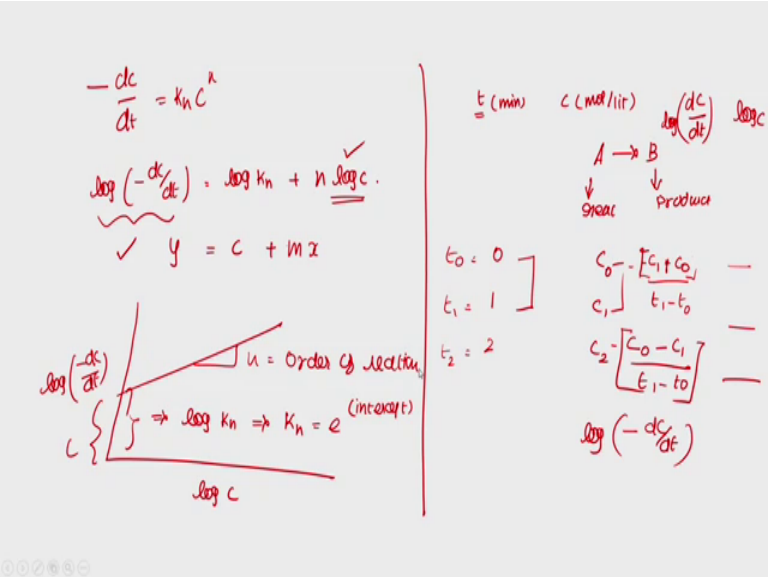

The general expression what we have is minus dc upon dt which is nothing but kn c power n. So what are we going to do is we are going to take log in both the side which is nothing but log kn plus n log c. So now it becomes a form, y equal to mx plus c. So in the laboratory what I would be doing is I will be taking at each minute so what is my concentration of the reacting species, the concentration for example, molds per liter. So if I take a simple example of A gives B, A is nothing but a reactant, B is nothing but a product. So I would be knowing mechanism from the chemistry.

So how would I be able to determine the concentration at various time. There may be a titration technique for example, some reaction so from that I would be able to determine at particular time what is the concentration remaining, concentration of A is remaining in the reaction or sometimes what may so happen is how much of B is produced at particular time of reaction. Since we have talked about the reacting species so I am saying like how much reactant is depleted at particular time.

So here I will be taking for zeroth so my concentration is c naught then at 1 minute my concentration is c c1 and second minute my concentration is c2 This is the way I will record. And what I would be requiring is my log of minus dc dt. So I would be needing I would be need of dc

dt. So log of dc dt so first I should be determining what is dc dt, then after that I will be taking log and also I would require log of c, log of c. So log of c is straight forward you will be doing it.

So dc dt how do you calculate? So what is a if I take what is dc, dc is nothing but c1 minus c naught upon t1 minus t naught. So this also I can write t not equal to 0, t1 equal to 1 minute, t2 equal to 2 minute, so remember we are talking about how much reactant is getting depleted. So when the reaction proceeds, the reactant will be consumed so c1 is nothing but low compared to c naught so that is where this minus comes, so I will be writing like so minus of if I take minus out, so then the c naught will be coming here.

So this is nothing but minus of c naught and plus c naught. So I will be having c naught minus c1 by t1 minus t naught. So one minus sign is here, so that is the way I will write minus dc dt. So if I take a log, then I will have this value. So from taking just a log of concentration column then I will be having log c. So now I am going to plot it. Plot it versus so m sorry it is not c it is mx. So x is nothing but log c. So in x axis log c and in y axis it is log minus dc dt. So I will be having, the linear line so which talks about the intercept.

So intercept is nothing but log kn so from this I will be able to calculate my rate constant at n th order reaction. So why we are doing this? I do not know priory what is my order of reaction, so this is nothing but f intercept. So this is what we call it as a c. So this slope is nothing but n which is nothing but order of reaction. So we are familiar with now how to calculate the order of reaction and how to calculate the rate constant at particular order. so this is what discussed here principle behind determining kn and n.

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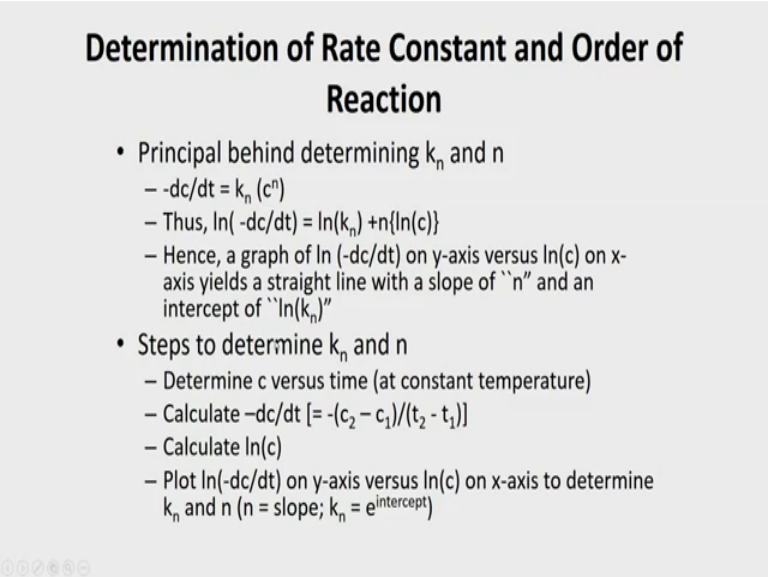

So whatever we discussed it is given in the slide, get you familiarize with the technique, or how to determine kn as well as n which is nothing but a order of reaction when you do not know really. So now we are slowly moving what is a analogy between what I learnt the kinetic expressions and how I am going to use in thermal processing of food. So one such situation I have already discussed is is sterilization where I would be employing temperature to kill the microorganisms. So this killing of microorganisms can be done is many ways. For example, they might be using bactericidal compound, or they may be using the physical reaction which is nothing but temperature, pressure and sometimes it is a electric field.

