Thermal Processing of Foods
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Lecture 15
Microwave and Radio Frequency Heating

Good morning all, today we are going to discuss about Microwave and Radio Frequency Heating. Till now, as we discussed earlier we have seen separate thermal processing and the thermal processing equipments required and three lectures mainly were on aseptic processing.

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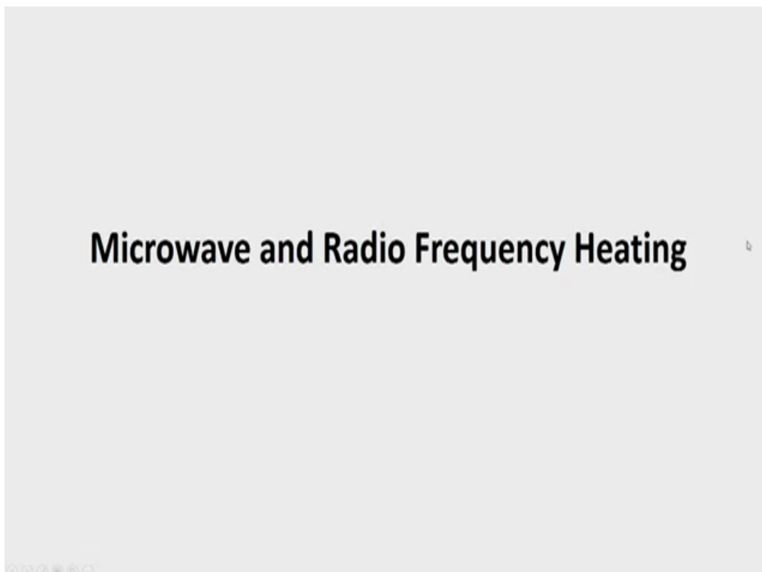

So, another few lectures we are going to discuss different non thermal processing. So, one such case is microwave and radio frequency heating, what we are going to discuss today.

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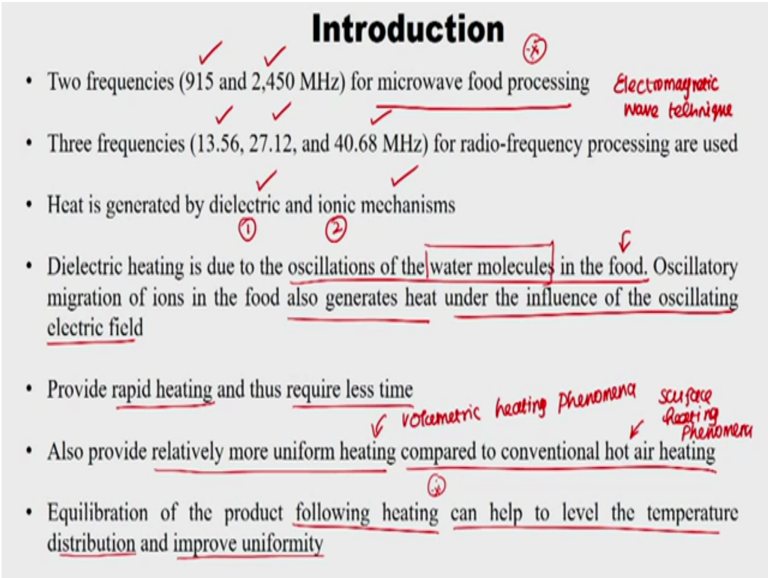

The introduction goes like this, for microwave food processing, it is a electromagnetic wave technique right. So, the frequency used are 915 megahertz and 2450 megahertz so which is mainly used for food processing applications right and as far as radio frequency processing is concerned, there are three frequencies which are used for food processing.

So, what are all they? 13.56 megahertz, 27.12 megahertz and 40.68 megahertz, actually in these two mechanisms either microwave or radio frequency the heat is generated by dielectric or ionic mechanisms. So, we are going to see one by one, what are all the frequencies and where the microwave frequency actually lies, everything we are going to see in the figure which is coming up.

The dielectric hitting is due to oscillations of the water molecules in the food. So that means, the food which you are going to apply for microwave processing should have the polar molecules which is nothing but the water molecules in it. Oscillatory migration of ions in the food also generates heat because we have already seen there are two mechanism by which the heat is generated, one is ionic polarization and another one is dielectric mechanism, right.

So, the migration of ions also generates heat under the influence of oscillating electric field. So, both radio frequency as well as the microwave food processing provide rapid heating and thus require less time. So, when we compare with the conventional food processing methods, it requires less time because it provides the rapid heating that you might have experienced in day to day life as well. So, when you pre heat the food in the microwave, you require less time than what you do in conventional cheating method.

Also provide relatively more uniform heating compared to conventional hot air heating. So this is due to volumetric phenomena, this is due to volumetric heating phenomena. So, what happens in the conventional hot air is, this is nothing but surface heating phenomena, right.

Another one is the equilibration of the product following heating can help to level the temperature distribution and improve the uniformity. So after the product heating, so after it is packaged, so it can help level the temperature distribution and improve the uniformity. So that this particular point also we will see over the number of slides.

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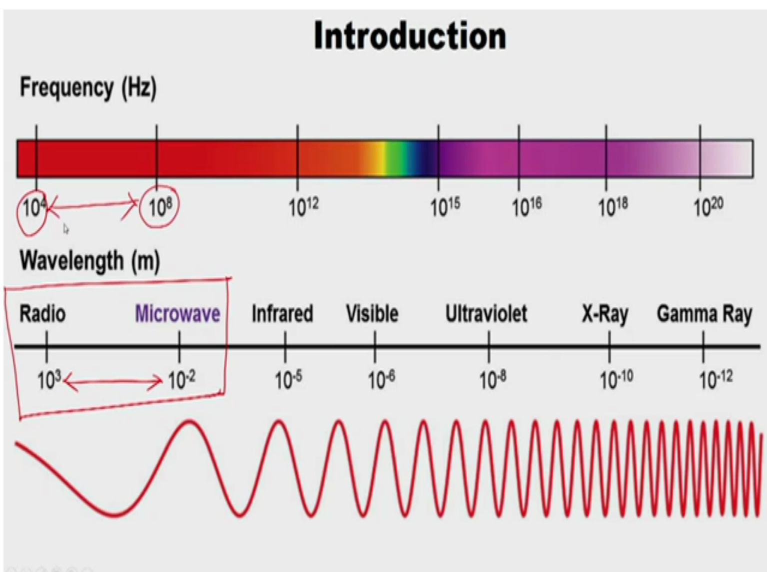

So this is introduction about the various frequencies of radio, microwave, infrared, visible, ultraviolet, X ray and gamma ray. So, the wavelength for radio frequency lies between 10 to the power of 3 to 10 to the power of minus 2 which is for microwave, so almost whatever we are going to discuss comes under this wavelength range 10 to the power of 3 to 10 to the power of minus 2, frequency wise this is a hertz, right. So, the radio frequency this one is 10 to the power of 4 and here it is 10 to the power of 8 for microwave. So, whatever the processing we are going to do comes in between this.

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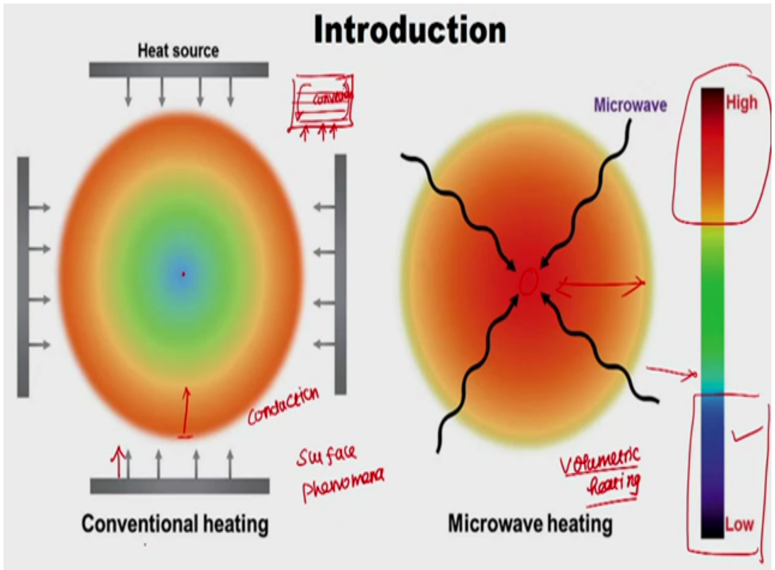

So this is we have seen, right we have just told, right one is surface phenomena, which is nothing but my conventional heating, the microwave heating is nothing but volumetric, volumetric heating, so what happens? So, when you apply a heat source, so it starts from the surface of the food, right food material or any material, then it slowly penetrates inside right. So, if it is a solid food the conduction would be, would be governing this penetration.

So, if it is a convection, we have already seen for example, you have a (())(05:49) inside that you have a liquid food, right. So, when the conventional or normal heating mechanism happens, so this will become a hot fluid because it is getting heated, it density lowers and it rises to the above and the cold fluid which is in the top layer which comes down then fills this space. So this is the convection phenomenon.

So, in both cases, the surface only gets heated first then when the heat has to penetrate inside the food material or any material right, but microwave heating, it does not happen as it is happening in the conventional heating. So directly it goes to the center of the food particle, right because it is a wave it can penetrate to the center of the food particle. So while penetrating also it heats other parts of the food material.

So, due to volumetric heating phenomena, so you almost see the uniform temperature distribution, so this comes under high range, this blue line is, blue comes for low range, right if you see in the surface, you will not find any low indicator, low temperature indicator, so somewhere around the surface you have something of this kind, right. So it is above the low temperature range. So in this way you get uniform heating during microwave heating, which is not happening in the conventional heating phenomenon.

