**Novel Technologies for Food Processing and Shelf Life Extension**

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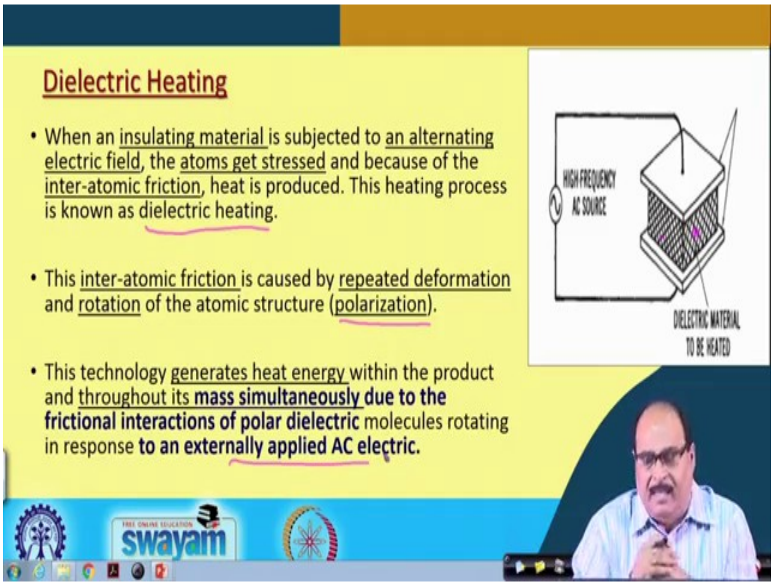
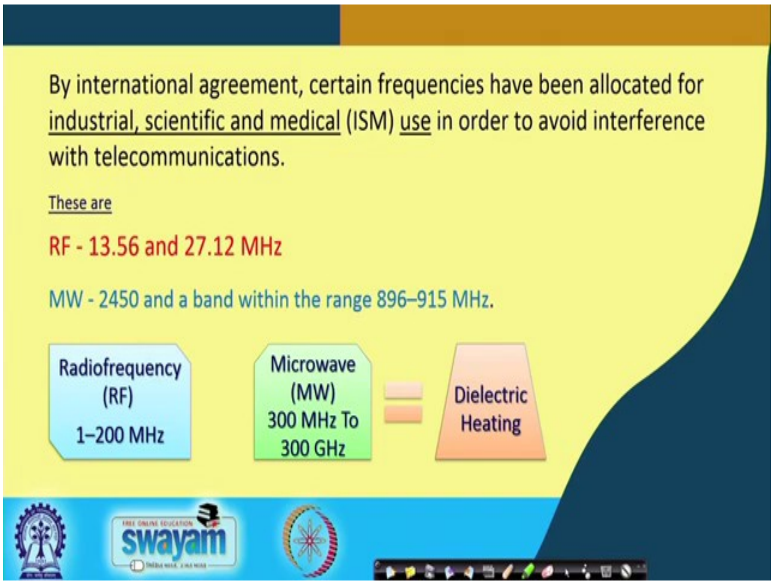
**Lecture - 17**
**Microwave Heating**

In this lecture, another novel and emerging technology in food processing and preservation i.e. microwave heating is discussed.

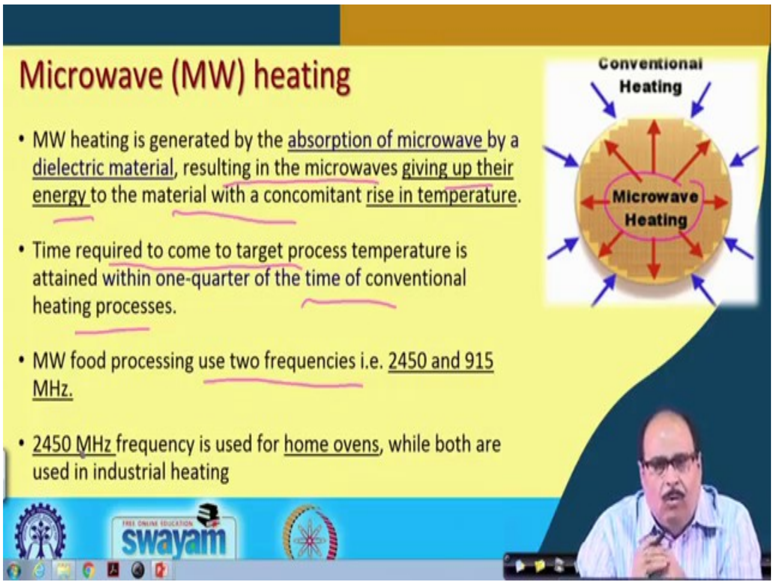



When an insulating material is subjected to an alternating electric field, the atoms in the material get stressed and because of the inter-atomic friction, heat is produced. There is some dielectric material kept (see Fig.) and an alternating electric field through some AC source is supplied to this material. This heating process is known as dielectric heating. This inter atomic friction is caused by repeated deformation and rotation of the atomic structure, which is also referred to as polarization.

