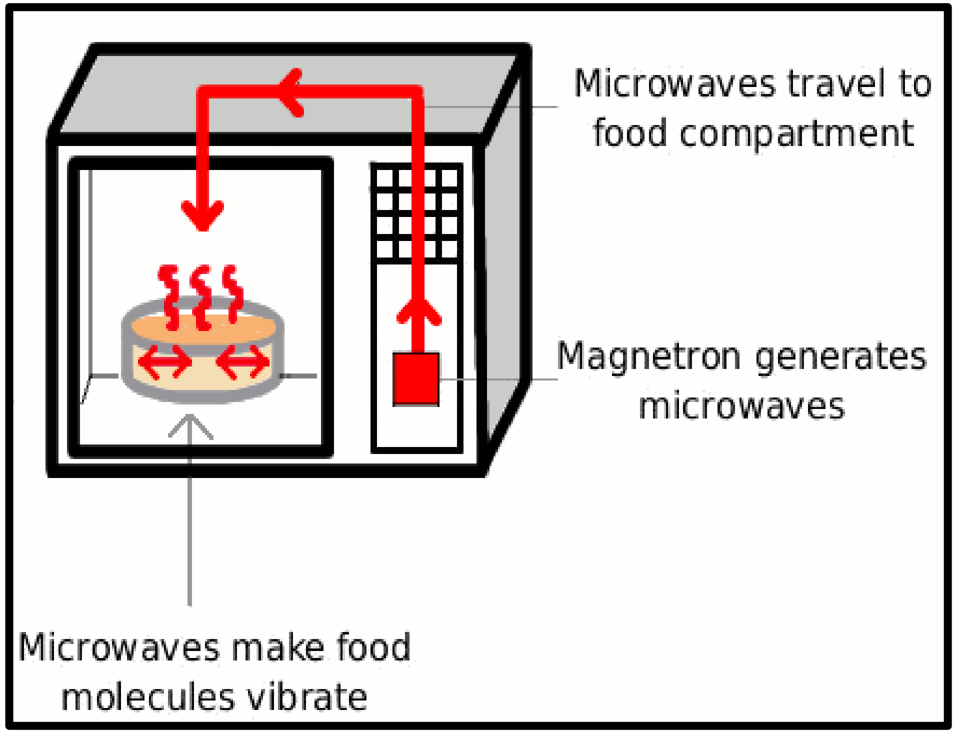
KERONE

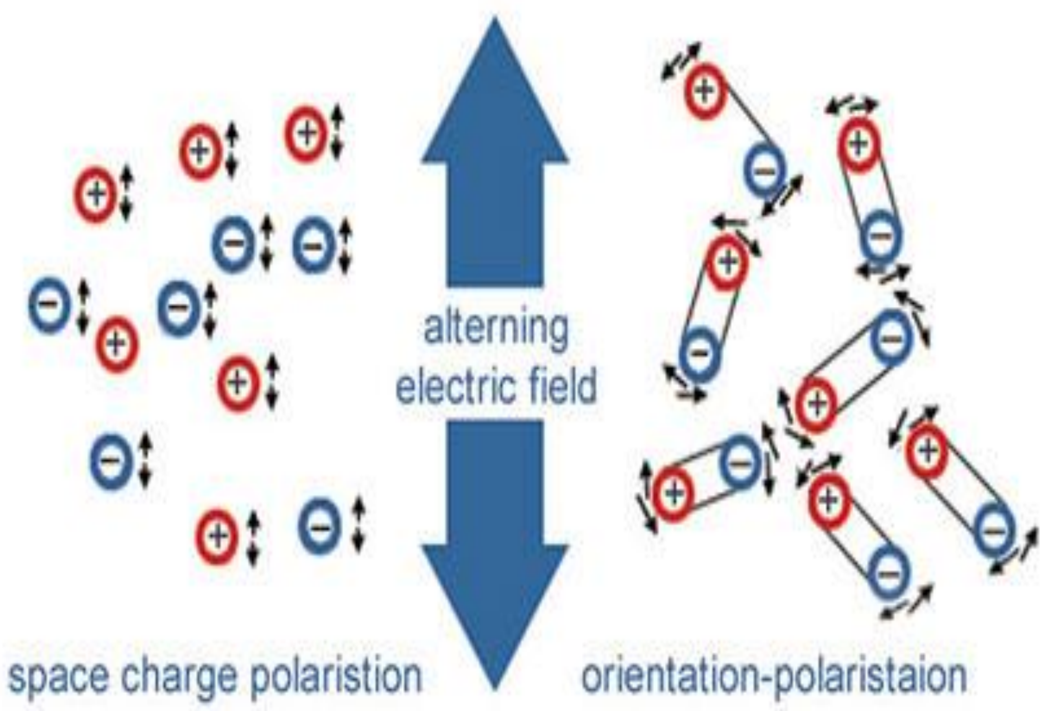
Microwave Heating Technology for Food Processing

1. Introduction

Microwave heating has vast applications in the field of food processing over a period of several decades. The applications of microwave heating in food processing include drying, pasteurization, sterilization, thawing, tempering, baking of food materials etc. Microwave heating has gained popularity in food processing due to its ability to achieve high heating rates, significant reduction in cooking time, more uniform heating, safe handling, ease of operation and low maintenance.
Moreover, microwave heating might change flavor and nutritional qualities of food in a lesser extent as opposed to conventional heating during cooking or reheating process.

Microwaves are electromagnetic waves whose frequency varies within 300 MHz to 300 GHz. Domestic microwave appliances operate generally at a frequency of 2.45 GHz, while industrial microwave systems operate at frequencies of 915 MHz and 2.45 GHz.





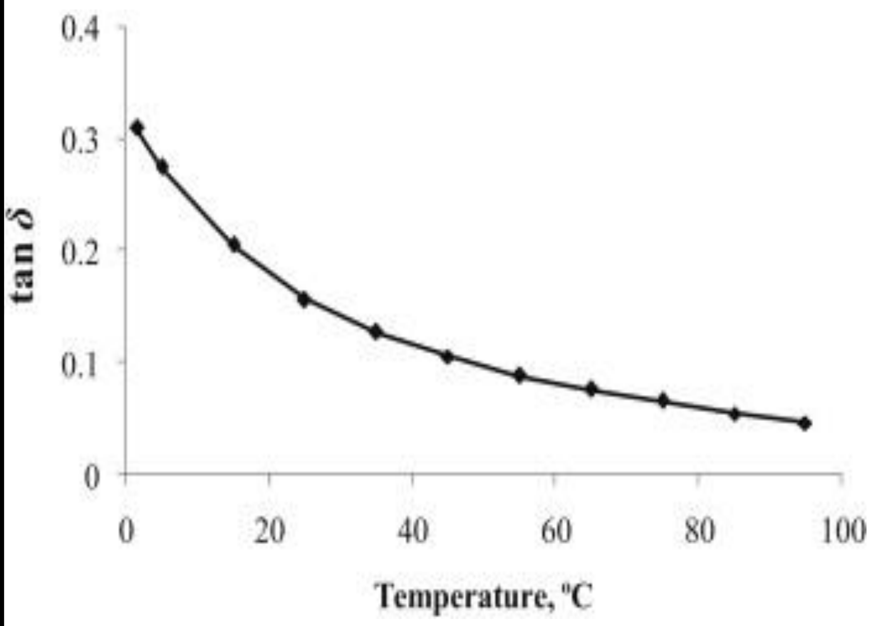
1.1 Microwave Heating Mechanism

Microwave heating is caused by the ability of the materials to absorb microwave energy and convert it into heat. Microwave heating of food materials mainly occurs due to dipolar and ionic mechanisms. Presence of moisture or water causes dielectric heating due to dipolar nature of water. When an oscillating electric field is incident on the water molecules, the permanently polarized dipolar molecules try to realign in the direction of the electric field.

