



## Advances in Food Pasteurization Techniques

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### Abstract

In the recent years, the consumer has been demanding highly nutritious, minimally processed foods with a longer shelf life. Thus began the need for reviewing and upgrading of traditional pasteurization techniques and the need for developing of new technologies for the pasteurization of food. The pasteurization techniques are classified into thermal and non-thermal techniques. The aim of this review is to discuss A] Thermal pasteurization techniques: HTST (High Temperature and Short Time pasteurization, LTLT (Low Temperature and Long Time) Pasteurization, UHT (Ultra High Temperature) Pasteurization, Pasteurization by water bath, Steam Pasteurization, Vacuum Steam Pasteurization, Infrared (IR) Heating Pasteurization, Microwave Heating Pasteurization, Dielectric (Radiofrequency) Heating Pasteurization. B] Non-Thermal Pasteurization Techniques: High Pressure Pasteurization (HPP) or Hydrostatic High-Pressure Pasteurization, Irradiation Pasteurization, pulsed electric fields (PEF) Pasteurization, UV (Ultraviolet) Pasteurization, Cold Plasma Pasteurization, Ultrasound Pasteurization, Supercritical Gas (SC) Pasteurization, Oscillating Magnetic Field Pasteurization, Pulsed Light Pasteurization. All these pasteurization techniques have their own advantages and limitations, so according to the characteristics of the food, one needs to wisely choose the technique. Non-thermal techniques are not in use despite their minimal processing and preservation of food quality attributes because they are expensive and complex with respect to thermal techniques.

**Key Words:** Food Pasteurization, thermal processing, non-thermal processing, novel technologies

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## Introduction

Pasteurization techniques have been extensively used in processing food products. It is one of the most common food processing methods and has been used for hundreds of years! Still none of the literature available has covered all the pasteurization techniques. All the literature has dealt only either with thermal or only non-thermal pasteurization techniques; even if both techniques are included there is absence of coverage of all the novel techniques in them. This paper covers both thermal as well as non-thermal pasteurization techniques along with their experimental observations and gives a brief incite about various pasteurization techniques which are either in industrial use or have a great potential application in food industries.

According to World Health Organization, around 0.6 trillion- almost 1 in 10 people in the world fall ill due to consumption of contaminated food and 4, 20,000 succumb to death every year, which results in a loss of 33.0 million healthy-life-years. Food industry experts are thus endeavored in their prime goal of developing improved food processing methods which are essential for food preservation and elimination of infectious micro-organisms ensuring its safety and quality. Mostly, to ensure the microbial safety of products, the use of heat through thermal processing, which includes pasteurization, sterilization, drying and evaporation are commonly implemented in the food industries. The illnesses prevented by pasteurization include TB, brucellosis, diphtheria, Q-fever, etc. Pasteurization can effectively kill and/ inactivate harmful bacteria such as *Salmonella*, *Listeria*, *Yersinia*, *Campylobacter*, *Staphylococcus aureus*, *Escherichia coli*, etc. Pasteurization is a key step in preservation and is important for ensuring the safety of the. It helps improving the product's "keeping" quality due to destruction of almost all disease producing bacteria and others. The prime objective of pasteurization is to render the food virtually free of any microbe that could endanger the health of the consumers. Pasteurization is the process which inactivates

enzymes and destroys relatively heat-sensitive microbes that can lead to spoilage in food, with minimal changes the properties of food like sensory attributes and nutritional attributes. It extends the shelf life of foods in low temperature range, usually 4.0°C for many days (milk) or for months (bottled fruit).

*Tracing the developments in food pasteurization:*

Traditional pasteurization methods-

The traditional thermal pasteurization methods depend essentially on the generation of heat by combustion of fuels, etc.; outside of the foods to be heated, and its transfer inside the food through conduction and convection mechanisms. These processes can effectively inactivate and kill harmful microbes, thus making food safer for consumption. However, because of significant losses of heat on the surface of the equipments and installation, reduction in heat transfer efficiency and thermal damage by overheating these methods of processing are limited. The thermal pasteurization processes such as HTST, LTLT or UHT involve production of heat for pasteurization but can cause uneven heating and can cause nutrient loss.

The other thermal pasteurization methods include water bath pasteurization, Steam pasteurization, Super-heated steam pasteurization, Vacuum steam pasteurization, etc.

Novel advances-

1. Thermal

Recently, electromagnetic technologies in food processing have gained increased industrial interest and have potential to replace, at least partially, the traditional well<sup>1</sup>. The promising alternatives to conventional methods of pasteurization are ohmic heating and dielectric heating, which includes radio frequency (RF) and microwave (MW) heating. These

novel thermal pasteurization technologies are regarded as volumetric forms of heating in which thermal energy is generated directly inside the food. The pattern of heat generation used in these methods allows overcoming excessive cooking times and uniform distribution of heat. Thus, these methods are heat as well as energy efficient. Infrared (IR) heating is also used as one of the novel thermal pasteurization technology. But heat produces alterations to flavor and taste in addition to nutrient loss<sup>2</sup>. Also, heat causes irreversible losses of nutritional compounds, undesirable changes in physicochemical properties and alteration of their antioxidant properties<sup>3</sup>. Therefore, there is need for development of non-thermal pasteurization processes.

## 2. Non-Thermal

Novel non-thermal pasteurization technologies can be simply defined as those technologies which do not consider temperature as the main factor for inactivation of micro-organisms and enzymes. The novel technologies such as pulsed electric fields, ultrasounds (US), high pressure processing (HPP) (PEF) and pulsed light treatment (PL), among others, offer energy efficient advantage of inactivation of microorganisms at near-ambient temperatures, avoiding thermal degradation of the food components, and consequently preserving the sensory and nutritional quality of the fresh-like food products. Evaluation of the potential use of non-thermal technologies, such as HP or PEF, is important because they inactivate microorganisms and enzymes to certain extent and can avoid the negative effects of heat pasteurization<sup>4</sup>.

Following thermal and non-thermal pasteurization techniques along with their experimental observations have been discussed in this paper.

