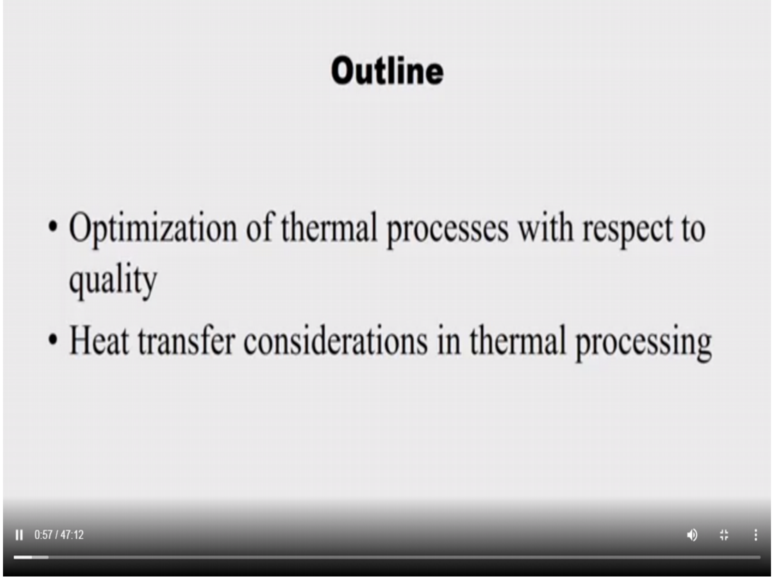
Thermal Processing of Foods
Professor R. Anandalakshmi
Department of Chemical Engineering
Indian Institute of Technology, Guwahati
Lecture 09 - Quality Considerations and Process Optimization

Good afternoon all. Today in continuation to yesterday's lecture, so we are going to see today quality considerations and process optimization in thermal processing of food. So the outline goes like this:

(Refer Slide Time: 00:48)

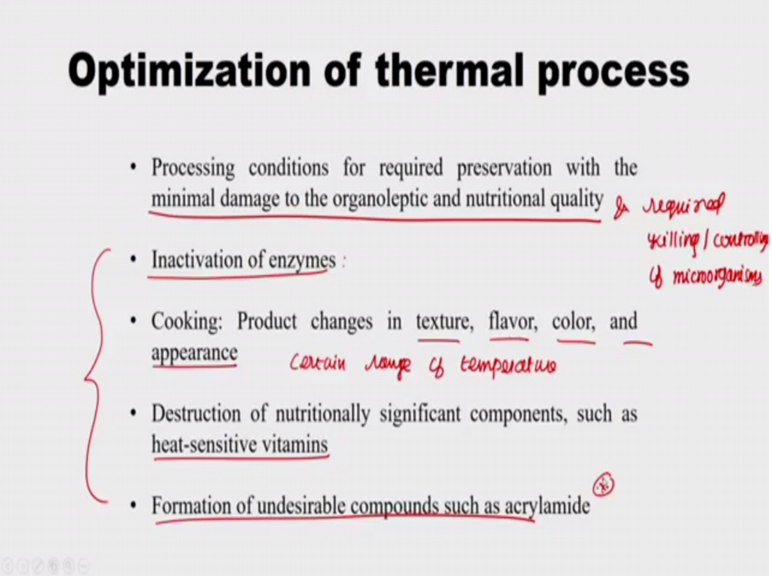


Outline

- Optimization of thermal processes with respect to quality
- Heat transfer considerations in thermal processing

The optimization of thermal processes with respect to quality and the heat transfer considerations in thermal processing and also if time permits we would like to see some of the examples, how to really optimize the thermal process.

(Refer Slide Time: 1:02)



Optimization of thermal process

- Processing conditions for required preservation with the minimal damage to the organoleptic and nutritional quality & required killing / controlling of microorganisms
- Inactivation of enzymes :
- Cooking: Product changes in texture, flavor, color, and appearance certain range of temperature
- Destruction of nutritionally significant components, such as heat-sensitive vitamins
- Formation of undesirable compounds such as acrylamide

So the optimization of thermal processes talks about the processing conditions for which the preservation with the minimal damage to the organoleptic as well as the nutritional quality. So normally thermal processing can be done for either one of the reason, one for maybe for sterilization or some foods it is for pasteurization. So when you do that the main aim was to inactivate the microorganisms, they may be spoilage organisms, so which may be killed or controlled and one more is the disease causing microorganisms, which are pathogens. To kill them also we do thermal processing.

Along with that there is a nutritional quality damage also, so we suppose to design a thermal process which will not damage more nutritional quality as well as it also has to kill the required level of microorganisms. So the optimization is something like minimal damage to this one and the required killing or controlling of microorganisms.

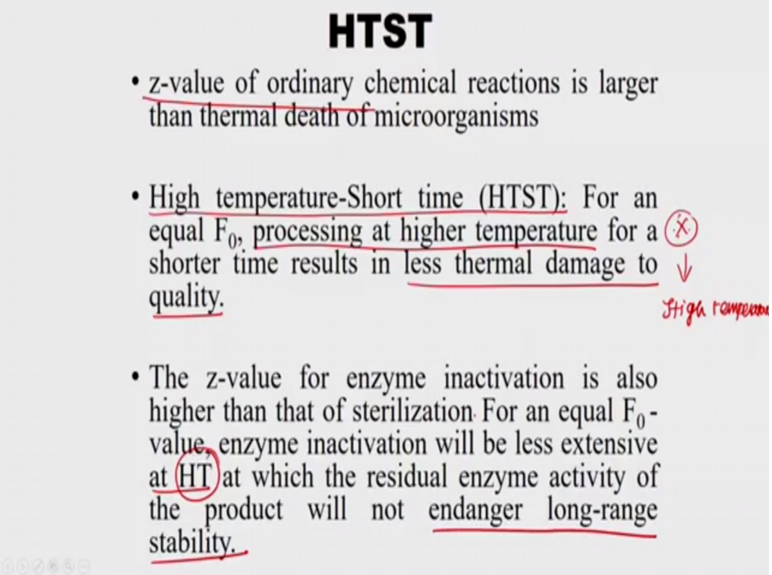
So along with this process there were few other process are also accompanied. The first one is inactivation of enzymes. So this is with respect to microorganisms. This is decided for long-term storage. Because the moment you increase the temperature the enzymes gets deactivated, due to that some of the metabolic reactions within the microorganisms gets damaged. So because of that also microorganisms gets killed.

So the enzymes which are required for metabolic reactions of microorganisms, if they get killed, if they get inactivated, then it is a desirable for long-term storing. Another one is along with this the cooking also happens. So that means the product changes in texture, flavor, color and appearance. So, this is decided certain range of temperature, but beyond certain range it is not favorable. For example, the food should be appealing, so if it is get fried too much, then we will not be liking it.

So there is a certain range of temperature, certain range of temperature, so this is actually a favorable but beyond certain range it is a problem. Another one is destruction of nutritionally significant components such as heat sensitive vitamins. So this also gets inactivated not only the enzymes which are favorable for microorganism metabolic reactions, but heat-sensitive vitamins, which are useful for us also gets denature.

So that is unwanted thing and sometimes what happens is some undesirable components. The example is acrylamide. So which also gets, maybe say it as a side reactions. So these kind of components also produced during thermal processing. So we need to take care all of them together when you design any thermal process.

(Refer Slide Time: 4:30)



HTST

- z-value of ordinary chemical reactions is larger than thermal death of microorganisms
- High temperature-Short time (HTST): For an equal F_0, processing at higher temperature for a shorter time results in less thermal damage to quality.
- The z-value for enzyme inactivation is also higher than that of sterilization. For an equal F_0-value, enzyme inactivation will be less extensive at HT at which the residual enzyme activity of the product will not endanger long-range stability.

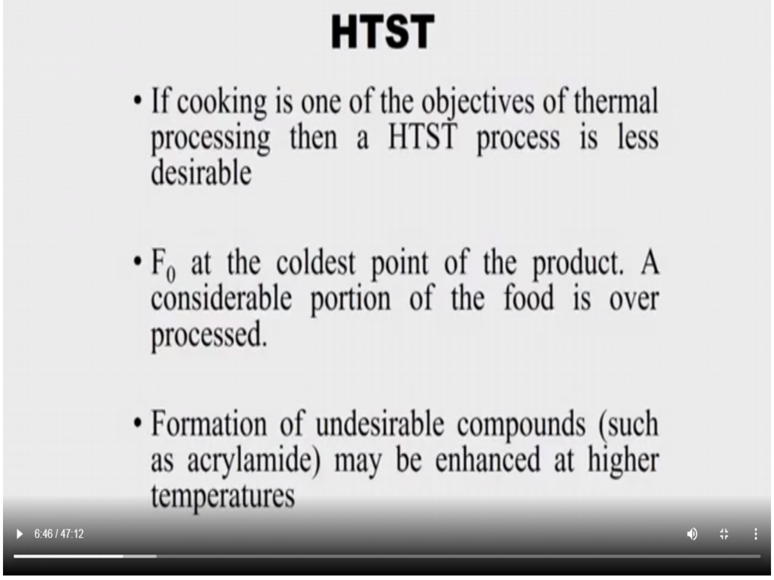
ⓧ
↓
High tempera

So we have already seen some of the examples as well as we discussed a lot about the z value. So if you remember the kinetic expression classes, we have also compared two cases, the vitamin destruction as well as the microorganism inactivation. So in that if you remember the z value for any ordinary chemical reaction is normally larger than the thermal death of the microorganisms. So for that case the concept of high temperature short time is introduced. So for an equal, F naught, F naught, also we have already discussed in the class. So, the processing at high temperature for a short time, so since my z value is higher for most of the chemical reactions, so I would like to go for higher temperature for a shorter time, so instead of lower temperature for higher time.

So, which results lesser thermal damage to the quality of the food as well as the quality of the vitamins or nutritional components. So this concept is introduced based on the z value which are higher than for most of the chemical reactions compared to thermal death of microorganisms. And one more thing is, here what we need to be a bit careful about is, the temperature what you choose, the high temperature. So that is within the favorable range of the particular nutritional quality. The higher temperature what I choose itself a denature the enzyme, then there is no point in going for that particular temperature.

So the temperature also should be optimized as a high temperature in which there should not be any denature of the enzyme. So z value for enzyme inactivation is also higher than the sterilization. So this we have already seen, so we have already discussed for an equal F naught value enzyme deactivation will be less extensive at HT, HT means higher temperature at which the residual enzyme activity of the product will not endanger the long range stability. This is what I told, so I have to choose high temperature in such a way that it should not endanger the long range stability of the product.

(Refer Slide Time: 6:46)

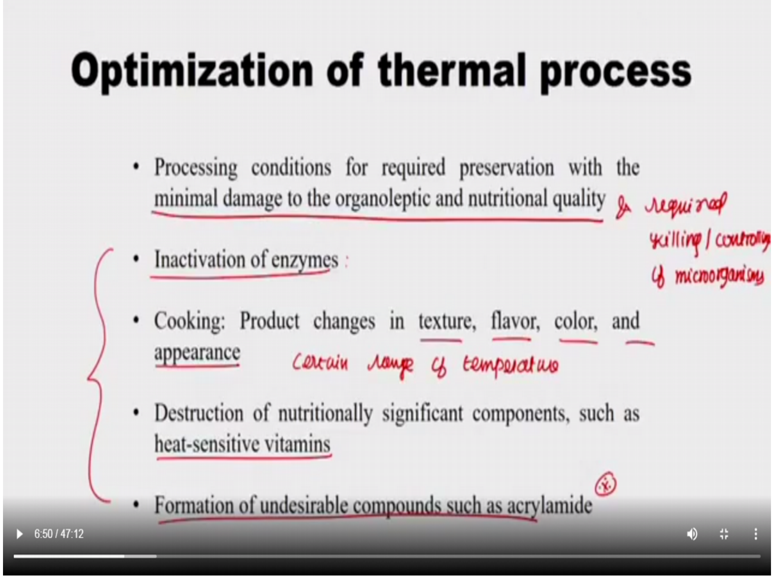


HTST

- If cooking is one of the objectives of thermal processing then a HTST process is less desirable
- F_0 at the coldest point of the product. A considerable portion of the food is over processed.
- Formation of undesirable compounds (such as acrylamide) may be enhanced at higher temperatures

And also what happens at HTST?