And the moment I talk about microorganism, it (inclu) it includes bacterias, yeasts as well as viruses. As you all know if you know little bit of micro biology, these bacterias are nothing but a prokaryotic, and yeasts are nothing but a eukaryotic cells, and viruses are nothing but the parasites. So we collectively talk about, in terms of microorganisms and the actions would be either it may be a bactericidal compound, or it may be a temperature or it may be a pressure or it may be any electric field, right but since the course is concentrating on thermal processing most of the time I will be talking about the physical action which is nothing but a temperature.

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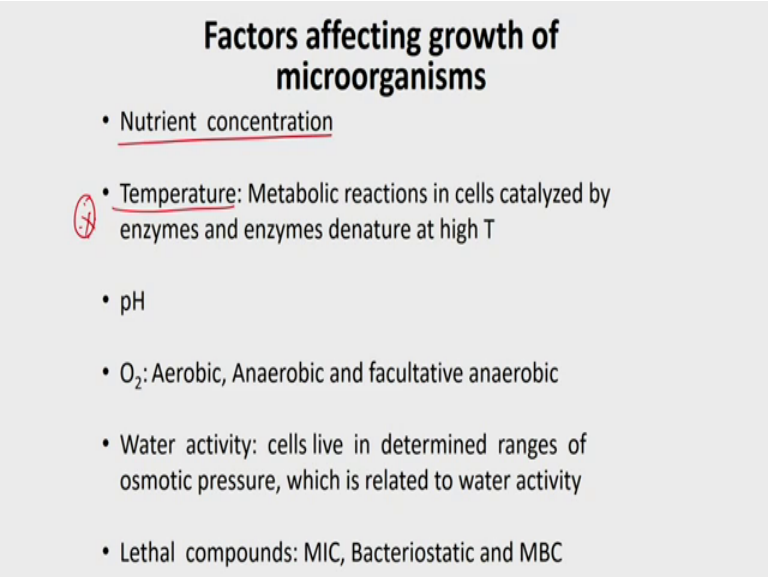

So in general these are all the properties, these are all the factors which affect the growth of microorganisms. So one is nothing but nutrient concentration, so here when I am talking about these factors so what I meant is this should be in particular range, particular range in the sense so till certain range it will be affecting the growth of microorganisms, but beyond certain range it will be affecting the growth of microorganisms.

So if you know the micro biology when you are preparing the culture medium, so you will be including the nutrient at particular concentration for example, if particular component beyond certain concentration that itself will be a inhibiter for the growth of microorganisms. So the second main important thing is nothing but a temperature. So this is what we will be concentrating whole course, how I will be processing thermally processing the food

So any metabolic reaction which happens in the cells are catalyzed by the enzymes. So what happens if the temperature goes beyond certain level, these enzymes getting denatured. So when enzymes getting (ne) denatured at high temperature, so they will not be able to catalyze any metabolic reactions. That is how the death of microorganism starts. and pH, pH is also another important parameter certain food require, certain pH or certain growth of microorganisms in it certain pH.

So this may be acidic pH, or alkalic neutral pH so that based on the microorganisms at which range of pH the microorganisms grow and at which range of pH the inactivation starts. Another important parameter is nothing but oxygen. So we already know there are three major categories, aerobic which requires oxygen, anaerobic which does not and facultative anaerobic it survives in both the condition whether oxygen is available or unavailable.

The fifth parameter is nothing but a water activity. So this cells live in the determined range of osmotic pressure. Each cells require certain osmotic pressure to be live or for the growth of microorganisms certain osmotic pressure is required but this is indirectly related to water activity. This is nothing but a vapor pressure of water to the saturation pressure of water at particular temperature. Apart from that, there are lethal components or inhibitory components so based on that there are three categories- one is minimal inhibitory concentration and bacteriostatic and the MBC is nothing but minimal bactericidal concentration.

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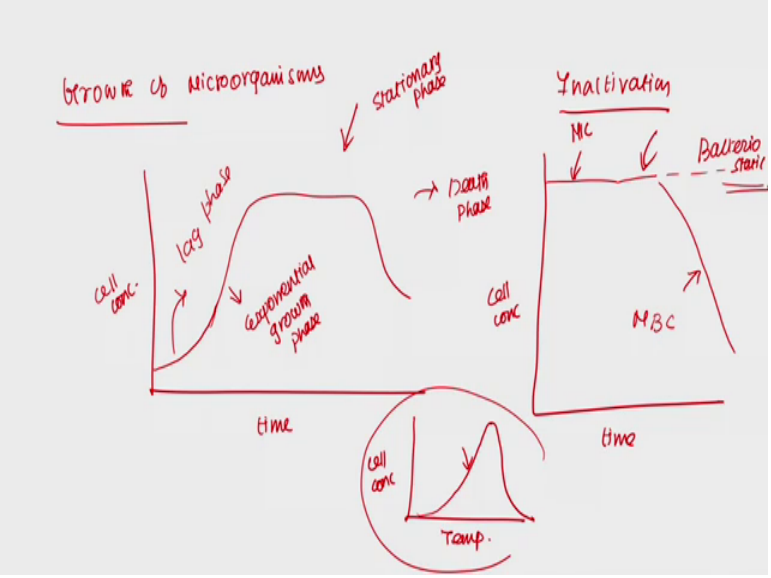

So if you go little bit, so growth of microorganisms, so normal growth curve is something like this. So we call it as a cell concentration. So what time, so there is something called lag phase, so it acclimatized to the environmental condition and there is a exponential growth. So this is nothing but a exponential growth phase and this is nothing but a stationary phase. So this is nothing but a death phase.