### Thermal Pasteurization techniques:

- 1) HTST(High Temperature Short Time)
- 2) LTLT(Low Temperature Long Time)
- 3) UHT(Ultra High Temperature )
- 4) Pasteurization by water bath
- 5) Steam Pasteurization
- 6) Vacuum Steam Pasteurization
- 7) Infrared (IR) Heating
- 8) Microwave Heating
- 9) Dielectric (Radiofrequency) Heating

### Non-thermal Pasteurization techniques:

- 1) High Pressure Pasteurization (HPP) or Hydrostatic High Pressure Pasteurization
- 2) Irradiation Pasteurization
- 3) Pulsed electric fields (PEF)
- 4) UV (Ultraviolet)
- 5) Cold Plasma Pasteurization
- 6) Ultrasound Pasteurization
- 7) SC (Supercritical gases)
- 8) Oscillating Magnetic Field
- 9) Pulsed Light Pasteurization



2	LTLT (Low Temperature Long Time)	LTLT is one of the most convenient methods used for pasteurization in food industry; especially dairy industry. Most of the microbes cannot survive LTLT. The loss of nutrients is more in LTLT than HTST.	Milk	63°C for 30 min UHT milk inoculated with the 'milk isolates' and <i>E. coli</i> Used.	<i>Chryseobacterium meningosepticum</i> , <i>Pseudomonas putida</i> , <i>Acineto-bacterbaum annii</i> and <i>Escherichia coli</i> Strains did not survive the LTLT at 63°C. Only <i>Bacillus cereus</i> Strain survived but reduced by less than 1 log at concentration 10000cfu/mL at 63°C.	5
3	UHT(Ultra High Temperature )	The selection of UHT pasteurization method indicates the preference of world towards increased sterility of product through shelf life. Advantages of UHT process includes extended shelf life, lower energy costs, and elimination of required refrigeration during storage and distribution.	Milk	130°C to 150 °C for 2 to 8s	Inactivation of heatresistant bacterial endospores of <i>Bacillus stearothermophilus</i> .  At lower temperature (<135) excessively long holding time is required; at higher temperature fraction of seconds required to destroy bacterial spores.	7
4	Pasteurization by water bath	Pasteurization by water bath is one of the simplest methods of pasteurization. Water bath can be efficiently used for canned foods and meat products.	Raw franks  Fully cooked franks	In circulating water bath  at 55 °C at 70 °C  at 55 °C at 70 °C	For <i>Escherichia coli O157:H7</i>  D value=21.36 D value=0.031 min and z value= 5.07 °C  D value=24.91 min D value=0.038 min and z value=5.08 °C	8
5	Steam Pasteurization	Steam Pasteurization provides advantages such as higher heat capacity which can	Freshly Raw Almonds	Steam above temp 95°C at absolute pressure of	5-log reduction of <i>Salmonella serotype Enteritidis</i> inoculated on raw	9

		be useful for increased thermal decontamination. This method is useful for irregular surfaced food materials.	Hard Red Spring wheat	143 kPa for 25s  185°C of Superheated steam, 6 min processing time  Superheated Steam at 130–175°C	almonds without visual quality degradation.  Reduction in DON( <i>Fusariummycotoxindeoxynivalenol</i> ) concentration of up to 52%  The Z-value for <i>G. stearothermophilus</i> spores: 28.4 °C.	10
6	Vacuum Steam Pasteurization	Steam under vacuum, which can be operated at temperatures above and below 100°C is used in Vacuum Steam Pasteurization as to eliminate the thermal resistant bacteria, effectively.	Flaxseed  Sunflower kernels  Black peppercorns	1 minute at 75°C	Yielded average log reductions of : <i>Salmonella PT30</i> was 5.48±1.22 CFU/g , <i>E.coliO157:H7</i> was 5.71±0.40 CFU/g and <i>E. faecium</i> was 5.23±0.61.  <i>Salmonella PT30</i> was 4.01±0.74 CFU/g, <i>E.coli O157:H7</i> was 5.40±0.83CFU/g and <i>E. faecium</i> was 2.99±0.92CFU/g  <i>Salmonella PT30</i> was 6.10±0.64 CFU/g	11
7	Infrared (IR) Heating	IR, a form of electromagnetic energy, transmits as a wave and penetrates the food and is then converted to heat. The IR pasteurization is more efficient method as compared	Onion	80°C (average 2226 W/m <sup>2</sup> ) for approximately 24 min	1.72+/- 0.45 log <sub>10</sub> CFU/10g reduction in aerobic plate count.  4.04+/- 0.47 log <sub>10</sub> CFU/10g reduction in <i>coliform</i> count	12

		to conventional methods as it provides faster heating rate and greater thermal efficiency.	Honey	0.2 W/cm <sup>2</sup> for 8 min	1.26+/- 0.14 log <sub>10</sub> CFU/10g reduction in <i>yeast</i> and <i>mold</i> count  3.85 log <sub>10</sub> CFU/mL Reduction in <i>yeast</i> count.	13
8	Microwave Heating	Microwave pasteurization offers major advantage over conventional thermal pasteurization is the significant reduction in processing time. The reduction in processing time results in fresher like taste and texture and also improves visual appeal of food.	Apple juice  Shell Eggs	2450 MHz 720–900 W for 60–90 s  1)Dry heat (hot air oven) at 55°C for 2 h,  2)moist heat at 57°C for 15 min  3)radiant energy (microwave oven) at power 9 for 20 sec	E. coli microbial reduction : Range of D values - D = 0.42 min at 900 W to D= 3.88 min at 720 W  Inactivation of <i>Salmonella typhimurium</i> (ST)  1)Dry heat- 2.1 log CFU/ml  2) Moist heat- 2.0 log CFU/ml  3)microwave heating- 1.2 log CFU/ml	14  15
9	Dielectric(Radiofrequency) Heating	Pasteurization by capacitive (RF) dielectric heating offers several advantages over conventional heating methods such as rapid and uniform heating, heating independent of the product's or the Medium's thermal conductivity,etc.	Ground black pepper  Wheat flour	6 kW, 27.12 MHz parallel-plate RF heating for 130s  27.12 MHz, 6 kW RF	More than 5.93 log CFU/g reduction of <i>Salmonella spp.</i> , 3.89 log CFU/g reduction in <i>E. faecium</i>  5 log reduction of <i>E. Faecium</i> after 25 min	16  17