(Refer Slide Time: 6:49)

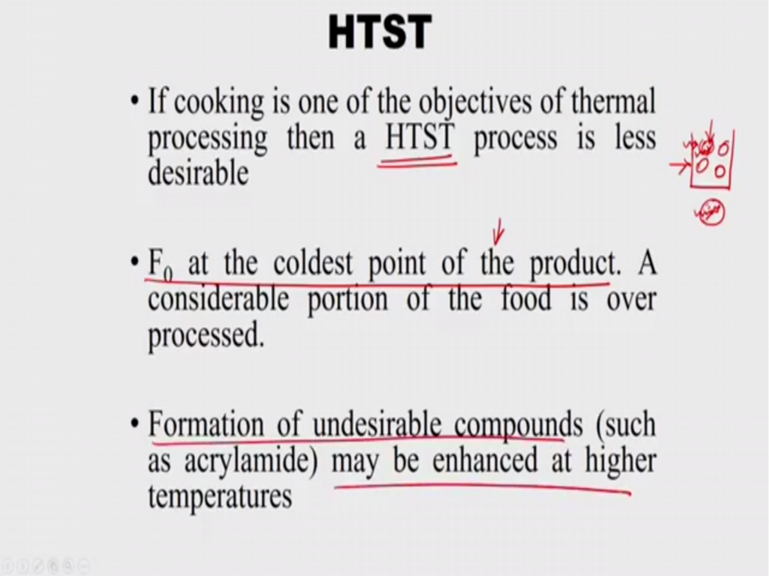


Optimization of thermal process

- Processing conditions for required preservation with the minimal damage to the organoleptic and nutritional quality & required killing / controllin of microorganisms
- Inactivation of enzymes :
- Cooking: Product changes in texture, flavor, color, and appearance certain range of temperature
- Destruction of nutritionally significant components, such as heat-sensitive vitamins
- Formation of undesirable compounds such as acrylamide

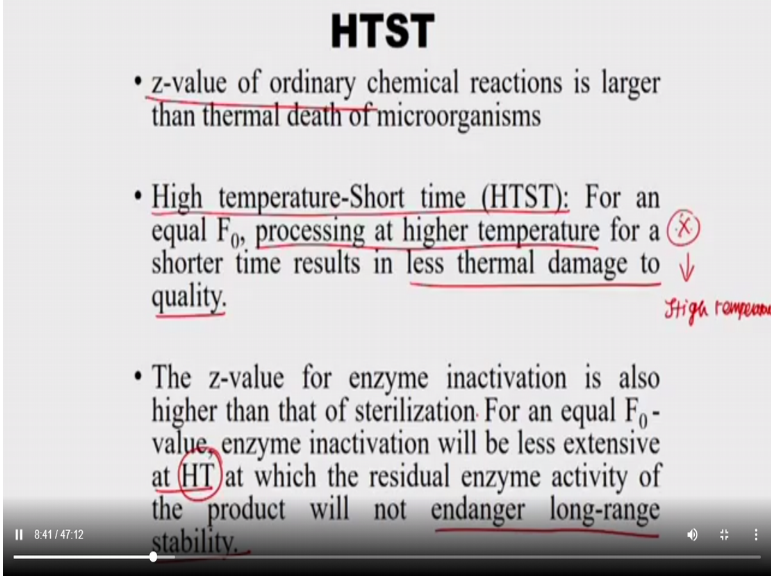
We have seen four qualities, one is inactivation of enzyme. So this also to be considered when you choose the high temperature.

(Refer Slide Time: 6:58)



HTST

- If cooking is one of the objectives of thermal processing then a HTST process is less desirable
- F_0 at the coldest point of the product. A considerable portion of the food is over processed.
- Formation of undesirable compounds (such as acrylamide) may be enhanced at higher temperatures



HTST

- z-value of ordinary chemical reactions is larger than thermal death of microorganisms
- High temperature-Short time (HTST): For an equal F_0, processing at higher temperature for a shorter time results in less thermal damage to quality.
- The z-value for enzyme inactivation is also higher than that of sterilization. For an equal F_0-value, enzyme inactivation will be less extensive at HT at which the residual enzyme activity of the product will not endanger long-range stability.

The next point is cooking. So if cooking is one of the objective of the thermal processing, so then HTST process is less desirable. So what happens for example, so I have a can, so inside my food product is there. So, my one of the aim is cooking the product also, so that means what happens? So, it has to, the heat has to pass through the packing material and also it has to pass through the food particle or food product.

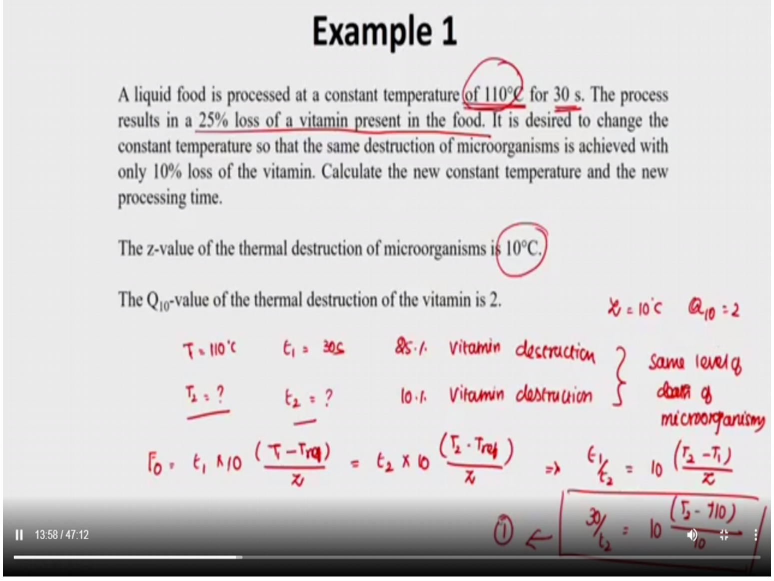
So what happens, normally the coldest point of the food, so that will be based on the geometric shape. So mostly it happens to be at the center. For example, this is the particle. So this is the way heat conducts through if it is a solid product. So this is the coldest point, so the remaining places the temperature would be higher than the coldest point. So what happens, so certain places your food is overcooked, certain places it is undercooked. So this kind of temperature gradient would occur.

So if cooking is one of the objectives then the going for HTST is less desirable because at that high temperature one part of food is overcooked other part of food is not cooked, not cooked in the sense it is either at the desired temperature or maybe at lower than the desired temperature.

So then the F naught at the coldest point is taken into account while I am deciding the time, the F naught is nothing but a time, so if I decide the time, then I will be taking into account the my coldest point of the product also reaches the my target temperature. So in that case the remaining portion would be over-processed. Another one is the formation of the undesirable components, this also get enhanced at higher temperature. So even though when you choose the HTST, that is nothing but high temperature short time process, so you need to be taking into account all these things, how to take care of the overcooking product.

And one more thing is the high temperature should be chosen based on the denaturing of the enzyme and we have to take care about the any undesirable component which gets produced at that particular temperature as well.

(Refer Slide Time: 9:04)



Example 1

A liquid food is processed at a constant temperature of 110°C for 30 s. The process results in a 25% loss of a vitamin present in the food. It is desired to change the constant temperature so that the same destruction of microorganisms is achieved with only 10% loss of the vitamin. Calculate the new constant temperature and the new processing time.

The z-value of the thermal destruction of microorganisms is 10°C.

The Q_{10}-value of the thermal destruction of the vitamin is 2.

$z = 10°C \quad Q_{10} = 2$

$T = 110°C \quad t_1 = 30s$ 25% Vitamin destruction

$T_2 = ? \quad t_2 = ?$ 10% Vitamin destruction

same level of death of microorganisms

$$F_0 = t_1 \times 10^{\left(\frac{T - T_{ref}}{z}\right)} = t_2 \times 10^{\left(\frac{T_2 - T_{ref}}{z}\right)} \Rightarrow \frac{t_1}{t_2} = 10^{\left(\frac{T_2 - T_1}{z}\right)}$$

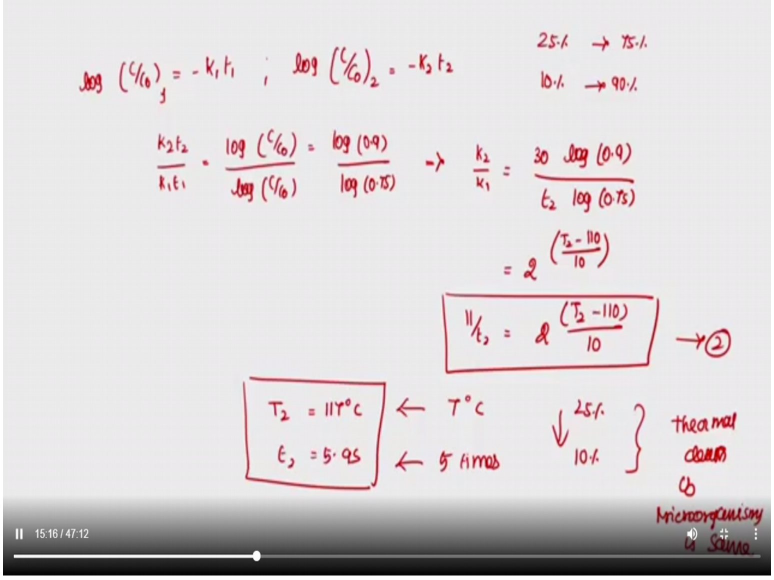
$$① \leftarrow \boxed{\frac{30}{t_2} = 10^{\frac{(T_2 - 110)}{10}}}$$

So this example talks about the liquid food is processed at constant temperature 110 degree for 30 second. So the process results in 25 percentage of the vitamin present in the food, so it is decided to change the constant temperature, constant temperature in the sense this they are going to change, so that the same destruction of microorganisms achieved. So the both the process, one is T 1 is 110 degree and the small t 1 this is nothing but 30 second. So this results 25 percentage of the vitamin destruction. But I do not know what is my T2 and I also do not know what is my small t 2 which gets 10 percentage vitamin loss.

In both the process I took the same level of death of microorganisms. So now calculate the new temperature. This side we have to calculate and the new processing time. So z value of the microorganism is given, z equal to 10 and Q 10 value is also given which is 2. So this Q10, is it F naught, F everything you would be familiar. I hope so, because we have discussed extensively in last classes.

So the first one is, F naught, so this is nothing but T 1 into 10 to the power of T 1 minus T reference upon z. So, if I want to compare the same F naught value, so that is what they supposed to tell the same destruction of microorganisms 10 T 2 minus T reference upon z, so which would give me T 1 upon T 2 which is nothing but T 2. Because, this will come as minus T 1 upon z, so T 1 I know 30 upon T 2 which is nothing but 10 to the power of T 2 minus this also I know 110 divided by 10. So this I got it. So this is this I did it based on F naught value. So now another thing is also given.