Due to high frequency electric field, this realignment occurs at million times per second and causes internal friction of molecules resulting in the volumetric heating of the material. Microwave heating might also occur due to the oscillatory migration of ions in the food which generates heat in presence of high frequency oscillating electric field. There are many factors which affect the microwave heating and its heat distribution and the most important of them are the dielectric properties and penetration depth.

2. Dielectric properties

The ability of a material to convert microwave to heat can be understood by knowing its dielectric properties. The real part of dielectric property, termed as dielectric constant, signifies the ability to store electric energy and the imaginary part of dielectric property, termed as dielectric loss, signifies the ability and convert electric energy into heat, $\varepsilon_r = \varepsilon_r' - j\,\varepsilon_r''$
where ε ' and ε" are dielectric constant and dielectric loss respectively and j = −1. The ratio of dielectric loss to dielectric constant is given by loss tangent and is expressed as,
tan δ = $\frac{k''}{k'} = \frac{\varepsilon''}{\varepsilon'}$
where κ ' and κ " are relative dielectric constant and relative dielectric loss respectively, which are given as $k' = \frac{\varepsilon'}{\varepsilon_0}$ and $k'' = \frac{\varepsilon'}{\varepsilon_0}$. Here, ε_0 is the permittivity of free space (ε_0= 8.854 x 10-12 F/m). The dielectric properties are mainly affected by the operating temperature and the microwave frequency used. Based on the microwave absorption, materials are classified into (i) absorbers or high dielectric loss materials which are strong absorbers of microwave (ii) transparent or low dielectric loss materials where microwave passes through the material with little attenuation and (iii) opaque or conductors which reflect the microwaves.



shows the variation in the dielectric properties for water with the temperature, expressed as tan δ. Based on this variation, it is possible to consider that the effects of microwaves are temperature dependent once tan δ decreases with the increase of temperature.

3. Microwave Baking and Cooking

Detailed references to the baking process of bread, cakes, pastry etc. by the help of microwaves on industrial scale can be found. An enhanced throughput is achieved by an acceleration of the baking where the additional space needs for microwave power generators are negligible. Microwaves in baking are used in combination with conventional or infrared surface baking; this avoids the problem of the lack of crust formation and surface browning. Advantage of the combined process is the possible use of European soft wheat with high alpha-amylase and low protein content.

In contrast to conventional baking microwave heating inactivates this enzyme fast enough (due to a fast and uniform temperature rise in the whole product) to prevent the starch from extensive breakdown, and develops sufficient CO_2 and steam to produce a highly porous. One difficulty to be overcome was a microwavable baking pan, which is sufficiently heat resistant and not too expensive for commercial use. By 1982 patents had been issued overcoming this problem by using metal baking pans in microwave ovens.

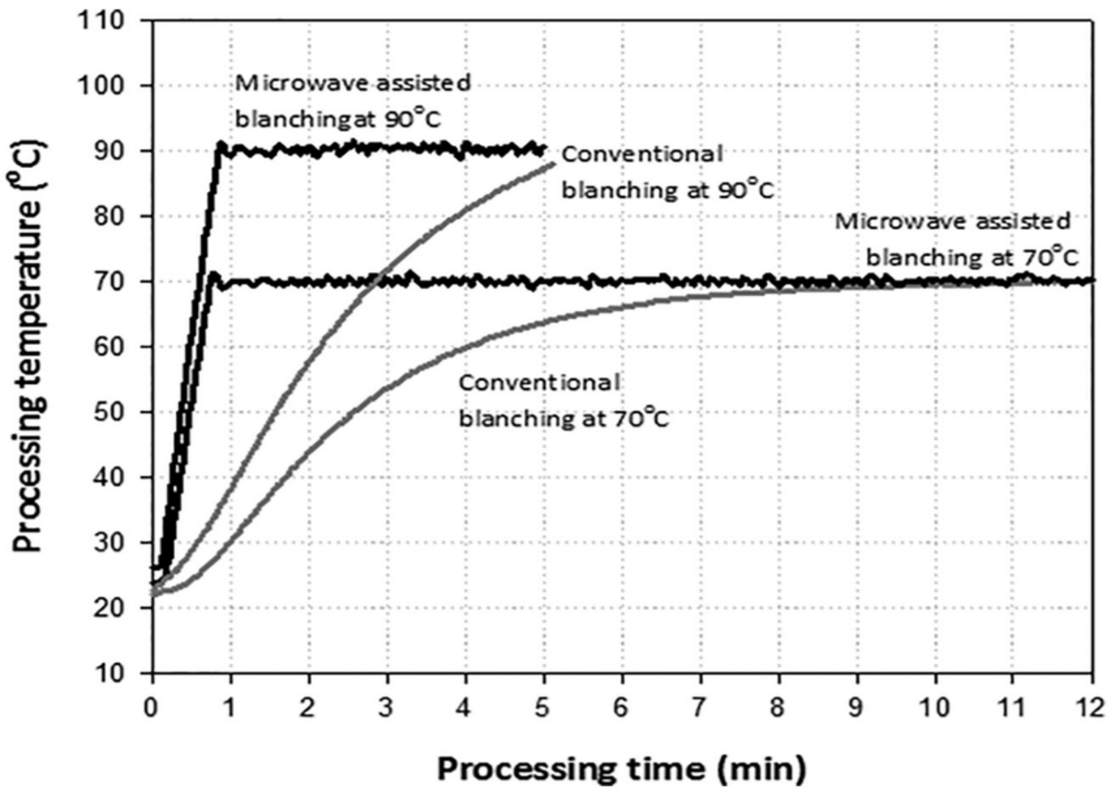
The main use of microwaves in the baking industry today is the microwave finishing, when the low heat conductivity lead to considerable higher baking times in the conventional process. A different process that also can be accelerated by application of microwave heating is (pre-) cooking. It has been established for (pre)cooking of poultry meat patties and bacon. Microwaves are the main energy source, to render the fat and coagulate the proteins by an increased temperature. In the same time the surface water is removed by a convective air flow. Another advantage of this technique is the valuable by- product namely rendered fat of high quality, which is used as food flavoring.

Roasts cooked by microwave took less time to reach endpoint temperatures in comparison with conventional methods. Meat cooked with microwaves does not have typical browned surface associated with other methods of cooking because of short cooking time. Radio frequency as a volumetric form of heating is another rapid cooking alternative in which heat is generated within the product, which reduces cooking times and could potentially lead to a more uniform heating. Microwave oven cooking tends to retain higher amounts of vitamins such as retinol, thiamin, and riboflavin compared with earth-oven-cooked meat. The difference in vitamin retention could be due to a higher cooking temperature of earth-oven cooking compared with microwave cooking.

4. Microwave Blanching

Blanching is generally used for color retention and enzyme inactivation, which is carried out by immersing food materials in hot water, steam or boiling solutions containing acids or salts. Microwave blanching of herbs such as marjoram and rosemary was carried out by soaking the herbs in a minimum quantity of water and exposed to microwave. Microwave blanching was observed for maximum retention of color, ascorbic acid and chlorophyll contents than that of water and steam blanching. Microwave blanched samples were found to have better retention of quality parameter than that of microwave dried samples without blanching. Similarly, waster-assisted microwave treatment of fresh jalapeno peppers and coriander foliage were found to have effect against the pathogenic bacterium Salmonella typhimurium which resulted in the reduction 4-5 log cycles of microbial population.
Blanching is also used to remove seed coat or teste which may reduce enzyme activity and moisture content and might interfere with further processing into specific products.

