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Review Article

PULSE LIGHT TECHNOLOGY: A NOVEL METHOD FOR FOOD PRESERVATION

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Abstract: The present globalized food industries ensure the health, nutrition and convenience of the food by application of advanced preservation techniques and food quality management. Fish and fishery products have attracted considerable attention as a source of high amounts of important nutritional components like high-quality protein, essential vitamins, minerals and healthy polyunsaturated fatty acids to the human diet. Thus, followed by drinkable yogurt (18%) and fresh soup (18%) among all the food products, fresh fish and seafood products secure third rank worldwide considering the fastest overall growth. Consumption of both freshwater and marine fish is expected to increase in the future. Due to highly perishable in nature fish is highly susceptible to spoilage, because of intrinsic and extrinsic factors. Present day consumers' preferences for fresh alike high-quality food products leads to the development of non-thermal technologies to retain high organoleptic quality and necessary nutritional attributes without potential health risk. Pulsed light (PL), an alternative to continuous ultraviolet light treatments for both solid and liquid foods, is an emerging non-thermal technology for preservation of food surfaces and food packages, consisting of short time high-peak pulses of broad-spectrum white light, thus, food quality is ensured. Fish and fishery products are prone to spoilage by food spoilage microorganism and potential human pathogens, which can alternatively be delayed by microbial inactivation with PL treatments on food, thus increasing the shelf life. Here is an extensive review; in-depth, and up-to-date analysis of existing information available in the last 20 years of scientific literatures regarding the principles, mechanisms of microbial inactivation, and applications of PL treatments on foods.

Keywords: *Pulsed light, Food safety, Non-thermal processing, Minimally processed, Microbial load*

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Introduction

Food-borne illness caused by consuming contaminated food remains a major cause of morbidity throughout the world. Clearly, the use of methods to reduce or eliminate food-related microbiological hazards will have a significant impact on the incidents of such diseases. Various food preservation techniques are developed and practiced now-a-days too, such as, drying and dehydration, freezing, thermal sterilization or canning and the addition of preservatives to ensure food safety; although, freezing and thermal sterilization or canning lead to the degradation and denaturation of certain macromolecules in food, especially protein, some heat-labile vitamins, some fat and carbohydrates, which impair food quality due to thermal shock. Thus, to prevent undesirable thermal shock and degradation of such food macromolecules, major efforts have been made to develop non-thermal technologies, which can produce safe but minimally processed foods with satisfactory nutritional and organoleptic qualities.

The most promising of these emerging technologies include high-pressure processing, the use of pulsed-electric fields, and the application of pulsed light. The inactivation mechanism of cellular microorganisms by continuous ultraviolet (UV) light and visible light is thoroughly studied. Recently, a novel method has been introduced; intense pulses of light with unique bactericidal effects on food surfaces has been generated using high-power electrical energy, thus advancement of food preservation moves few steps forward. Non-thermal methods allow the processing of foods below temperatures used during thermal pasteurization; thus, flavour, essential nutrients, and vitamins undergo minimal or no changes. The non-thermal food preservation method includes application of high hydrostatic pressure, use of ultrasound, filtration, irradiation, addition of antimicrobial compounds, and employing electrical methods such as oscillating magnetic fields, light pulses and pulsed electric fields.

During the last decade technological advancement was focused on high electric field processing, high pressure processing technology and pulsed light processing.

Units used to characterize PL treatment

i. Fluence rate: Measured in Watt/meter^2 (W/m^2) and it is the energy received from the lamp by the sample per unit area per second.
ii. Fluence: Measured in Joule/meter^2 (J/m^2) and is the energy received from the lamp by the sample per unit area during the treatment.
iii. Dose: Sometimes used as a synonym of fluence.
iv. Exposure time: Length expressed in time (seconds) of the treatment.
v. Pulse width: Time interval (fractions of seconds) during which energy is delivered.
vi. Pulse-repetition-rate (prr): number of pulses per second (Hertz [Hz]) or commonly expressed as pps (pulses per second).
vii. Peak power: Measured in Watt (W) and it is pulse energy divided by the pulse duration.

Several names

I. Pulsed ultraviolet light [1]
II. High intensity broad-spectrum pulsed light [2]
III. Pulsed light [3] and
IV. Pulsed white light [4]

Types

The term light is generally used to mean radiations having wavelength ranging from 180 to 1100 nm, which includes ultraviolet rays (UV 180-400 nm), roughly subdivided into UV-A, 315-400 nm, UV-B, 280-315 nm, UV-C, 180-280 nm), Visible light (400- 700 nm) and Infrared rays (IR 700-1100 nm).