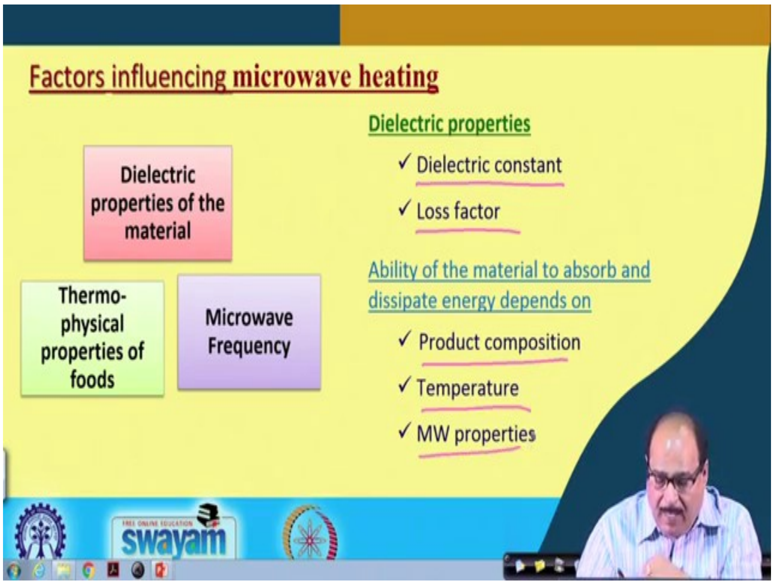
This technology i.e. dielectric heating generates heat energy within the product and throughout its mass simultaneously due to the frictional interactions of polar dielectric molecules rotating in response to an externally applied AC current. So, it is an advanced form of heating with a much better performance in comparison to the conventional heat processes which are normally used in food processing.



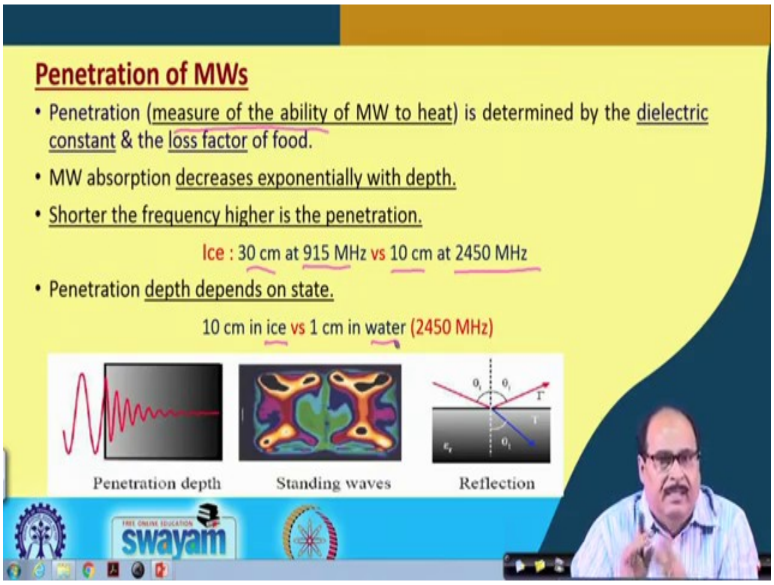

Under the international agreement, only certain frequencies are allowed for the industrial, scientific and medical use. And, this is just to avoid interference with the telecommunication system. Dielectric heating may be of two forms i.e. radio frequency heating or microwave heating. So, for radio frequency heating, 13.56 and 27.12 MHz frequencies or in general, 1 - 200 MHz range are normally used. Whereas, microwave frequencies may be within the range of 300 MHz - 300 GHz. The microwave systems which are generally used in food processing have frequencies in the range of 2450 MHz and the band width within the range of 896 - 915 MHz.