Blanching also helps to remove damaged or discolored seeds, foreign material and dust. The microwave blanching of peanuts and found that microwave blanching was better than traditional blanching techniques in terms of energy and time savings. It was observed that the microwave blanching of peanuts at high process temperatures resulted in the occurrence of stale/floral and ashy-off flavors. The resulting off-flavors may be related to the increased concentrations of phenylacetaldehyde, guaiacol and 2,6-dimethylpyrazine which might have occurred due to the Maillard reactions and thermal degradation of microwave blanched peanuts at high temperatures. Further, impact of different microwave blanching parameters on sensory attributes of roasted peanuts was investigated. The factors examined were microwave exposure time, amount of air circulation and initial moisture content of peanuts. It was found that the highest total off note (off flavor) occurred for the treatment of 11 min without air circulation and for temperatures reaching 128 °C or higher. On the other hand, short-duration treatment with internal temperatures not exceeding 110 °C observed to be acceptable for microwave blanching. Similarly, peanuts with internal temperatures greater than 110 °C and final moisture content of 5.5% or below yielded acceptable blanchability of greater than 85% industry standard.



5. Microwave Drying

In drying of food materials, the goal is to remove moisture from food materials without affecting their physical and chemical composition. It is also important to preserve the food products and enhance their storage stability which can be achieved by the drying. Dehydration of food can be done by various drying methods such as solar (open air) drying, smoking, convection drying, drum drying, spray drying, fluidized-bed drying, freeze drying, explosive puffing and osmotic drying.

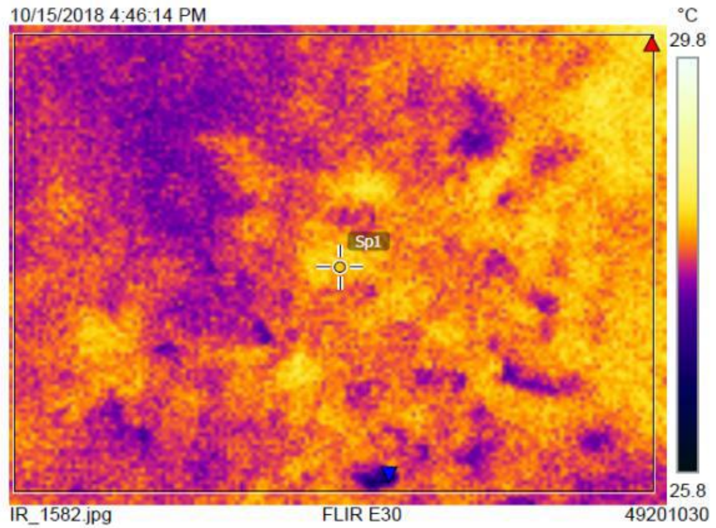
Microwave drying has the advantages of achieving fast drying rates and improving the quality of some food products. The energy absorption level is controlled by the wet products which can be used for selective heating of interior parts of the sample containing moisture and without affecting the exterior parts. Microwave drying is considered very useful during falling rate period. During falling rate period, the diffusion is rate-limiting, resulting in the shrinkage of the structure and reduced surface moisture content. However, in microwave drying, due to volumetric heating the vapors are generated inside and an internal press gradient is developed which forces the water outside.

Thus, shrinkage of food materials is prevented in microwave drying. Microwave energy combined with other drying methods can improve the drying efficiency as well as the quality of food products which is far better than that achievable by microwave drying only or by other conventional methods only.

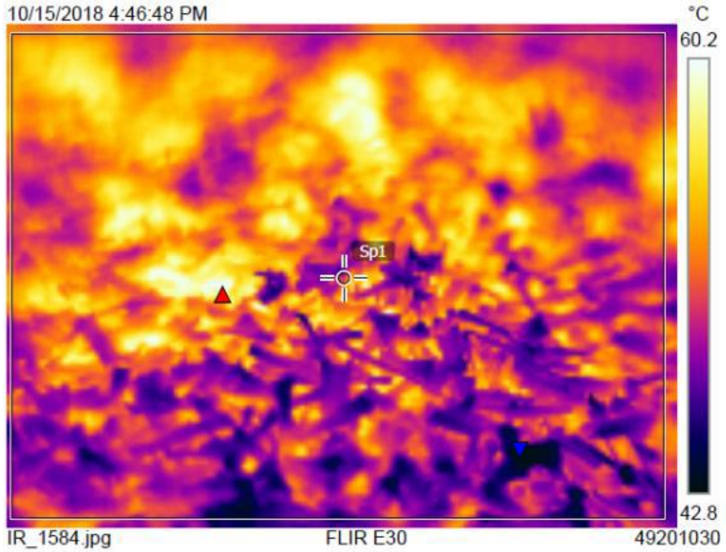
In microwave drying of parsley, drying took place mainly in the constant rate period and the falling rate period. The drying time was found to decrease with an increase in the microwave output power. Microwave dried parsley leaves retained the color and the change in microwave power level did not affect the color parameters. In another study, microwave drying of carrot slices were found to occur in the falling rate period and not during constant rate period. At high microwave power, rapid mass transfer from the center to the surface occurs due to generation of more heat. It was also found that as the slice thickness increases, β-carotene content and rehydration ratio decrease. High volumetric heating causes high internal pressure inside the samples which result in boiling and bubbling of sample. Thus, β-carotene content and the rehydration ratio were found to be reduced.

THERMAL IMAGES

Before Microwave Treatment



After Microwave Treatment



5.1 Microwave Assisted Air Drying

Microwave assisted air drying is one of the methods where hot air drying is combined with microwave heating in order to enhance the drying rate. Microwave can be combined with hot air in three different stages of the drying process. At the initial stage, microwave is applied at the beginning of the dehydration process, in which the interior gets heated rapidly. At rapid drying period, a stable temperature profile is established in such a way the vapor is forced outside due to improved drying rate. This creates porous structure called as 'puffing' which can further facilitate the mass transfer of water vapor. At the reduced drying rate period or at the final stage of drying, the drying rate begins to fall where the moisture is present at the center and with the help of microwave heating, vapor is forced outside in order to remove bound water.

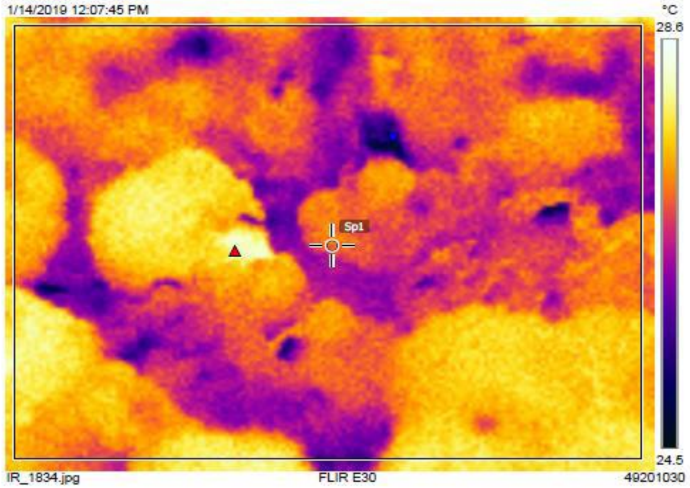
For drying of high moisture fruits and vegetables, a reduction in moisture content is time consuming especially in the final stage of drying. Microwave assisted drying as final 25 stage of air drying overcomes these disadvantages with high thermal efficiency.