			Shell Eggs	<p>heating at temperature 75-85°C for 3 kg wheat flour</p> <p>2step process :</p> <p>1) Heat the egg in 35.0 °C water for 3.5 min using 60 MHz RF energy.</p> <p>2) Heat the egg for an additional 20 min with 56.7°C water.</p>	<p>5 log reduction of <i>S. Enteritidis</i> after 18 min</p> <p>Yolk get preferentially heated to 61°C for first step.</p> <p>Overall Result: Two-step process reduced the population of <i>E. coli</i> by 6.5 log</p>	<sup>18</sup>
10	<p>High Pressure Pasteurization (HPP)</p> <p>OR</p> <p>Hydrostatic High Pressure Pasteurization</p>	<p>HPP is a cold pasteurization technique by which food, already sealed in packages, are introduced into a specific device and subjected to a high level of isostatic pressure transmitted by a fluid.</p>	<p>Apple juice and apple Cider</p> <p>100% Pomegranate juice</p>	<p>Tin = 25°C ; P = 2500 bar Tout = 70°C</p> <p>P (4000–6000 bar), T(25–50°C ) operating time (5, 10 min) initial microbial load 10000 CFU/mL</p>	<p>7-log reduction in <i>E. coli</i></p> <p>Microbial load lower than 1 CFU/mL per cycle</p>	<sup>19</sup>  <sup>20</sup>
11	Irradiation Pasteurization	<p>Food irradiation is a non thermal, food pasteurization process which exposes foods to radiation that penetrates food to destroy or prevent growth of microbes, and insect. It also delays sprouting and ripening.</p>	<p>Prawn</p> <p>Red Meats</p>	<p>Threshold dose : 4.5 kGy T= -10± 2°C</p> <p>1 kGy (a low, sensorially acceptable dose)</p>	<p>15.5 &amp; 11.5 Log cycle reduction in <i>S. aureus</i> &amp; <i>E. coli</i> respectively</p> <p>2-3 log cycle reduction in <i>Salmonella</i></p>	<sup>21</sup>  <sup>22</sup>



12	Pulsed electric fields (PEF)	PEF is nonthermal method of food pasteurization that uses short electrical pulses for microbial inactivation. The microbial inactivation obtained using PEF is in the range 2-10.	Whole milk Fruit juice And Skimmilk fruit juice beverages.  Liquid egg yolk  Liquid egg white	35 kV/cm, 1,800 $\mu$ s  20–30 kV/cm, 0–210 $\mu$ s  20–30 kV/cm, 0–120 $\mu$ s	A 5 log cycle reduction in <i>L. innocua</i> . Shelf life at 4.0°C was increased to 56 days  Maximum inactivation levels of 5 log <sub>10</sub> cycles of <i>E. coli</i> and <i>S. enteritidis</i> .  2.90 and 3.70 log cycle reduction for <i>E. coli</i> and <i>S. enteritidis</i> .	23  24  24
13	UV (UltraViolet)	The germicidal properties of UV is primarily due to the absorption of UV by DNA, which results to form cross links with the neighbor bases of pyrimidine nucleotide in same strand of DNA, which leads to cell death.	Beer  clear apple juice	Thin Film Flow Reactors : 9.70milliJ/cm <sup>2</sup> (180000 J/l; 5.0 l/h, d=2.50 mm)  Turbulent Flow Reactors 1,377 J/l (3,800- 4,200 l/h)	more than 5 log reduction in <i>E. coli</i>  <i>E. coli</i> reduced by 7.45 log cycles and no yeast mold or APC was observed.	25  26
14	Cold Plasma Pasteurization	Cold plasma is a novel technique for pasteurization of foods. The destruction of microbes is due to the bombardment of radicals of high intensity on surface of the cells.	Sliced cheese  Mango & melon skin  Tomatoes	Atmospheric pressure plasma ; 120 s  Atmospheric plasma jet ; 5 s  Dielectric barrier discharge ; 300 s	> 8 Log reduction in <i>L. monocytogenes</i>  up to 3 Log reduction in <i>E. coli</i>  3.8 Log reduction in <i>S. typhimurium</i>	27  28  29
15	Ultrasound Pasteurization	Using ultrasound food processing can be done within less time with less cost of	Chocolate	Ultrasound of 160.0 kilo Hz and 100.0 Wfor	A 4.0 log cycle reduction in viable cell	30

		processing. It also eliminates the post treatment of the waste water while consuming very less energy compared to traditional processes.	Apple Cider	10 minutes in a peptone-water.  20kH, 17.7 min 40°C	Counts of <i>Salmonella</i> species.  5.3 log reduction in <i>Escherichia coli</i>	31
16	SC (Supercritical gases)	CO <sub>2</sub> and N <sub>2</sub> O in supercritical state have been researched as a novel nonthermal technology for pasteurization and sterilization of foodstuffs. It has been shown that this technology is successful in the inactivation of microorganisms and enzymes.	Elderberry  Apple	18 MPa, 45 °C and 90 min CO <sub>2</sub> volume ratio: 95.83%  12 MPa, 35 °C, and 10 min	5.38 & 5.23 log cycle reduction of <i>yeast</i> and <i>mesophilic bacteria</i> , respectively.  <i>Lactic acid bacteria</i> and <i>yeast</i> were completely inactivated	32  33
17	Oscillating Magnetic Field	This technique is used for pasteurization and sterilization of foods in which pulses are applied to the food of decaying or else constant amplitude sin wave. The growth of microbes can be encouraged or stopped by exposure to magnetic fields.	Brown'N Serve Rolls  Orange juice	Mixed with mold spores at 3000 spores/cm <sup>3</sup> ; Single pulse of a 7.50 T, 8.50 kHz  Inoculated with <i>Saccharomyces</i> at 25,000 cells/mL; 1 pulse of a 40 Tesla, 416 kHz	Reduction from 3000 spores per cm <sup>3</sup> to 1 spore per cm <sup>3</sup>  Reduction from 25,000 cells/mL to 6 cells/mL	34  34
18	Pulsed Light Pasteurization	Among soft pasteurization technologies for food products, pulsed UV light process is currently being studied extensively.	Strawberries	Pulse energy (J)= 7; Number of pulses=3,750 Pulse width = 30 μs	3 Log Reduction in <i>Botrytis cinerea</i>	35  36