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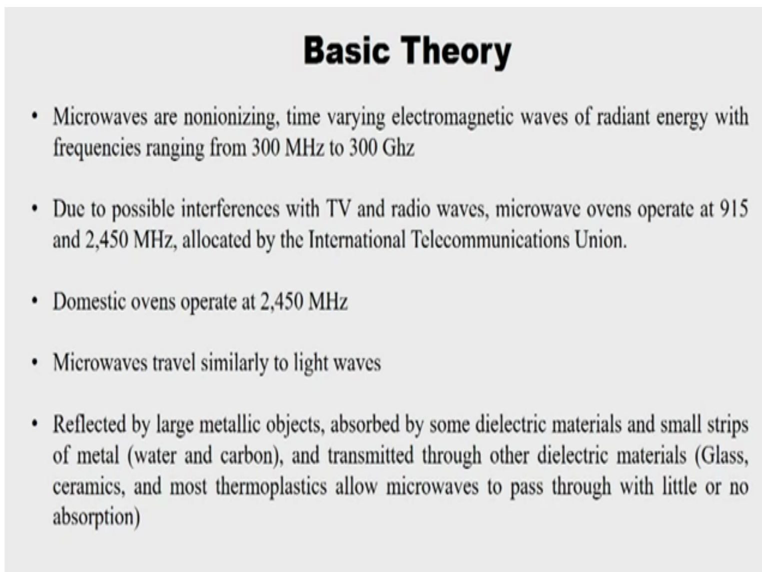

So, who introduced the first microwave heating? Is Spencer who patented the idea in 1945, 1991 microwave heating has become so popular and microwave heatings were developed originally for military requirements even the pasteurization or canning operations, it was developed originally for military requirements only because they wanted to have the food which is going to be used for you know long days for their food consumption. So that is the way the pasteurization also came into existence, how do I increase the shelf life of the food or how do I pack it in the can and which will not go waste for a few days. So all these concepts came for military requirements only at first.

So, here also the microwave techniques were developed originally for military requirements to design and manufacture microwave radar, navigation and communications during the Second World War. (The) In food processing what are the advantages of microwave? Speed of heating, energy saving, because we require only less time so we can save energy as well.

Precise process control, if I want to control the temperature or power input I can control and fastest startup and shutdown times because we might have seen in some of the thermal operations there is something called come up time, right even though you switch on your heating medium it will take some time to reach to the particular (())(8:55) temperature. So, those kind of timings can be reduced or can be nullified using microwave.

And higher quality products in terms of taste, texture and nutritional content, nutritional content, require less time as well as high temperature right. So this will be taken care by the microwave heating.

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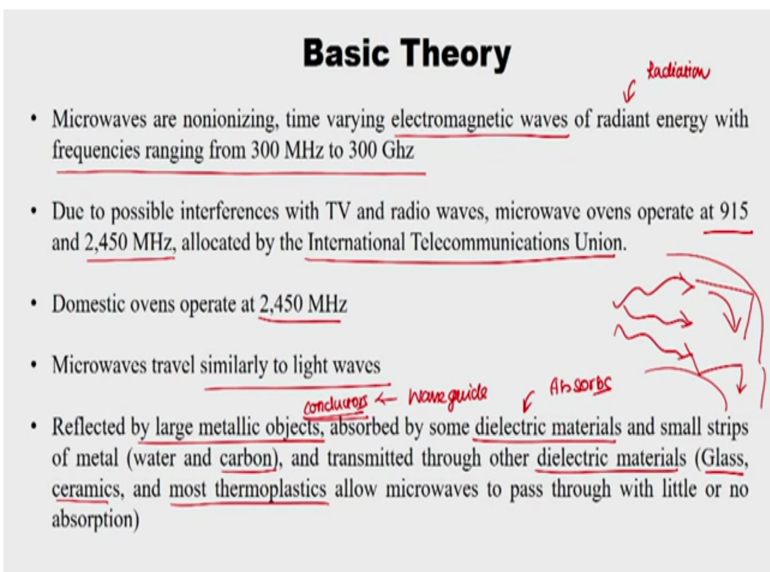

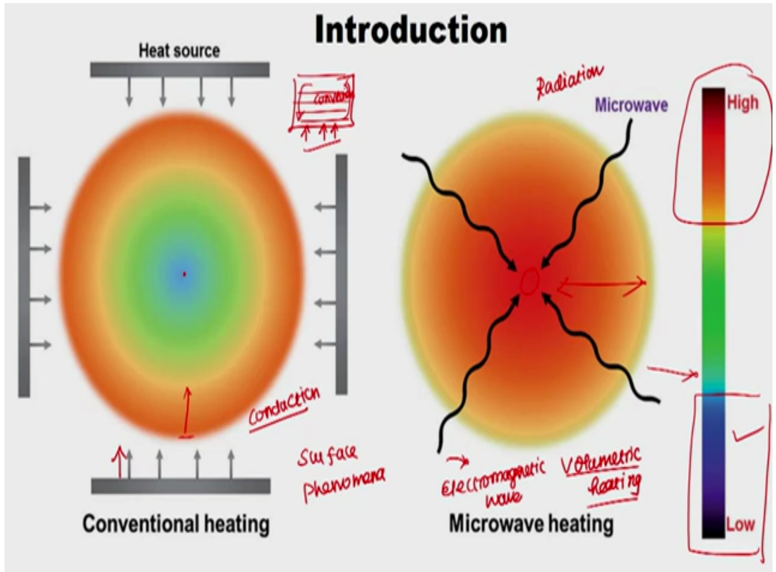

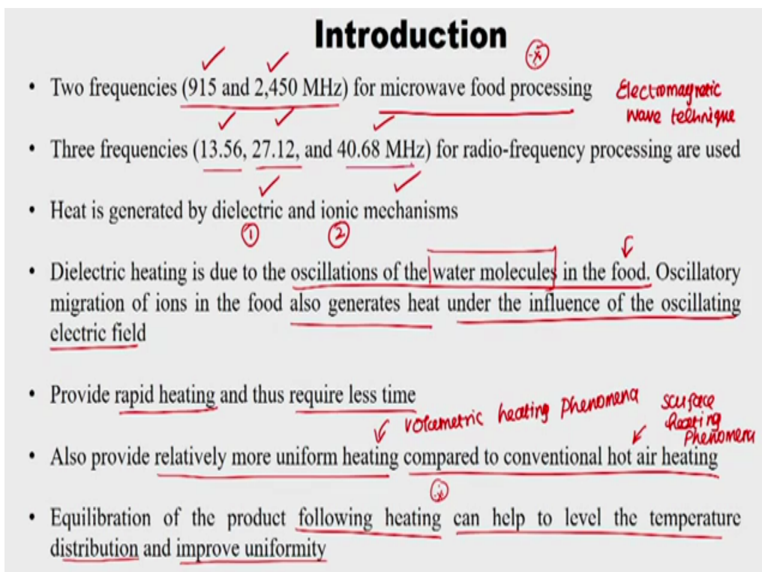

So now, we are getting into basic theory of microwave, microwaves are non-ionizing, time varying electromagnetic waves of radiant energy, so this comes under radiation phenomena. So, what we discussed here right. So, this is either by conduction or by convection. So this comes under radiation phenomena of heat transfer and these are electromagnetic waves okay.

Radiant energy with the frequencies ranging from 300 megahertz to 300 Gigahertz, right. Due to possible interferences. So, why we, here also told, right there are only two frequency ranges applicable for microwave food processing and there are three frequency ranges applicable for radio frequency, why it is so? Because not to interfere with the other signals right. So due to possible interferences with the TV or radio waves, microwave ovens operate at 915 and 2450 megahertz allocated by the International Telecommunications Union, otherwise, there is no theory behind why I need to fix this particular frequency, the same applicable with radio frequency as well, not to interfere with the other signals.

So, domestic ovens normally operate at the higher frequency 2450 megahertz and microwaves travel similarly to light waves and reflected by large metallic objects, so metallic objects microwaves gets reflected. So metallic objects are conductive, right they are good conductors of heat, right and observed by some dielectric materials and some small strips of metal, one exception is nothing but carbon, it also observes the microwave, so absorbed by some dielectric materials.

So, dielectric materials are the one which absorbs the microwave energy, small strips of metal which is also a exceptional one and transmitted through other dielectric materials, there are certain dielectric materials through which microwave is transmitted, which are glass, ceramics and most thermo plastics which allow microwaves to pass through with little or no absorption.

So these materials can be used as that containers, right so which allows the microwave because it has to penetrate through the containers to the food material. So, so these are all the materials which allows the microwave to pass through, which pass through, only pass through or with little absorption. So that means little heating also may be there, right.

So, the metallic objects only reflect and dielectric materials are the one which absorbs the microwave energy and there are certain dielectric materials which only helps in transmitting the microwaves right. So these reflected by large metallic object, which are nothing but conductors of heat. So, they can be used as a wave guide so wave guide in the sense.

So, when waves are coming like this, so I want these waves to be accumulated at one particular point, right. So I wanted to use these metallic object which reflects the microwave energy as a wave guide so, that even if the wave goes here it reflects back to the place where I wanted right. So, this can be used as a wave guide.

And absorbs that material those were dielectric materials that are nothing but our food particles because we already told dielectric materials are polar molecules, so food contains water so that is nothing but a dielectric material and there are certain electric material which transmits the microwave energy those materials can be used as a packaging material.

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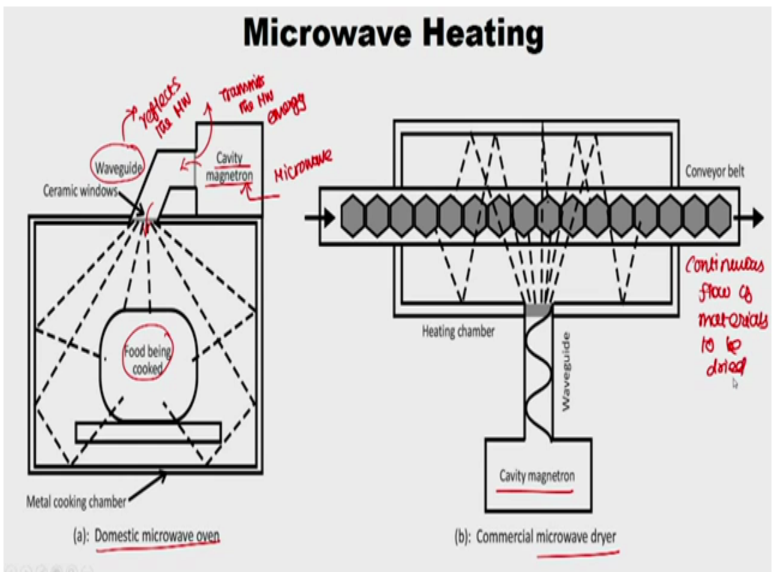

So this is the basic diagram how microwave food processing, how it happens in the domestic and microwave drying process how it happens commercially, right. So this is a cavity magnetron in the domestic microwave oven, the cavity magnetron is the one which produces the microwave, right from the cavity magnetron it passes through here and it is a wave guide I already told so these are all the material which reflects the microwave energy then it goes through the ceramic windows, we already have seen ceramics are the one which transmits the microwave energy, right.