Pulsed light is a modified and claimed improved version of delivering UV-C to bodies. The continuous working mode of classical UV-C treatment is termed as continuous-wave (CW) UV light. Inactivation of microorganisms with CW-UV systems is achieved by using low-pressure mercury lamps designed to produce energy at 254 nm (monochromatic light), called germicidal light [5]. It is also done with the help of Xenon lamps that can produce flashes for several seconds. Application of very short electric pulses (1-100 µs) are featured in PEF processing at electric field intensities ranges of 0.1-1 kV cm^{-1} (reversible permeabilization for stress induction, plant cells), 0.5-3 kV cm^{-1} (irreversible permeabilization of plant and animal tissue) and 15-40 kV cm^{-1} (irreversible permeabilization of microbial cells).

Principles of pulsed light system

Pulsed light (PL), an alternative to continuous ultraviolet light treatments for both solid and liquid foods, is an emerging non-thermal technology for preservation of food surfaces and food packages, uses intense and short duration pulses consisting of short time high-peak pulses of broad-spectrum white light, thus, food quality is ensured [6]. The inactivation efficiency of pulsed light depends on the intensity (measured in J/cm^2) and number of pulses delivered. Short-duration, high peak energy light pulses are generated from high-speed electronic pulses by magnifying power of multiple times as a result of advanced engineering technologies. Pulsed light system consists of the three main components, the power supply, the pulse configuration device, and the lamp. In a high-power capacitor, energy is stored for a fraction of a second from which it is released to a specially designed xenon lamp unit within a much shorter time (nanoseconds to milli-second).

This released high energy to the lamp leads to production of an intense pulse of light that typically lasts for a few hundred microseconds with a broad-spectrum wavelength (from 180 to 1100nm) ranging from UV to near-infrared: UV (180-380nm), visible light (380-700nm), and infrared (700-1100nm), focuses to the treatment area. The pulse light generated delivers a spectrum of 20,000 times more intense than incident sunlight at the earth's surface. The pulsed light intensity is directly proportional to the microbiocidal effects. Depending on the treatment application, the permutation-combination of flashing frequency, the number of lamps, and flashing configuration take place.

Mechanism of action

The efficacy of pulsed light technology in microbial destruction is associated with its broad-spectrum UV content, short duration, high peak power, and the ability to regulate both the pulse duration and frequency output of flash lamps. Precisely, the UV region is the pivot point to the efficiency of pulsed-light technology as no cellular destruction is observed for UV wavelength of 320 nm or higher. However, literatures reveal that both the visible and infrared regions, consisting of high peak power of pulsed light, contribute to kill microorganisms. The various mechanisms explaining the lethal effect of pulsed light are related to the photochemical and photo- thermal effect of UV spectrum [7-11].

Photochemical mechanism

The primary cell target of pulsed light is nucleic acids because DNA is a target molecule for these UV wavelengths [12-14]; thus, chemical modifications and DNA cleavage are associated with the photochemical mechanism of UV pulse light. The germicidal effect of UV light has been attributed primarily to a photochemical transformation of pyrimidine bases in the DNA of bacteria, viruses, and other pathogens to form dimmers [15,16] that prevents DNA to unzip for replication, thus the organism becomes incapable to reproduce. Without sufficient repair mechanisms, such damage results in mutations, impaired replication and gene transcription, and ultimately the death of the organism [17-19]. UV light is endowed with germicidal properties within the wavelength range of 100-280 nm. Several studies suggest that shorter wavelengths are more efficient against microbes than longer wavelengths, because of their higher energy levels [3]. Disinfection can almost entirely be attributed to the UV part of the lamp (6- 9 log reduction), and UV-C alone is responsible for 50% of the effect.

Photo thermal mechanism

The lethal action of pulsed light also can be due to a photo thermal effect. With energy exceeding 0.5 J/cm^2, the disinfection is achieved through bacterial disruption during their temporary overheating resulting from the absorption of all UV light from a flash lamp. The difference in UV light absorption by bacteria and that of a surrounding medium leads to overheating, the available bacterial water is vaporized, generating a small steam flow that accelerates membrane disruption [10].