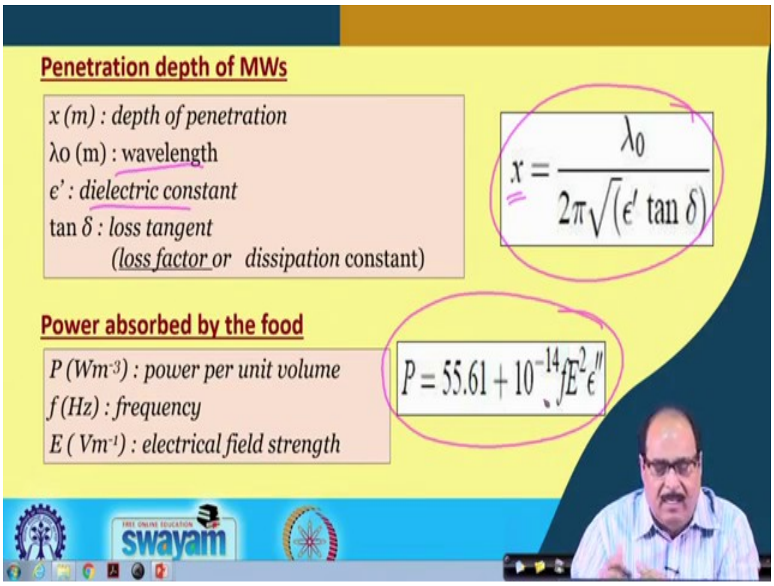

Microwave heating is generated by the absorption of microwave by a dielectric material. And, this results in the microwaves giving up their energy to the material with a concomitant rise in temperature. In the picture shown, the conventional heating source transfers heat either through conduction or convection. But, in the case of microwave heating, heat is generated internally and obviously, the time required to attain the target process temperature is very short. Some researchers have worked on these aspects and concluded that it takes about one-quarter of the time which is required for conventional heating processes. Microwave food processing uses two frequencies, i.e. 2450 and 915 MHz. Normally, 2450 MHz frequency is used for home ovens whereas, for industrial ovens, both 2450 and 915 MHz are used.




The microwave heating process is influenced by certain factors of the material, the environment and others factors. The important factors influencing this process include the dielectric properties of the material, thermo physical properties of the food and frequency of the microwave used. Among the dielectric properties, dielectric constant and the loss factor are the important ones. Ability of the material to absorb and dissipate microwave energy depends upon the product composition, temperature and microwave properties.




The penetration of microwaves which is taken as measure of the ability of the microwave to heat is determined by dielectric constant and loss factor of the food. Microwave absorption decreases exponentially with depth. Shorter the frequency, higher is the penetration. Example of ice can be taken; at 915 MHz, the microwave can penetrate 30 cm deep whereas, at 2450 MHz, it can penetrate only 10 cm deep. Also the penetration depth depends on the state of the matter. For example; if two microwaves of 2450 MHz are there, it can penetrate 10 cm in ice, but only 1 cm in water. So, depth, frequency and state of the matter are the factors which influence microwave heating process.



The penetration depth can be measured by the equation:

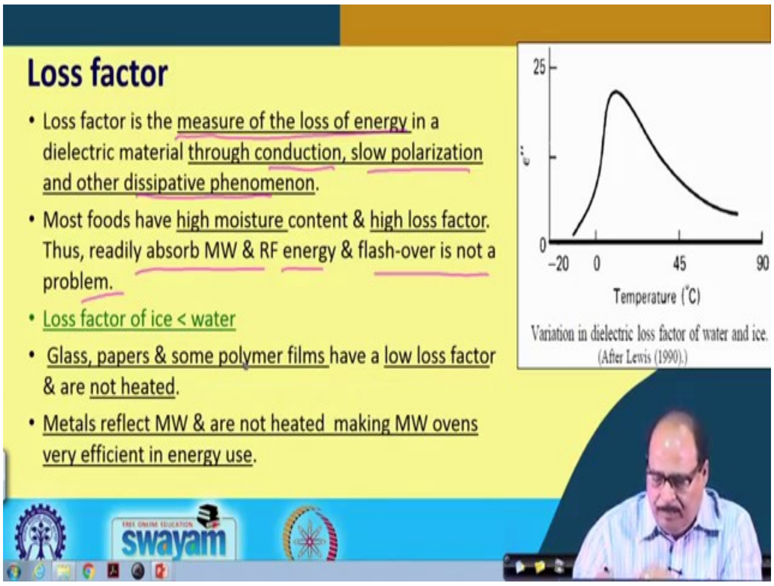
$$x = \frac{\lambda_0}{2\pi\sqrt{(\epsilon' \tan \delta)}}$$

€ is the dielectric constant and the loss tangent by this equation one can calculate; if the dielectric constant and the loss tangent of the material are known.