(Refer Slide Time: 11:53)



$\log\left(\frac{C}{C_0}\right)_1 = -k_1 t_1$; $\log\left(\frac{C}{C_0}\right)_2 = -k_2 t_2$

25% → 75%

10% → 90%

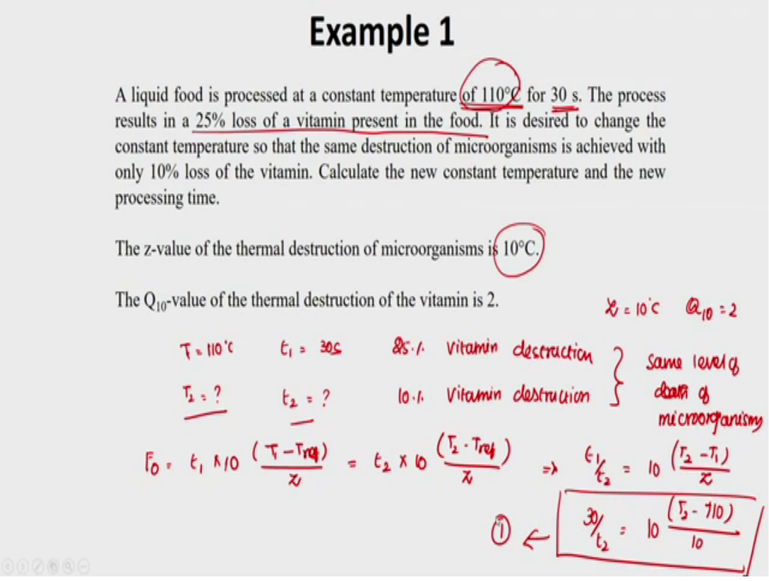
$$\frac{k_2 t_2}{k_1 t_1} = \frac{\log\left(\frac{C}{C_0}\right)}{\log\left(\frac{C}{C_0}\right)} = \frac{\log(0.9)}{\log(0.75)} \rightarrow \frac{k_2}{k_1} = \frac{30 \log(0.9)}{t_2 \log(0.75)}$$

$$= 2^{\left(\frac{T_2-110}{10}\right)}$$

$$\boxed{\frac{11}{t_2} = 2^{\frac{(T_2-110)}{10}}} \rightarrow ②$$

$$\boxed{\begin{matrix} T_2 = 117^\circ C \\ t_2 = 5.95 \end{matrix}} \begin{matrix} \leftarrow T^\circ C \\ \leftarrow 5 \text{ times} \end{matrix}$$

$\downarrow$ 25% 10% } thermal death of microorganisms is same



Example 1

A liquid food is processed at a constant temperature of 110°C for 30 s. The process results in a 25% loss of a vitamin present in the food. It is desired to change the constant temperature so that the same destruction of microorganisms is achieved with only 10% loss of the vitamin. Calculate the new constant temperature and the new processing time.

The z-value of the thermal destruction of microorganisms is 10°C.

The Q_{10}-value of the thermal destruction of the vitamin is 2.

$z = 10^\circ C$ $Q_{10} = 2$

$T = 110^\circ C$ $t_1 = 30s$ 25% vitamin destruction

$T_2 = ?$ $t_2 = ?$ 10% vitamin destruction } same level of death of microorganisms

$$F_0 = t_1 \times 10^{\frac{(T-T_{ref})}{z}} = t_2 \times 10^{\frac{(T_2-T_{ref})}{z}} \Rightarrow \frac{t_1}{t_2} = 10^{\frac{(T_2-T_1)}{z}}$$

$$① \leftarrow \boxed{\frac{30}{t_2} = 10^{\frac{(T_2-110)}{10}}}$$

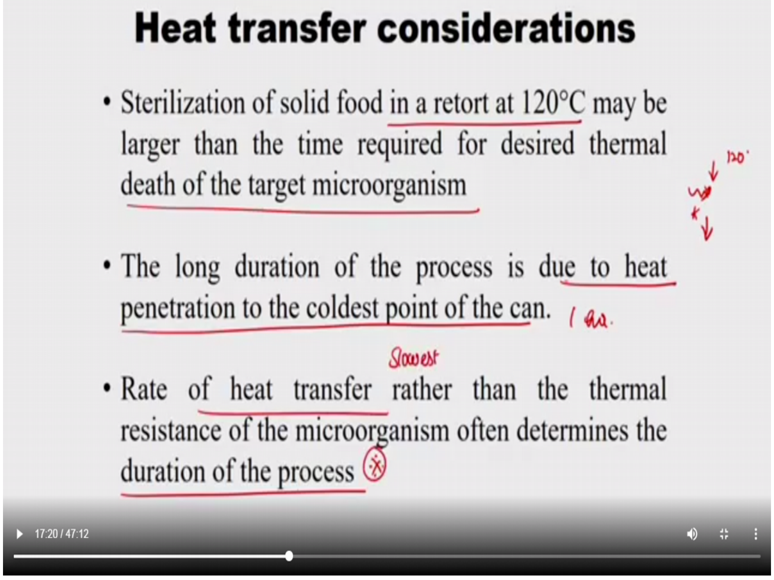
So, my log reduction is given, log of C upon C naught. Because it is a destruction of enzyme, so that is nothing but K 1 T 1 so I will put it the first thing, so another one is log of C upon C naught. So, at second case minus K 2 upon T 2. So, if you take it this one K 2 T 2 upon K 1 T

1 is nothing but log of C upon C not which is nothing but log of what we told is 25 percentage destruction. And another one what they have given is 10 percentage. So remaining would be 75 percentage. So here remaining would be 90 percentage.

So in the second case we have 0.9, so divided by log of C upon C naught. So in the second case it will be log of 0.75, so which gives me K 2 upon K 1 which is nothing but 30 into log of 0.9 divided by T 2 log of 0.75, so which is equivalent to 2 into T 2 minus 110 divided by is what is 10. So this you do the calculation. So what I have done already, so what we got is K 1 K 2, so this is there. So it is something like 11 upon T 2 which is equivalent to 2 into T 2 minus 110 upon 10. So I have my second equation here. And this is my first equation.

So compare both and we got around 117 degree centigrade and T 2 is 5.9 second. So this is the way I need to fix the temperature. So what it was asked this so instead of 25 percentage loss of vitamin, so I will get 10 percentage loss of vitamin, instead of if it is processing at 110 degree at 30 second, so now we are processing at 117 degree at 5.9 second. So the temperature is increased here 7 degree, but almost six times reduction in your time, so earlier it was processed at 30 second. So now it is going to be processed at 5.9 second almost 6 seconds, so I should say five times reduction. So this would give me 25 percentage loss of vitamin to 10 percentage loss of vitamin but both the cases my thermal death of organism is same. Let us see. So this is the way I optimize the process.

(Refer Slide Time: 15:18)



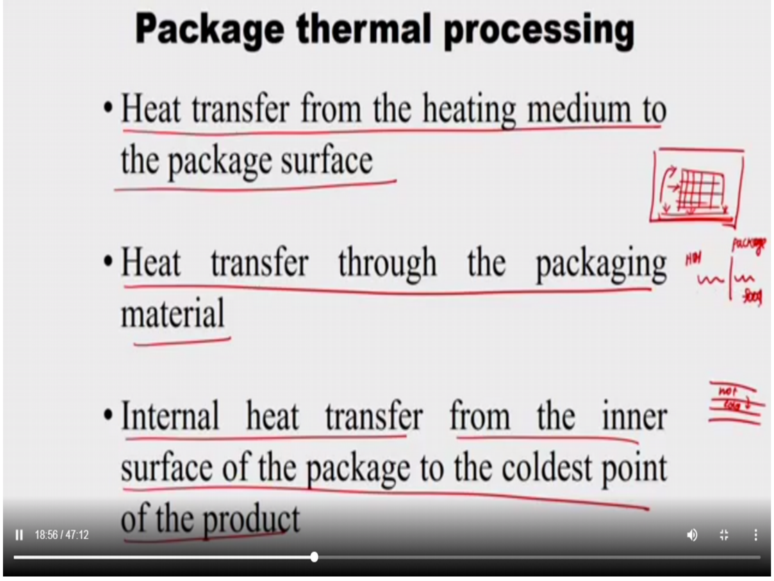
Heat transfer considerations

- Sterilization of solid food in a retort at 120°C may be larger than the time required for desired thermal death of the target microorganism
- The long duration of the process is due to heat penetration to the coldest point of the can.
- Rate of heat transfer rather than the thermal resistance of the microorganism often determines the duration of the process

So now the second one is the heat transfer consideration. So when I take when I sterilize what are all the heat transfer considerations, so I need to take. So normally sterilization of solid food in a retort at 120 degree may be larger than the time required for desired thermal death of the target microorganism. So normally what we say is okay. So this particular temperature you need to process at particular time. For example, last example, we have seen if it is 117 degrees if we are maintaining so it should be processed at six years for the desired thermal death. So normally what happens is we already discussed about. So it is the temperature of the coldest point of the food, so that should reach at 120 so that my target of thermal processing would be complete.

So more than the thermal death of target organism the time required is chosen based on the heat transfer considerations of the food product. For example, so if it has less thermal conductivity, if it is a solid food, if it has less thermal conductivity, it will take longer time for the temperature to reach the coldest point. So based on this slowest process, normally we know any kinetic process consideration has to be decided based on the slowest step. So the slowest step here is nothing but the heat penetration to the coldest point of the can. So this thermal death of microorganism can happen in 2 seconds or 3 seconds or 4 seconds, but this heat penetration takes almost one hour. So the process is designed for 1 hour, than 3 minute which causes the death of target microorganism. So, rate of heat transfer process rather than the thermal resistance of the microorganism often determines the duration of the process. So, this is the slowest step. So based on this only I will decide my duration of the process.

(Refer Slide Time: 17:21)



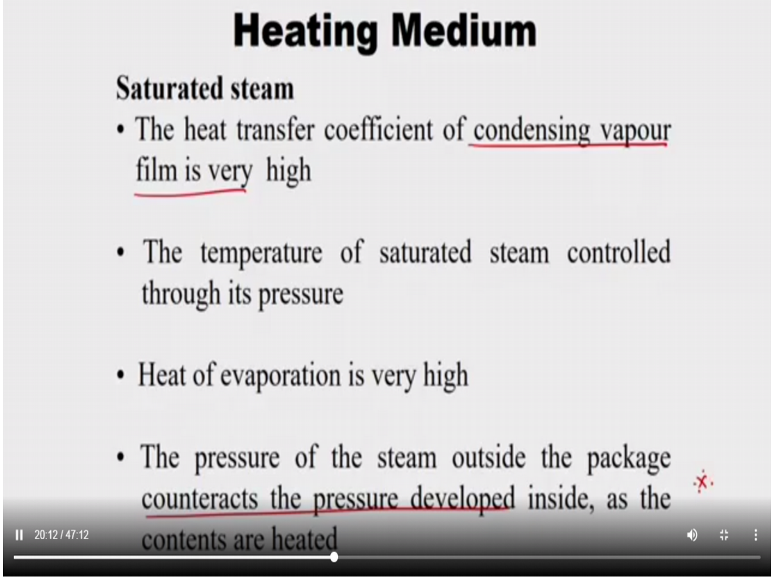
Package thermal processing

- Heat transfer from the heating medium to the package surface
- Heat transfer through the packaging material
- Internal heat transfer from the inner surface of the package to the coldest point of the product

So if that is the case, so what are all the thermal resistance involved in packaging thermal processing? The first one is for example, I have a retort. So in this retort, my product is kept so here I have in the wall I have the spray nozzles for the heating medium to be in. The first thing is heat transfer from the heating medium to the package surface. So the steam to package surface that is one kind of heat transfer. Another is heat transfer through the packaging material, packaging material in the sense the pack. So first one is, this is heat transfer medium HRM sorry HTM, heat transfer medium to the packaging and packaging to the food. So this is your food.

So 3 kind of, one is, another is internal heat transfer from the inner surface of the package to the coldest point of the product. So you might be familiar with this procedure because if the counter is you take any heat exchanger double pipe heat exchanger, so what happens is this is my for example hot fluid. This is cold fluid. So this hot fluid should pass through the wall of the cold fluid, then the heat transfer happens. The same thing here, from the heat transfer medium to package, package to food, so internal heat transfer, heat transfer through the packaging and heat transfer from the heating medium to the packaging.