THERMAL IMAGES

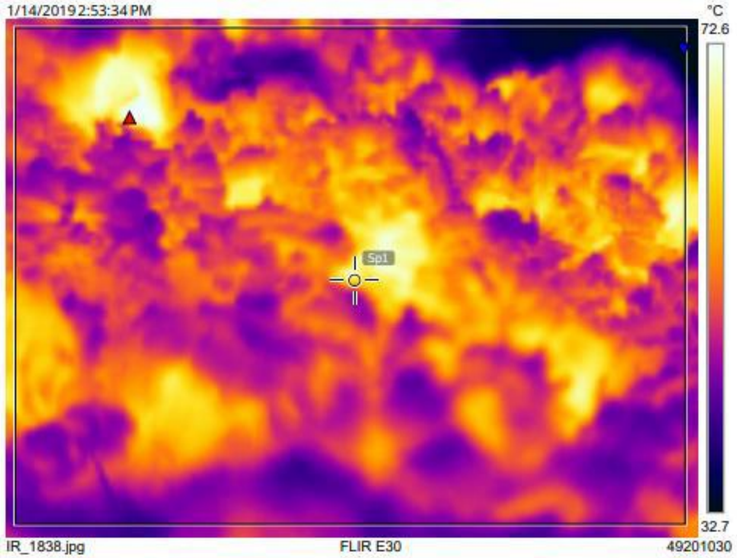
Hot air drying does not improve moisture loss at the final stages of drying process, since the diffusion process is very slow. Drying of banana is difficult as it falls under the falling rate period. But, hot air drying combined with microwave finish drying reduced the drying time by 64% as compared to convective air drying. In drying of kiwifruits, shrinkage was found to be more predominant during sole microwave heating than that of hot air drying. But, lesser shrinkage of kiwi fruits was found to be observed with combined hot air-microwave drying. Also, kiwifruits dried by combined hot air- microwave displayed higher rehydration capacity than those of kiwifruits dried by sole microwave or hot air drying.

In summary microwave assisted air drying is found to be helpful at the final stages of drying food products especially for fruits and vegetables. Besides increasing the drying rate, microwave assisted air drying enhances the rehydration capacity of dried products and also overcomes shrinkage problems.

Before Microwave Treatment



After Microwave Treatment



5.2 Microwave Assisted Vacuum Drying

During vacuum drying, high energy water molecules diffuse to the surface and evaporate due to low pressure. Because of this, water vapor concentrates at the surface and the low pressure causes the boiling point of water to be reduced. Thus vacuum drying prevents oxidation due to the absence of air, and thereby maintains the color, texture and flavor of the dried products. In the absence of convection, either conduction or radiation or microwaves can be combined with vacuum drying to improve its thermal efficiency.

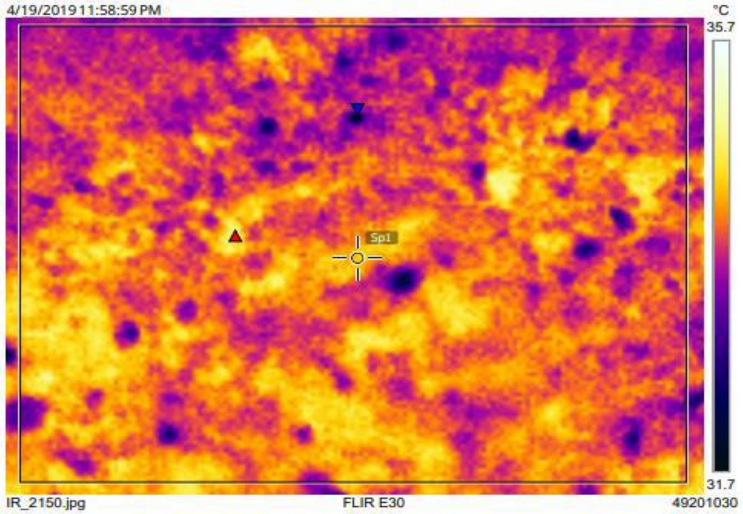
Vacuum microwave drying of banana slices was examined at a microwave power supply of 150 W and under a vacuum of less than 2500 Pa. It was determined that the drying was achieved in less than 30 minutes without exceeding 70 °C and the quality of the product was found to be good and was comparable to that of freeze dried product. The dried product also provided excellent taste and flavor with no shrinkage or change in color.

In microwave vacuum drying of model fruit gel (simulated concentrated orange juice), a reduction in the moisture content from 38.4% to 29 less than 3% was achieved in less than 4 minutes whereas conventional air drying took more than 8 hours to reach 10% moisture.

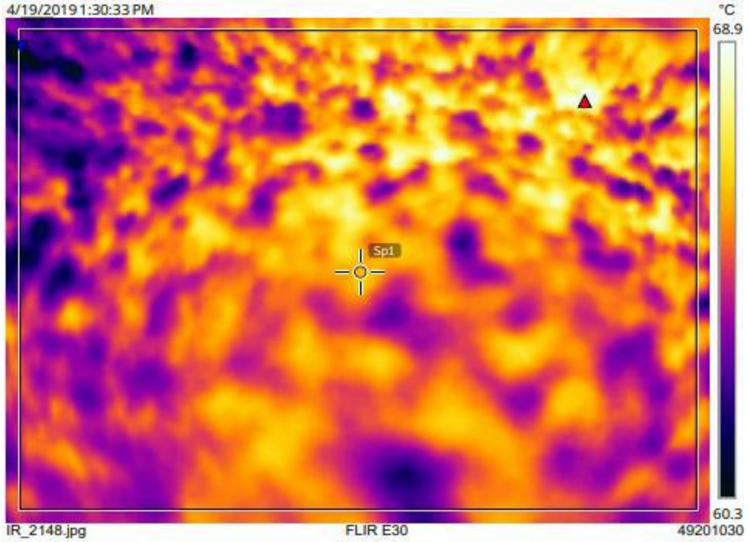
A study on microwave vacuum drying of carrot slices showed that the microwave vacuum dried products had higher α-carotene content and vitamin C content, softer texture, had higher rehydration potential and lesser color deterioration than that of air drying. The losses of α and β-carotene content was found to be very low due to rapid heating rate and depletion of oxygen during vacuum operation. Vitamins are generally sensitive to the thermal damage and oxidation, whereas microwave vacuum drying eliminates both and hence high quantities of vitamins were retained. The processing time of the microwave vacuum drying at 70 °C was found to be shorter (1.5 hours) compared to that of convective drying (3.5 hours). But, microwave vacuum drying at high power (600 W) led to significant loss of β-carotenes. In summary, microwave drying at moderate power causes low loss of β-carotenes while reducing the operation time.