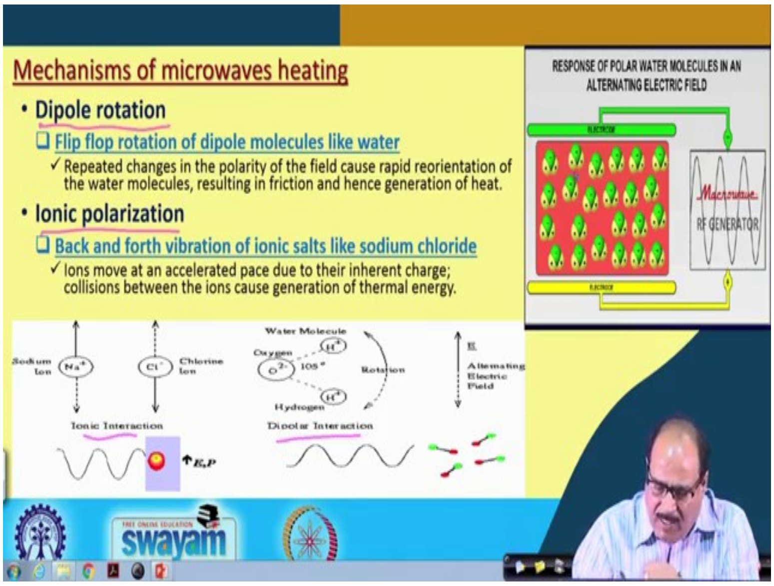
Similarly, the power generated in the food or power absorbed by the food can be calculated using this equation:

$$P = 55.61 + 10^{-14} f E^2 \epsilon''$$

Where, P is the power per unit volume, f is the frequency and E is the electrical field strength.

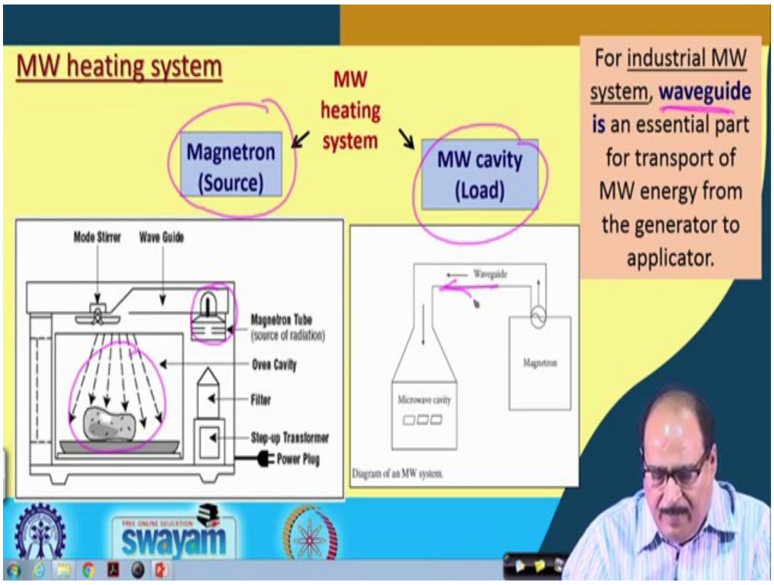



Loss factor is an important characteristic. It is the measure of the loss of energy in a dielectric material. This loss may be due to conduction, slow polarization and other dissipative phenomena. Most of the foods have high moisture content and therefore, they have high loss factor. And high loss factor means that they can readily absorb microwave and radio frequency energy and flash over is not a problem. Loss factor of ice is less than that of the water. It has been shown here by some researchers the variation in dielectric loss factor of water and ice (see Fig.). It shows that the water has more loss factor than ice. So, water can be heated more easily than that of the ice. Glass, paper and some polymeric films have a low loss factor and are not heated. Metals reflect microwave and they are not heated making the microwave oven very efficient in energy use.



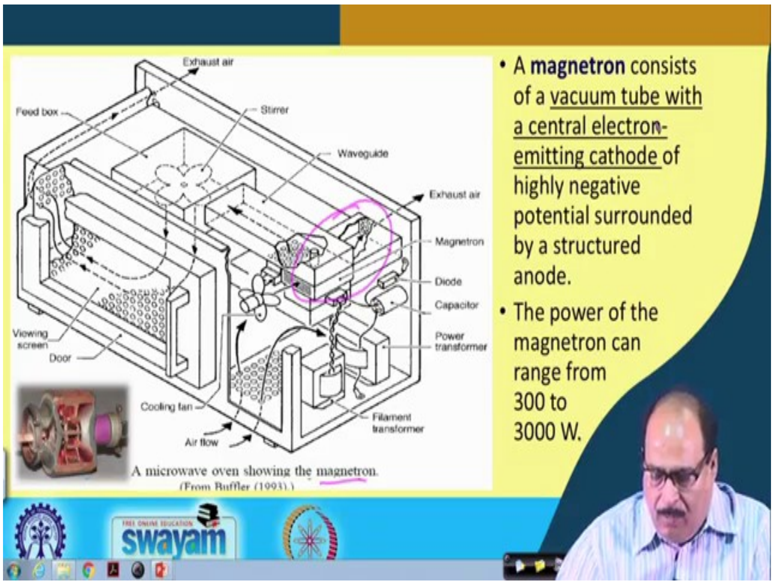

Mechanism of MW heating: Either it may involve heating through dipole rotation or through ionic polarization. In the dipole rotation, flip flop rotation of dipole molecules like water occurs; H is positive and O that is negative (see Fig.). The repeated changes in the polarity of the field causes rapid reorientation of the water molecule. And, this results in friction which further generates heat.