(Refer Slide Time: 19:01)



Heating Medium

Saturated steam

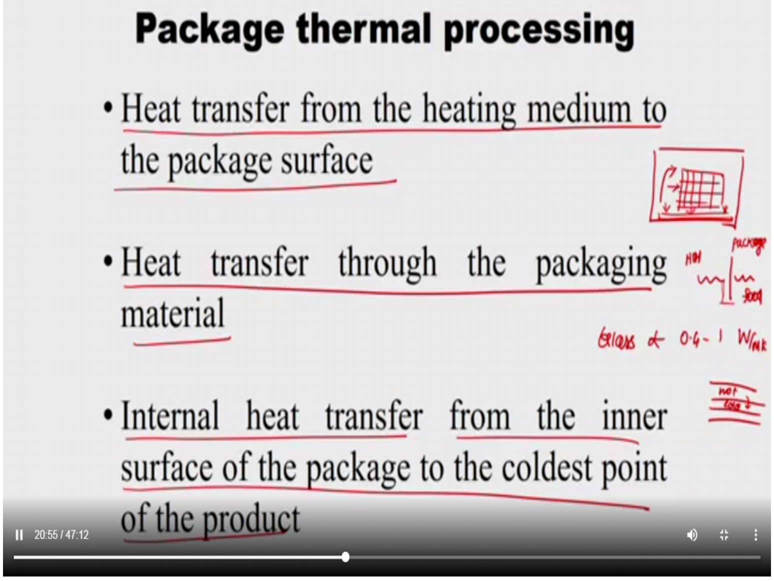
- The heat transfer coefficient of condensing vapour film is very high
- The temperature of saturated steam controlled through its pressure
- Heat of evaporation is very high
- The pressure of the steam outside the package counteracts the pressure developed inside, as the contents are heated

So what are all the heating medium, famous heating medium used is the most famous is saturated steam. So because of the following reasons, one is heat transfer coefficient of the condensing vapor film is high. So that means what happens, so when the heating medium is given into the retort, so after some time, so the condensing vapor forms the film near the packaging.

If the heat transfer coefficient of the particular film is low, then that will also add up extra resistance in for the heat transfer. So this is very high. So we will not be having any issue. So that is the one reason. Another is the temperature of the saturated stream controlled through its pressure. So the pressure and temperature relation is well and good in saturated steam. So that is another reason and one more is heat of evaporation is high, so for particular mass of the steam the heat content carried away by the steam is high. So, that is nothing but a heat of evaporation. So that is also high and pressure of this steam outside of the packaging counteracts the pressure. This is very much important because otherwise the rupture of the packaging occurs.

So most of the food contains the water inside, so the pressure developed inside and outside the packaging will counterbalance and there will not be any rupture of the packaging. So for these reasons steam is, saturated steam is favorable, but also there is a disadvantage.

(Refer Slide Time: 20:28)

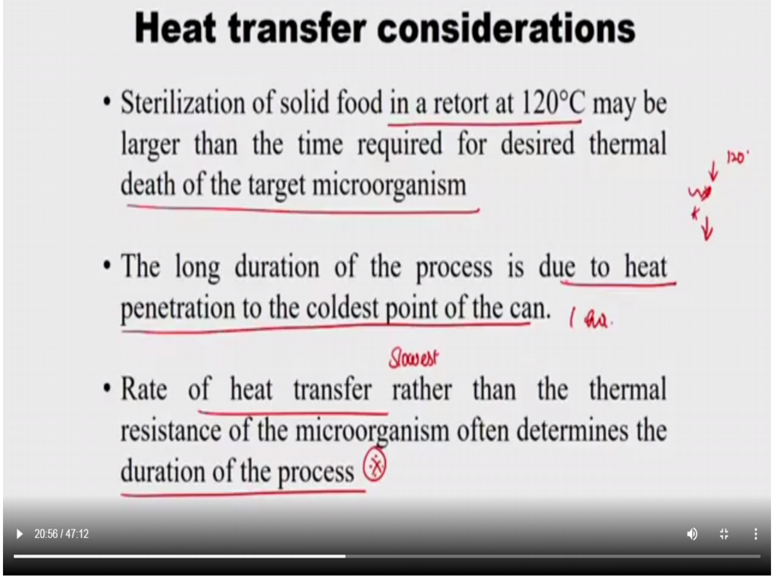


Package thermal processing

- Heat transfer from the heating medium to the package surface
- Heat transfer through the packaging material
- Internal heat transfer from the inner surface of the package to the coldest point of the product

So as I told earlier it is not only the heat transfer medium which transfers heat efficiently, but it also has to pass through the packaging. So if you have a packaging of low thermal conductivity material, for example glass, so the glass the thermal conductivity varies between 0.4 to 1 watt per meter Kelvin. So in such case what happens is there will be thermal gradient in the packaging material.

(Refer Slide Time: 20:56)

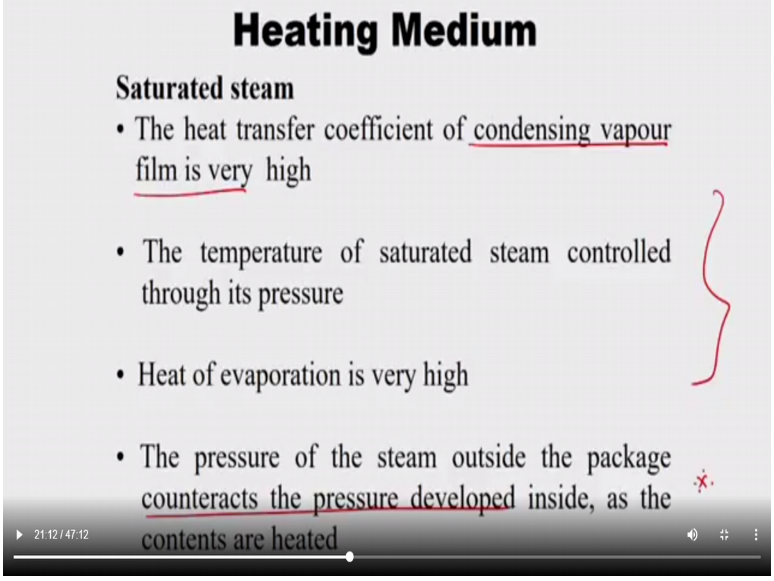


Heat transfer considerations

- Sterilization of solid food in a retort at 120°C may be larger than the time required for desired thermal death of the target microorganism
- The long duration of the process is due to heat penetration to the coldest point of the can.
- Rate of heat transfer rather than the thermal resistance of the microorganism often determines the duration of the process

So this thermal gradient causes the thermal stresses, but you are outside your steam will be of high pressure. So this thermal stress is also there which is developed for low thermal conductivity material. So this is this makes unfavorable situation.

(Refer Slide Time: 21:12)



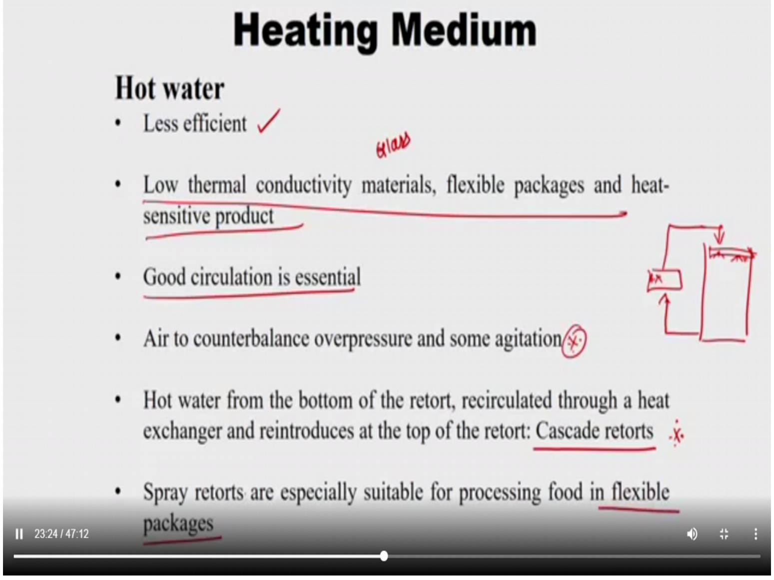
Heating Medium

Saturated steam

- The heat transfer coefficient of condensing vapour film is very high
- The temperature of saturated steam controlled through its pressure
- Heat of evaporation is very high
- The pressure of the steam outside the package counteracts the pressure developed inside, as the contents are heated

So we have a certain advantages of these kind but also one needs to take care the packaging material, whether it is a low thermal conductivity or high thermal conductivity. So that is one issue with the saturated steam.

(Refer Slide Time: 21:25)



Heating Medium

Hot water

- Less efficient ✓
- Low thermal conductivity materials, flexible packages and heat-sensitive product
- Good circulation is essential
- Air to counterbalance overpressure and some agitation
- Hot water from the bottom of the retort, recirculated through a heat exchanger and reintroduces at the top of the retort: Cascade retorts
- Spray retorts are especially suitable for processing food in flexible packages

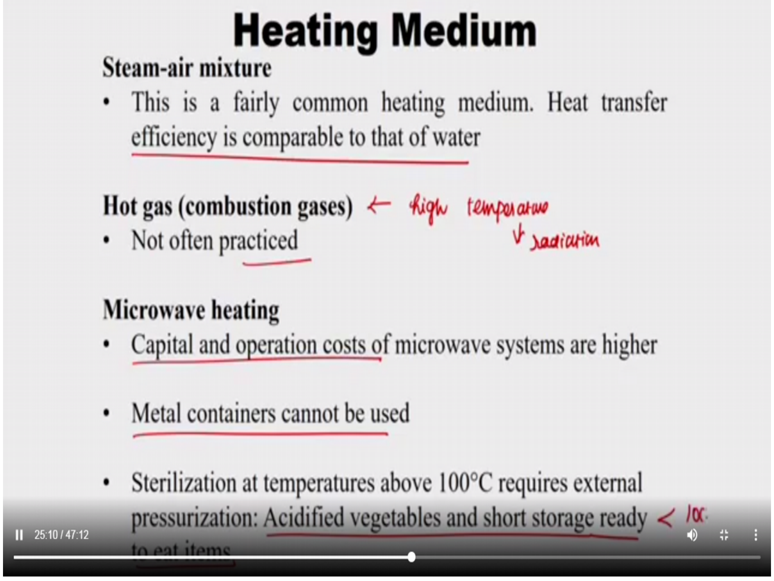
And hot water is also another heating medium. So compared to saturated steam this is less efficient and where it is favorable means so this is what I told low thermal conductivity material, it is nothing but the glass. So the K when there is a thermal gradient developed in the glass which is nothing but a low thermal conductivity material the hot water is outside. So you will not have much thermal gradient between the heat transfer medium and the packaging material. So in such cases hot water is a favorable one and good circulation is essential.

So if good circulation of hot water is not there then we will develop cold points in heat transfer medium as well. So to avoid that good circulation is also essential and air to counterbalance over pressure and some agitation. So sometimes what happens along with the hot water they send air also to counterbalance the overpressure and sometimes agitation is also needed to enhance the heat transfer.

So there is something called cascade retorts. The cascade retorts are nothing but so you have a retort. So what happens is here I have a perforated plates, hot water is sent through this then bottom I will take it up and put a heat exchanger then heat it up again, then it is circulated. So this is nothing but a cascade retorts to avoid any temperature gradient in the hot water itself, the temperature gradient in the sense to keep it uniform particular temperature. So this kind of design also tried and spray retorts are nothing but you have sprays in the wall of the retort, so through which your steam is being fed inside the retort.

So this is mostly happens in the flexible packages. So flexible packages, we use spray retorts and if it is a hot water we use cascade retorts the bottom we collect the hot water and again heat it and give it to top and hot water is used as a heating medium, especially when low thermal conductivity materials are tried as a packaging material.