THERMAL IMAGES

Before Microwave Treatment



After Microwave Treatment



5.3 Microwave Assisted Freeze Drying

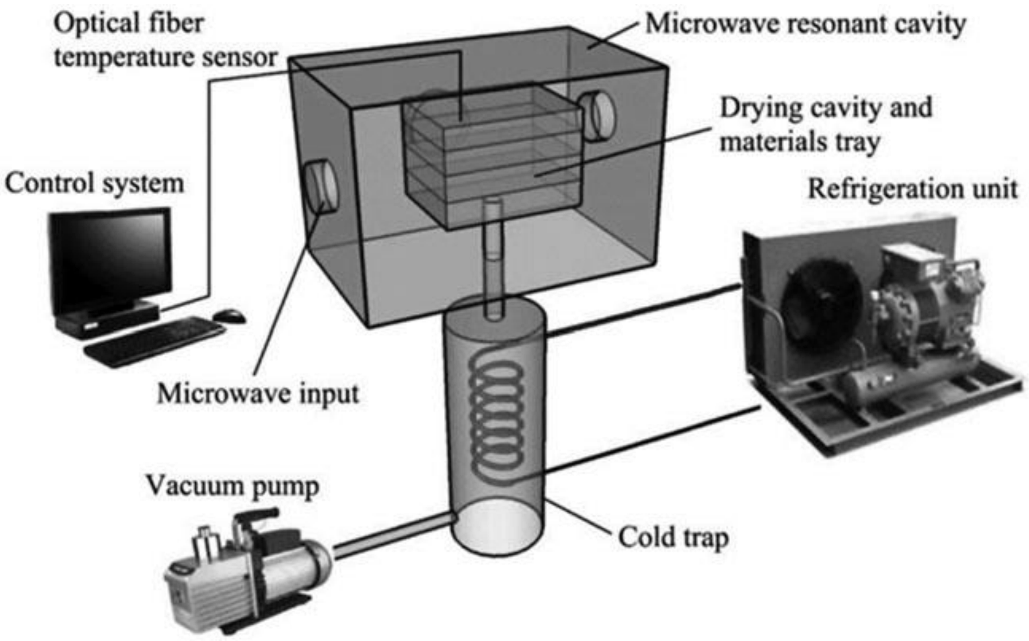


Figure 5.3.1
Scheme diagram of the microwave freeze dryer

Freeze drying is considered as a gentle dehydration technique applied for heat sensitive foods, pharmaceutical and biological materials. In freeze drying, the temperature is lowered and, by applying vacuum or low pressure, the frozen water is directly transferred to the vapor phase without going through the liquid phase. Thus the pores are preserved and those can be rehydrated quickly. The loss in terms of flavor can also be minimized using this method. Since freeze drying is time consuming, this method is applied only for high premium or heat sensitive materials. Microwave freeze drying can be applied in two different ways, such as i) freeze drying accompanied concurrently with the help of microwave and ii) microwave drying applied after freeze drying. In the first type, the whole drying process takes place under vacuum environment and microwave field is applied to supply the heat of sublimation required for freeze drying.
In second type, the drying process was divided into two stages, (i) freeze drying followed by (ii) microwave/vacuum microwave drying.

Freeze drying combined with microwaves offers advantages like reduced processing time and better product quality. Although the quality of freeze dried products is better than other conventional drying methods due to its low processing temperature and lack of oxygen in the process. However, freeze drying is an expensive and lengthy dehydration process, which lead to small throughput and high capital and energy costs.

The heating of the frozen food by microwave energy causes the frozen bulk temperature to increase. With increasing bulk temperature, frozen molecules of water receive enough energy and transit from solid phase to gas phase (sublimation of frozen molecule of water). These molecules migrate (from frozen bulk) into vacuum region of chamber. In other words, the moisture is removed from frozen region, and food material is dried. This sublimation starts from the outer layer. Now, a new region forms in frozen bulk from interface of food material and vacuum and dried region (Figure 4.3.3). As the time proceeds, the interface between dried and frozen regions will retreat. Therefore, the frozen bulk of material is thinned, and the volume of dried section increases. Microwave freeze drying has the advantages of obtaining products of high quality and better appearance.

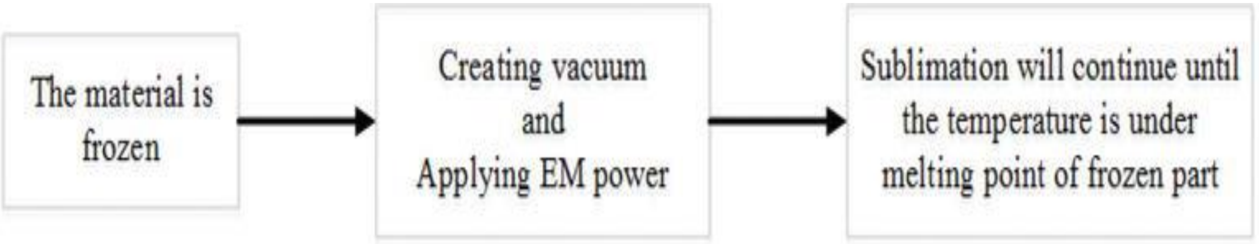


Figure 5.3.2
Steps must be passed in microwave-assisted freeze-drying process.

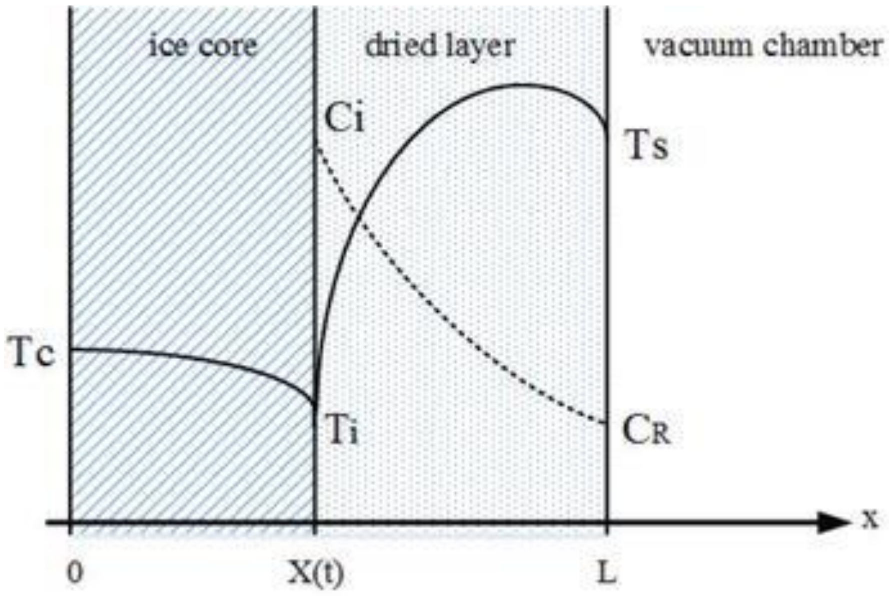


Figure 5.3.3
Profile of different layers with typical variations of temperature in them for an infinitely long slab of material with thickness L

6. Microwave Pasteurization and Sterilization

Pasteurization and sterilization are done with the purpose of destroying or inactivating microorganisms to enhance the food safety and storage life [Nott and Hall, 1999]. In order to ensure that pathogenic microorganisms are killed, the food material is maintained at a particular temperature for a particular period of time. Pasteurization is a process in which pathogenic microorganisms such as bacteria in the vegetative form are destroyed by the thermal treatment. Pasteurization also involves inactivation of undesirable enzymes which causes cloud loss in certain juices.

Pasteurization can be achieved by Microwave system without affecting the color, flavor or nutritive value of food materials. The possibly high and nearly homogeneous heating rates, also in solid foods (heat generation within the food) and the corresponding short process times, which helps preserving a very high quality yield is advantages of microwave compared to conventional techniques.

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6.1 Microwave Pasteurization Mechanism

Destruction of microbes or enzymes by microwave or radio frequency waves at sublethal temperatures was explained by one or more of the following theories: selective heating, electroporation, cell membrane rupture and magnetic field coupling. The selective heating theory suggests that the micro organisms are selectively heated due to microwaves and reach temperature higher than that of surrounding fluid. This causes the microorganisms to be destroyed more quickly. the electrical potential across the cell membrane causes pores, which results in the leakage of cellular materials. According to the magnetic field coupling theory, the internal components of the cell are disrupted due to the coupling of electromagnetic energy with critical molecules such as protein or DNA. Microwave pasteurization systems typically take 1.5 to 2 min to raise product temperatures to 70°C. Microwave pasteurization has been tested on many food products and has been shown to be effective in inactivating a number of different microorganisms.