In ionic polarization, back and forth vibration of ionic salts like sodium chloride (sodium ion plus positive chloride ions) occurs and these ions move at an accelerated place due to their internal charge and collision between these ions can cause generation of internal energy. So, these are the ways by which actually the molecular collision results. The oppositely charged ions when they are put in the microwave field, they try to realign towards the oppositely charge of the microwaves. And, this leads to molecular movement and finally, friction causes the generation of the heat.

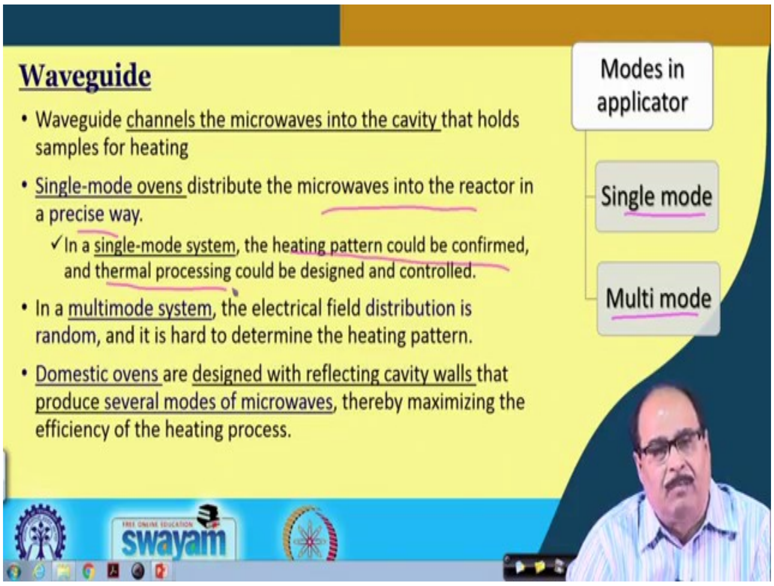



There are two main units or components of microwave system; one is magnetron, the source to generate the microwave and other is the microwave cavity where the material to heat is loaded. In the schematic representation of the microwave system, the oven cavity and slip-up transformer and electrical power plug meters are shown. Energy is given to magnetron which normally produces the microwave energy and then this energy is passed inside the oven.

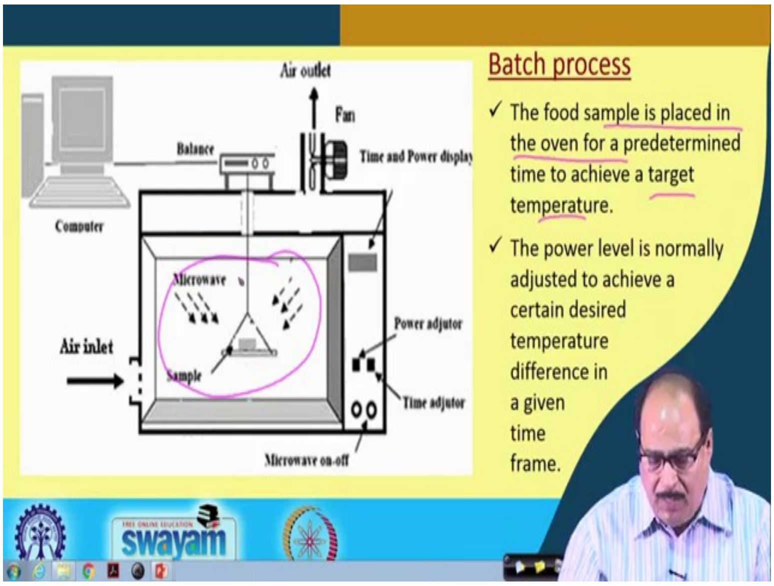
Waveguide becomes an important or essential component. The microwaves are generated in the magnetron separately and then with the help of the waveguide, these are transported to the microwave cavity. So, this magnetron and waveguide become two important components for consideration for proper design or manufacture of the microwave heating systems.