(Refer Slide Time: 23:40)



Heating Medium

Steam-air mixture

- This is a fairly common heating medium. Heat transfer efficiency is comparable to that of water

Hot gas (combustion gases) ← high temperature ↓ radiation

- Not often practiced

Microwave heating

- Capital and operation costs of microwave systems are higher
- Metal containers cannot be used
- Sterilization at temperatures above 100°C requires external pressurization: Acidified vegetables and short storage ready to eat items < 100

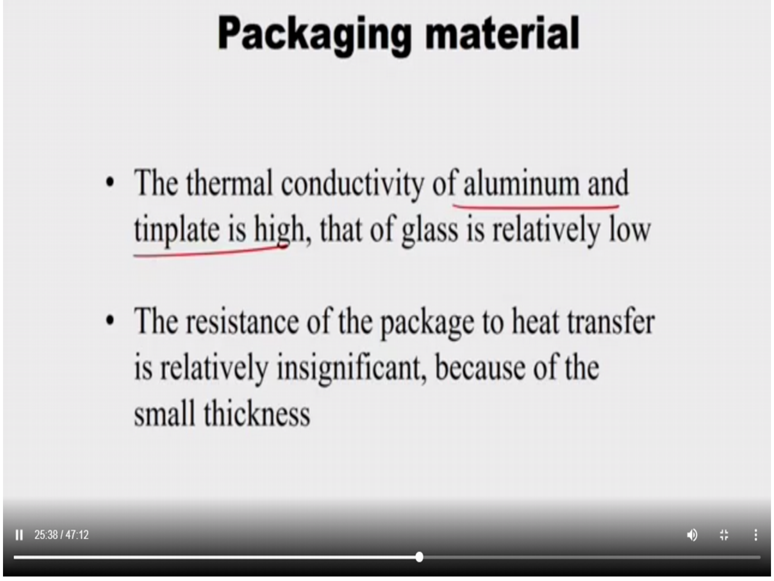
And other heating mediums are steam and air mixture. This is also fairly common heating medium and this efficiency is comparable to the tough water because steam alone having good efficiency, but sometimes it is unfavorable. Hot water is sometimes it is favorable, sometimes it is not favorable. So the steam and air mixture will give comparable efficiency of water and the hot gas also one of the heating medium, but what happens is this due to high temperature there may be a radiation heat transfer.

Mostly happens by radiation, so I do not think so this is that popular, that is also one of the heating medium and another the developing technology is microwave heating. So the moment you go for microwave heating the problem is capital and operation costs of microwave system. And also you cannot use for normal packaging material because the metal containers cannot be used that is where most of the canning process is done using metal containers. So that is one of the issue and also one of the problem is if you go for sterilization temperature, which is normally 121 degree Centigrade, then maintaining the external pressurization would be a problem in microwave heating.

So for these reasons microwave heating is not picked up that well, but there are some acidified vegetables and short storage ready to eat meals. This is less than 100 degree

Centigrade. The pasteurization was already done using microwave heating. So these are all some light about the heating medium.

(Refer Slide Time: 25:20)



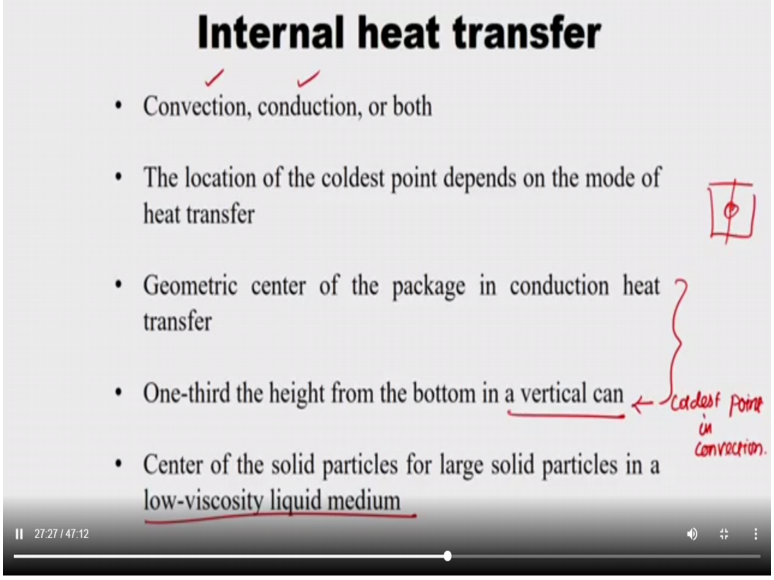
Packaging material

- The thermal conductivity of aluminum and tinplate is high, that of glass is relatively low
- The resistance of the package to heat transfer is relatively insignificant, because of the small thickness

First, heat transfer from heating medium to package. The second is packaging material. The packaging material we have already told, the thermal conductivity should be good, so for that mostly aluminum tins or tinplate is used as a packaging material because their thermal conductivity is good but glass is also used but the thermal conductivity is relatively low. So when you use glass packaging then you need to choose heating medium based on the packaging material. If you choose low thermal conductivity, then heating medium should be of water or steam air mixture. So if we are using high thermal conductivity material then saturated steam can be tried.

And most of the time this heat transfer is negligible due to the reason small thickness. The thickness of the wall is so minimum, so there will not be any appreciable heat transfer resistance. So normally it is negligible.

(Refer Slide Time: 26:13)



Internal heat transfer

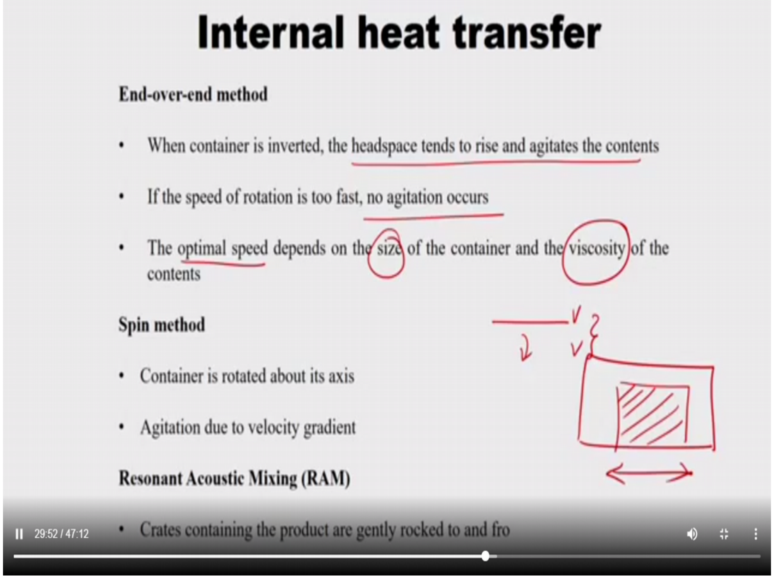
- Convection, conduction, or both
- The location of the coldest point depends on the mode of heat transfer
- Geometric center of the package in conduction heat transfer
- One-third the height from the bottom in a vertical can
- Center of the solid particles for large solid particles in a low-viscosity liquid medium

Coldest Point in Convection.

And internal heat transfer. So, internal heat transfer happens in two ways. One is conduction, another is convection, sometimes both happens. If you have a liquid food and having solid food particles, then through liquid it happens to be a convection, then in the solid particle in the solid food particle it will be a conduction. So this is something of I already told it the coldest point of the food. If it is in geometric center of the packaging in the conduction heat transfer, conduction, if you have a solid food, so then the center of the food particle is nothing but a coldest point. So if you have a vertical can which has a liquid food then one-third height from the bottom is to be regarded as a coldest point. Point in convection.

And center of solid particles for large particles in a low (viscous), low viscosity liquid medium is nothing but so your viscosity will not add any extra resistance because viscosity is nothing but a flow resistance. So if you have flow resistance, and if you are using heating so it will reduce your viscosity bit but it will add up to resistance. So if it is a low viscosity liquid medium, which has large solid particles, it is mostly taken as a conduction. So it is nothing but then coldest point will be in the center of the solid particles.

(Refer Slide Time: 27:42)



Internal heat transfer

End-over-end method

- When container is inverted, the headspace tends to rise and agitates the contents
- If the speed of rotation is too fast, no agitation occurs
- The optimal speed depends on the size of the container and the viscosity of the contents

Spin method

- Container is rotated about its axis
- Agitation due to velocity gradient

Resonant Acoustic Mixing (RAM)

- Crates containing the product are gently rocked to and fro

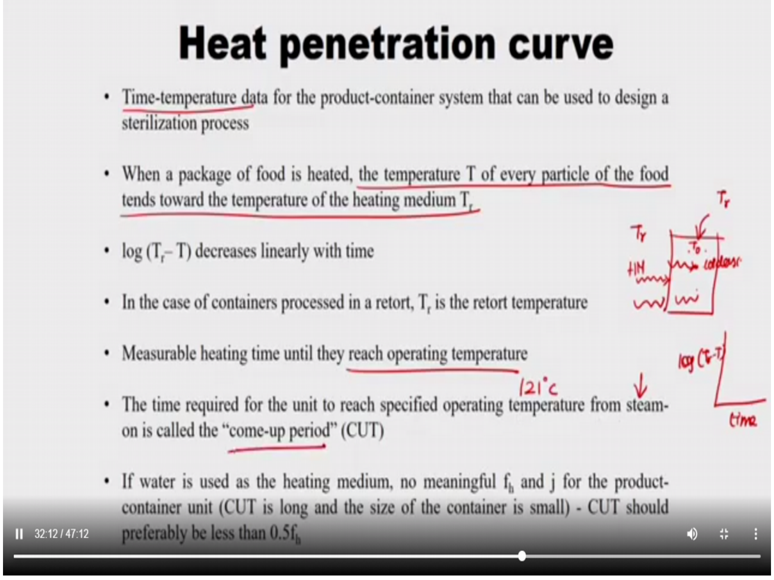
The next one is the agitation. So we have already mentioned somewhere how the heat transfer can be increased. One is the some agitation, some agitation purpose. So how the heat transfer is increased internally? Internally in the sense of when transfers from package inner wall to the food particle or the food, which is there in the container. So one is End-over-end method, another one is spin, another one is resonant acoustic mixing. The end-to-end method is nothing but I have a container which has a food. What I will do is I will agitate like this. So when you do, what happens, so this liquid go to top, then it comes here.

So when the headspace tends to rise and agitates the contents if the speed of rotation is too fast no agitation occurs. So if I do like this very very fast, so then it becomes stagnant, there will not be any agitation. So the optimal speed, you know, one is size of the container, if it is a small container then your agitation would be different compared to large because the time it takes to come here and go back will be different.

So the optimal speed how do you decide is based on your size as well as the viscosity of the content inside the packaging. Spin method is nothing but this you might have seen, so just I will rotate based on the axis. So when you rotate your router axis will have some velocity and inside food particle will have some other velocity. So based on velocity gradient, your agitation happens and resonant acoustic mixing is nothing but we have already seen this is my retort, so here I have my crates.

So this go to and fro like this. So this is the way the agitation happens and there is a vertical agitation as well. But that is picking up recently. So these are all various agitation method to increase the internal heat transfer tried in the retort.

(Refer Slide Time: 29:53)



Heat penetration curve

- Time-temperature data for the product-container system that can be used to design a sterilization process
- When a package of food is heated, the temperature T of every particle of the food tends toward the temperature of the heating medium T_r
- log $(T_r - T)$ decreases linearly with time
- In the case of containers processed in a retort, T_r is the retort temperature
- Measurable heating time until they reach operating temperature
- The time required for the unit to reach specified operating temperature from steam-on is called the "come-up period" (CUT)
- If water is used as the heating medium, no meaningful f_h and j for the product-container unit (CUT is long and the size of the container is small) - CUT should preferably be less than $0.5f_h$

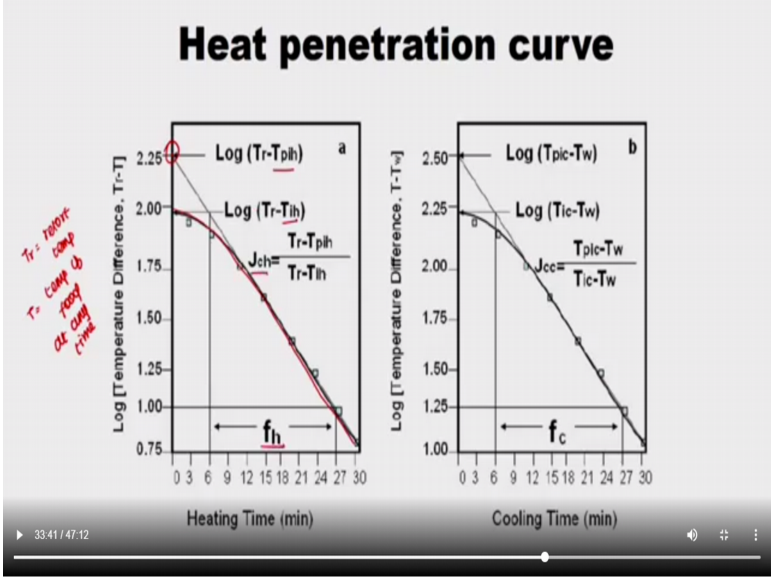
And the important topic of this lecture is this heat penetration curve. So any I would require my time temperature data for the product container system that can be used to design a thermal sterilization process. So what we have seen now, so this is my packaging. So my heat transfer medium is there, so from this heat has to conduct or convect to the packaging material, from the packaging material it would reach the coldest point.