Factors determining the efficiency of pulsed light

The eloquent incident of PL on the sample is the key factor determining the efficiency of pulsed light. The energy emitted by the flash lamp differs from the incident energy on the sample. The distance from the source of light to the target, and propagation media such as air, water, or fruit juice affect the level of energy ultimately reaching to the target. Closer the sample to the lamp, higher the inactivation efficacy of PL. Sample thickness is inversely proportional to the microbial inactivation with PL. Due to the restricted penetrability of the UV light, the decontamination and sterilization of the surfaces become hampered while overlapping opaque samples; moreover, light is depleted during treatment of fluid samples. High surface contamination again decreases the sterilization efficacy by pulsed light because of overlapping of microorganisms at high population densities. Thus, microorganisms residing in the upper layers will become mostly exposed followed by inactivated; on the other hand, the lower layers will become shadowed the rest from the light. The composition of food also affects the efficacy of the sterilization by PL. The factors determining the efficiency of pulsed light are as follows:

A. Type of micro-organism includes Optical properties: *e.g.*, degree of scattering and absorption of light; the incident beam of light undergoes refraction due to difference in the optical density between the substrate and the surrounding air; and the resistant nature of micro-organisms to pulsed light.

B. Interaction between light and the substrate considers the following: For transparent and colored food materials, refraction is particularly relevant. For opaque food materials, reflection, for smooth surfaces specular reflection, for rough surfaces diffuse reflection and for translucent materials scattering are relevant.

C. The distance from the light source is described by the term Optical Penetration Depth. Shorter wavelengths lead to deeper penetration into the food.

D. Another determining factor is proper design of PL system.

Design of pulsed light system

Pulsed-light equipment may vary from manufacturer to manufacturer. The system of pulsed light consists of several common components.

1) A high voltage power supply provides electrical power to the storage capacitor

2) A storage capacitor stores electrical energy for the flash lamp

3) A pulse-forming network determines the pulse shape and spectrum characteristics

4) The gas discharge flash lamp

5) A trigger signal initiates discharging of the electrical energy to the flash lamp, which is the key element of a pulsed light unit.

Parts of pulsed light system - Flash Lamp

The flash lamp is the important element of any Pulsed light unit and it converts 45% to 50% of the input electrical energy to pulsed radiant energy [20]. This is filled with an inert gas such as xenon or krypton. Xenon is a gas of choice due to its efficacy in microbial inactivation and higher conversion efficiency as well. The principal structural components of the flash lamp consist of envelope, the seals and the electrodes, the envelope being a jacket that contains the filling gas and surrounds the electrodes too.

Envelope

The envelope, typically made of clear fused quartz, named as Suprasil (about to 1 millimetre of thickness), must be transparent to the radiations that are emitted by the lamp.

It must be impervious to the filling gas as well as air and it should be able to withstand high temperatures and thermal shocks. It should also have mechanical strength.

Electrodes

Metallic electrodes protrude into each end of the envelope and are connected to the capacitor that is charged to a high voltage. The electrodes provide electric current into the gas. The lifetime of the lamp is determined by the cathode and hence it is an important component.

Seals

The whole assembly of the flash lamp needs to be sealed. Commonly used seals include solder seals, rod seals and ribbon seals.

Description

The duty of the cathode is to provide unsputtered and adequate number of electrons, because sputtering, caused due to hot spots created during peak power supply, may lead to corrosion of the cathode material. This in turn would reduce the lifetime of the cathode. The anode should have sufficient mass or surface area to sustain the loading of power caused by the electron bombardment from the electric arc. The whole assembly of the flash lamp needs to be sealed. Commonly used seals include solder seals, rod seals and ribbon seals. The gas in the flash lamp undergoes ionisation when subjected to a high voltage, high-current electrical pulse and plasma formation takes place near the anode because of the electrons travelling towards it. A very large current pulse is generated and allowed to pass through the ionized gas so as to excite the electrons surrounding the gas atoms causing them to jump at higher energy levels. While jumping back the electrons at lower energy levels, quanta of energy is released, thus producing photons. Overheating problems are encountered during this operation and hence cooling devices are to be provided for long lamp life and undeviating operation. Cooling fans can be used to serve the purpose.

Other pulsed light sources are explored such as solid-state Marx-generator for pulsing an ultraviolet lamp in microbial inactivation applications, static discharge lamps with spectral outputs similar to the flash lamps and sparker technology which generates a light and sonic sound pulse [21]. Conversion efficiency of electricity to light is about 50%. The spectral distribution is 25% ultraviolet, 45% visible light and 30% infrared. The flashing rate is 1-20 flashes/sec; thus, few flashes are sufficient for the process of pasteurization or sterilization against microbial contamination.

Generation of pulsed light

The pioneer company producing PL equipment for disinfection was Pure Pulse Technologies Inc. (San Diego, California), a subsidiary of Xenon Corp., which commercialized the Pulse Light System. Microorganisms on specific agar containing petri dishes, or food samples are placed in a vertically movable shelf, which can be moved to regulate and control the distance between the target sample and light source, a linear Xenon flash lamp centrally placed at the top of the chamber, inside the lamp housing.