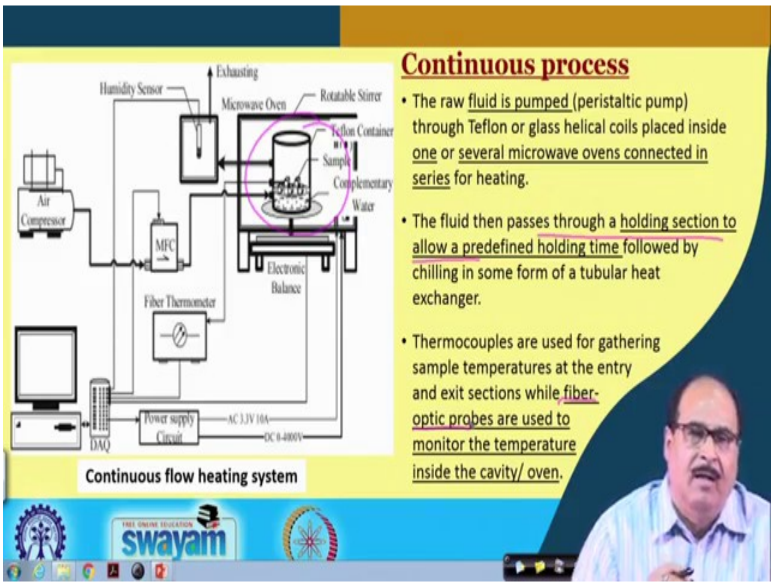

The schematic figure shows a microwave oven showing the positioning of the magnetron. The magnetron actually consists of a vacuum tube with a central electron emitting cathode of highly negative potential surrounded by a structured anode. The power of the magnetron can range from 300 - 3000 W depending up on the capacity of the microwave system or of the equipment.



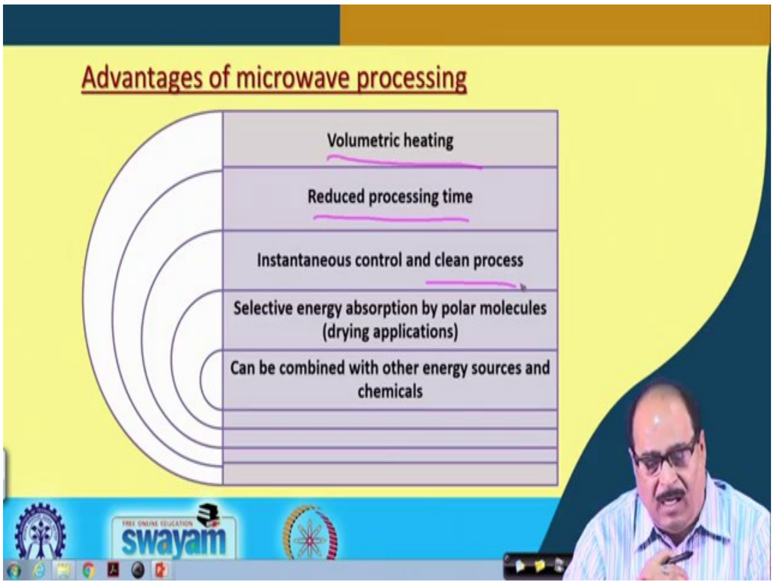

The waveguide channels the microwave into the cavity that holds the sample for heating. There are several modes of waveguide in applicator: single mode and multimode. Single mode ovens distribute the microwave into the reactor in a precise way. In a single mode system, the heating pattern could be confirmed and thermal processing could be designed and controlled whereas, in a multimode system, the electrical distribution is random and it is hard to determine the heating patterns. Domestic ovens are generally designed with reflecting cavity walls and that produce several modes of microwaves and thereby they maximize the efficiency of the heating process.




The microwave process can be a batch or a continuous process. In a batch process, the food sample is placed in the oven for a predetermined time to achieve a target temperature. And, the power level is normally adjusted to achieve a certain desired temperature difference in a given time frame. The schematic of the batch process shows the conventional microwave oven. There is an air inlet, air outlet and one balance system to conduct the drying studies.