So unless I know how this time versus temperature curve is there unless I know time versus temperature data, I will not be able to design efficient sterilization process. So for that thing I need this particular heat penetration curve. So when the temperature of the every particle of the food tends to toward the temperature of the heating medium, the heating medium we call it here as or TR. So when I give TR to heat the food products, so every food product initially at a temperature T naught so it tends to come to TR.

So I will when I plot this time versus log of TR minus t, so that is nothing but heat penetration curve. This penetration depends upon many reason, if it is a liquid viscosity is one of the parameter, if it is a solid food thermal diffusivity so that we will discuss anyway in the next subsequent classes. In case of containers process retort, TR is the retort temperature. So actually if it is a retort, it is in the retort what we told is first steam is on, so the steam if for example it is at 120 degree Centigrade, so it will take some time, the retort will take some time to reach to its steam temperature.

So that is nothing but 120 degree Centigrade. So this is to reach operating temperature it takes some time. The time required for the unit to reach specified operating temperature from steam is on is called come up period. So when I will switch on the steam, so for example, my process operating temperature is 121 degree Centigrade, so this will take some time, my retort will take some time to reach this up to particular temperature. So this is nothing but come up period we call it as CUT.

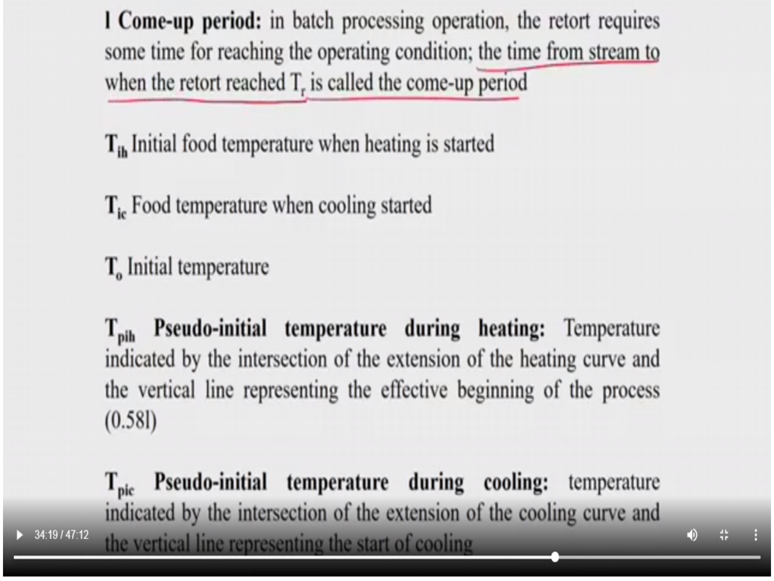
(Refer Slide Time: 32:14)


Heat penetration curve

So this is the heating curve as well as cooling curve. So what happens, I will keep my crates and in the retort then I will switch on the steam. So it will take some time to reach the particular sterilization temperature. So that is nothing but come up period then after it reaches the sterilization temperature required temperature, it will be kept at a particular time period. Then the cooling starts, starts in the sense it should come to environmental temperature.

So cooling curve as well as heating curve. So, this way my curve looks like. So this is heating time, which is in minutes versus log of temperature difference. TR minus t, so TR is nothing but here retort temperature. So this T is temperature of the food at any time. So there are certain things we need to understand but here the heating starts at zero, but we already told so it takes particular come up time. So here what I do is I will just extend this as a linear line so and it touches the y-axis at this point. So this we call it as a log of T r minus T pih. So the remember here we have certain abbreviations T pih, T ih. T r, I have already told there is something called J ch. Another is f h.

(Refer Slide Time: 33:41)



- **Come-up period:** in batch processing operation, the retort requires some time for reaching the operating condition; the time from stream to when the retort reached T_r is called the come-up period

T_{ih} Initial food temperature when heating is started

T_{ic} Food temperature when cooling started

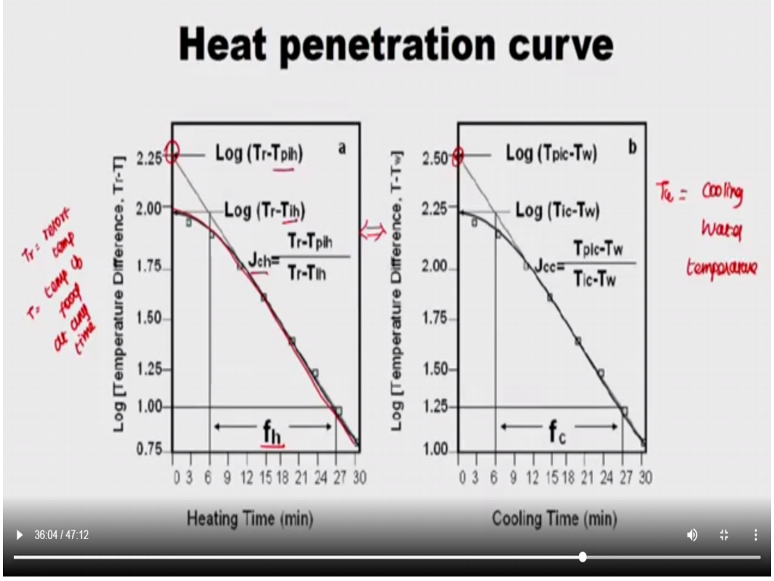
T_o Initial temperature

T_{pih} **Pseudo-initial temperature during heating:** Temperature indicated by the intersection of the extension of the heating curve and the vertical line representing the effective beginning of the process (0.58l)

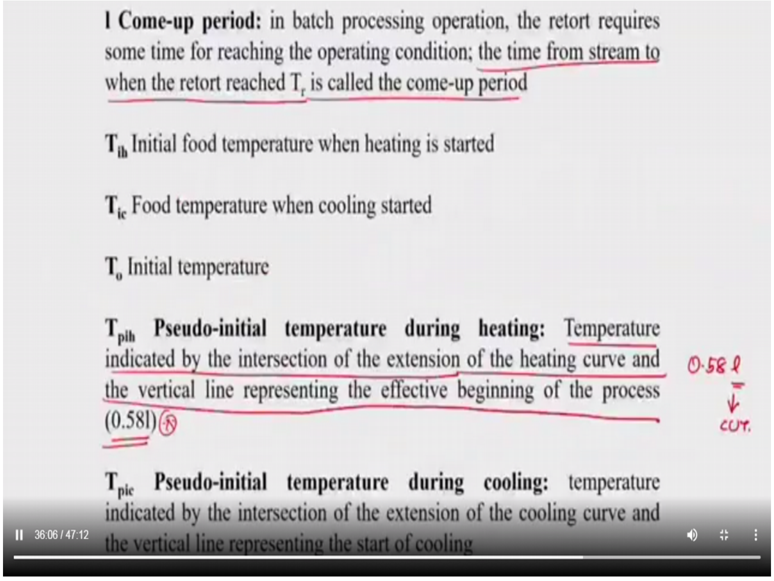
T_{pic} **Pseudo-initial temperature during cooling:** temperature indicated by the intersection of the extension of the cooling curve and the vertical line representing the start of cooling

So here it is. First one is come up period, I have already told in batch processing operation the retort require some time for reaching the operating condition. So that is nothing but the time from steam to when the retort reached T r is called come up time, this we have already seen. T ih is nothing but initial food temperature when heating is started.

(Refer Slide Time: 34:05)



Heat penetration curve



l Come-up period: in batch processing operation, the retort requires some time for reaching the operating condition; the time from stream to when the retort reached T_r is called the come-up period

T_{ih} Initial food temperature when heating is started

T_{ic} Food temperature when cooling started

T_o Initial temperature

T_{pih} **Pseudo-initial temperature during heating:** Temperature indicated by the intersection of the extension of the heating curve and the vertical line representing the effective beginning of the process (0.58l)

0.58 l
↓
CUT.

T_{pic} **Pseudo-initial temperature during cooling:** temperature indicated by the intersection of the extension of the cooling curve and the vertical line representing the start of cooling

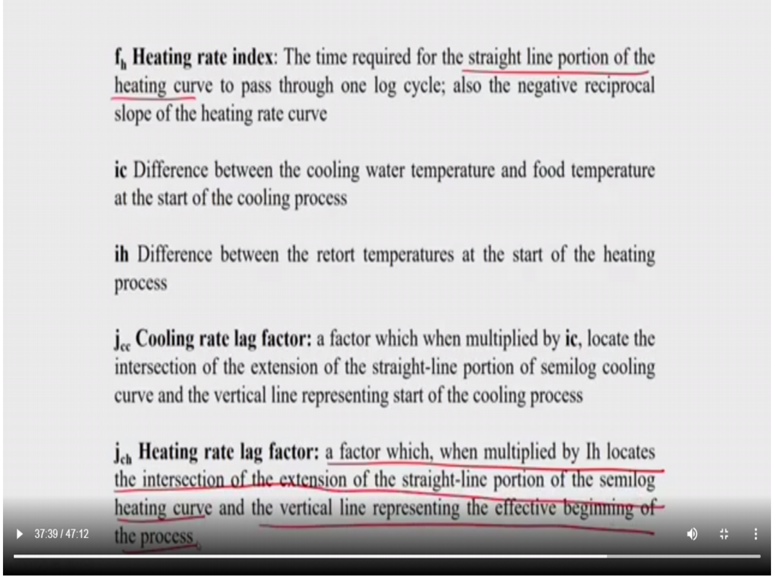
So initial food temperature when heating is started, since we have told here the temperature difference, so here it is log of T r minus T ih, and food temperature when cooling is started. So this is comparable diagram, heating as well as cooling. So here it is T ic, so T w here is cooling water temperature.

Initial temperature as T naught, initially food is at initial temperature and pseudo initial temperature during heating. So that is what I told here, the we have to see what is T pih, pseudo initial temperature during heating. So this is nothing but temperature indicated by the intersection of extension of the heating curve and the vertical line representing effective beginning of the process.

So this is my linear curve when it cuts the y-axis, so that is nothing but T pih. So since we have told the difference, temperature difference between T r minus t so this is because this is nothing but log of T r minus T pih. And the similar is nothing but pseudo initial temperature during cooling, so that is nothing but here, so I will extend my cooling curve linear cooling curve to the point where it cuts the y-axis. So that is nothing but T pic minus T w.

And normally we used to take, so this we discuss a bit while doing problems. So normally what happens is we take point 0.58 of l. So this is nothing but CUT. So this we will discuss with some example. So as of now it is nothing but 0.58 of come up period. The next one is pseudo initial temperature during cooling, this we have already seen.