		Pulsed light is being used for quick inactivation of microbes from food surface, food package material, and equipments.	Milk	Pulse energy (J)= 1.27; Number of pulses = 16	7.2 Log Reduction in <i>Staphylococcus aureus</i>	
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## 1. Thermal Pasteurization

### 1.1 HTST and LTLT Pasteurization

A Low-Temperature, Long-Time (LTLT) process is known as batch pasteurization. This method was developed for inactivation of tuberculosis pathogen. The High Temperature, Short Time (HTST) process was used first to pasteurize milk, commercially. The HTST and LTLT processing are promising thermal food pasteurization technologies. The bactericidal effect of HTST and LTLT is related to the temperature to which food is subjected and treatment time. These heating processes are used to study the thermal inactivation of selected microbes. In an experimental study, the milk was first treated with ultra-high temperature (UHT) to kill the microbes which were present initially. Then, the milk was subjected to LTLT pasteurization method for about 40 min and HTST pasteurization method for about 10 min, separately. The experiment resulted in elimination of the other microbes except *Bacillus cereus*, such as *Chryseobacterium meningosepticum*, *Pseudomonas putida*, *Acinetobacter baumannii* and *Escherichia coli* strains via both the pasteurization methods. In case of HTST method, Only *Bacillus cereus* strain survived but reduced by 1 log at concentration 10000 CFU/mL at 90°C while at 72°C its concentration is reduced by less than 1 log at concentration 10000 CFU/mL. In case of LTLT method, Only *Bacillus cereus* strain survived but reduced by less than 1 log at concentration 10000 CFU/mL at 63°C<sup>5</sup>. In another experiment, with cream and chocolate milk at process conditions as 75°C (166F) for 15 s with target bacteria (most resistant bacteria) including *L. monocytogenes*, *E. coli*, *Salmonella spp.*, and *C. burnetii* was observed within just 1 min at temperature about 70°C<sup>6</sup>. The loss of nutrients is less in HTST as compared to LTLT.

### 1.2 UHT Pasteurization

Development of the UHT (Ultra Heat Temperature) process had difficulties due to possibility of contamination of processed food without commercial aseptic systems. The selection of UHT pasteurization method indicates the preference of world towards increased sterility of product throughout its shelf life. Benefits offered by this thermal process include energy efficiency, prolonged shelf life and cost efficiency as the treated product no longer requires refrigeration during storage as well as distribution. The two types of heating methods used for UHT are: Direct Heating (by steam inject) and Indirect Heating (by plate/tubular heat exchangers). Indirectly heated milk receives greater heat load than direct heating mode for same bactericidal effect; more heat induced flavor of Indirect heating method is not approved by consumers, but Indirect heating method, has advantages such as greater stability to age gelation. It is responsibility of company to choose the heating method for UHT based on their situation as both methods have some advantages and some disadvantages. In an experiment with milk, at process conditions as heating at 130°C to 150 °C for 2 to 8s results in inactivation of heat resistant bacterial endospores such as that of *Bacillus stearothermophilus*<sup>7</sup>. In spite of pasteurization, the shelf life of this UHT milk is affected by the various factors that such as the cow's age, lactation stage, microbial content of raw milk and temperature at which milk is stored, etc.<sup>37</sup>. Therefore, shelf life of UHT milk can be increased by considering the above-mentioned factors and along with new improved manufacturing methods.

Table 1: Summary of different pasteurization techniques

Thus, to increase the shelf life of UHT milk, the techniques such as usage of raw milk (bacterial count <25000CFU/mL) stored at low temperature (<4°C) and time (<48hours) ISI-heating, LTI (Low Temperature Inactivation of heat resistant enzymes), membrane processing, UHPH (Ultra High Pressure Homogenization) can be used.

### 1.3 Pasteurization by Water Bath

Pasteurization by water bath is one of the simplest methods of pasteurization. Water bath can be efficiently used for canned foods and meat products. Pasteurization of red Lamuyo-type sweet peppers in a water bath at 70 °C for 10 min have no much significant impact on bioactive compounds such as fiber, carotenoids and antioxidant activity) and also on the texture. Thus, Water bath can be compatible to use in combination with various food processing.

In an experimental study, at 55 °C to 70 °C, the range of thermal inactivation D values of *E. coli* O157:H7 were observed to be around 21.36 -0.031 min for raw franks during cooking while for fully cooked franks during post cooking pasteurization, the higher D values about 24.91 to 0.038 min were observed. The z value of *E. coli* O157:H7 in raw franks and fully cooked franks were 5.07 °C and 5.08 °C, respectively. There is no significant difference in z values of the both the products in spite of having statistically significant differences in their D values<sup>8</sup>.

### 1.4 Steam Pasteurization

Steam Pasteurization provides advantages such as higher heat capacity which can be useful for increased thermal decontamination. Also, this method is useful for uniform pasteurization of irregular surfaced food materials. Biggest advantage of this method is it can be used in combination with many other food processing methods.

Reduction of certain pathogenic bacteria which occur naturally in foods can be done effectively by technique of Steam pasteurization. The huge amount of heat transfer and thereby significant increase in surface temperature to the targeted foods facilitates the pasteurization by steam<sup>38</sup>. Steam pasteurization is superior to pasteurization by water bath as, at a given temperature water possess a smaller heat capability than the same amount of steam and in addition, steam

also offer protection from surface-attached micro-organisms by penetrating through cavities, crevices and feather follicles, effectively<sup>39</sup>.