A very large current pulse is generated and allowed to pass through the ionized gas so as to excite the electrons surrounding the xenon atoms leading them to jump at higher energy levels. The electrons release this energy and drop back to a lower orbit by producing photons. The pulsed operation of xenon discharge lamps is characterized by two stages *viz*. plasma formation near the anode and plasma decay stage.

Applications of Pulsed Light System

During application in various food system, the adverse effect of wavelengths in retaining food flavour or quality are taken care off. The flashlights are arranged in arrays to continuously sterilise the packaging film in aseptic processing, to on-line sterilise the transparent liquids or to pasteurise the solid foods surface within plastic packaging as broadband light transmit soundly through most of the plastic packaging materials, except polycarbonate, polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polystyrene. Due to the spontaneous transition of some atoms from an excited state to a lower energy state, light can be emitted and can be delivered either continuously or in the form of pulses [22].

Pulsed light works with Xenon lamps that can produce several flashes per second. During the pulse light treatment, the spectrum produced is 20000 times brighter than sunlight at the surface of the earth [23]. CIFT (Central Institute of Fisheries Technology, ICAR) has developed a Pulse light system. While current passes through the gas chamber of the lamp unit, an intense broad-spectrum burst of light is emitted having wavelengths ranges from UV to near infrared (100 to 1100 nm).

Consumer-demand for fresh food products has made it necessary to modify industrial transformation methods. During some processing and preservation process, handling causes cross contamination, which may be regarded as hazard entry point. Hence, quality can be assured by treatment with pulsed light without altering its properties, thus shelf life of food products can be increased. Moreover, various applications at laboratory level can efficiently be done with pulsed light technology. However, the commercialization and industrialization of pulsed light technology has so far been practised for sterilization of packaging material.

•Closures, cups, films and preforms used in the food and beverage industry, can be treated with a pulsed light. Trials on food product surfaces (bread and cakes, meat and seafood, vegetable and fruit, *etc.*) and on transparent liquids have also yielded positive results.

•Disinfection of air and water for aseptic applications

•Inactivation of spoilage and pathogenic microorganisms in fluid foods - niche applications

•Surface microbial control

•Disinfection of utensils and surfaces

•Disinfection of packaging and closures

•Surface sterilization of fruits and vegetables

•Hurdle treatment

Application on food processing equipment

Literature review reveals that meat contacting stainless-steel surfaces can efficiently be sterilized by pulsed ultraviolet (UV) light treatment to make free from *Listeria monocytogenes* and *Escherichia coli* O157:H7 contamination. A four-lamp batch scale apparatus which generated 3 Joule/cm^2 with an input voltage of 3000 Volts was used.

Pulsed light field technology in combination with other non-thermal processing technologies

Pulsed light technology in combination with other non-thermal processing technologies was experimented on a blend of apple and cranberry juice and the efficacy of the combination of technologies was determined on the basis of quality attributes such as odour and flavour. The various non-thermal technologies to be combined with were, high intensity pulsed light (3.3 Joule/cm^2), ultra-violet light (5.3 Joule/cm^2), manothermosonication (5 bar, 43°C, 750-Watt, 20 kilohertz), and pulsed electric field processing (34 kilovolt/cm, 18 Hertz, 93 microsecond) as literature review says.

Mitigation of allergen using pulsed ultraviolet light

Peanut allergy is a severe Immunoglobin E mediated reaction with food. Peanut allergy can be prevented by complete avoidance. Pulsed ultraviolet light treatment of soy extracts is found to decrease the levels of soy allergens (glycinin, β-conglycinin), Gram-negative bacteria, Gram-positive bacteria, and fungal spores. The colour of the spores can play a significant role in fungal spore susceptibility. Due to the presence of pigment in UV protecting *Aspergillus niger* spores absorbing more in the UV-C region than that of *F. culmorum* spores, *A. niger* spores are more resistant than *Fusarium culmorum* spores [24].

Effects on Solid foods

For complex surfaces, such as those of foods like meat and fish, it will be difficult to illuminate or reach all parts of the surface to obtain a sterilising effect [25]. The type of equipment for food preservation depends on some factors such as ozone build-up, surface area of food product and dimensions of each treatment unit and desired degree of decontamination. A cooling unit facility maybe required in the case of a food under treatment which is temperature sensitive [26].