(Refer Slide Time: 36:15)



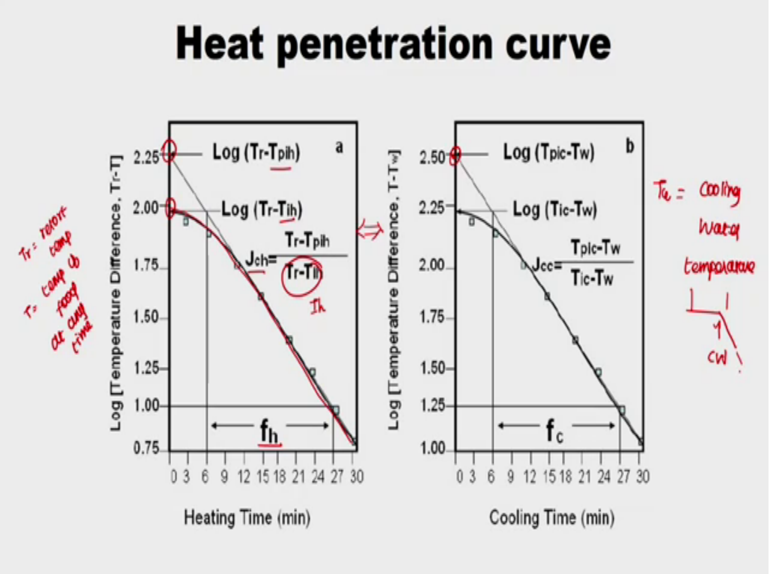
f_h Heating rate index: The time required for the straight line portion of the heating curve to pass through one log cycle; also the negative reciprocal slope of the heating rate curve

ic Difference between the cooling water temperature and food temperature at the start of the cooling process

ih Difference between the retort temperatures at the start of the heating process

j_{cc} Cooling rate lag factor: a factor which when multiplied by **ic**, locate the intersection of the extension of the straight-line portion of semilog cooling curve and the vertical line representing start of the cooling process

j_{ch} Heating rate lag factor: a factor which, when multiplied by Ih locates the intersection of the extension of the straight-line portion of the semilog heating curve and the vertical line representing the effective begining of the process



Heat penetration curve

So after that there is something called heating rate index. So here it is heating rate index. So heating rate index is nothing but the time required for the straight line portion of the heating curve, straight line portion of the heating curve to pass through one log cycle. One log cycle in the sense if you see here so this is 1, so 1 when it cuts the linear heating curve, so that is the time and 1 so this means 2, 2 when it cuts the linear line, so this is, so this time is nothing but f h, so that is here heating rate index.

Straight line portion of the heating curve to pass through one log cycle, so that is the time required. Sometimes it is called negative reciprocal of the slope of the heating curve. So this is already 1, 1 upon this is nothing but f h. So f h is reciprocal of the slope. And another is i c difference between the cooling water temperature and food temperature at the start of the process. Anyway, we have seen what is P ic, what is P ih. So this is nothing but difference between the retort temperature and the start of the heating or cooling process. And J cc. So one more thing is here we have is J ch and J cc, cooling and heating.

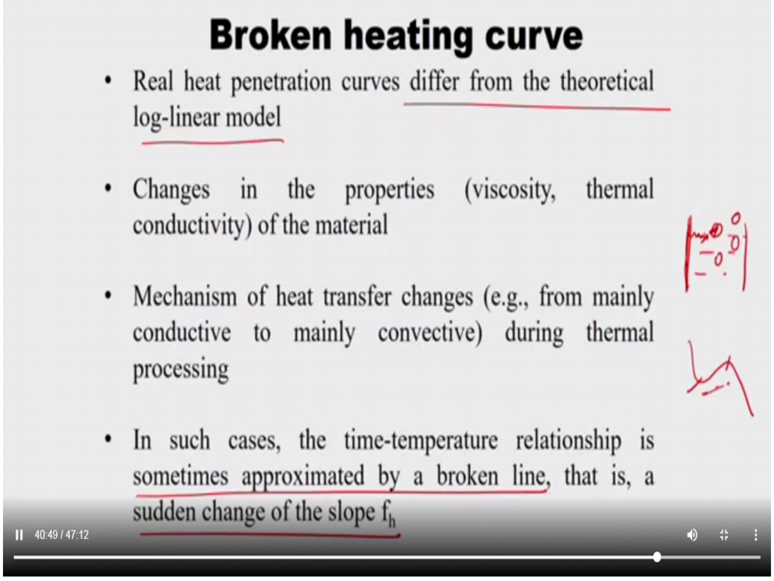
So heating rate log factor and cooling rate log factor. So this is a factor which when multiplied by ih the intersection of the extension of straight line portion of the semi-log heating curve and the vertical line representing effective beginning of the process. So, what would we say?

So this is nothing but log of T r minus T pih this point. So this point is nothing but log T r minus T ih this is initial, when initial heating starts. So, this we call it as ih. ih is initial heating period, this heating rate lag factor J ch is multiplied with ih which is nothing but difference between the retort temperature and initial heating temperature. This would give me T r minus T pih. T r minus T pih is nothing but my pseudo initial temperature during heating.

And cooling rate lag factor is almost a similar which is applicable for the cooling. So these are all the things you get to know. So this is the initial temperature. So what I get curve of this kind so then I will make it to linear curve. So where it cuts the y-axis that is nothing but log T r minus t, so this is nothing but log T r minus T pih, p is here pseudo. ih is nothing but T r minus T ih, f h is nothing but when one log reduction happens in the log of T r minus t then that time is nothing but f h. J ch when multiplied by ih that gives me T r minus T pih.

The similar represented for cooling curve as well. After the sterilization period the cooling starts. So this we will keep it at a particular time. So then the cooling starts here my cooling water is employed. So then your product gets to normal temperature, what do you choose to be. But this is ideal curve ideal heat penetration curve.

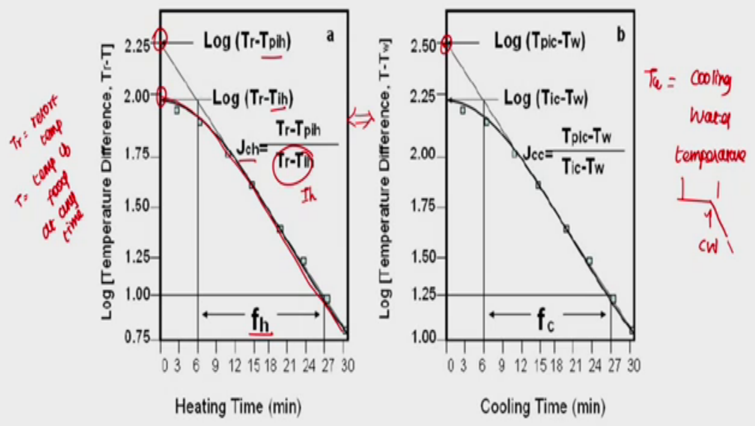
(Refer Slide Time: 39:23)



Broken heating curve

- Real heat penetration curves differ from the theoretical log-linear model
- Changes in the properties (viscosity, thermal conductivity) of the material
- Mechanism of heat transfer changes (e.g., from mainly conductive to mainly convective) during thermal processing
- In such cases, the time-temperature relationship is sometimes approximated by a broken line, that is, a sudden change of the slope f_h

Heat penetration curve

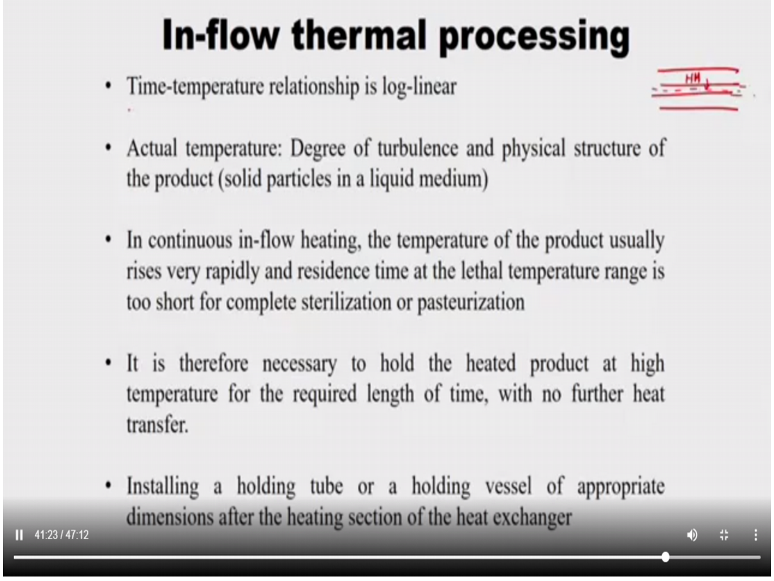


But when you go for normal, so the heat penetration curve differs from the theoretical log linear. So this is what we have done is log linear, semi log plot. So, this becomes a linear curve. So, normal curve will not follow the log linear model. So what were the reasons? One is change in properties; viscosity, thermal conductivity of the material, another one is mechanism of heat transfer. Whether sometimes what happens, this we told one example. In the packaging, I have a liquid medium in that I have a food chunks. So here it happens to be a convection, from the inside package material heat has to transfer via convection. Then when it sees the solid food particle, it becomes a conduction.

So this convection to conduction transition, so I will not be having any information for time temperature data and another one is changes in properties, so the viscosity, thermal conductivity which also determines. So there may be a deviation from the log linear plot and in such cases the time temperature relationship is sometimes approximated by a broken line.

For example, I have something of this kind. So this till here I will have information, from here I will have information. So this I will put it as approximate, so this is the way it should be. So based on this sudden change of slope, that is the broken line is based on the sudden change of the slope f h.

(Refer Slide Time: 40:52)

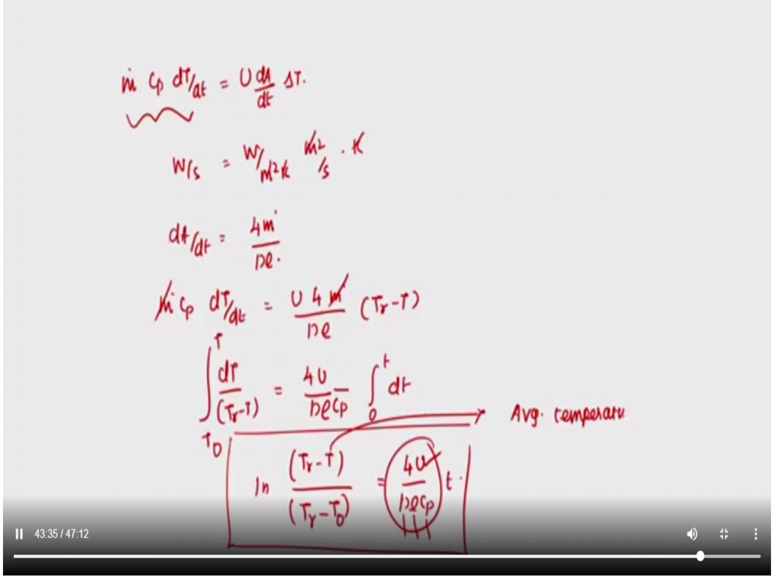


In-flow thermal processing

- Time-temperature relationship is log-linear
- Actual temperature: Degree of turbulence and physical structure of the product (solid particles in a liquid medium)
- In continuous in-flow heating, the temperature of the product usually rises very rapidly and residence time at the lethal temperature range is too short for complete sterilization or pasteurization
- It is therefore necessary to hold the heated product at high temperature for the required length of time, with no further heat transfer.
- Installing a holding tube or a holding vessel of appropriate dimensions after the heating section of the heat exchanger

So the next one is in-flow thermal processing, inflow thermal processing in the sense here, we told whatever we talked about in the inside the retort that is nothing but a batch process but this can also be done in a inflow thermal processing. Inflow thermal processing means I already told, one example would be the heat exchanger where you are heating medium is here and your food is flowing inside the pipe. So, the heating medium to the wall and here to the food. So this also time temperature relationship is log linear.