So this is growth of microorganisms but we are not going into detail there should not be any discontinuity. So here we are talking about inactivation. So I already told inactivation can be done in many ways so for example, this is my cell concentration so this is over the time so if I am applying some bactericidal compound so how does it behave, sometimes what happens is to the bactericidal component, so they learnt how to survive with any bactericidal compound as well as sometimes physical actions.

So this we call it as a bacteriostatic, so this we call it as a MIC this is so minimum inhibitory concentration. So when I apply some bactericidal component so there is minimum concentration is required to inactivate the microorganisms. So then after that the microorganisms the cell concentration starts decreasing so this we call it as a MIB. So minimal inhibitory, MBC minimum bactericidal concentration. So this in general about the bactericidal component. But in this course we are going to talk about what is the effect when I apply temperature as my inhibitory compound.

It is not inhibitory compound. I am using temperature as a physical action to kill the microorganisms. So this looks like when I time versus this is cell concentration, cell concentration so this is nothing but temperature. So that is my physical action. So first it is something like that. As I told temperature certain ranges required for the growth. Then after certain temperature, it is starts decreasing. So this is what we are going to talk about as a inactivation kinetics. But this is true for any of other physical action.

For example, if I am applying the electric field, so certain organisms know how to resist them, how to resist certain electrical field and they starts still surviving. Certain organisms will get killed upon particular physical action. So sometimes what happens is the death microorganisms also acting as a shield and which protects rest of the microorganisms that is the way this bacteriostatic phase happens. But anyway we are not going to go into detail about that.

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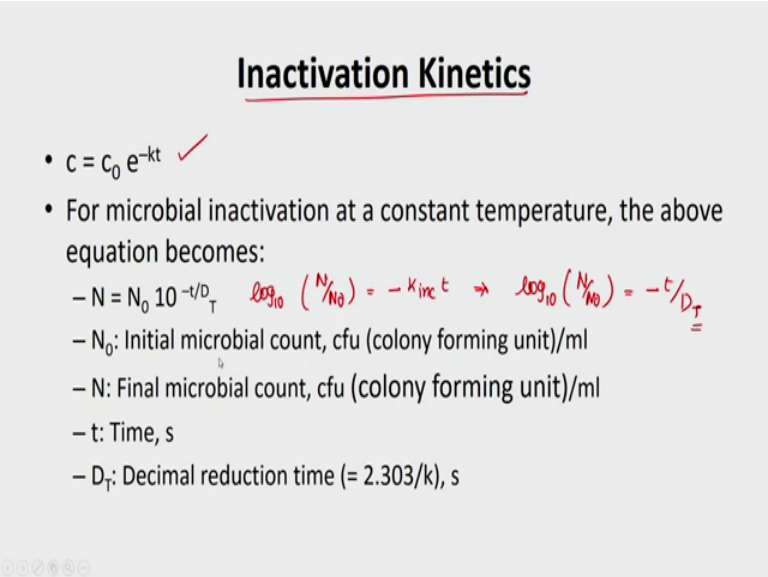

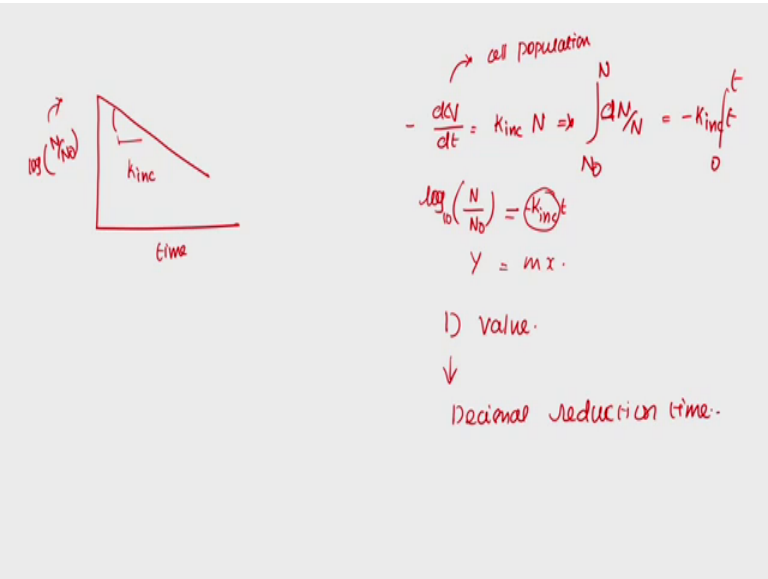

So now we learnt what is the inactivation kinetics. How it is going to happen in terms of temperature. So we already told most of the inactivation kinetics of the microorganisms follows first order reaction. So we will go little bit detail. So for example, here dN upon dt so there we have talked about the concentration. Here N means cell population. So which is nothing but k, so this rate constant I am putting as inc, so that it will be something different. So into k inc and N. N is nothing but a population.

So if you are getting so this is nothing but log of N naught upon N which is nothing but minus k inc minus because this minus I have taken here so this is t. So what is this, this is nothing but y equal to mx. So this is my t time. So this is log N naught upon sorry this is nothing but N upon N naught . So when you are this remains same dN upon dt which is nothing but k in inc into N which becomes dN upon N which is equal to minus k inc t so if I am N naught to N so this happens 0 to t so N upon N naught minus k inc t.

So now I am doing it time versus N upon N naught , so N naught is, N is what the cell population at that particular time. So N naught is nothing but initial cell population so I will get because it is a the negative slope so then this slope is nothing but k k inc. So this is the way I will relate here the N equal to N naught 10 to the power of minus t upon dt is nothing but here we have taken in log 10 so one can define in this way also. So this k inc so how do I relate, this K inc is related to some value called D value. So this we call it as decimal reduction time, so what is called decimal reduction time that we will see.