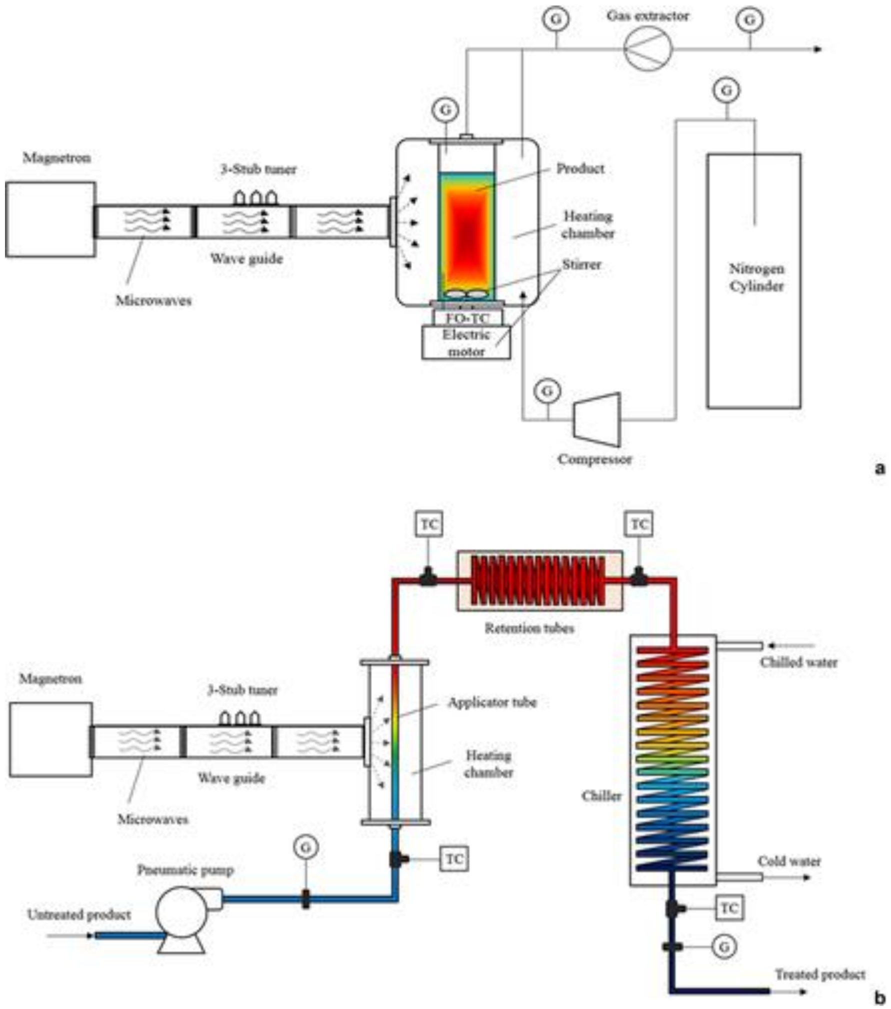
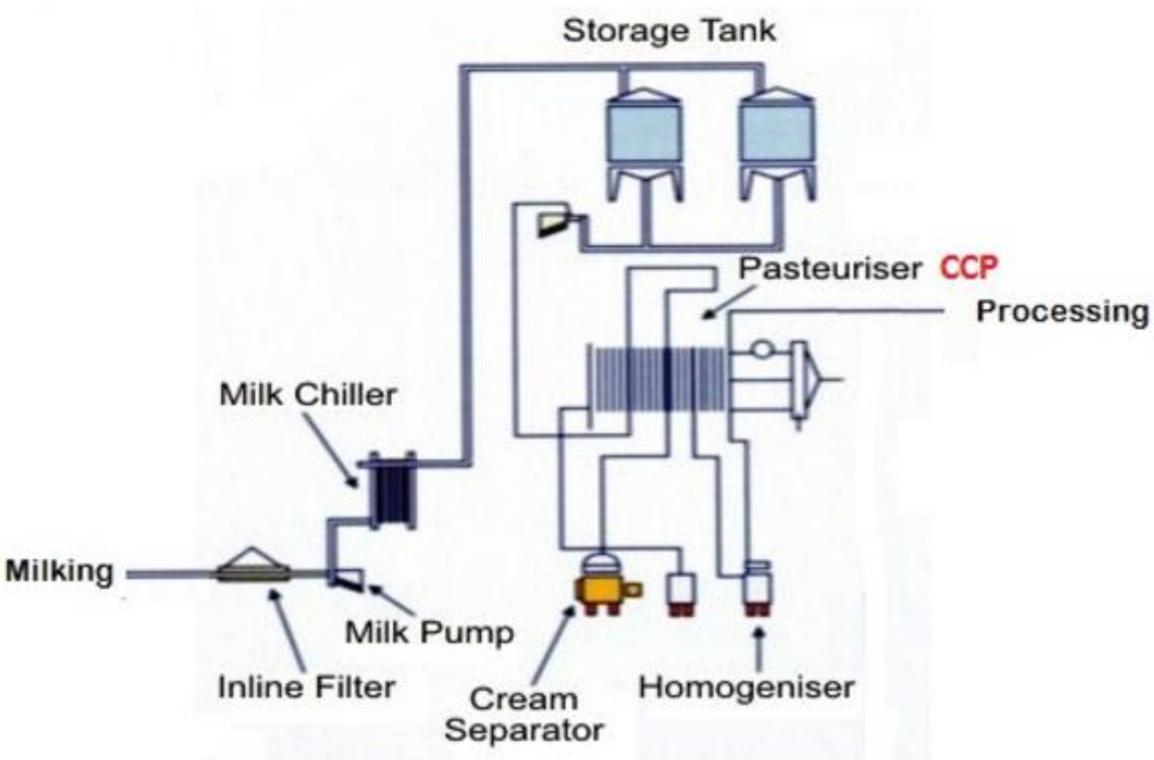


Figure 6.1.1
Microwave heating of liquid foods applied in batch (a) and continuous flow (b) systems. Thermocouple (TC), pressure gauge (G), fiber optic thermocouple (FO-TC).

6.2 Microwave Pasteurization of Fluid Food Materials



The application of microwave pasteurization has been largely applied to fluid foods such as pasteurization of fresh juices and sterilization of milk. Microwave pasteurization systems typically take 1.5 to 2 min to raise product temperatures to 70°C. This is considered sufficient to control *L. monocytogenes* (≥6 log reduction) for a shelf life of 7 days under refrigeration. For a shelf life of ~9 weeks, heating at 90°C, for a minimum of 10 min in the coldest spot, is required to control nonproteolytic *C. botulinum.*