Wave guides are the one the material mostly metals are good conductors of heat. So which reflects the microwave energy, so that it will not deviate from the path, right and again it transmits through ceramic windows and this is your food being cooked and it goes here reflects and comes back to the food material that is the way the heating is done, microwave heating is done.

The similar to this for microwave dryer, so these are all the particles to be dried so this is conveyed through your conveyer belt and here you have a cavity magnetron. So this is a wave guide, this is the way it goes here and it passes through the ceramic window, then it goes and reflects back and that is the way the food which has to be dried will be dried using microwave okay. So this is the conveyor belt so it is a continuous process, it is just an example there are other control mechanisms everything is there. So it is just to explain you the principle of microwave heating, continuous flow of materials to be dried.

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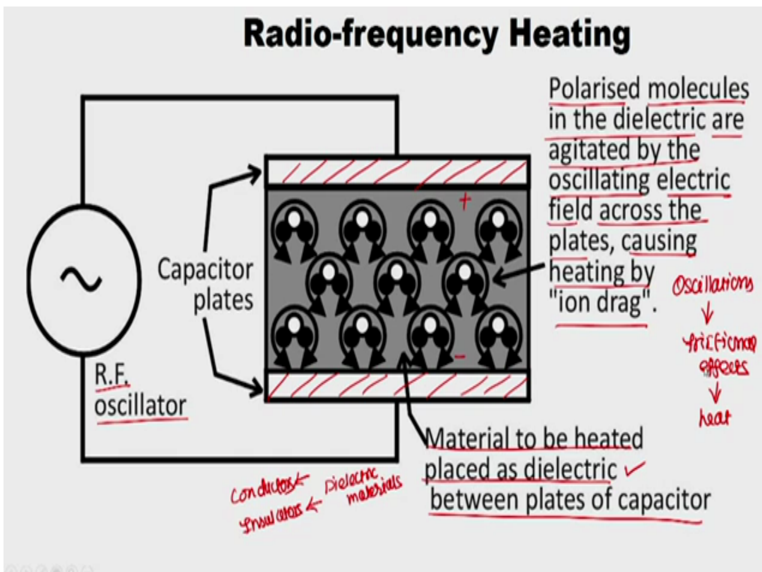

So, the similar processing for radio frequency is, so here we have radio frequency oscillator so which creates the radio frequency energy and it is passed through in between the capacitor plates right, which absorbs the radio frequency energy, then in between you have a, this these are all the polarized molecules in the dielectric or agitated by the oscillating electric field across the plates, causing heating by ion drag, right.

So, what happens? So, I am creating here the radio frequency so these two are capacitive plates, which absorbs the radio frequency and the polarized molecules which is kept in between the capacitive plates, which are agitated by the oscillating electric field, the field is generated by the radio frequency was observed by capacitive plates which helps the polarized molecule to get heated by using oscillating the electric field across the plates which causes the heating by ion drag.

So, the oscillation further, the oscillations further (())(17:06) (frictiona) frictional effects so which generates the heat. What happens is, based on the ionic moment the plus will go here, the minus will go here, they align them according to the frequency which is generated by the radio frequency accelerated that is it. So, when they are aligning themselves to the field of radio frequency, there may be ion drag. So this ion drag creates the frictional efforts which further creates the heating effect. So this is the material to be heated placed as dielectric between the plates of capacitor right.

So, by now, we know what is dielectric, dielectrics are not a conductors which conducts only the heat or electricity, but which does not conduct the microwave it just transmit and the insulator, sorry this conductors reflects and insulate a transmits sometimes it also absorb, the dielectric material comes in between so these are the materials which absorbs the microwave energy, mostly polar molecules right. So, here what happens? This dielectric material when they align themselves according to the radio frequency, so there will be a ion drag. So which further creates a frictional effects that is converted into heat.

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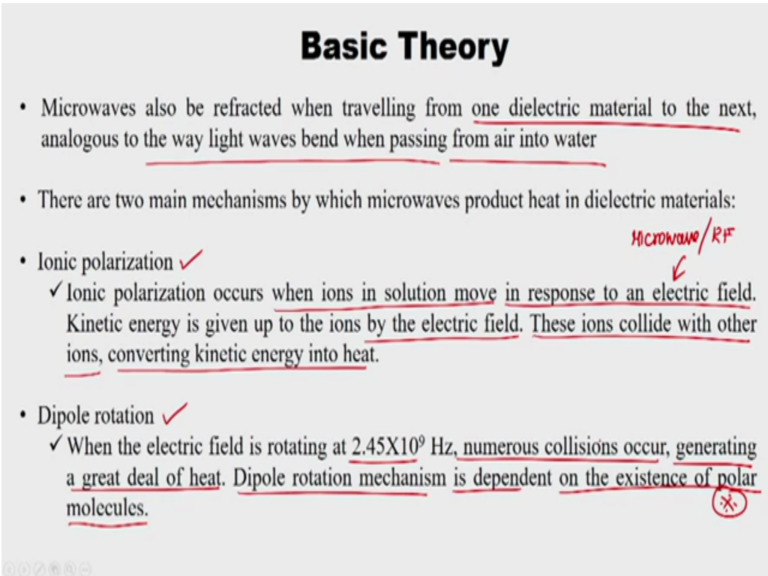

So, microwaves also refracted when traveling from one dielectric material to the next. So this you have already seen refractive index. So this is also applicable for microwave, it is analogous to the light waves bend when passing from air to water. So the same refractive index, which is applicable for light, so there will be an analogous to this mechanism, the same mechanism can be applicable for microwaves as well. So, when it travels from one dielectric material to another, it will be refracted.

And there are two mechanisms by which microwaves produce heat in the dielectric materials, one is ionic polarization, another one is dipole rotation, right. The ionic polarization occurs when ion in the solution move in response to an electric field. So this is applicable for both microwave as well as radio frequency, right the kinetic energy is given up to the ions by the electric field to move, these ions collide with each other and converting kinetic energy into heat, this is what I just explained.

So, when ions in solution move in response to the electric field and the kinetic energy is given up to the ions by the electric field, which is created by either microwave or radio frequency, when they collide each other there will be a friction, kinetic energy will be converted into heat.

What is Dipole rotation? When the electric field is rotating at 2.5 into 10 to the power of 9 hertz that is nothing but whatever the microwave energy you are giving to the molecules, here numerous collisions can occur generating a great deal of heat. Dipole rotation mechanism is depends on the existence of polar molecule. So this is very much important, you need to have polar molecules then only they can align themselves based on the electric field given to them. So due to their collision when they rotate, it gets collided with each other so which generates the heat.

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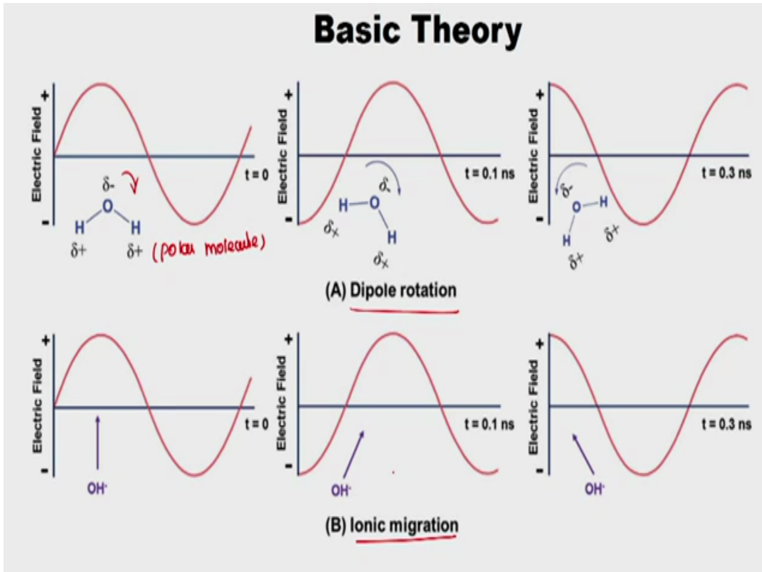

So this is the example, one of the first one is dipole rotation. So this is my water molecule which is nothing but a polar molecule, right. So the H plus ions this is 2 hydrogen ions, this is OH plus and OH minus. So, when it rotates it may be this direction or it may be this direction, due to this rotation there may be a collision between the molecules which further generates the heat. The ionic migration is nothing but the OH minus 10 to go to positive side and H plus ions come and align near the negative side, right due to attraction between the positive and negative side.

So, due to this migration there may be a collision so which further produces the heat so this is due to dipole plus minus there will be a rotation, whether minus can come here or plus can go here. So this is due to rotation, due to rotation collision happens and you will get the heat due to frictional or kinetic energy conversion and here the ionic migration, the ions positive or negative ions try to align themselves according to the electric field applied. So due to which your heating will be produced.