So here if you see N equal to N naught 10 to the power of minus t upon DT because we have told log of N upon N naught into k minus is equals to minus k dt so this is also equivalent to log N upon N naught which is nothing but minus k inc t so this k inc I am writing as log 10 N upon N naught which is nothing but minus t upon DT. So this T is nothing but a reference temperature when we discuss in detail then we will get to know.

So this N naught is nothing but initial microbial count, CFU colony forming unit per ml. N is nothing but final microbial count so I should be telling at particular time what is my final microbial count and t is time which may be in seconds or minutes. So DT is nothing but decimal reduction time which is also in terms of seconds or minutes. If you represent this as a minute and this also minute and it goes like that.

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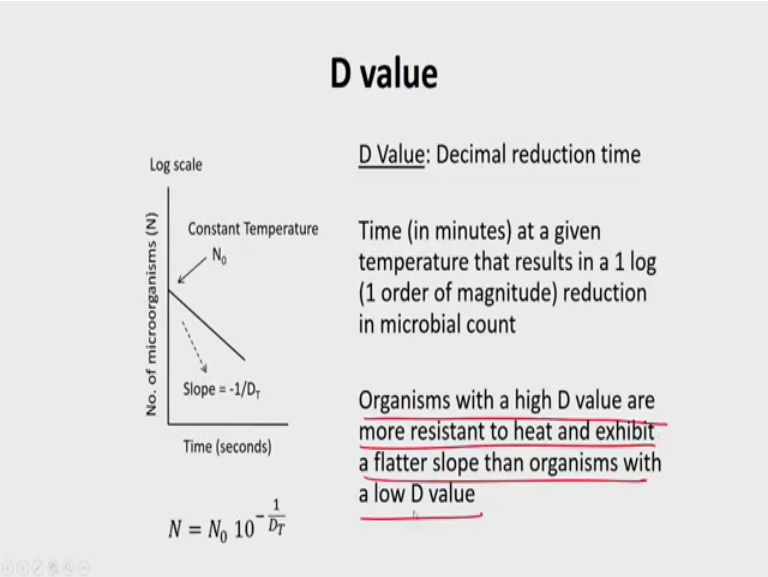

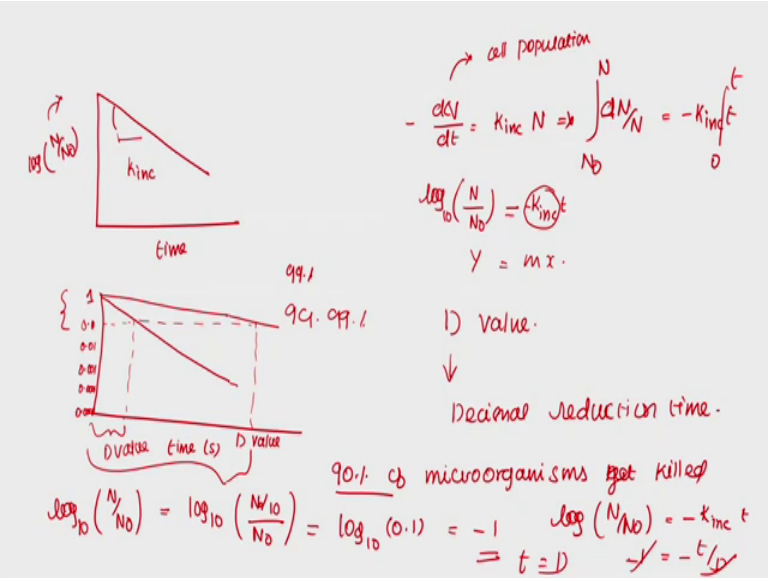

So we talked about already, so how do I relate my slope into decimal reduction time. So the D value goes like this decimal reduction time. Time in minutes at a given temperature so that is what I told T represents the at a given temperature that results in a 1 log reduction in a microbial count, 1 order of magnitude. So now we will be seeing in this in detail here so for example, so this is my time in seconds so this is my log of N upon N naught so this I have the slope. So what is says about so instead of this I will be putting in numbers. So that you will understand it better, so this is my 1.

1 is nothing but my initial concentration N naught, so this is where it starts so that is 1. So then this is 0.1, the next one is 0.01, the next one is 0.001, so then next one is 0.0001, so then next one is 0.00001. So it says about 1 log reduction, 1 log reduction in the sense so 90 percentage of microorganisms get killed. 1 log reduction remaining I will be having only 10 percentage of the microorganisms. so if I have to put log of N upon N naught, So what did I say 90 percentage of the microorganisms get killed at 1 log reduction.

So this will be nothing but so log 10 so how much would be the initial concentration would be having so only I will be having N by N naught by 10^{th}. 1 by 10^{th} of will be having. So or otherwise 10 percentage of the microorganisms would be survived so that is nothing but 0.1 of N naught. So this is N naught. So this will be nothing but log of 10 0.1 so this is minus 1 so we have already told this is equivalent to so log of N upon N naught is nothing but minus k inc into t. So this is minus 1 which is nothing but minus t upon D so minus minus so t equal to D.

So to get 1 log reduction, so 1 log reduction in the sense here, so what should be my value, so this is nothing but my D value. So for example, I need to get it killed 99 percentage. Here I told 90 percentage if it is 99 percentage what you would be having is 1. So 1 is nothing but 0.01. So it will be like minus 2 so this is nothing but t equal to 2D. So if I want to kill the 99.99 percentage of the microorganism then what I would be having so here I will be having 0.01 percentage so which is nothing but 0.0001 so which is nothing but minus 4. So your D would be 4 log reduction, for 4 log reduction.

So how much is the time requirement, so that is way D value is getting calculated. So now I hope you will be able to calculate and understand that D value. So this T represents at particular temperature. So this is N is nothing but here I talked about in terms of what is it log scale. So here it is represented as N so N is nothing but number of microorganisms so that is nothing but a cell population and N naught is nothing but a initial concentration. So 10 to the power of minus 1 upon DT we already told that this is nothing but minus k inactivation which is nothing but a decimal reduction time Dt. And this is something important, so what is organisms with high D value or more resistant to heat and exhibit a flatter slope than organisms with lower D.