Effects on liquid foods

Bhavya and Umesh Hebbar, [27] and Caminiti *et al*. [28] reported the effect of PL treatment on microbial inactivation in liquid foods such as milk, apple juice, apple cider, orange juice, sugar syrup and infant food. Microorganisms such as *S. aureus, E. coli, L. innocua,* and *S. thyphimurium; E. coli* (ATCC 25922), *E. coli* O157:H7, and *L. innocua; E. coli* (ATCC 25922) and *E. coli* O157:H7; *E. coli, and L. innocua; B. subtilis spores, S. cerevisiae, G. stearothermophilus spores, A. acidoterrestris spores, and A. niger;* and *L. monocytogenes* respectively were reported to be significantly reduced in their log count due to inactivation by Pulsed Light Technology [27, 28].

Pulsed Light treatment for fishes

Bhavya and Umesh Hebbar, [27] reported the effect of PL treatment on microbial inactivation in fishes such as Tuna (against *V. parahaemolyticus* and *L. monocytogenes*), various fishery products (against *P. phosphoreum, S. liquefaciens, S. putrefaciens, B. thermosphacta, Pseudomonas,* and *L. innocua*), shrimp fillets, Salmon fillets and Flatfish fillets (against *L. monocytogenes*) respectively [27].

Advantages of pulsed light system

Unavailability of continuous mercury UV light hampers the complete destruction of DNA, process speed, penetration ability, low product temperature, personnel safety and process flexibility which can be overcome by application of Pulsed UV light. Pulsed UV light offers faster processing, little or no product temperature build up, process flexibility, freedom from toxic lamp materials, penetration of plastic packages, and ease of meeting special lamp configuration requirements. Sanitization and sterilization by Pulsed UV light technology are practised during total DNA destruction, low heat, and penetration. The high intensity light lasts for a second, although 20,000 times brighter than sunlight is devoid of thermal manifestation that leads to retention of food macromolecules nutritional quality without denaturation [29]. The most important reasons for considering Pulsed UV light systems for sanitization are, total DNA destruction, safety, in-line production, temperature integrity, process effectiveness, process speed, process flexibility, free of toxic substances, worker-friendly technology (safe and easy to use). Pulsed UV light technology are associated to the above features due to very high peak power; instant on/off capability (no warm-up required); controlled and narrow pulses; less inherent heat; and special lamp configurations without mercury.

Disadvantages of PL system

•The possibility of shadowing occurs when microorganisms readily absorb the rays, as in the case of *A. niger*, and are present one upon another. This makes the organisms in the lower layers very hard to destroy in contrast to those in the upper layer [30], although the use of relatively high peak powers can overcome the shadowing effect.

•For a PL treatment to inactivate microorganisms, contact between photons and microorganisms should occur. Therefore, anybody between the light source and the microorganism that absorbs light will impair the disinfection process.

•Inactivation will be less, when the food item is opaquer and thicker.

•PL is safe to apply but some precautions have to be taken to avoid exposure of the workers to the light and to evacuate the ozone, generated by the shorter UV wavelengths.

Conclusion

The Pulsed Light Processing is a new concept and has many applications in the food industry as a non-thermal technique of food preservation. While developing the applications of pulsed light processing, the food to be processed, the microbial type and load affect, the efficacy of the treatment should be taken into consideration. For commercial preservation as well, more research is required to determine the extent of microbial sterilization, to quantify the ability to increase the shelf life by correlating the texture profile parameters with microbiological, biochemical and sensory evaluation of food items. Though the process has some limitations, but if complemented with other processing techniques and preservative factors (hurdles), this technology can help in better food preservation with minimal effects on the food quality and achieve food safety. Using an adequate mix of hurdles is not only economically attractive; it also serves to improve microbial stability and safety, as well as the sensory and nutritional qualities of a food, which are required to be duly investigated. There are some microbial species resistant to the pulsed light processing technique and so such species should be studied and also the foods contaminated by them should be considered separately for processing.

This technique has showed potential in reducing peanut allergy. It can be further studied for its application in reducing other allergies associated with food. This technique being still new and hardly commercialized, should be researched for economization. Thus, the huge possibilities of Pulsed Light Processing Technology to be a potential non-thermal food preservation method and its global commercial application must be necessarily explored in near future.

Application of research

Pulsed light (PL), an alternative to continuous ultraviolet light treatments for both solid and liquid foods, is an emerging non-thermal technology for preservation of food surfaces and food packages, consisting of short time high-peak pulses of broad-spectrum white light, thus, food quality is ensured. Due to perishable nature of fish and fishery products, they are prone to spoilage by food spoilage microorganism and potential human pathogens, which can alternatively be delayed by microbial inactivation with PL treatments on food, thus increasing the shelf life.

Research Category: Pulsed light food preservation technology

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