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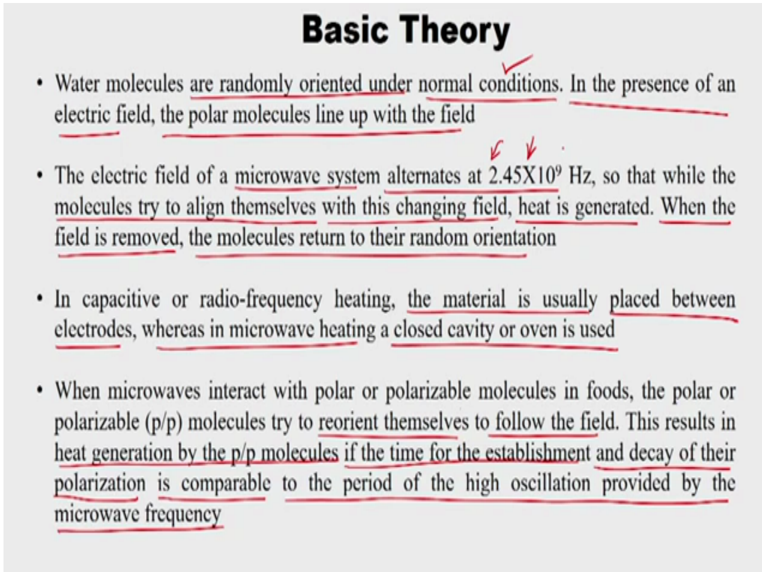

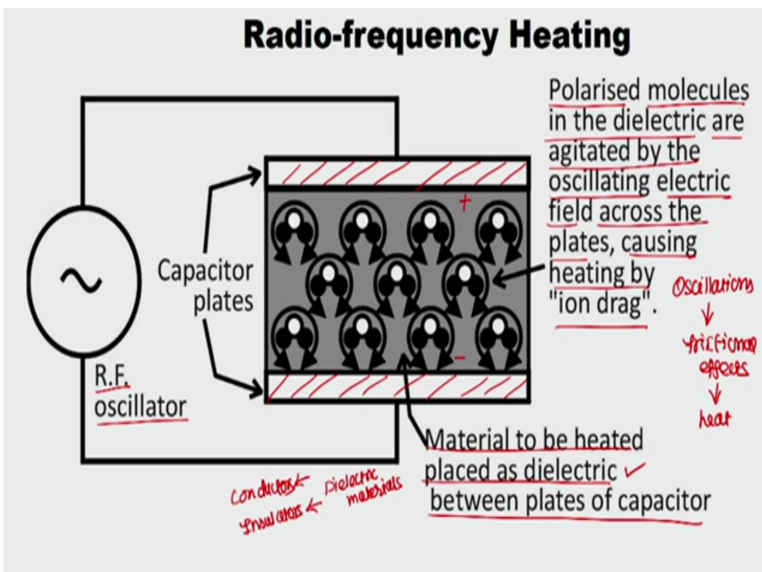

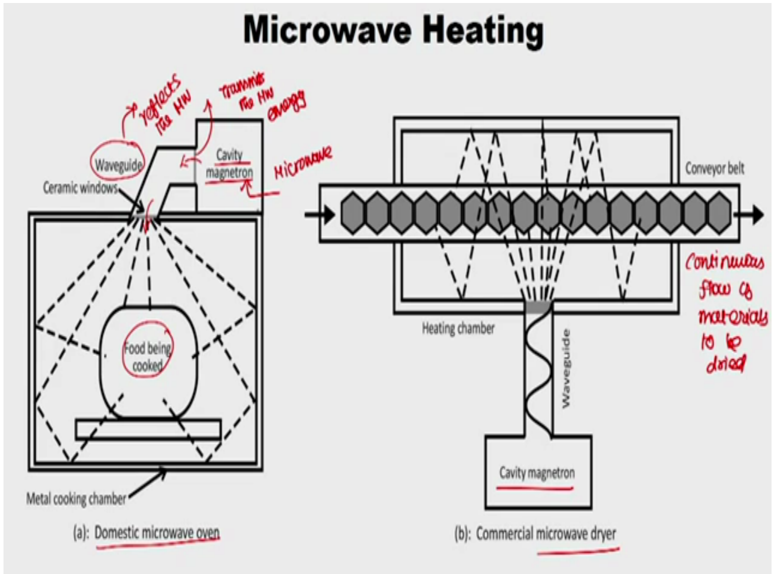

The water molecules are randomly oriented under normal conditions. Normal condition if you see OH minus and H plus will be distributed throughout the material in the presence of an electric field, the polar molecules line up with the field. That is what I told based on the applied field, based on the positive and negative ion side, negative side the ions will try to orient themselves.

The electric field of a microwave system alternates at 2.45 10 to the power of 9 hertz. So that while the molecules try to align themselves with this changing field, because they have already random motion, so when they see, when they get the electric field, so they try to align themselves to the, according to this field, after which the heat is generated due to collision between the molecules, when the field is removed the molecules returned to their original random condition or random orientation.

In capacitive or radio frequency heating the material is usually placed between the electrodes, whereas in microwave heating energy a closed cavity or oven is needed. So, if you see here, so your dielectric material which has to be heated it is kept between the electrodes and if you see for microwave energy you need a closed cavity. So here also there is a closed cavity so that your energy will reflect and heats the material.

When microwaves interact with polar or polarizable molecules in food, the polar or polarizable molecules try to reorient themselves to follow the field. This results in heat generation by the polar or polarizable molecules, if the time for the establishment and decay of their polarization is comparable to the period of the high oscillation provided by the microwave frequency. So what they wanted to mention here is we have already seen in normal condition it randomly orients, right but when you apply a electric field it try to align themselves to the applied electric field.

So you need to give that particular time for the molecules to get it aligned and due to that collision to produce the heat. So, if the given microwave frequency is not enough for them to align or the amount of time with which the microwave frequency is applied to the dielectric materials to produce the heat. So these two are very much important to get the particular heating done so that is what so it has to be established for a particular time and it has the power what you give, right the frequency what you create as well as the time at which the frequency is applied to the dielectric materials based on which you are heating will be done.

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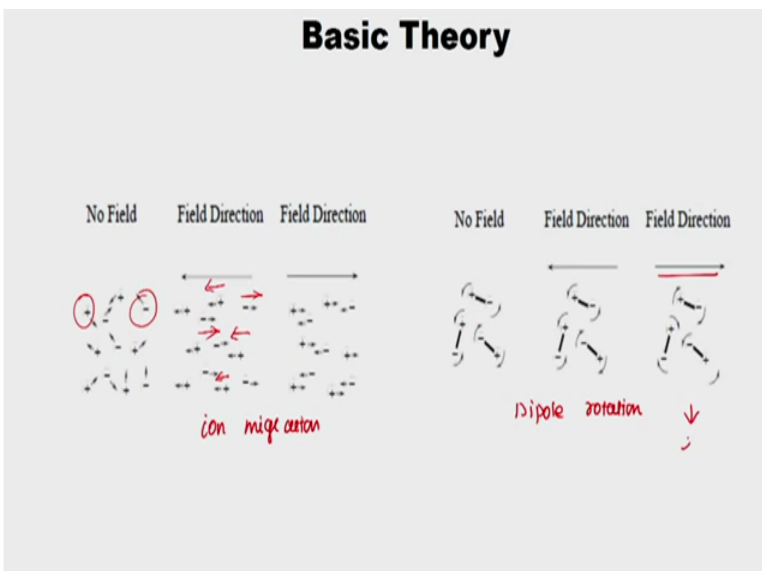

So this is again one of the diagram with which so this is nothing but an ionic migration, ion migration. So this is nothing but dipole rotation, right so ionic migration what happens this plus and minus random without field, if field is applied, so this direction all plus ions move right so all plus if you see this direction, all minus ions will move this direction, right. So, in this way they orient themselves, right.

And if the field direction is this then you are plus all move this direction and minus, so if your field direction this side all plus move this direction and minus will move this direction and this is for dipole rotation. So the same way, the plus minus it rotates randomly in the no field, if the field direction is applied here the plus try to rotates this way and if the field direction is this side and plus try to rotates in that way. So when it rotates it, it collides that is the way kinetic energy is converted into heat.

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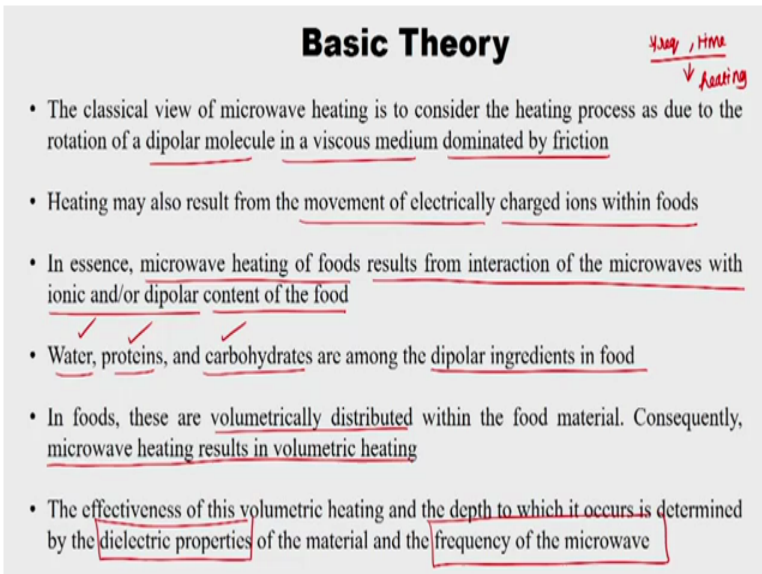

The classical view of microwave heating is to consider the heating process as due to the rotation of a dipolar molecule in the viscous medium dominated by friction. The heating may also result from the moment of electrically charged ions within the food. So if, if the food has electrically charged ions, right so then heating may also results from there. In essence, microwave heating of foods results from interaction of the microwaves with ionic or dipolar content of the food.

If it is a dipolar content, it is rotation, if it is interacting with the ionic due to ionic migration the heat will be generated. Water, proteins and carbohydrates are among the dipolar ingredients in the food. In food, there are volumetrically distributed, means water, proteins as well as carbohydrates are volumetrically distributed within the food material. Consequently, microwave heating results in the volumetric heating phenomena. The effectiveness of this volumetric heating and depth to which it occurs is determined by the dielectric properties of the material, right and the frequency of the microwave.

This just I have also mentioned, what we told us, the frequency what you apply and the time with which the frequency is applied both will have the effect on heating to be done on the dielectric material. The same way here the effectiveness of the volumetric heating and the depth to which it occurs determined by the dielectric properties.

For example, my dielectric materials will have very good absorption of the microwave energy then it is good for the material to get heated, but if it, if the absorption of microwave energy by the dielectric materials are low, then accordingly my heating may be affected. So it is based on dielectric properties of the material and the frequency of the microwave.

