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Intense Pulse Light in Food Technology-A Review

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***Abstract:** This Review Article deals with the principle, working of Pulse Light system, its mechanism of action in inactivation of microorganisms, its applications in food processing and preservation, factor affecting its effectiveness, its nutritional and toxicological aspects; and the research needed in this area for its complete and diversified application.*
***Keywords:** PLC, Pulse Light, Voltage, Contamination, Toxicological, inactivation.*

I. INTRODUCTION

The technique of pulsed light food processing was developed as a non-thermal food processing technique, that involves discharge of high voltage electric pulses (upto 70 Kilovolt/cm) into the food product placed between two electrodes for few seconds (Angersbach et al., 2000). It is one of the emerging technologies which are used for the replacement of traditional thermal pasteurization among non thermal processes (Heinz et al., 2002). It is a decontamination technique which aims at reducing the pests, spoilage microorganisms and pathogens from food without much effect on its quality (Bank et al., 1990). It is recognized by several names in scientific literature i.e., Pulsed ultraviolet light (Sharma and Demirci, 2003), high intensity broad-spectrum pulsed light (Roberts and Hope, 2003), Pulsed light (Rowan et al., 1999) and pulsed white light (Marquenie et al., 2003). The pulsed light processing can be described as a sterilization or decontamination technique used mainly to inactivate surface micro-organisms on foods, packaging material and equipments. This technique uses light energy in concentrated form and exposes the substrate to intense short bursts of light (pulses). Typically for food processing about one to twenty flashes per second are applied. Ultraviolet light, broad spectrum white light and near infrared light can be used for pulsed light processing (Green et al., 2005). Ultraviolet-C treatment for preserving food was discovered in 1930s (Artes and Allende, 2005).

A. Principle

It is the non thermal method of food preservation that involves the generation of pulsed light with gradually increasing from low to high energy and then releasing the highly concentrated energy as broad spectrum bursts, to ensure microbial decontamination on the surface of foods and packaging foods. Within fraction of second, the electromagnetic energy gets stored in the capacitor and is then released in the form of light within a billionth of a second, which results in power amplification and minimum additional energy consumption (Green et al., 2005). The inactivation efficiacy of pulsed light depends upon intensity (measured in Joule/cm-2) and the number of pulses delivered. The flow chart of pulsed electric field is shown in Figure 1.

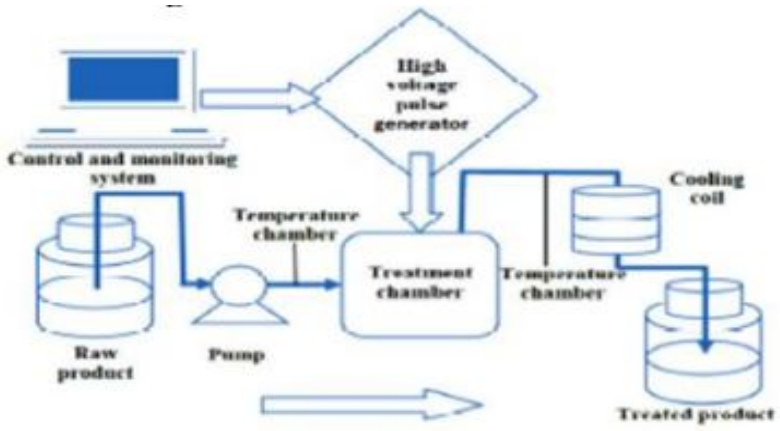


Fig. 1 Flow chart of a PEF food processing system with basic component (Maged *et al.*, 2012)

1) Pulsed light is produced using engineering technologies that multiply power many fold Accumulating electrical energy in an energy storage.
2) capacitor over relatively long times (a fraction of a s) and releasing this storage energy to do work in a much shorter time (millionths or thousandths of a s) magnifies the power applied The result is a very high power during the duty.
3) cycle, with the expenditure of only moderate power consumption (Dunn and others 1995) The pulsed light process developed by PurePulse.
4) Technologies Inc. utilizes flashes of intense broad-spectrum pulsed light (BSPL) to sterilize pharmaceuticals, medical devices, packaging, and water.
5) The system delivers a spectrum 20,000 times more intense than sunlight at the earth's surface The intense flashes of light are less than 1 millisecond in duration (PurePulse Technologies Inc. 1999).
6) A different system using pulsed UV light for microbial control has been patented in the United States with patent pending in Chile (Lagunas-Solar and Pyne 1994)
7) This technology uses monochromatic excimer lamps at a wavelength of 247 nm rather than the xenon flash tubes
8) This technology is in commercial production in Chile and is being used on grapes exported to the United States