So if you are able to see what I have drawn. So for example, if I have this flatter slope, so what I would be having for 1 log reduction so maybe I will put something like till here. So if I extend it,

so what happens so instead of this I will be having for 1 log reduction itself, so this D value so that means what at particular temperature if my D value is high those organisms are bit heat resistant. So if I will be able to survive at that particular temperature more long time so that means I am able to resist that particular amount of heat which is given at that particular temperature. So that is why you get flatter slope.

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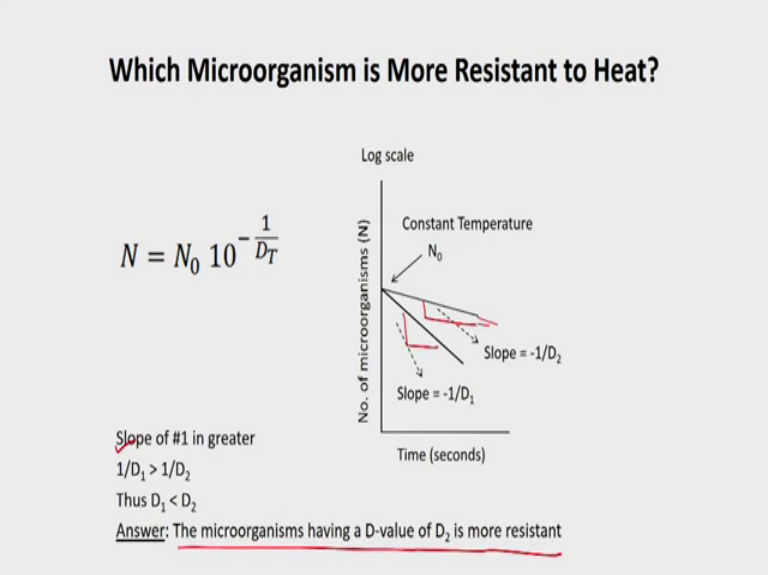

Here I will be explaining you. So which organisms is more heat resistant. So here if you see your slope is nothing but minus 1 upon D1so here if you calculate for example, your slope so any particular value if you calculate your slope so for particular Dy you will get more Dx. So the slope of minus 1 upon D1 is higher slope. In terms of slope this is higher when compared to 1 upon D2 so thus, D1 is less than D2. So that means what the microorganisms having D value of D2 is more resistant, more heat resistant. What is D2 values, so this one is more heat resistant that is why you get maximum D value.

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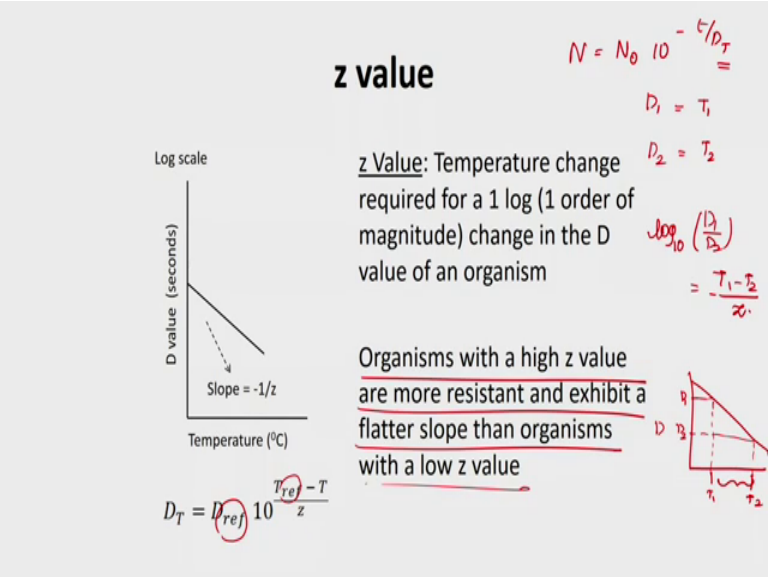

So another one important concept here is the z value. The z value is nothing but temperature change required for a 1 log change in the D value of an any organism. So for example, here what we talk about is earlier if you see the equation is nothing but 10 to the power of minus t upon DT, this T I told at reference temperature or reference temperature you can take.

For example, if I get at D1 I am getting at particular temperature T1, if I get D2 at particular temperature T2., so here I have put T1 as a reference temperature and T2 was normal T. So what I would be having, I would be having log 10 D1 minus D2 is nothing but T1 minus T2 upon z. So this z value is nothing but a slope. This is nothing but minus 1 upon z. So this is D value at seconds or I will be putting something like this.

So if I have a temperature T1 if I have a temperature T2. So this is my, this thing so this is my D value so for T1 I will be having D1 value at T2 I will be having D2. So this is nothing but my z value. 1 log reduction from D1 to D2 it is a 1 log reduction. So what is a temperature range it will be having. The same what we discussed already the organisms with high z value are more resistant and exhibit a flatter slope. So if you compare both of the concepts, so it is a different temperature what would be my D value and from that how I am calculating the slope.