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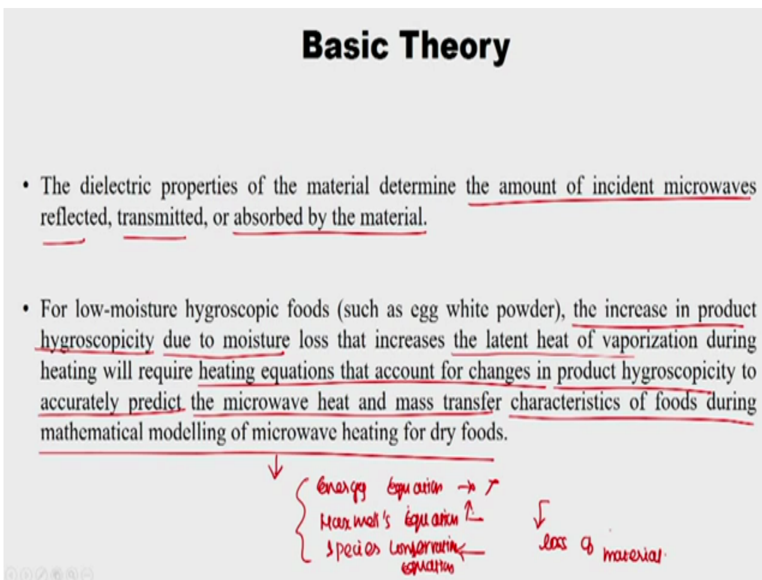

The dielectric properties of the material determine the amount of incident microwaves reflected, transmitted, absorbed by the material. For low moisture hygroscopic foods such as egg white powder, the increase in product hygroscopicity due to moisture loss that increases the latent heat of vaporization during heating will require heating equations that account for changes in the product hygroscopicity to accurately predict the microwave heating and mass transfer characteristics of foods during mathematical modeling.

When you model microwave heating. There are three equations, first in certain classes before we have discussed so what I will be solving is, if it is only conduction, solid food, so I will be solving the energy equation, to get to know the temperature, right. If it is a microwave heating, I need to solve extra Maxwell, Maxwell's equation to give this wave form of energy to the energy equation, right.

So along with that if I have a moisture food right, so the increase in product hygroscopicity due to moisture loss that increases the latent heat of vaporization. So there may be latent heat of vaporization which converts the normal moisture which is there in the food into water vapor. So there will be a loss of material, right. So this also to be taken into account while doing the modeling part.

So, you need to solve species conservation equation as well, species conservation equation, right. So, heating equations that account for changes in the product hygroscopicity to accurately predict the microwave heat and mass transfer characteristics of the food, mass transfer as well as heat transfer we need to solve okay.

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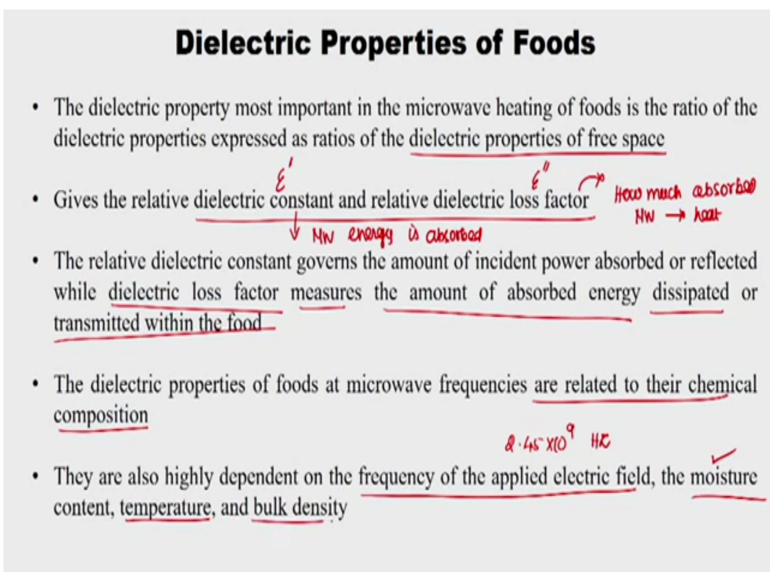

So, the dielectric properties of the food, right the dielectric property most important in the microwave heating of the food is the ratio of the dielectric properties expressed as the ratios of dielectric properties of the free space, right. The dielectric property of the particular material to the dielectric property of the free space is nothing but dielectric property.

Gives the relative dielectric constant and relative dielectric loss factor. So this is nothing but epsilon dash and dielectric loss factor is nothing but epsilon double dash. So this talks about how much microwave and energy is getting absorbed. So this talks about how much absorbed energy is getting converted into heat, how much absorbed microwave energy is converted into heat or loss, right.

The relative dielectric constant governs the amount of incident power absorbed or reflected while dielectric loss factor measures the amount of observed energy dissipated or transmitted within the food. So, how much it is getting converted into heat that talks about the dielectric loss factor, dielectric constant talks about how much is absorbed or reflected.

The dielectric properties of food at microwave frequencies are related to their chemical composition, we already told how much dielectric material or polar molecule you have that much it can absorb and it can be converted into heat. They are also highly depend on the frequency of the applied electric field, we already told so that is why we told this is very much important 10 to the power of 9 hertz and the moisture content of the food because water is important here and the temperature and the bulk density of the food material.

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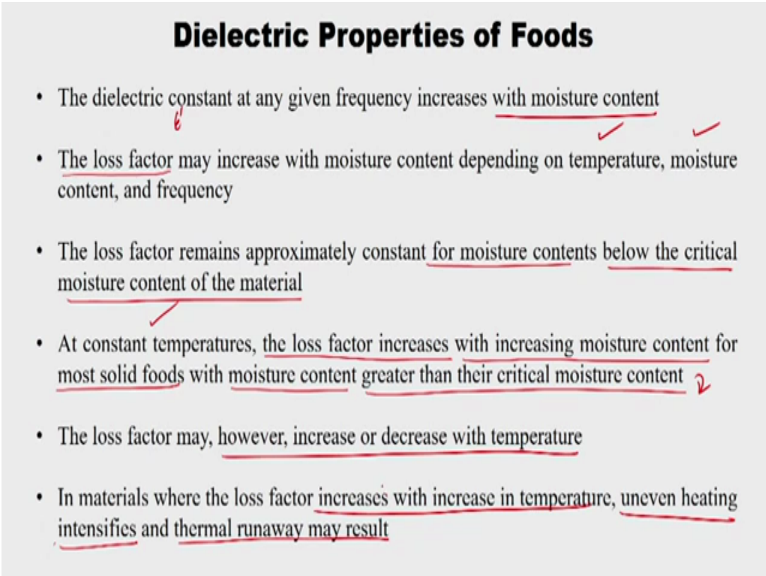

The dielectric constant at any frequency increases with the moisture content because how much of is the moisture it can absorb that much microwave energy. So this is nothing but a absorption of microwave energy. The loss factor may increase with the moisture content depending on the temperature moisture content and frequency. So to absorb I need a water molecule for the loss factor there may be a loss, there may be observed energy converted into heat. So I cannot directly relate the loss factor with the temperature, but it may increase or it may decrease with the temperature.

The loss factor remains approximately constant for moisture contents below the critical moisture content of the material. At constant temperatures the loss factor increases with increasing moisture content, for most of the solid foods with moisture content greater than their critical moisture content. So we have three factors here temperature, moisture content and frequency. So, if you fix the temperature, loss factor increases with the moisture content which is for most of the solid food with the moisture content greater than their critical moisture content.

The loss factor may, however, decrease or increase with the temperature, this is what I told. So the loss factor also includes loss as well as the conversion of heat. So we cannot directly relate to temperature and directly say it increases or decreases.

In materials where the loss factor increases with the increase in temperature, uneven heating in materials were loss factor increases with the increase in temperature, uneven heating intensifies and thermal runaway may result. So the loss factor is nothing but conversion of absorbed microwave energy into heat right. So, when the temperature is increasing, when the loss factor is also increasing means so the amount of microwave energy absorbed is getting converted into heat with minimum loss. So that means your heating will be very much high. So the uneven heating intensifies and there may be a thermal runaway condition.

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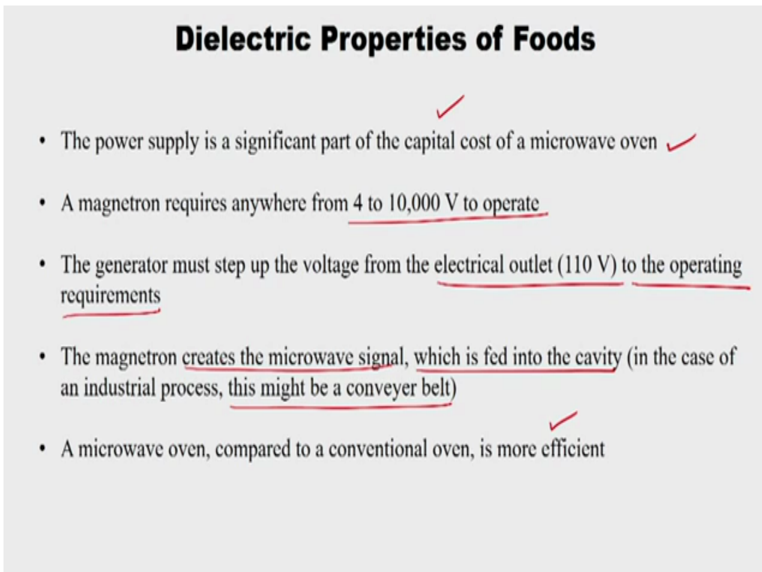

The power supply is a significant part of the capital costs. So, when you compare we have told the advantages of the microwave heating, but disadvantages its capital cost. A magnetron requires anywhere from 4 to 10,000 volt to operate and the generator must step up the voltage from the electrical outlet of 110 volt to the operating requirements, what it is required and the magnetron creates the microwave signal which is fed into the cavity, in the case of an industrial process this might be a conveyor belt for our domestic purpose this is the cavity.

And a microwave oven, compared to conventional oven it is more efficient but only problem is the capital cost and apart from that, so you need to see this the voltage regulation to use the microwave.