### 1.5 Superheated Steam

Superheated steam provides several advantages such as an oxygen free environment, increased heat transfer that may improve thermal degradation, accelerated drying rate, and improved energy efficiency. The process pasteurization with superheated steam though useful for the effective elimination of various pathogens like microbes, spores; it has many disadvantages like high capital cost, complexity of the equipment, incompatible with heat sensitive food properties. Some studies have reported that products such as potato, potato chips, noodles, etc., can be processed with superheated steam. In an experiment with Raw Almonds, used steam for pasteurization. They used the steam at a temperature above 95°C at absolute pressure of 143 kPa for 25s. This resulted in 5-log reduction of *Salmonella serotype Enteritidis*, which were inoculated on raw almonds and that too without any visual degradation in the quality of almonds. However, for steam pasteurization of more than 35 s, discoloration and visible formation of wrinkles were observed on the almonds<sup>9</sup>. In another experiment with Hard Red Spring wheat was treated with superheated steam at 185°C of for 6 min which led to 52% reduction in DON (*Fusarium mycotoxin deoxynivalenol*) concentration whereas for superheated steam at 130–175°C, the Z-value for *G. stearothermophilus* spores was found to be 28.4 °C<sup>10</sup>.

### 1.6 Vacuum steam pasteurization

The pasteurization techniques such as steam pasteurization or pasteurization by water bath can increase the moisture content in food which may result in increased growth of microbes. Thus, to avoid this, vacuum steam-pasteurization is used. The process involves the usage of steam under vacuum to operate at temperatures above or below 100 °C which is useful for thermal decontamination of microbes and then the steam is removed with vacuum cycles. The vacuum steam-pasteurization can be efficiently used for low moisture foods such as whole flaxseed, quinoa, sunflower kernels, milled flaxseed and whole black peppercorns and also this method can be used for meat processing.<sup>40</sup> employed vacuum steam pasteurization technique on flaxseed, quinoa, and sunflower kernels, wherein they carried out

pasteurization at 75°C for one minute which resulted in several log reductions of *Salmonella* PT 30, *E. coli* O157:H7 and *E. faecium*. Similarly, with same pasteurizing condition, on milled flaxseed and black peppercorns average log reductions of 3.02±0.79 and 6.10±0.64 CFU/g were observed for *Salmonella* PT 30°C. Interestingly, after pasteurization at 85°C, > 6.0 log reductions were observed and for *Salmonella* PT 30 and *E. coli* O157:H7, *E. faecium* may be used as a potential surrogate<sup>11</sup>.

### 1.7 Infrared (IR) Heating Pasteurization

Infrared (IR) Heating provides many advantages over conventional heating such as high thermal efficiency, alternate source of energy, reduced quality losses, fast heating rate, shorter response time, uniform drying temperature, high degree of process control, possibility of selective heating, etc. In general FIR (Far-Infrared) radiation is more potent for food processing owing to the fact that most food components absorb the radiative energy in that region. Infrared (IR) Heating may have disadvantages such as low penetration power; prolonged exposure of biological materials may cause fracturing, not sensitive to reflective properties of coatings. The study of effect of IR radiation on optical and physical properties of food substances is crucial for the design and optimization of IR based pasteurization. IR heating is very useful thermal pasteurization technique which helps to inactivate pathogens such as food bacteria, spores, yeasts and moulds in both liquid and solid foods. The various parameters such as infrared power level, temperature of food sample, bandwidth and peak wavelength of IR heating source, sample depth (Usually, the effect of IR radiation on microbial inactivation decreases as the thickness of sample food increases), types of microorganisms, moisture content, physiological phase of microbes (exponential or stationary phase), and types of food materials affects the efficacy of the microbial inactivation by IR pasteurization.

**Studies done on effect of temperature on inactivation of some microbes:**<sup>41</sup> in 1975 investigated dry heat inactivation of *B. subtilis* spores by IR radiation. The obtained D values indicated that for inactivation of pathogens shorter treatment times were required when operated at higher temperatures and the estimated Z value was 23°C. The reduction of

about 0.76, 0.90, and 0.98 log<sub>10</sub> was observed for bacterial suspension of *Escherichia coli*, when it was exposed to IR radiation for 2 minutes at the temperatures 56, 58, and 61 °C, respectively<sup>42</sup>.

<sup>43</sup> have reported 2.5 to 5.2 log (estimated) reduction in *Monilia fructigena* pathogen when IR heating technique at approximately 50°C (surface temp) for 10s, was used for pasteurization of strawberry. In another study, when IR heating was performed on onions at 80°C (average 2226 W/m<sup>2</sup>) for approximately 24 min, 1.72±/− 0.45 log<sub>10</sub>CFU/10g reduction in aerobic plate count, 4.04±/− 0.47 log<sub>10</sub>CFU/10g reduction in coliform count and 1.26±/− 0.14 log<sub>10</sub>CFU/10g reduction in yeast and mold count was observed<sup>12</sup>. Further, in case of Liquid food Honey, for process condition as 0.2 W/cm<sup>2</sup> IR heating for 8 min, 3.85 log<sub>10</sub>CFU/mL reduction in yeast count was observed<sup>13</sup>.

### 1.8 Microwave Heating Pasteurization

MW heating seems a very attractive thermal pasteurization technique, owing to its well-known advantages over conventional heating. It serves many advantages and major one can be stated as reduction in processing time. The reduction in processing time results in fresher taste and texture and also improves visual appeal of food. Microwaves heats the targeted food directly with no need for intermediate fluid, thus it is more effective, faster and economically profitable treatment. The effects of parameters like mass, shape, water content, chemical composition, temperature and frequency of treatment on the dielectric properties of the foods during heating must be studied thoroughly for the scale up and usage of this technique in food processing industry<sup>44</sup>. The destruction of microbes by MW pasteurization can be explained/ understood by various theories such as selective heating, electroporation, cell membrane rupture and magnetic field coupling.<sup>14</sup> studied the effect of MW heating of Apple juice at processing conditions of 2450 MHz, 720–900 W for 60–90 s. They observed *E. coli* microbial reduction and the range of D values was noted as D= 0.42 min at 900 W to D= 3.88 min at 720 W<sup>14</sup>. In another study, in case of shell eggs, radiant energy (microwave oven) at power 9 for 20 sec was used for pasteurization and noticeably, 1.2 log CFU/ml reduction in *Salmonella typhimurium* (ST) was obtained in just 15s<sup>15</sup>.