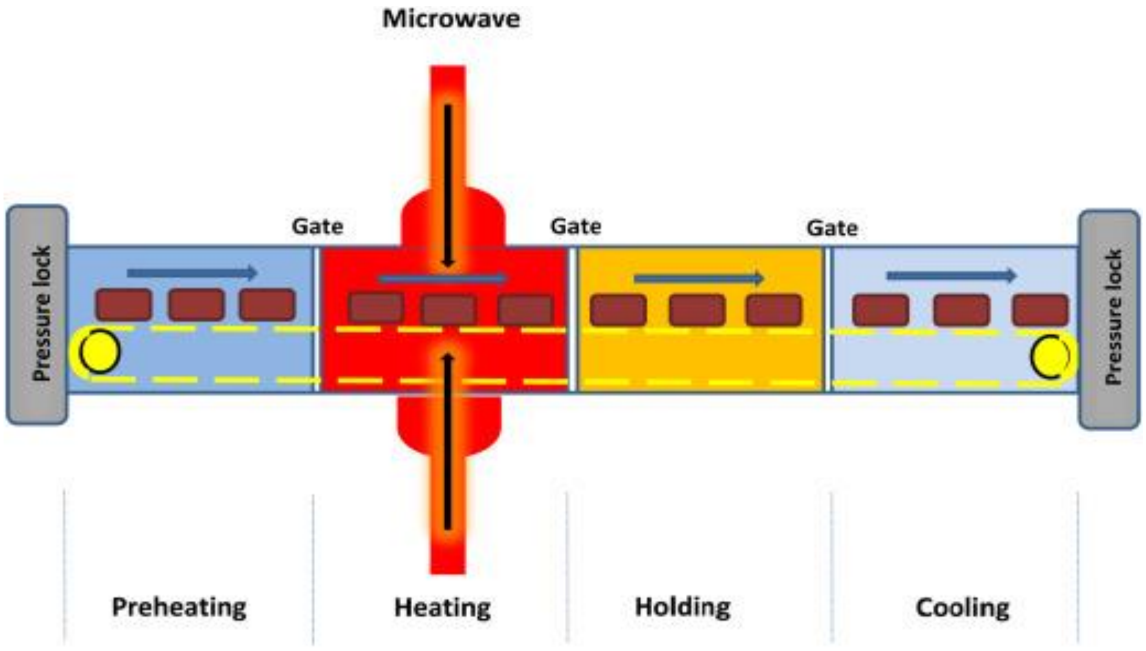
The complete inactivation of *Y. enterocolitica, C. jejuni,* and *L. monocytogenes* occurred at 8, 3, and 10 min when the cells were heated at a constant temperature of 71.1°C using microwaves with initial microbial loads of l06–107 K/mL. This direct volumetric heating significantly reduces the processing time resulting in greater retention of nutrients, sensitive vitamins, and aromatic constituents.

6.3 Microwave for Solid Food Materials

Pasteurization of in-shell egg can be achieved with the help of microwaves. It was known that the albumen had higher dielectric properties than yolk. On contrary, microwave heating of in-shell egg did not show any significant difference in the heating rate of albumen and yolk. The enhanced interior heating might be due to the combination of egg geometry, dielectric properties and size of the egg. The microwave pasteurization of shell eggs can be achieved without losing the shell integrity of eggs. Microwave pasteurization was used for the inactivation of Salmonella typhimurium in the yolk of shell eggs.

A 22% reduction of microbes was attained for microwave irradiation of 15 seconds whereas 36% reduction was achieved by moist heat treatment of 15 minutes. Microwave pasteurization of pickled asparagus achieved the required temperature for pasteurization twice as fast as (15 min for 1 kW and 9 min for 2 kW) conventional heating (30 min). The thermal degradation of asparagus was more when it was subjected to conventional treatment compared to when it was subjected to microwave heating.

6.4 Microwave Sterilization



Spice	Initial moisture content	Initial colony count (CFU/g)	Irradiation time (minuts)	Moisture content after treatment	Averege temperature after treatment (°C)	Colony count after treatment (CFU/g)
Curry	6,02%	4,90E+05	6	3,36%	68,2	4,85E+05
			8	2,13%	71,5	7,00E+05
			10	2,04%		3,20E+05
			12	ND	68,0	5,90E+05
Chilli	4,22%	4,50E+05	6	ND	65,1	3,20E+05
			8	2,01%	75,1	4,45E+05
			10	1,74%	72,2	7,00E+05
			12	0,61%	83,4	5,30E+05
Turmeric	9,44%	1,42E+06	2	8,10%	67,5	2,02E+06
			3	ND	80,0	1,45E+06
			4	5,00%	92,5	1,69E+06
			6	2,40%	102,5	1,53E+06

Packed food products can be sterilized using various novel techniques such as UV light, microwave irradiation, ozone and cold plasma. There are cases for which food materials can be treated as such while others in the packed conditions. The irradiation and industrial microwave treatment was found to save cost and time and improve the quality. Glass, paper and ceramic were used for microwave packaging. Significant reduction in bacterial count (Pseudomonas fragi and Escherichia coli) was achieved after microwave heat treatments on food solids. A significant reduction in the thermal processing time while making food safe for consumption is the major advantage of microwave sterilization processing. The shelf life of a product is determined by its microbiological safety and sensory attributes. Normal shelf life expectancy of microwave-sterilized products prepackaged in plastic containers or pouches is 2-3 years or longer. With innovative plastic technologies coming to the market, the new generations of plastics may increase the expected shelf life even longer.

7. Microwave Disinfestation

Microwave System is one of the most popular physical method that can be used to disinfest all products of vegetable origin infested by pests such as Cereals (rice included), Seeds like pine-nuts, Legumes(beans, chickpeas, lentils), and Dry fruits(dates, currants). Major causes of loss of the agro food are Post Harvest phase and in Storage, Biological Infestations which begin on field (significantly depreciate a lot of products in a very short time). The decreasing cultivatable land and increasing demand of food due to ever increasing population has resulted that food safety should be taken at most priority.

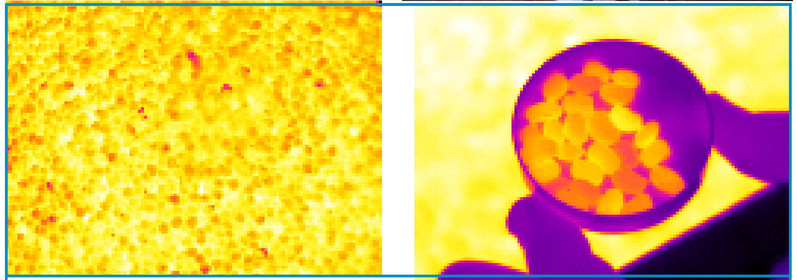
Conventional Disinfestations Methods such as Conditioning of Silos and Warehouses, Fumigation, Controlled Atmosphere and Extreme Temperatures having some limitation such as High costs and long treatment times, Handling of dangerous chemicals, Persistence in food of toxic residues and Pollution.

Microwave based system are very advantageous over these systems due to its speed (shorter response time), Ease of handling (No chemical processing involved), also it does not produce polluting gases or toxic residuals.

Advantages – Microwave Pest Control Method:

- Full efficacy: 100% mortality rates on pests in all life stages (eggs, larvae, pupae and adults).
- No significant change in quality: physical characteristics in wood and nutritional characteristics in food.
- Absence of polluting effects harmful to operators and the environment.
- Plant origin products free from exotic pest scan be exported without any phytosanitary concern in response to the ongoing FAO-IPPC needs.
- No toxic residues in the end products.
- Energy saving.

Microwave Power: 12kW
Achieved Temperature: ~60°C
Capacity: ~600kg/h



Uniform Distribution of Temperature

Tests conducted on samples of beans

Sample No	Sample -g-	Weight -kw-	Power -sec-	Exposure -° C-	Temperature % Mortality	
					Eggs	Adults
1	500	1	60"	46.2-48.7	43.5	20
2	500	1	90"	57-62.9	100	100
3	500	1	120"	61.7-7-70.9	100	100

The lethal effect on eggs was verified immediately after the treatment and again after an incubation of 45 days.

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8. Effects of microwaves on microbial cultures depending on the frequency, power (or delivered energy) and microbial species

Delivered energy	Frequency of microwaves	
	800–1900 MHz	2450 MHz
1–2 W; 30, 60, 120 and 180 minutes	E. coli, Klebsiella pneumoniae, ENHANCED GROWTH	
550 W, 5–30 seconds		P. aeruginosa, P. acidovorans, S. aureus and S. epidermidis, ENHANCED GROWTH
600 W, 2–4 minutes		E. coli and spores of Bacillus cereus, KILLED
650 W, 2–5 minutes		P. aeruginosa, S. aureus, Candida albicans, and B. subtilis, KILLED
800 W, 1 minute		S. aureus, Salmonella enteritidis, E. coli and B. cereus, KILLED
10 and 60 mW/cm2, 5–60 minutes		Aspergillus versicolor and Penicillium brevicompactum) and actinomycetal (Thermoactinomyces vulgaris and Streptomyces albus) spores, VIABILITY OF FUNGI DECREASED, VIABILITY OF ACTINOMYCETES INCREASED
2000 W, 2 minutes		Bacillus licheniformis spores, CORTEX HYDROLYSIS and Bacillus subtilis, AGGREGATION OF CYTOPLASMIC PROTEINS

8.1 Conditions Affecting the Growth of Microorganisms

Water

Water content and the available of water activity can affect the growth of microbes in food.