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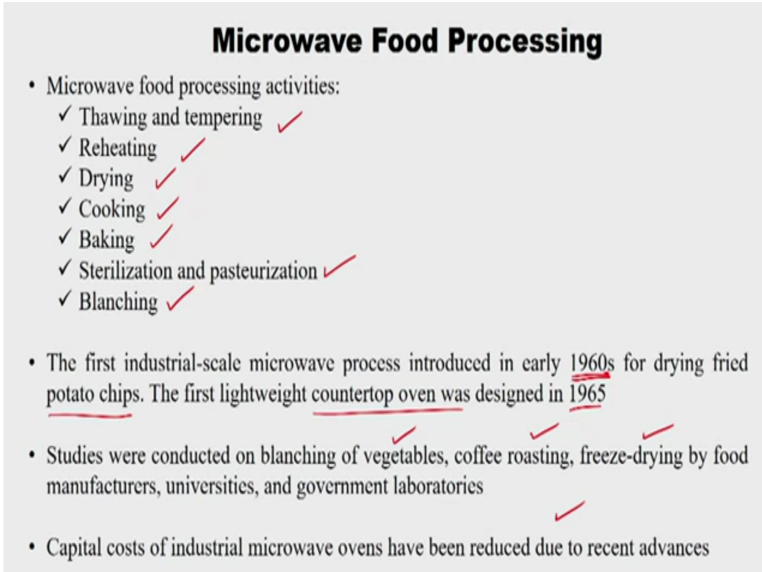

So these are all the introduction about the microwave energy and radio frequency energy and what are all the characteristics of the food material because what we learnt is the applied frequency is very much important and also the materials what you process, right so that should be dielectric materials which absorbs the microwave energy and also due to ionic rotation or dipole rotation or ionic migration the microwave will be converted into heat.

The food processing thawing, tempering, reheating, drying, cooking, baking and sterilization and pasteurization, blanching all the operations microwave can be applied. So the first industrial microwave oven was introduced in 1960 to dry fried potato chips. The first lightweight countertop oven, what we use in our domestic applications is designed in 1965.

And blanching of vegetables, coffee roasting, freeze drying of food, everything it started, when it started it was used to for these applications and capital costs of industrial microwave ovens have been reduced, we just discussed, right. So the capital cost of microwave oven is one which reduces its applications in wide areas. So they have been reduced due to a recent advances.

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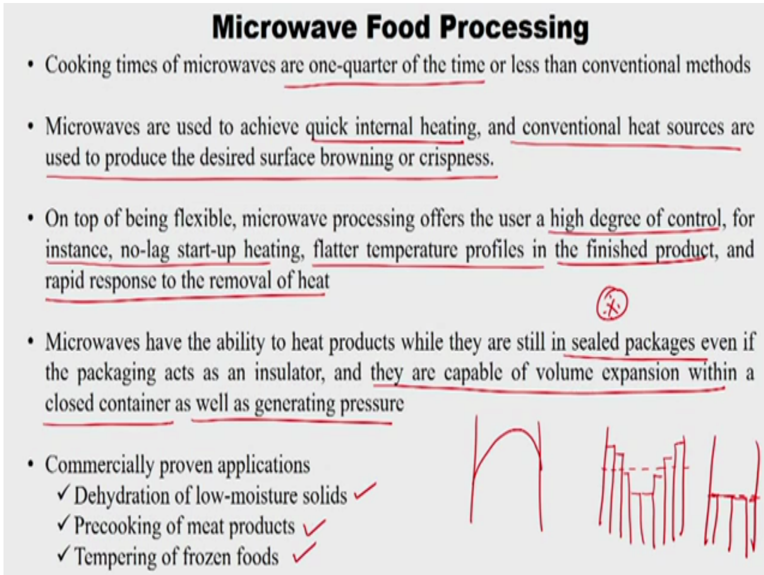

The first one is the cooking normally what we do, the cooking times of microwave ovens are one quarter of the time or less than the conventional method what we use. And microwaves are used to achieve quick internal heating and conventional heat sources are used to produce the desired surface browning or crispiness, we have already seen the microwave heating is a volumetric phenomena. So it first heats the inside part of the food, it is not first a heating so it penetrates through the food material or dielectric material, right food materials or dielectric materials because it has water, carbohydrates etc.

So, so, the internal part will be heated very quickly and very uniformly and in the surface if you apply conventional heat source then you will get the desired browning and crispiness, right. On top of being flexible microwave processing offers user high degree of control, for instance no lag startup heating, I told (38:20) period, flatter temperature profiles, flatter temperature profiles in the sense for example, normal continuous flow process you will get the velocity profile of this kind or if you heat it, the surface will be heated first, right somewhere like this, you will get the bar chart if you do it the bar chart right.

So the average somewhere here it comes, right if you apply microwave so normally the heating would be very uniformed and also your average temperature comes somewhere like this right. So you will get flatter temperature profiles in the finished product and rapid response to the removal of heat.

And microwaves have the ability to heat the products while they are still in the sealed package. This is the very good advantage because I can just heat it with the sealed packets itself, even if the packaging acts as an insulated, right but I do not need to heat the packaging, right. So even if it is a insulator the microwave can penetrate through the insulator and it can heat the food directly and they are capable of volume expansion within the closed container as well as generating pressure.

The commercially proven applications are dehydration of low moisture solids drying and precooking of meat products, tempering of frozen foods.

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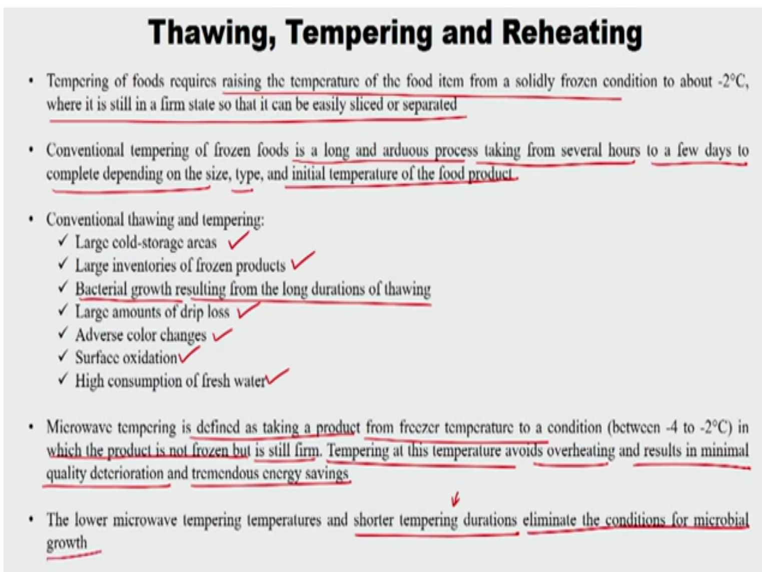

Then thawing, tempering and reheating, the tempering of food requires rising the temperature of the food item from the solidly frozen condition to the state where it can be sliced and separated. So when I store the food in the frozen condition, when I take it out, what we normally used to do is we used to little heat, or we usually keep it in the atmospheric temperature so that with long hours so that it can come to the normal atmospheric temperature for further processing or slicing or separation. But that is what I told, if conventionally it is a long and arduous process taking from several hours to a few days to complete depending on the size, type and initial temperature of the food product.

The conventional thawing and tempering offers these disadvantages, one is large cold storage areas because I need to take it out and keep it for long hours to get the non-firmed product, large inventories for, large inventories of frozen products, and sometimes what happens is bacterial growth results from the long durations of the thawing, large amounts of drip loss, adverse color changes, surface oxidation and high consumption of freshwater everything happens.

Microwave tempering is defined as the taking the product from the freezer temperature to a condition which the product is not frozen, but it is still firm, right. So, it gives me the product which is still in the firm condition, but it is not a frozen condition so that I can do further operation right. So the slicing or the separation or further whatever the operation I wanted to do.

Tempering a temperature avoids overheating and results in minimal quality deterioration and tremendous energy savings when compared to conventional tempering. A lower microwave tempering temperatures and short tempering durations, the duration are very, very short, eliminate the conditions for microbial growth.

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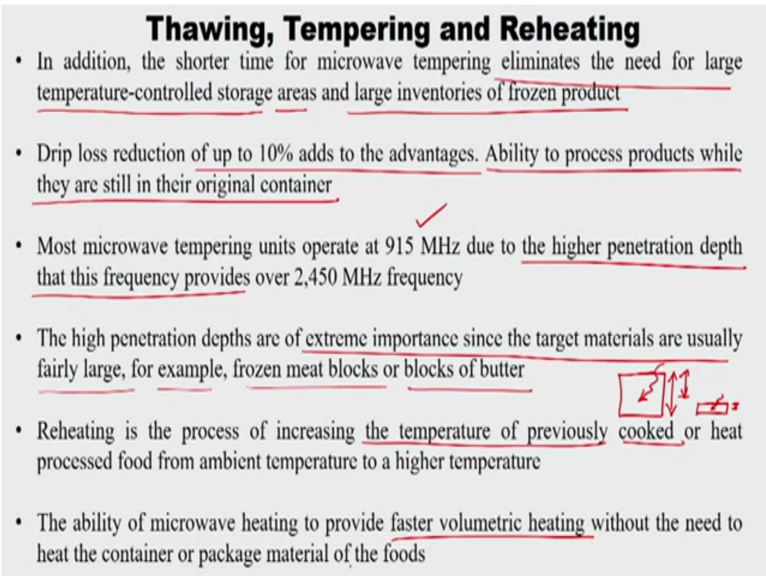

In addition to shorter time, microwave tempering eliminates the need for the large temperature controlled storage areas and large inventories of frozen product. So what I told, I have to remove the frozen product, if I am doing conventional tampering, I need to maintain the temperature for long hours in the storage area. So, what I require is large temperature controlled storage area as well as large inventories for the frozen food. So, due to less timing, as well as shorter tempering durations as well as the microwave tempering temperatures, these two disadvantages of conventional tempering can be avoided.