### 1.9 Radiofrequency Heating

The capacitive (Radio Frequency, or RF) dielectric heating is one of the most efficient heating techniques that allow rapid, uniform heating throughout a medium. The externally applied AC electric field causes frictional interactions between rotating polar dielectric molecules rotating which is responsible for simultaneous generation of the heat energy within and throughout the mass of food material. On account of several benefits offered by capacitive (RF) dielectric heating mainly including rapid and uniform heating, heating independent of the product's and/ the medium's thermal conductivity, high energy efficiency, high energy densities, and reduced production floor-space requirements, it is said to be better than conventional pasteurization techniques. Additionally, the method is industrially viable as it can be used for batch and/or continuous flow processing. RF heating technology has potential for pasteurizing low-moisture foods. The factors listed above that influence dielectric properties of the foods during heating must be completely studied before implementation of this technique on commercial scale. RF energy penetrates into dielectric material more deeply with more uniform heating along the depth of a food package than microwave energy. It indicates that RF heating may be particularly useful when applied to institutional size packaged food products. In an experiment, RF heating performed just for 130s, resulted in >5.93 log CFU/g reduction of *Salmonella* spp. in ground black pepper without significant quality loss<sup>16</sup>. In case of wheat flour, RF heating (27.12 MHz, 6 kW) at temperature 75-85°C for 3 kg wheat flour was performed which resulted in 5 log reduction of *E. Faecium* after 25 min or 5 log reductions of *S. Enteritidis* after 18 min. The study also showed that *E. faecium* can be used as a surrogate in an inoculated pack. In addition, the study highlighted the potential of RF heating for pasteurization of low-moisture foods demonstrating that *E. faecium* the F-value can be used to design RF pasteurization processes<sup>17</sup>. In another experiment with shell eggs, a radio frequency (RF) apparatus was assembled, and a 2-step process was developed that uses RF energy and hot water, to pasteurize eggs in less than half the time than only with hot water process. Two step process: 1) Heat the egg in 35.0°C water for 3.5 min using 60 MHz RF energy 2) Heat the egg for an additional 20 min with 56.7°C water<sup>18</sup>.

## 2. Non-Thermal Pasteurization

### 2.1 High pressure processing (HPP) Pasteurization

HPP also known as Hydrostatic High Pressure processing provides an alternative to the thermally processed food in the form of minimal processing & long shelf life. It is a commercially viable solution to pasteurize around room temperatures. HPP works on 1)The Isostatic Principle 2)The Le-chatelier Principle 3)The Principle of microscopic reordering and 4)The Arrhenius relationship. It could be performed as a batch process or semi-continuous process for pumpable foods. The pressure used for HPP lies in the range of 1000-10000 bars. Through the isostatic principle, the pressure in the container is rapidly and evenly transferred to the food product. All parts of the food product receive identical pressure. HPP is not affected by the size of the product or its external shape. The process achieves pasteurization and inhibits enzyme activity under normal temperatures. Application of HPP at ambient temperatures causes destruction in vegetative cells; also inactivation of certain enzymes takes place, with minimal loss in organoleptics. HPP is applied to foods like meat, fruit and vegetable juices, marine foods etc. At ambient conditions HPP at 4000-6000 bar is effective against pathogens and spoilage vegetative bacteria, virus, yeasts, molds etc. When apple juice and apple Cider was treated at 2500 bar at 70 C, a 7 log cycle reduction in *Escherichia coli* was found<sup>19</sup>. In another experiment with 100% pomegranate juice having high bioactive compounds content, which contained a initial microbial load of 10000 CFU/ml was treated under hydrostatic high pressure, with P (4000-6000 bar), T(25-50 C) for a operating time of 5-10 min. The result obtained was that the microbial load after each cycle was always lower than 1 CFU/ml<sup>20</sup>. The application of hydrostatic high pressures resulted to be particularly interesting on the pomegranate juice, characterized by a high added value, due to the high content of nutraceutical components (tannins, anthocyanins, and polyphenols).

### 2.2 Irradiation Pasteurization

Food irradiation is the application of ionizing form of radiation (which travels as particle or RM wave and carries energy which is sufficient to detach electrons from atoms and molecules thus causing their ionization) to food, which results in an extended shelf life of foods by reducing or eliminating microorganisms and insects thus resulting in Pasteurization of food. Sources of irradiation are:

- 1) Gamma irradiation- It uses gamma rays which are high in energy. These are emitted

by radioactive Co 60 or Cs 137. Due to high penetration energy, it is possible to treat bulk foods.

- 2) Electron beam irradiation –It uses beta rays which are a stream of high energy electrons coming out from an electron gun. Electrons can penetrate only upto several centimeters of food hence foods are treated in relatively thin layers.
- 3) X-irradiation –Above both properties are combined here. X-rays penetration in foods is more than electron beams thus can be applied to bulk foods.

Irradiation is classified according to the dose rate as a)Low dose [ $<1$  kGy], b)Medium dose [1-10 kGy], and c)High dose [ $>10$  kGy]. Medium doses are generally applied for pasteurization and high doses for sterilization of foods.

When, prawns(frozen) were treated with irradiation of different doses around  $-10 \pm 2^\circ\text{C}$  (threshold for the detection of irradiation flavor being 4.5 kGy), the results showed a 15.5 & 11.5 Log cycle reduction in *S. aureus* & *E. coli* respectively at 4.5 kGy<sup>21</sup>.

<sup>22</sup> demonstrated that when red meats were irradiated with 1 kGy (a low, sensorially acceptable dose) showed 2-3 log cycle reduction in *Salmonella*, which is very appreciable at such a low level of dose. It inhibits the growth of sprouts on potatoes and other foods. It also delays ripening of fruits.