(Refer Slide Time: 41:27)



$$\dot{m} C_p \, dT/dt = U \frac{dA}{dt} \Delta T.$$

$$W/s = W/m^2K \;\; m^2/s \; . K$$

$$dA/dt = \frac{4\dot{m}}{D\rho}.$$

$$\cancel{\dot{m}} C_p \, dT/dt = \frac{U 4 \cancel{\dot{m}}}{D\rho} (T_r - T)$$

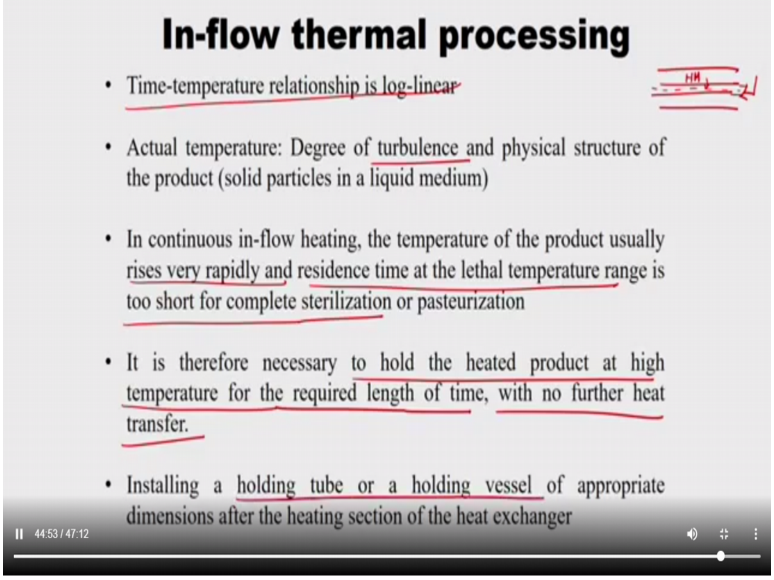
$$\int_{T_0}^{T} \frac{dT}{(T_r - T)} = \frac{4U}{D\rho C_p} \int_0^t dt$$

$$\boxed{\ln \frac{(T_r - T)}{(T_r - T_0)} = \frac{4U}{D\rho C_p} t.}$$

For example, m dot Cp dT upon t is nothing but U, so this is nothing but heat what you have given Q is equal to U A dT, M cp del T is nothing but h a del T which is U a del T, so this is watt per second, so this is also watt per meter squared Kelvin, meter squared second Kelvin. So this is the way and we already know d A upon dt is nothing but 4m dot upon D Rho. So if you substitute m dot C p dT upon dt, so this del T I will take it as U for m dot d Rho, so this del t I will take it is T r minus t. So, m dot m dot goes there. So dT upon T r minus t is nothing but 4 U D Rho C p into 0 to t, so this becomes T naught to T.

So you will have ln T r minus T upon T naught minus T which is nothing but 4U D rho C p into t. So this is nothing but constant properties. This is heat transfer coefficient diameter and density and specific heat. So this is time. So this is also even if it is a constant flow process, so this becomes linear log relationship only, so this is T r minus T naught. So this is T is nothing but average temperature.

(Refer Slide Time: 43:37)



In-flow thermal processing

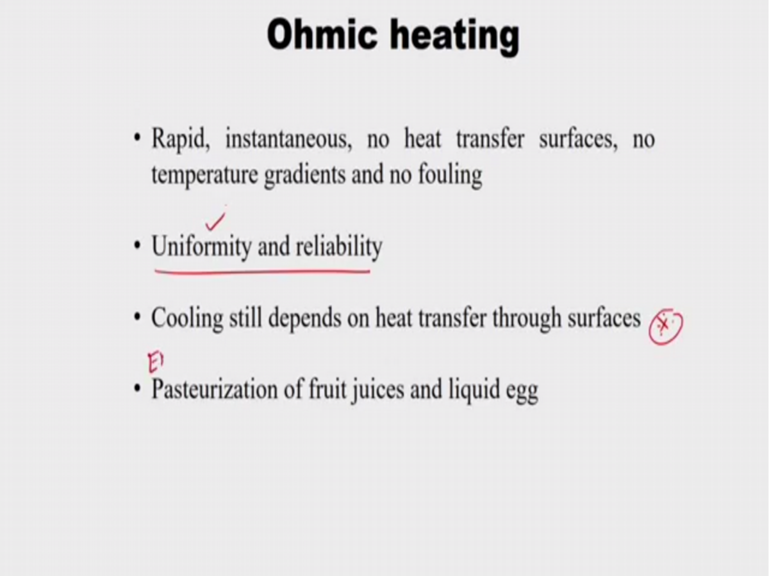
- Time-temperature relationship is log-linear
- Actual temperature: Degree of turbulence and physical structure of the product (solid particles in a liquid medium)
- In continuous in-flow heating, the temperature of the product usually rises very rapidly and residence time at the lethal temperature range is too short for complete sterilization or pasteurization
- It is therefore necessary to hold the heated product at high temperature for the required length of time, with no further heat transfer.
- Installing a holding tube or a holding vessel of appropriate dimensions after the heating section of the heat exchanger

So this is also follows log linear relationship, but actual temperature what happens is degree of turbulence, whether any turbulence is there and physical structure of the product. I already told you if it is a completely solid particle if it is a suspension or solid particles in liquid medium will have different properties and in continuous flow heating the temperature of the product usually rises very rapidly. So residence time of lethal temperature range is too short for complete sterilization.

So what happens is, in this thing so your resistance is small, so your temperature rises rapidly. So to get the lethality range I had to hold it for some time. So the residence time at lethal temperature range is too short, so I need to hold it, even though it has already reached the required temperature I need to hold it for some time to get the required lethal range, lethality for any sterilization or pasteurization.

So that is where the concept of holding tube came to, it is therefore necessary to hold the heated product at high temperature for required length of time with no further heat transfer. No heat transfer will happen, that holding tube will have to hold the particular food product at that particular temperature. So that is nothing but a holding tube, holding vessel. So this is decide in inflow thermal processing. So this is after the heating, after the heat exchanger there will be a holding section so where the food product is maintained at constant temperature, but it will be hold for some time. Some time in the sense the required time to get the particular lethality during sterilization or pasteurization.

(Refer Slide Time: 45:19)



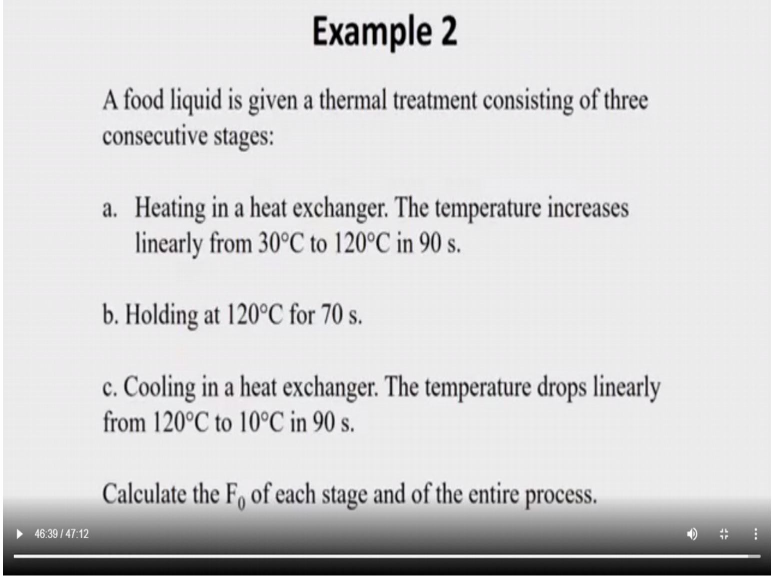
Ohmic heating

- Rapid, instantaneous, no heat transfer surfaces, no temperature gradients and no fouling
- ✓ Uniformity and reliability
- Cooling still depends on heat transfer through surfaces ⊗
- E Pasteurization of fruit juices and liquid egg

And apart from that it can be done by ohmic heating as well. So the ohmic heating the advantages are it is rapid, instantaneous and no heat transfer surfaces involved because whatever you have seen earlier both retort processing as well as inflow thermal processing you had to have a heat transfer medium and the packaging surface then again inside of the packaging surface to the food. So there are series of heat transfer surfaces is also involved and but here there is no heat transfer surface and no thermal gradient as well as no fouling as well.

Fouling is nothing but due to after some time that scaling happens inside the exchanger. But the issue is uniformity and reliability that you may not get during ohmic heating and one more thing is also there even though you do heating by ohmic, the cooling still depends upon the heat transfer through surfaces. The cooling water has to be done via any heat transfer surface only. So this is another disadvantage and I will not be getting the uniform temperature distribution and reliability and the example would be for ohmic heating is pasteurization of fruit juices and liquid egg. So this is some glance about ohmic heating.

(Refer Slide Time: 46:39)



Example 2

A food liquid is given a thermal treatment consisting of three consecutive stages:

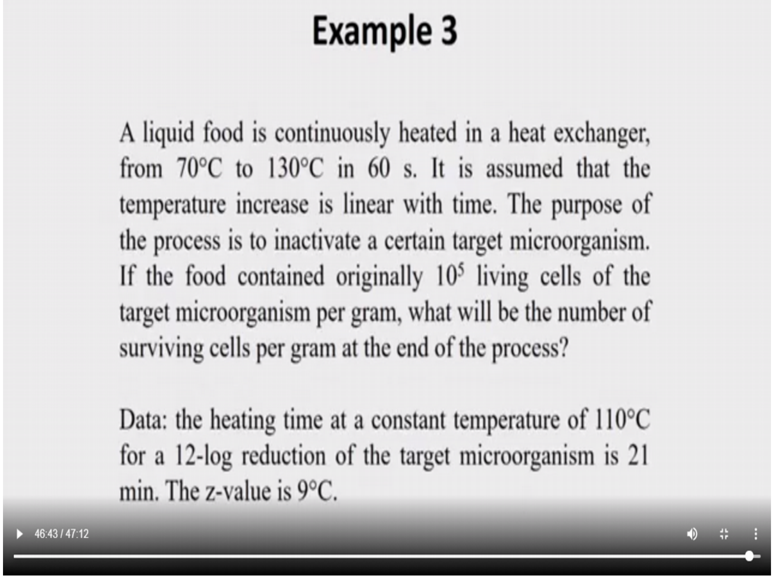
a. Heating in a heat exchanger. The temperature increases linearly from 30°C to 120°C in 90 s.

b. Holding at 120°C for 70 s.

c. Cooling in a heat exchanger. The temperature drops linearly from 120°C to 10°C in 90 s.

Calculate the F_0 of each stage and of the entire process.

(Refer Slide Time: 46:43)



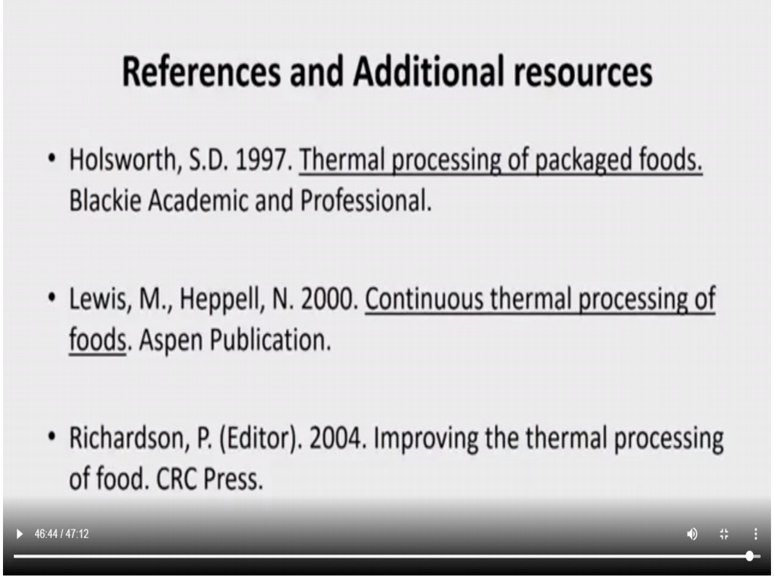
Example 3

A liquid food is continuously heated in a heat exchanger, from 70°C to 130°C in 60 s. It is assumed that the temperature increase is linear with time. The purpose of the process is to inactivate a certain target microorganism. If the food contained originally 10^5 living cells of the target microorganism per gram, what will be the number of surviving cells per gram at the end of the process?

Data: the heating time at a constant temperature of 110°C for a 12-log reduction of the target microorganism is 21 min. The z-value is 9°C.

We will see these examples two and three in subsequent classes.

(Refer Slide Time: 46:45)



References and Additional resources

- Holsworth, S.D. 1997. Thermal processing of packaged foods. Blackie Academic and Professional.
- Lewis, M., Heppell, N. 2000. Continuous thermal processing of foods. Aspen Publication.
- Richardson, P. (Editor). 2004. Improving the thermal processing of food. CRC Press.

So these are all the references. Thank you.