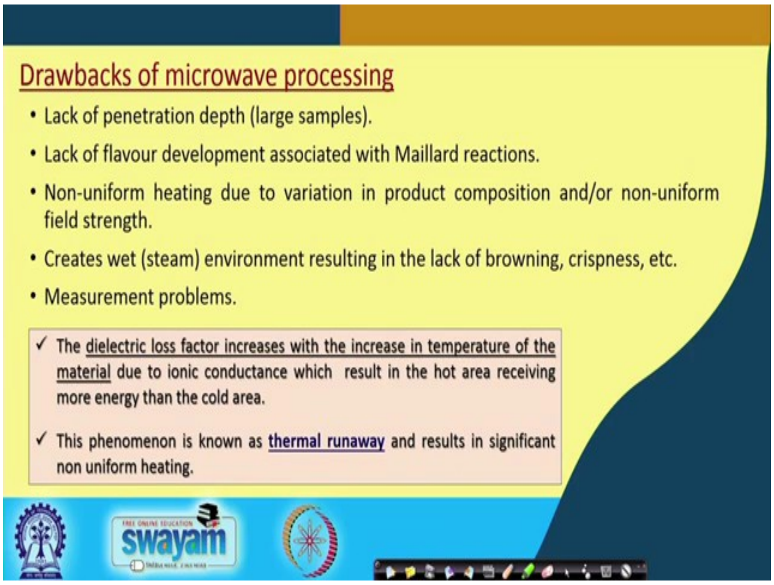


In the continuous process (see the diagram), the raw fluid or sample is pumped using peristaltic pump through Teflon or glass helical coils placed inside the microwave oven or cavity. And, it may be one cavity or may be several microwave ovens connected in series for the desired heat frequency or for desired heating process. And, the fluid after being exposed to the desired amount of microwave is allowed to pass through a holding section and held for a predefined or predetermined holding time. This is then followed by chilling in some form of a tubular heat exchanger or such other device. For measurement purposes, thermocouples are normally used for measuring sample temperature at the entry and exit points. Whereas, fiber optic probes are used to monitor the temperature inside the cavity or oven.



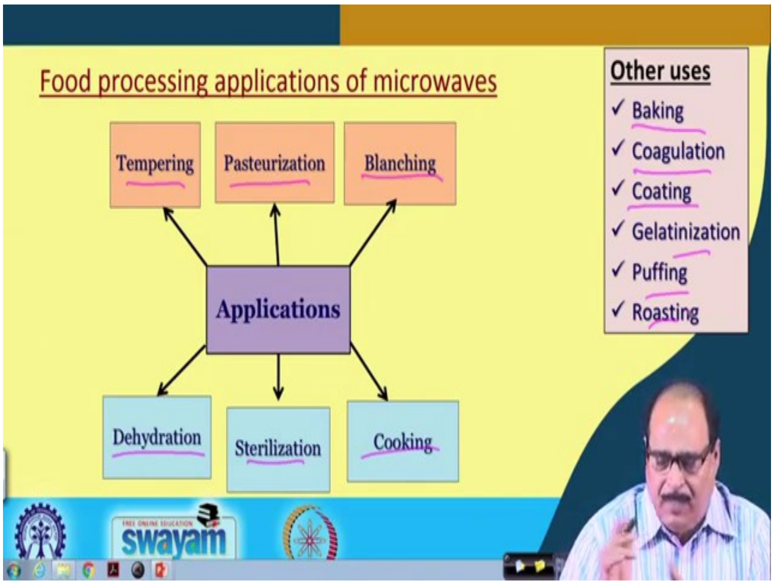

Advantages of microwave processing: It is a type of volumetric heating. So, the heat is uniform, it is instantaneous, not much heat transfer and other problem which is associated with the conventional heating processes.

It results in reduced processing time and is a clean process. Selective energy absorption by the polar molecules facilitates its use in the drying applications. It can be combined with other energy sources and chemicals etc. to improve the efficiency of those processes.

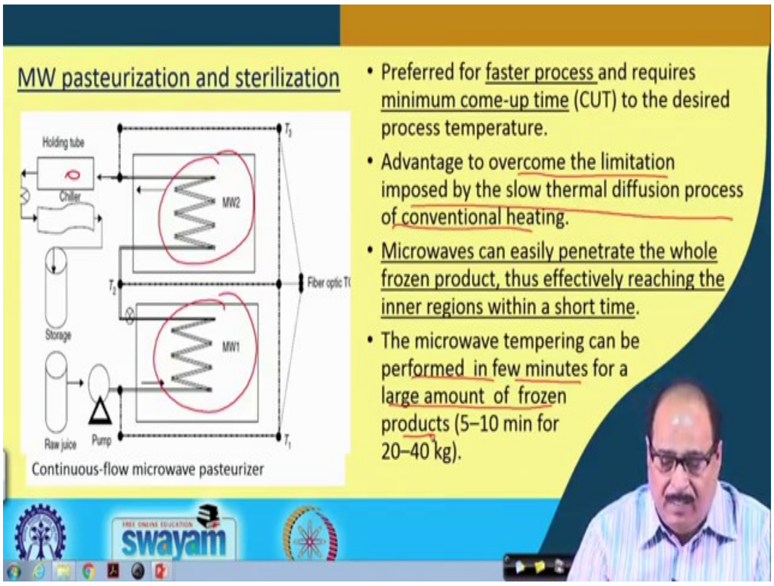



Of course like any other process, the microwave processing also has certain drawbacks. If compared with other processes like RF heating etc., the microwave generally lack the desired penetration length or they have less penetration power. And therefore, particularly its application for the large samples may become problematic. Also because of the internal heating, the development of flavour etc. which are associated with the Maillard reactions and other things, they lack here. For example, delicate brown color development, crispiness, etc. cannot result due to low surface heating. So, in these types of processes, it limits its use.