### 2.3 Pulsed electric fields (PEF) Pasteurization

The PEF processing is a promising food pasteurization technology which works on non-thermal basis. The bactericidal effect of PEF depends on the strength of the electric field and the time of treatment. PEF is a better alternative to thermal pasteurization in the foods which are protein based because for almost same microbial inactivation, the effect on foods that are protein based is less by PEF than done by thermal processing. Numerous experiments show that small molecule compounds in foods that are plant based, which include the compounds which give aroma, phytochemicals related to health, are not affected noticeably. PEF with high voltage, short pulses leads to ruptures in microbes cell membranes and causes inactivation of endogenous enzymes at ambient

temperatures in foods. There is saving of energy with PEF compared to when other traditional thermal methods are used. When whole milk and skim milk fruit juices were treated at PEF 35 KV/cm for 1800  $\mu\text{s}$ ; 5.00 log reductions was achieved of *L. innocua*. Also the shelf life at 4.0°C was increased to 56 days<sup>23</sup>. When Liquid egg yolk was treated with a PEF of 20–30 kV/cm for upto 210  $\mu\text{s}$  inactivation of upto 5 log cycles of *E. coli* and *S. enteritidis* were obtained<sup>24</sup> whereas when Liquid egg white was treated with a PEF of 20–30 kV/cm for 0–120  $\mu\text{s}$ , the inactivation obtained was 2.9 log for *E. coli* and 3.7 log for *S. enteritidis*<sup>24</sup>. Intense PEF conditions are needed for foods which are protein based.

### 2.4 Ultraviolet (UV) Pasteurization

Sterilization of drinking water is done by using UV since 1910. Nowadays it is frequently used in sterilization of drinking water, wastewater sterilization and the decontamination of air and surface. UV is effective in inactivating a wide range of microorganisms; however, the ability of UV to penetrate food is dependent on the colour as well as the transparency of the food. The limited UV penetrability and its dependence on food properties need to be considered in the design of UV processing systems for specific food product. The effect of light on food is dependent on both optical characteristics of food and the light including the duration, intensity, and spectrum. The UV wave lengths showing greatest effect for inactivating microbes is around 260 nm. These are absorbed in the DNA of the cells. Because the DNA composition varies from one species to other, the UV absorption peak is within 260 to 265 nm. UV radiation can be classified as:

UV-A: 320 to 400 nm,

UV-B: 280 to 320 nm,

UV-C: 200 to 280 nm

The UVC is most very dangerous to microbes. The germicidal properties of UV is primarily due to the absorption of UV by DNA, which results to form cross links with the neighbor bases of pyrimidine nucleotide in same strand of DNA, which leads to cell death. In an experiment with beer, greater than 5 log reduction of *Escherichia coli*, was obtained at 9.70 mL/cm<sup>2</sup> for 180000 J/L, 5.0 L/h at d-2.50 mm<sup>25</sup>. In other experiment, clear apple juice subjected to

1377 J/L which was inoculated with *E. coli*, 7.45 log reduction was obtained and there was no yeast, mold or APC detection<sup>26</sup>.

## 2.5 Cold Plasma Pasteurization

Cold plasma is a novel technique for the destruction and inactivation of microbes. The generation of plasma takes place when an inert gas comes in contact to electricity. Cold plasma is the plasma produced at ambient temperature (30-60°C), mostly used in food industry. Plasma means fully ionized gas consisting of free electrons, photons and atoms in excited state with neutral charge, thus it has zero net charge. Classification of Plasma:

A) Thermal Plasma: generated using high Temperature and pressure from heavy electrons.

B) Non thermal plasma (near ambient temperature plasma): generated using electrification or by use of EM waves in gas at less pressures Or vacuum around 30 to 60 °C.

The destruction of microbes is due to the bombardment of radicals of high intensity on surface of the cells. Due to the Lesions, the microbes are not able to recover easily and it leads in the destructions of the cells very fast, the phenomenon is called 'etching'. Non thermal plasmas' efficiency is dependent on a) the type of substrate and b) Characteristics of microbes like type, load etc. The charged particles also cause the DNA to denature and breakage of chemical bondings. Being a surface phenomenon it's not effective in an in vitro system of foods like microbes or enzymes which are intact in the tissues. In an experiment with sliced cheese, it was treated at Atmospheric pressure plasma for 120 s and yielded a result of more than 8 log reduction in *L. monocytogenes*<sup>27</sup>. When Atmospheric plasma jet was applied to Mango & melon skin for 5 s up to 3 Log reduction in *E. coli* was <sup>28</sup>. When dielectric barrier discharge was applied for 300 s on tomatoes, 3.8 Log reduction was observed in *S.typhimurium*<sup>29</sup>. Cold plasma technology is also used to inactivate endogenous enzymes.

## 2.6 Ultrasound Pasteurization

Using ultrasound food processing can be done within less time with less cost of processing. It also

eliminates the post treatment of the waste water while consuming very less energy compared to traditional processes. Ultrasounds are usually the Waves with frequency of 20 kilo Hertz or greater. The frequency used by ultrasound instruments range between 20 kilo Hertz to 10 megahertz. Power ultrasound which has frequency ranging from 20 to 100 kilo Hertz has an ability to create Cavitation and hence it is used in food to destroy microbes.

Transducers are used to convert mechanical energy into ultrasonic vibrations. Change in pressure is created by the ultrasonic wave which is responsible for destruction of microbes. The destruction is caused due to thinning of cell membrane also there is local heating with the production of free radicals.

The longitudinal waves gets created when the ultrasonic wave interacts with the liquid thereby creating alternate regions of compressions and expansions which leads to the formation of gas bubbles which increase their area while expansion is taking place. After a certain point the bubble breaks leading to shock waves. This causes the Temperature and pressure to go up 5500°C and 50000 kPa respectively. This is responsible for bactericidal effect of ultrasound. These zones are localized and hence affect a small area thereby killing the microbes in that area. The increase in temperature can negatively affect fat and proteins and may lead to decrease in the nutritional value and sensory characteristics. Ultrasound is a green technology.

4 log cycle reduction in the viable cell count of *Salmonella* species in a chocolate product when wastreated with ultrasound of 160 kilo Hz, 100W for 10 min in the peptone water was observed<sup>30</sup>. In other experiment, Apple Cider was treated with 20kHz ultrasound for 17.7 minutes at 40°C, a 3 log cycle reduction in *Escherichia coli* was observed <sup>31</sup>.