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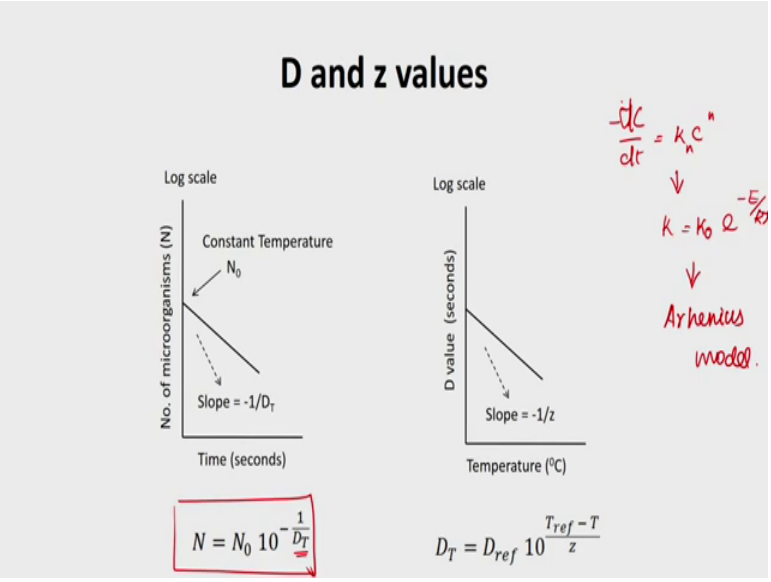

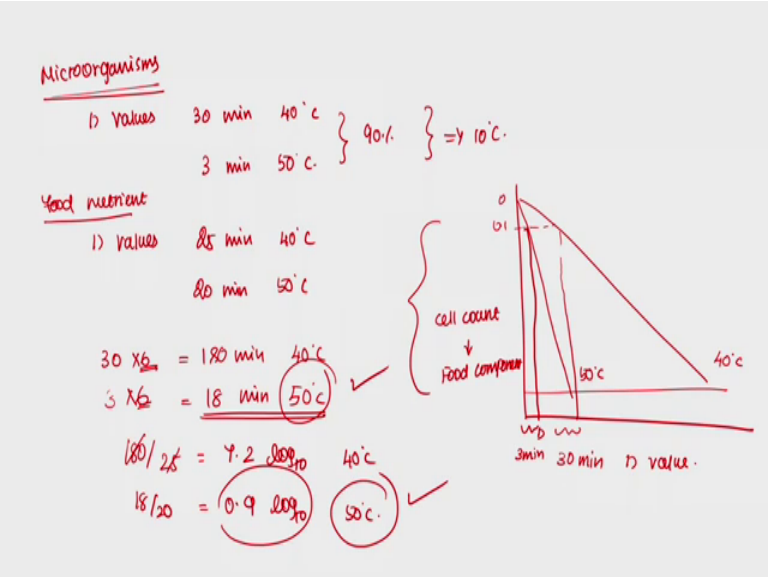

So maybe I will explain, so this is the conclusive remarks on D and z values. The equation is N equal to N naught 10 to the power of minus 1 upon DT. So this DT is nothing but decimal reduction time. The z value is I will be calculating at particular temperature particular D value. So when I plot it temperature versus D value. So if you remember bit of your chemical reaction engineering so any kinetic expression for example, we discussed when we start the class minus dc upon dt is nothing but kcA, kn power cn.

So this k is nothing but a rate constant which is again the function of temperature e upon RT. So this z value is more related to the kinetic expressions. Kinetic expressions in the sense so here it is also referred to kinetic expressions but here how my microorganism is getting deactivated at particular temperature with time. So it talks about how long does it require at particular temperature to kill microorganisms from initial count to final count. So here it talks about more of temperature dependency. It is related to the kinetic model which is nothing but we call it as a Arrhenius model.

So this is nothing but (each) each temperature what is my D value so I will plot it so this also follow linear expression. The slope is nothing but minus 1 upon z. So now I will be just giving one example. For example, any D value so for particular microorganism, so it takes D values of 30 minute at say 40 degree so and it takes 1 log reduction. 1 log reduction is nothing but something 90 percentage. So I will be putting 3 minute then at 50 degree centigrade. So what is my z value? I already told 1 log reduction in D value.

So this is nothing but a 10 degree centigrade. So it is not only about the microorganisms. Sometimes I need to do trade off, trade off in the sense the initial of the when we start the lecture itself I have told you that c talks about not only the microbial count its sometimes talk about enzyme activities, sometimes talks about nutrient content everything. So if I say some of my food components, some my food products, have the similar D values for example, it has some 25 minute at 40 degree so it has some 20 minute at 50 degree.

So how this things look like? For example, if I have microorganisms this thing so this is something at when I will get greater slope so this is at 55. Based on my experience what we discussed earlier so this will happen at 40, when I increase the temperature the inactivation would be faster. So if I take 1 log reduction 0.1 so what happens is sorry this is 50 degree. 1 log reduction is something 0.1 so if I sorry so I have D value so this is nothing but I am talking about D value. So this may be a cell count as well as some food component. Food component in the sense what I meant here is may be some nutrient content, some vitamin or something.

If I have this extended here so that is nothing but a 30 minute. That is what I have mentioned here. So this is nothing but 3 minute. If I fix something like 6 log reduction, 6 log reduction in the sense my micro biologist says “for that particular food processing I would require 6 log

reduction of any microorganism." So how does it does that if it is 30 minute so it becomes 180 minute. So then if it is 3 minute so this becomes 18 minute. So it require 180 minute to process at 40 degree, and 18 minute to process at 50 degree. So similarly so this is nothing but for any food components or maybe you can put food nutrient instead of saying component.

So this is food nutrient so this D value is 25 minute so if I get 180 upon 25, so this is something about 7.2 log 10. So if I have 18 upon 20 so this becomes around 0.9 log 10. so this is at 40 degree, so this is at 50 degree. So if you understand the things clearly, ao I would require 18 minute which is less time at 50 degree centigrade. So also I am getting 0.9 log reduction only in terms of food nutrient because my aim is to kill the micro organism not to reduce any food nutrient.

So in that case I will be choosing my 50 degree centigrade as a higher temperature as my target. So that I will get minimum reduction in the food nutrient and maximum reduction because it is not maximum reduction because I have fixed my microorganism reduction as a 6 log reduction. So 6 log reduction I would be requiring only 18 minute at 50 degree. So I am also getting less log reduction in the food nutrient. So this is the way I do the trade of using D value and z value. So it is extensively used in designing the sterilization process.