The drip loss reduction up to 10 percentage adds the advantage when it is done by microwave. Ability to process the products while they are still in their original container, already be discussed, right we need not remove the packaging material. So most of microwave tempering units operate at 915 it is not the domestic frequency range due to higher penetration depth that this frequency provides so 915 provides higher penetration depth that is why we do not use it for home cooking or domestic cooking because there we use the quantity to be processed is not that large quantity, right.

And high penetration depths are of extreme importance since the target materials are usually fairly large, for example, frozen meat blocks or blocks of butter. If you do it in home, then it will be very small blocks, right so, if you do it in the industry wise it will be a large block so you need more penetration depth, penetration depth in the sense, for example, this I have a material, so the microwave which passes through should have that depth right.

So, if I have a 915 megahertz frequency it has a higher penetration depth. For example, if I have a small block then I do not require that penetrating depth, the depth is here very small when compared to here okay. So the reheating is the process of increasing the temperature of previously cooked food, this you are used to it, in home we used to do cooked food we just to keep it in the microwave oven and get it reheated. The ability of microwave heating to provide faster volumetric heating without the need to heat the container or packaging material of the foods is the one of the main advantage.

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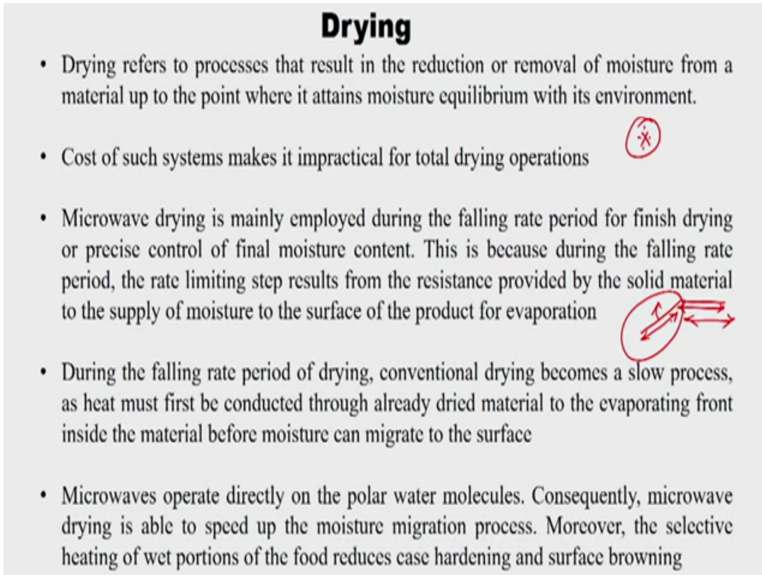

And in the drying phenomena, it is also very much important so normally in conventional drying what happens is there is two periods, one is constant rate period and another one is falling rate period. So in the constant rate period, what happens is the surface moisture will be removed first, then after that internal moisture will diffuse to the surface then it is removed by the hot air, this is the conventional process, right.

So, if you remember what happens when the microwave energy penetrates, first it penetrates to inside the material. So that means the falling rate period moisture removal will be done by microwave heating and the surface phenomena can be taken care by conventional drying mechanism. So, if we combine both of them then we will get maximum efficiency compared to either totally apply conventional air drying or totally apply microwave drying, right.

So in the conventional air drying the surface moisture removal will be first, when it comes to microwave drying so the internal moisture content would be removed first. So when you apply both of them then you will get the better efficiency.

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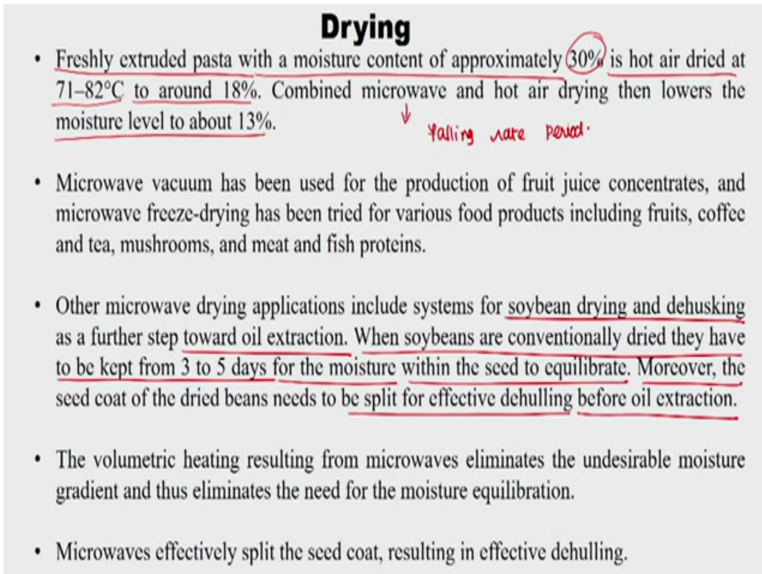

So that is why it is told the freshly extruded pasta with the moisture content of approximately 30 percentage initial moisture content is hot air dried at 71 to 82 degrees centigrade to around 18 percentage. But combined microwave and hot air drying then lowers the moisture level to 13 percentage almost 5 percentage moisture reduction extra you get when you combine the microwave drying in the falling rate period, right.

And some of the applications were soybean drying and dehusking, dehusking in the sense you need to remove the outer layer as well as a further step toward the oil extraction, when soybeans are conventionally dried they have to be kept for 3 to 5 days for the moisture with in the seed to equilibrate.

Moreover, the seed coat of the dried beans needs to be split for effective dehulling before oil extraction. So that means I need not dry it for 4 to 5 days to remove the moisture content in the microwave processing. Moreover, the dehulling will be the easiest operation if I do it with the microwave.

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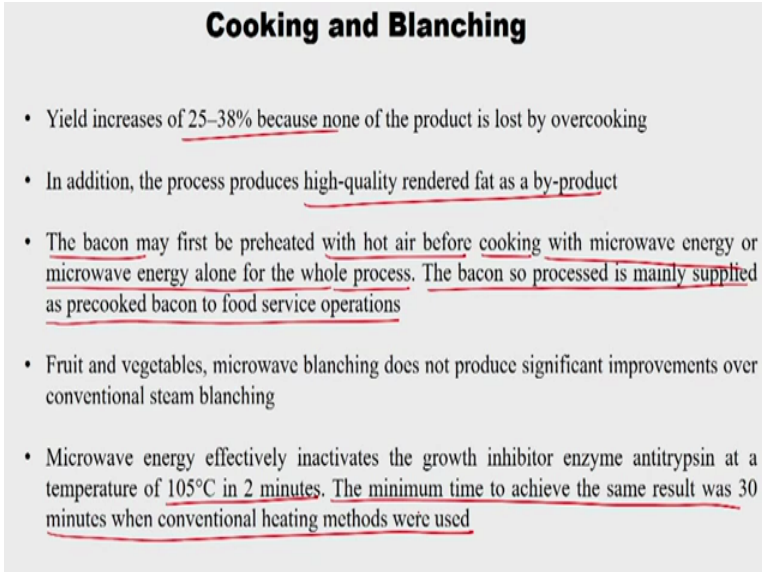

Then cooking, it is a normal operation so it improves the yield of 25 to 38 percentage and also it renders high quality fat as a byproduct. And these are examples, the bacon may be first preheated with the hot air before cooking with the microwave energy or microwave energy alone for the whole process. The cooking, the bacon so processed is mainly supplied as a precooked bacon for food service operations.

So, the cooking also it can be done and blanching we have already seen in the blanching operations, one of the heating medium would be microwave, if you use the microwave energy so the time is 105 degrees centigrade in 2 minutes only. The minimum time to achieve the same result was 30 minutes when conventional heating methods are used.

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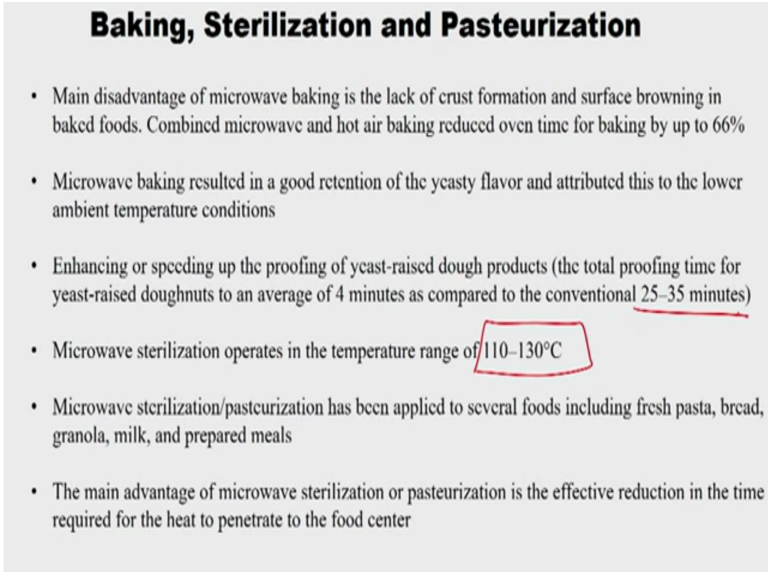

Baking, Sterilization and Pasteurization

- Main disadvantage of microwave baking is the lack of crust formation and surface browning in baked foods. Combined microwave and hot air baking reduced oven time for baking by up to 66%
- Microwave baking resulted in a good retention of the yeasty flavor and attributed this to the lower ambient temperature conditions
- Enhancing or speeding up the proofing of yeast-raised dough products (the total proofing time for yeast-raised doughnuts to an average of 4 minutes as compared to the conventional 25–35 minutes)
- Microwave sterilization operates in the temperature range of 110–130°C
- Microwave sterilization/pasteurization has been applied to several foods including fresh pasta, bread, granola, milk, and prepared meals
- The main advantage of microwave sterilization or pasteurization is the effective reduction in the time required for the heat to penetrate to the food center

And then the baking, sterilization, pasteurization also the same microwave can be used as a heating medium. So that when we were discussing the sterilization and pasteurization also, we have discussed this particular thing. So only thing is here the temperature as well as the time requirement would be lesser when you use the microwave heating.