## 2.7 Supercritical fluid(SC) Pasteurization

CO<sub>2</sub> and N<sub>2</sub>O in supercritical state have been researched as a novel non-thermal technology for pasteurization and sterilization of foodstuffs. SC fluids are substances in their pure form that are above their critical conditions of temperature and pressure. It has been shown that this technology is successful in the inactivation of microorganisms and enzymes. SC-CO<sub>2</sub> technology is emerging as a



potential non thermal technique for destruction of spoilage bacteria, pathogens and endogenous type of enzymes which cause the spoilage of foods mainly juices. Along with the maintenance of sensory qualities, SC-CO<sub>2</sub> helps preserve the compounds that are associated with good health effects. SC-CO<sub>2</sub> is better as compared to HPP or Ultrasound as it allows to process at low T than Ultrasound and low P than HPP. The Temperatures used for Supercritical fluid Pasteurization are usually less than 50 C. The mechanism for this process is yet to be fully understood, there are many conflicting views about this. Spilimbergo, Elvassore, and Bertucco proposed that a modification in intracellular and extracellular pH could be a reason for inactivity of microbes. As proposed by <sup>45</sup>, the initiation of inactivation is dependent on the time taken by CO<sub>2</sub> to diffuse into microbial cells. This could be true because the effect is dependent on time for which exposure takes place. The instrument used for SC-CO<sub>2</sub> processing of liquid foods is dependent on the application and the process could be operated in batch, semi-continuous, continuous or pseudocontinuous mode. <sup>32</sup> showed that when, Elderberry was treated with SC-CO<sub>2</sub> at 18 MPa, 45 °C for 90 min maintaining CO<sub>2</sub> volume ratio: 95.83%, it yielded a 5.23 and 5.38 log cycle reduction of the *mesophilic bacteria* and *yeast*. Whereas <sup>33</sup> demonstrated that Applewheat treated with SC-CO<sub>2</sub> at 12.0 MPa, 35 °C, for 10.0 minutes, *Lactic acid bacteria* & *yeast* were completely inactivated.

## 2.8 Oscillating Magnetic Field Pasteurization

The growth of microbes can be encouraged or stopped by exposure to magnetic fields. Researches on the biological effects of magnetic field date back to as early as 1938. Magnetism is the phenomenon as a result of which, substances exert an attracting or repulsing force on other substances. Magnetic fields are homo-genetic or hetero-genetic, which could be in a static or a pulse operation.

Homogeneous magnetic field: uniform field intensity

Heterogeneous magnetic field: non-uniform field intensity

Static magnetic fields have constant strengths with respect to time and their generation takes place from direct current electromagnet or a permanent magnet. The application of Oscillating magnetic fields takes place as constant amplitude or as decaying amplitude sin waves and they show a gradient of intensity with

respect to time. Oscillating magnetic fields are generated by AC electromagnets with the application of the field in the form of pulses, with the intensity of field altering regularly. One possible reason for the deactivation of microbes is due to change in DNA's synthesizing. The bio-molecule and bio-membrane gets oriented parallel or perpendicularly with respect to the applied OMF. There could also be a drift of ions through the plasma membranes. One important thing for the application of OMF is that given food should be having high electric resistance, more than 10 to 25 ohm cm. There are numerous food items having resistivity lying in this arena. Typical example of application of OMF is juice of orange. Around 30 ohms-cm is the resistivity of juice of orange. The intensity required is dependent on the resistivity of the sample and thickness of the sample. The microbes get inactivated at oscillations above 2 Tesla. The results are not consistent about growth and deaths of microbes hence it has not got more commercially acceptability. Also info is lacking on the instruments etc. Complete sterilizations could be achieved by multiple oscillations. <sup>34</sup> showed that when Brown N Serve Rolls dough after repackaging with 3000 spores/cm<sup>3</sup>, treated with a single pulse of 7.50 T, 8.5 kilohertz after chopping the rolls and plating it, the spore concentration of the mold obtained was just around 1 spore/cm. In other experiment, <sup>34</sup> showed that after inoculation of juice of orange with initial count of *Saccharomyces* being 25x10<sup>3</sup> bacteria/cm<sup>3</sup> and being maintained at 20.0 C, after subjection to a Single pulse of 40.0 T and 416.0 kilohertz, the resultant count on standard plate was only around 6 bacteria/cm<sup>3</sup>.

## 2.9 Pulsed Light Pasteurization

Among soft pasteurization technologies for food products, pulsed UV light process is currently being studied extensively. Pulsed light is being used for quick inactivation of microbes from food surface, food package material, and equipments. Pulse Light has immense potentials for food industrial applications. Accumulation of electro-magnetic (EM) energy is done in capacitors for very short time (milli or nano seconds), which causes the power to amplify without extra energy requirements. The disadvantages of continuous ultraviolet light are less depth of penetration and its less power of emission. Pulsed light is characterized by greater penetration and more emissive power. Thus, Pulsed light has better effect for destruction or inactivation of microbes than continuous ultraviolet light as the energy here is very much higher. Typical instruments used for the production of pulsed light consists of

xenon lamps (adjustable), power source, high volt connections to allow transferring high current pulses. Short and intense bursts of light are emitted from the lamp as the current pass through the chamber of gas. This light consists of waves from ultraviolet to near infrared. The wavelengths lie in the range of 100 to 1100 nm. Care needs to be taken to avoid over-heating of foods. Also technological developments are needed to have better penetration. <sup>35</sup>showed that on applying a pulsed light of Pulse energy = 7 J, number of pulses=3,750 and Pulse width of 30  $\mu$ s, a 3 Log reduction in *Botrytis cinerea* was obtained. <sup>36</sup>obtained a 7.2 Log reduction in *Staphylococcus aureus* on treating milk with Pulse energy of 1.27 J with 16 pulses.

## Conclusion

Food pasteurization has been in use for many decades and various different techniques of pasteurization are in use in food industry. The most widely implemented techniques for food pasteurization include the thermal techniques like HTST, LTLT etc. The consumer is now demanding minimally processed but safe to consume food which should retain all its characteristics, hence various non-thermal techniques are being investigated and many of them have been put to use in the food industry. These techniques include High pressure processing, irradiation pasteurization, ultrasound pasteurization, pulsed light, oscillating magnetic field, supercritical, ultrasound pasteurization etc. All these non-thermal techniques help the food manufacturers dealing with pasteurizing food at or near ambient temperature conditions. All these techniques have huge industrial applications and further research is needed to increase their efficiency and lower their cost.

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