It causes measurement problems; it becomes difficult to insert the probe etc. into the cavity oven without any loss of the microwave energy. Another drawback of the microwave processing is that, dielectric loss factor increases with the increase in the temperature of the material due to ionic conductance. This results in the hot areas receiving more energy than the cold areas and, this phenomenon is known as thermal runaway which results in significant non-uniform heating.




Regarding food processing application of the microwaves, it can be used for tempering purposes, pasteurization, sterilization, blanching, dehydration, cooking or even for other food processes. They can also be used for baking, coagulation, coating, gelatinization puffing, roasting, etc. So, for wide ranging process applications, for preparation of different products or to improve the characteristics of the product and to increase their shelf life etc., these microwaves can be used.

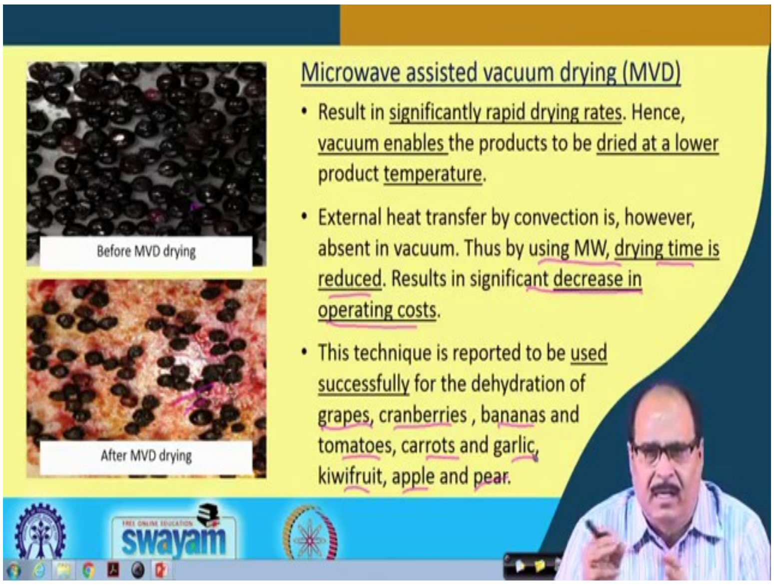



So, whatever the process where heat is used, these microwaves can also be used but with different objectives. In this figure, a continuous flow pasteurizer is shown. So, it can be batch system one or several can be connected together.

The material after being exposed to the microwave for desired time, it is passed through the second unit and after that, it is sent to the holding tube then followed by chilling. So, it is a faster process, come up time is normally less, required temperature can be obtained instantaneously and thus, energy efficiency is more here.

It has advantages to overcome the limitations imposed by slow thermal diffusion processes of the conventional heating. Microwaves can easily penetrate the whole frozen product, thus, effectively reach the inner regions within a short time. Microwave tempering can be performed in few min for a large amount of frozen product; even 24 - 40 kg weighing frozen products can be tempered just within 5 to 10 min.


The figures show microwave pasteurization in-container solid foods where the filling of product, then film and valve applications, cooking & pasteurization for the product is done and microwave sterilization equipment (extracted from literature).




Similarly, microwave assisted vacuum drying (MVD) of the food is another interesting application of microwave. There is not much difference in the color, structure and other characteristics like shrinkage, etc., but the water is removed, the size has reduced (see picture). So, MVD results in significantly rapid drying rates and the vacuum enables the product to be dried at a lower product temperature. So, the combination of microwave and vacuum becomes a very good and novel means of drying particularly of those materials which have heat sensitive components, bio actives or health ingredients which face the danger of getting evaporated in the conventional processes. They can be retained to a greater extent in the microwave assisted vacuum drying.

And here, as external heat transfer by convection is absent in the vacuum, by using microwave, drying time and operational cost are reduced significantly. Many researchers have successfully used this technology for dehydration of grapes, cranberries, bananas, tomato, carrot, garlic, kiwifruit, apple, pear, etc. Mostly fruits which contain heat sensitive components or which because of the low loss tangent, their drying and the dehydration becomes difficult. So, for drying of such products, this becomes a very good process.

Microwave processing is a novel technology or an advanced heat processing technology which generally eliminates the problems which are there in the conventional heating processes. And, it is an improved means of thermal technology of the heating system for the food, that provide reduced process time, improved product quality, better energy savings and better economies in the products.