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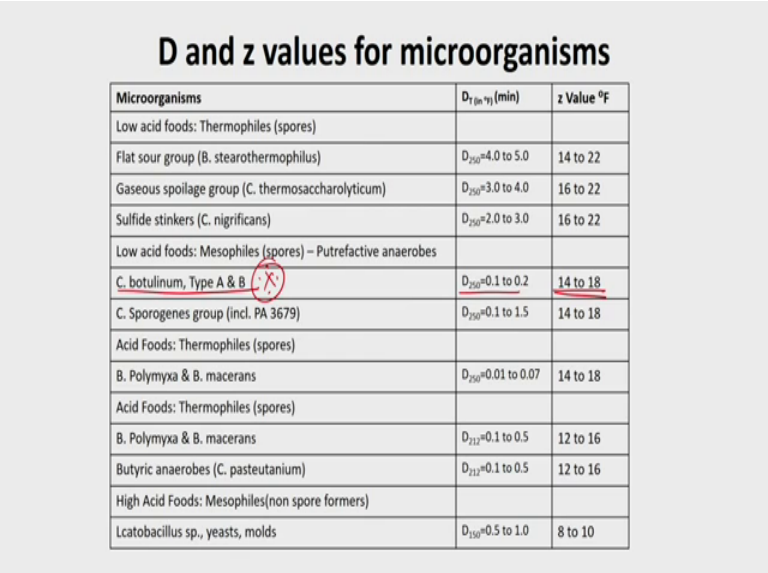

So here it is given for various microorganisms for example, if this is mainly important in the milk sterilization C. botulinum, type A and B so which requires D of 0.1 to 0.2 minutes at 250 degree Fahrenheit and which which is having a z values of 14 to 18. So these are all listed out different microorganisms and their D and z values.

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D and z values for Enzymes & Quality Attributes

Microorganisms	$D_{T\,(in\ ^oF)}$ (min)	z Value ^oF
Peroxide from black radish	$D_{80} = 232$	28
Peroxidase from green beans	$D_{80} = 15$	27
Polygalacturonase from papaya	$D_{80} = 20$	6.8
Lipoxygenase from peas	$D_{80} = 0.09$	8.5
Catalase from spinach	$D_{80} = 0.02$	8.3
Lipase from Pseudomonas spp.	$D_{120} = 25$	26
Protease from Pseudomonas spp.	$D_{120} = 300$	28
Thiamin in carrot puree (pH =5.9)	$D_{121} = 158$	25
Thiamin in pea puree (natural pH)	$D_{121} = 247$	27
Lysine in soybean meal	$D_{121} = 786$	21
Chlorophyll Ain spinach (natural pH)	$D_{121} = 34.1$	45
Anthocyanin in grape juice (natural pH)	$D_{121} = 17.8$	23.2
Betanin in beet root juice (pH 5.0)	$D_{100} = 46.6$	58.9
Carotenoids in paprika (natural pH)	$D_{60} = 0.04$	18.9

And quality attributes are given for various enzymes as well. So peroxide from black radish, peroxidase from green beans, and catalase from spinach and thiamin in carrot puree which is at pH 5.9 so what should be the if I give 121 which is nothing but the sterilization temperature, the D value is about 158, so z value is nothing but 25. So this is the way I combined D and Z values and get my quality attributes for the particular thermal processing.

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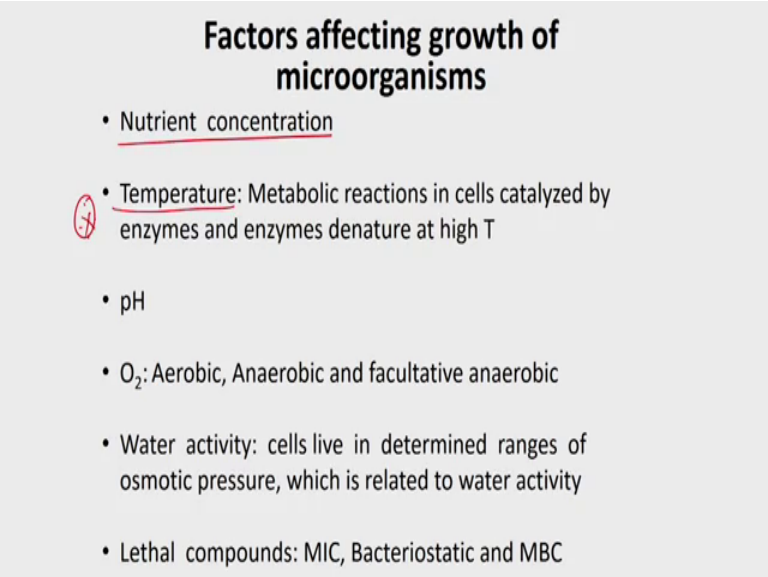