Temperature

Temperature is the most important factor that determines the rate of growth, multiplication, survival, and death of all living organisms. High temperatures damage microbes by denaturing enzymes, transport carriers, and other proteins. Microbial membrane are disrupted by temperature extremes. At very low temperatures membranes also solidify and enzymes also do not function properly.

Table: Growth Temperatures (°C) for Microbial Growth

Group	Min.	Opt.	Max.
Thermophiles	40	55	75
Mesophiles	5	37	45
Psychotrophs	-3	20	30

Oxygen Requirements

Micro-organisms can be classified into three general groups regarding their oxygen requirements.

- Aerobes – can only grow in the presence of oxygen
- Anaerobes – Can only grow in the absence of oxygen
- Facultative Anaerobes – adaptable. Grows best aerobically but can grow anaerobically

pH

pH refers to negative logarithm of hydrogen ion concentration. Microbial growth is strongly affected by the pH of the medium. Drastic variations in cytoplasmic pH disrupt the plasma membrane or inhibit the activity of enzymes and membrane transport proteins.

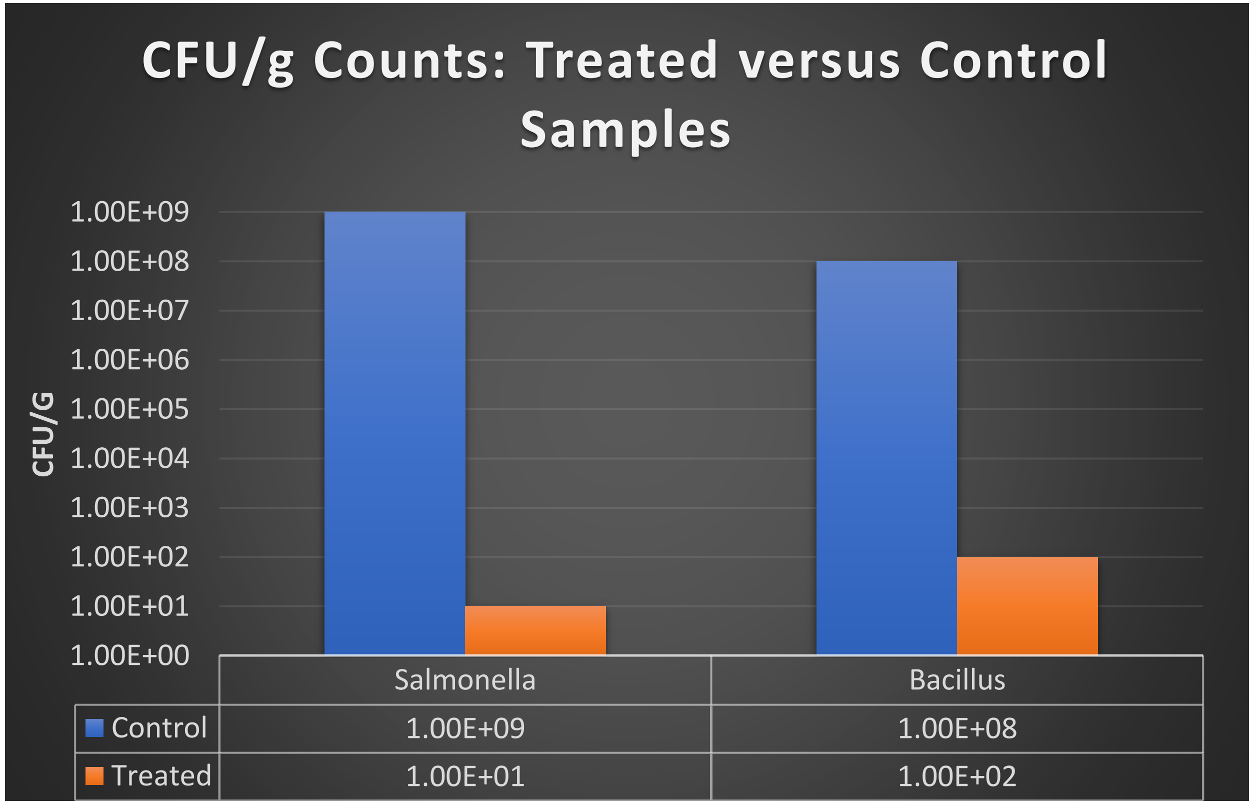
Table: pH ranges for Microbial Growth

Group	pH
Low acid	>5.0
Medium acid	4.5 - 5.0
Acid	3.7 - 4.5
High acid	< 3.7

8.2 Mechanism Of Microwaves Action On Living Organisms

When irradiating living organisms, microwaves produce two types of effects: thermal and non-thermal. Thermal effects are the consequence of absorption of microwave energy by cell molecules, causing them vibrate much faster and producing general heating of the cell. The extent of microwave absorption within a cell depends on its dielectric constant and electrical conductivity. The concept of non-thermal effects of microwaves came from experiments in which bacterial cultures were to a large extent destroyed by microwave-induced heating than by other heating methods producing the same working temperature and from studies showing an increase in the growth of bacteria induced by microwaves. The mechanism of the non-thermal action of microwaves is still not completely understood. However, it seems that changes in the secondary and/or tertiary structure of functional proteins ensue as a consequence of rotation and lining-up of the molecules with a rapidly alternating electric field (more than a billion times per second)

Graphical representation of the log reductions generated by the microwave unit. Growth was reported at 10^1 for Salmonella since that was the limit of detection for enumeration:



The effect of MW radiation on 94strains of Enterobacteriaceae was studied and it was found that microwave irradiation increased the enzyme activity of bacteria in suspension. Low power MW treatment (2450MHz; 90 W; 2 min exposure) on Aeromonas hydrophila de-creased its total protease activity by 33%. Urease activity and aflatoxin production in S. aureus and Aspergillus parasiticus respectively was completely inhibited by MW exposure. Low power (100 W, 60 s) microwave radiation reduced not only the cell number but also the acid resistance and verocy-totoxin productivity in enterohemorrhagic E. coli. investigated influence of MW on soil bacteria.

The suppression and the stimulation of the growth for different bacterial species is observed under the impact of microwaves. Spore suspensions responded to microwave radiation upon a shorter time of exposure than suspensions of vegetative bac-terial cells. The influence of microwave radiation on the biomass accumulation and the intensity of other physiological processes in streptomycetes species led to changes in the number and activity of these microorganisms in the soil mi-crobial complex.

Summery

Microwaves have been successfully used for many food processes such as cooking, drying and pasteurization of food materials. Enhanced organoleptic and nutritional food properties combined with food safety is the aim of modern food processing technologies. Microwave (MW) heating has the advantages to overcome the limitation of slow thermal diffusion imposed by conventional heating. This technology knows a growing industrial demand thanks to its flexible and rapid heating performance. MW heating is successfully used for food drying and decontamination. In general, coupling MW heating with other heating methods largely improved the microbiological safety, the drying efficiency, and the quality of various food products. Physical modeling and simulation are important tools to understand and to optimize MW heating processes.

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