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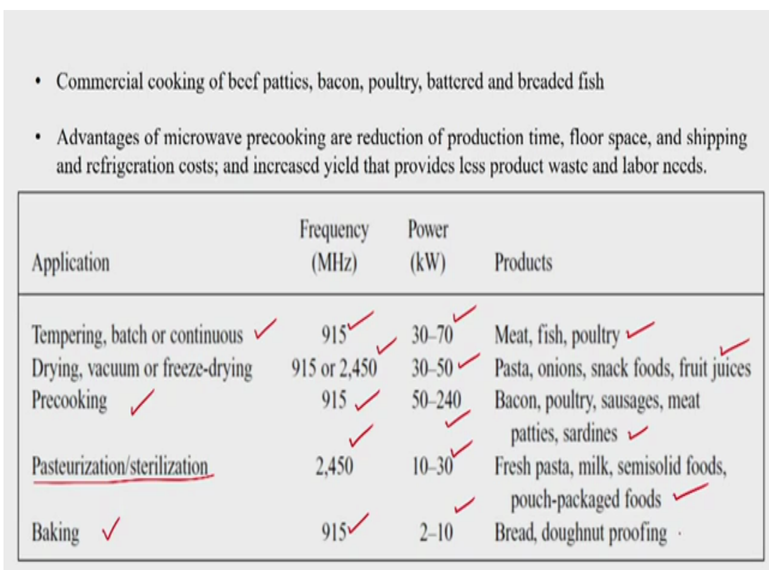

- Commercial cooking of beef patties, bacon, poultry, battered and breaded fish
- Advantages of microwave precooking are reduction of production time, floor space, and shipping and refrigeration costs; and increased yield that provides less product waste and labor needs.

Application	Frequency (MHz)	Power (kW)	Products
Tempering, batch or continuous	915	30–70	Meat, fish, poultry
Drying, vacuum or freeze-drying	915 or 2,450	30–50	Pasta, onions, snack foods, fruit juices
Precooking	915	50–240	Bacon, poultry, sausages, meat patties, sardines
Pasteurization/sterilization	2,450	10–30	Fresh pasta, milk, semisolid foods, pouch-packaged foods
Baking	915	2–10	Bread, doughnut proofing

So these are for different applications what should be your frequency and power range and what are all the products can be processed for tampering, batch or continuous the frequency range is 915, the power range is 30 to 70 kilo watts, the processed products are meat, fish poultry.

The drying, vacuum or freeze drying the frequency range is 915 or 2.4 into 10 to the power of 9 hertz, the power is 30 to 50. Pasta, onion, snack foods and fruit juices are the products and precooking the same frequency range of 915, the power is 50 to 240 kilo watt. The bacon, poultry, sausages, meat patties and sardines.

The pasteurization and sterilization the frequency ranges 2.4 into 10 to the power of 9 hertz and the power is 10 to 30 kilowatts, the fresh pasta, milk, semi solid foods and pouch packed food processed. The baking 915, 2 to 10 kilowatt and bread, donut and proofing.

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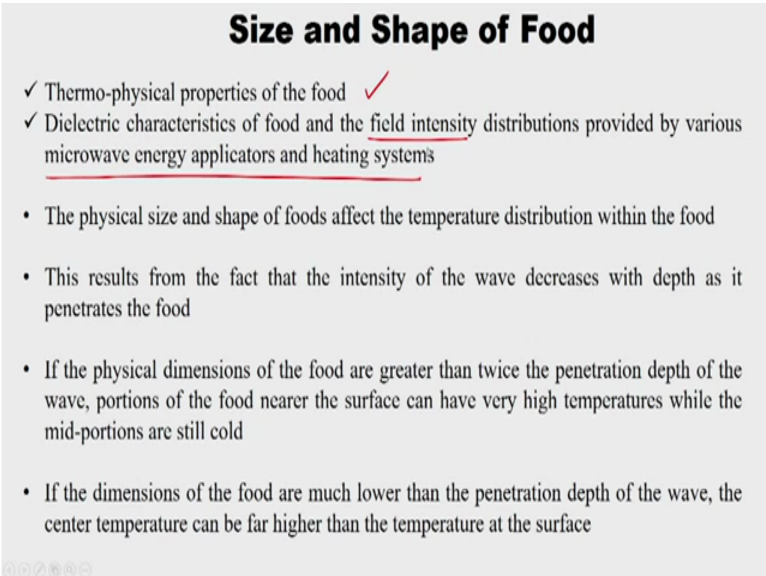

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And when you apply the microwave heating there are two main properties to be taken care, one is thermo physical properties of the food, other one is the applied field intensity just we have seen, right here the applied field intensity which frequency range you are using and also the applicators and the heating system what you use, right. The thermo physical properties of the food is nothing but a size and shape. So, whether it is a cylindrical shape or rectangular shape, or whether it is thick product or thin product all comes under the size and shape of the food.

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Surface Area and Specific Heat

- Higher product surface area therefore results in higher surface heat loss rate and more rapid surface cooling
- During microwave heating, the highest temperature is not at the surface of the product (despite the higher intensity of power absorbed there) but somewhere in the interior.
- How much a food product will heat given a specific amount of energy depends on its heat capacity.
- The implication of this for microwave heating is that different food products heated together have different temperature histories
- To control this, some microwave food packages are sealed tight to allow heat transfer between hotter and colder foods, thus giving similar temperature history for different foods in the same package

And a surface area also matters and specific heat also matters, specific heat is nothing but a capacity to withhold the heat and surface area is nothing but we just have seen since it is a volumetric phenomena, the heating at the surface would be lower than the heating of the internal surface. So that also affects your heating profile.

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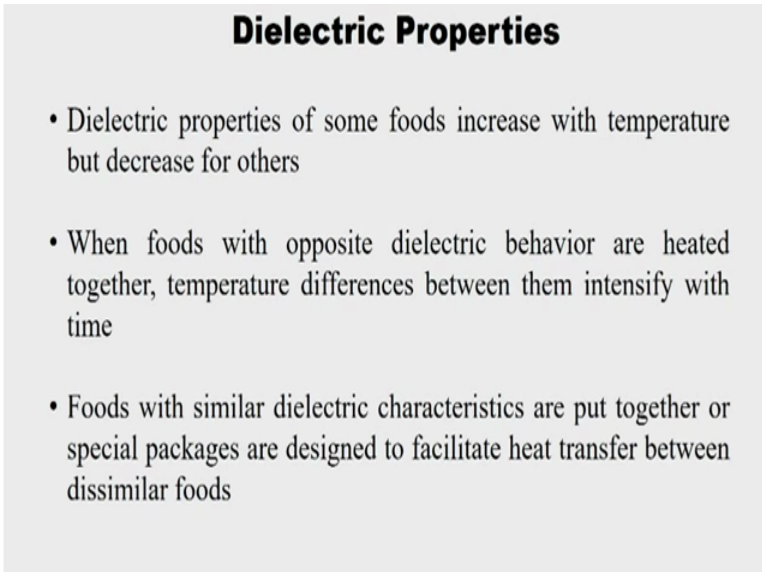

And dielectric properties we have discussed enormously in the first few slides.

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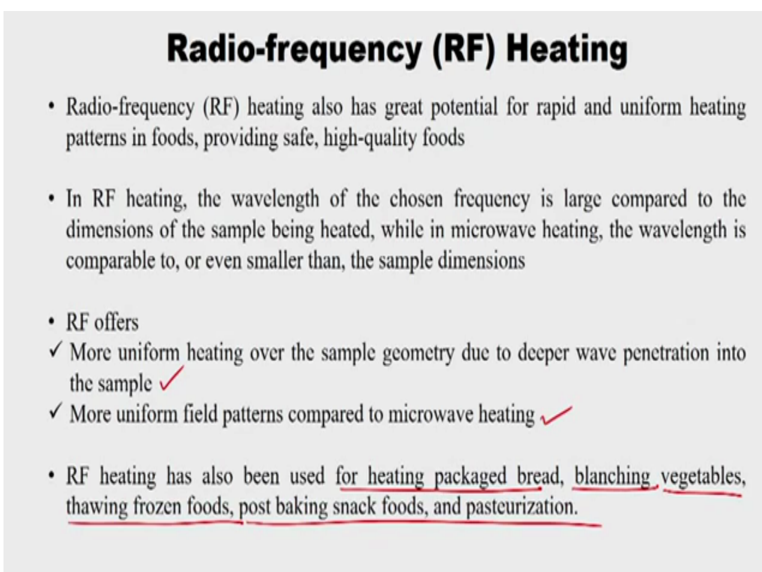

And radio frequency heating, it is similar to the microwave processing, only the difference is between the electrodes your dielectric materials are kept and it also offers more uniform heating as well as more uniform field patterns. And this RF heating also can be used for eating packaged bread, blanching of vegetables, thawing of frozen food and post baking snack foods and pasteurization.

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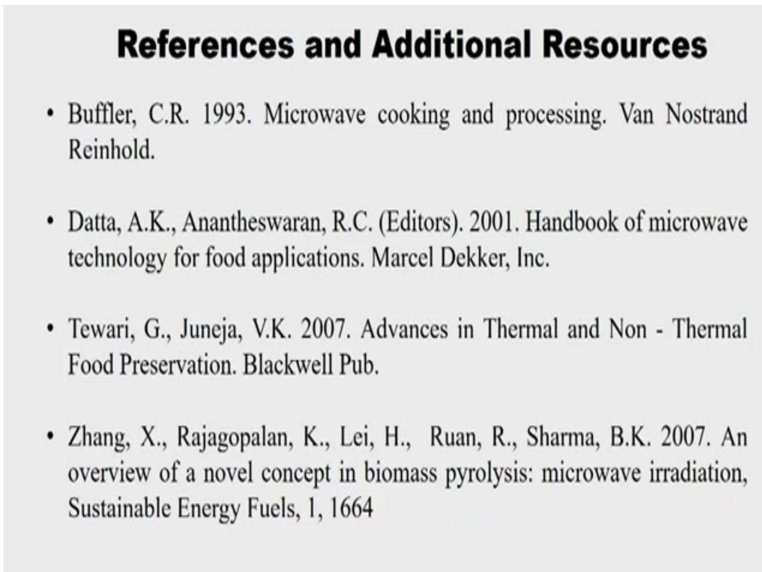

So these are references and additional resources, you would like to refer further. Thank you.