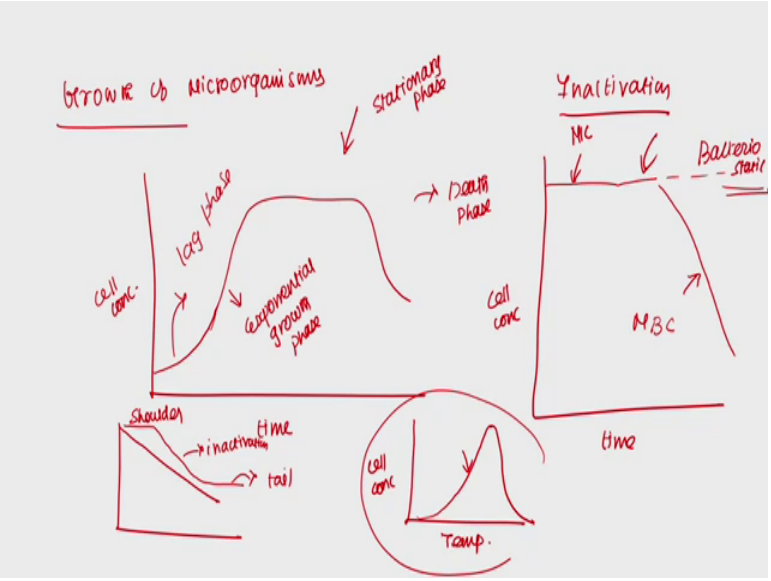

So and also here when we talk about the kinetic expressions I have already told there were few factors affecting the growth of microorganisms. So based on these factors affecting there were many models for example, temperature and pH only if they talk about they call it as a secondary model. And when they talk about activity also they call it as a tertiary model. There were many models available but still we have taken here the Arrhenius model. Arrhenius model and my microorganism inactivation is following the first order reaction. So here I talk about the growth

phase as well. So when I am talking about the inactivation, what I told is it is following linear line, so that does not happen in sometime.

Sometimes the inactivation happens something of this kind so there is something like stationary phase and there is something like decrease phase. Then we call it as this as shoulder. And this is actual inactivation. And sometimes here this becomes a tail. The shoulder is nothing but if the organism is heat resistant it will not immediately decrease. So you will not get immediate reduction in the number of viable cells.

So there will be constant period which will be called as shoulder that after that inactivation happens. It may not be a linear and there is a tail. Tail in the sense here microorganism learnt how to resist the heat. So these are all also possible but what we have discussed in this course is only about the linear inactivation of microorganisms.

So that one should keep in mind and there are many model based on your process and based on your microorganism and based on your food component, you will be able to choose which is your best model to be studied or which is the best model from the experiments one will be able to tell which model microorganisms inactivation is following. So these are all tables this you will get in the references itself.

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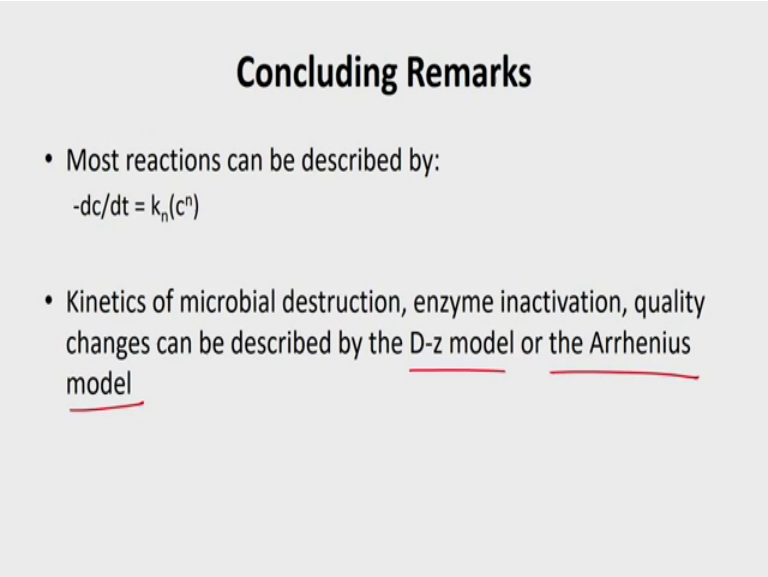

So what we have discussed today is one is most of reactions can be described by minus dc upon dt which is equivalent to kn c power n. So this we call as kinetic expression or where e kn is nothing but a rate constant which follows Arrhenius model which is nothing but k naught e power minus e by rt that is where my temperature is comes into play. We call it as a thermal processing of food or in sterilization process I am killing microorganisms by using physical action which is nothing but a temperature. And also we have studied kinetics of microbial destruction and enzyme (in in) inactivation and quality changes.

Quality changes in the sense for example, we were able to compare D and z value for one particular process which has microorganisms to deactivate at the same time my food nutrient should not get deactivate more or my enzyme activity should not be reduced more and for that which is the temperature I should choose, one example we have seen. And this can be described by D z model or Arrhenius model. So the Arrhenius model is nothing but what I told. So your z value is function of temperature which is following minus e upon rt. So we will be doing some of the problems based on whatever we learnt today so that we would be seeing probably in next few classes.

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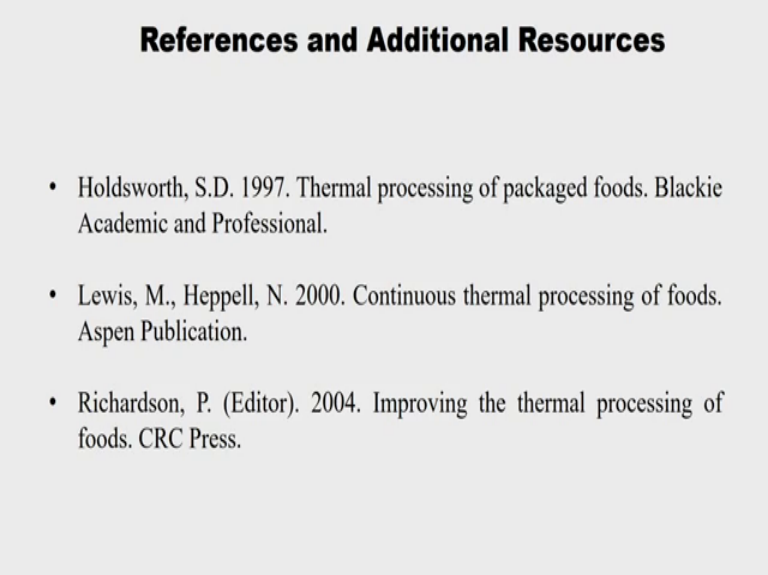

So this is references and additional resources which you would like to refer for further clarifications. Thank you.