Pulsed light (PL) is a technique use to decontaminate surfaces by using short time pulses of an intense broad spectrum, rich in UV-C light. UV-C is the portion of the electromagnetic spectrum corresponding to the band between 200 and 280 nm. Power is magnified by storing electricity in a capacitor over relatively long times (fractions of a second) and releasing it in a short time (millionths or thousandths of a second). The emitted light flash has a high peak power and consists of wavelengths from 200 to 1100 nm (Dunn, Bushnell, Ott, & Clark, 1997; Dunn, Ott, & Clark, 1995).
This technique has received several names in the scientific literature: pulsed UV light (Sharma & Demirci, 2003), high intensity broad-spectrum pulsed light (Roberts & Hope, 2003), pulsed light (Rowan et al., 1999) and pulsed white light (Marquenie, Geeraerd, et al., 2003). According to Wekhof (2000), the first works on disinfection with flash lamps were performed in the late 1970s in Japan, and the first patent dates from 1984 (Hiramoto, 1984). Bank, John, Schmehl, and Dracht (1990) seems to be the first work published in the scientific literature on the application of PL to inactivate microorganisms. The technique of UV-C treatment to preserve foods was discovered in the 1930s (Arte´s & Allende, 2005). PL is a modified and claimed improved version of delivering UV-C to bodies.
The classical UV-C treatment works in a continuous mode, called 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 (Bintsis, Litopoulou-Tzanetaki, & Robinson, 2000). More recently, Medium-pressure UV lamps which emit a polychromatic output, including germicidal wavelengths from 200 to 300 nm (Bolton & Linden, 2003) because of their much higher germicidal UV power per unit length. Another possibility for UV-C treatments is the use of excimer lasers, which can emit pulsed light at 248 nm (Crisosto, Seguel, & Michailides, 1998). The following units are commonly used to characterize a PL treatment.

a) Fluence rate: is measured in Watt/meter2 (W/m2) and is the energy received from the lamp by the sample per unit area per second.
b) Fluence: is measured in Joule/meter2 (J/m2) and is the energy received from the lamp by the sample per unit area during the treatment.
c) Dose: used sometimes as a synonym of fluence. Exposure
d) time: length in time (seconds) of the treatment. Pulse width: time interval (fractions of seconds) during which energy is delivered.
e) Pulse-repetition-rate (prr): number of pulses per second (Hertz [Hz]) or commonly expressed as pps (pulses per second).
f) Peak power: is measured in Watt (W) and is pulse energy divided by the pulse duration.

Formal definitions can be found in IUPAC (1996). Proper determination of the fluence received by the treated body is the most important factor in characterizing a PL treatment; however, it is sometimes neglected or improperly reported. The same problem also exists in the literature on CW UV treatments (Bolton & Linden, 2003; Hijnen, Beerendonk, & Medema, 2006). Fluence determination can be complex, requiring a good knowledge of light properties. Recommendations on fluence determinations for future research can be found in Bolton and Linden (2003), Jin, Mofidi, and Linden (2006), and Ryer (1997).

B. Pulsed Light Devices

The pioneer company producing PL equipment for disinfection was Purepulse Technologies Inc. (San Diego, California), a subsidiary of Xenon Corp., which commercialized the PureBright system. Applications included water purification systems and virus inactivation systems for biopharmaceutical manufacturers. References by Dunn et al. (1995, 1997) correspond to the early efforts of this company, which is no longer active, to promote this novel technology. A brief history of the evolution of the pioneer companies related to PL can be found in Wekhof (2000).

As far as we know, there are nowadays two commercial companies producing disinfection systems based on PL. One is SteriBeam Systems from Germany, the other is Xenon Corporation from USA. References by Kaack and Lyager (2007), Wekhof (2000), and Wekhof et al. (2001) are associated with SteriBeam, while results reported by Demirci (Hillegas & Demirci, 2003; Jun et al., 2003; Krishnamurthy et al., 2004; Ozer & Demirci, 2006; Sharma & Demirci, 2003) were obtained with a Xenon Corp. device, mainly the model SteriPulse -XL 3000. Information regarding devices for industrial applications can be found at the websites of these companies. The basic benchtop equipment for laboratory studies is composed of a treatment chamber and a control module (Fig. 2). The treatment chamber is built of stainless steel. It has a shelf to hold the samples (microorganisms on agar in Petri dishes, or food samples), which can be displaced vertically, allowing to regulate the distance between the target and light source. The light source is a linear Xenon flash lamp located at the top centre of the chamber, inside the lamp housing. A basic benchtop equipment was used in the works by Go´mez-Lo´pez et al. (2005a, 2005b), Hillegas and Demirci (2003), Krishnamurthy et al. (2004), Lammertyn, De Ketelaere, Marquenie, Molenberghs, and Nicola€ı (2003), Marquenie, Geeraerd, et al. (2003), Marquenie, Michiels, Van Impe, Schrevens, and Nicola (2003), Ozer and Demirci (2006), Sharma and Demirci (2003), Takeshita et al. (2003) and Wuytack et al. (2003) Experimental units used by Jun et al. (2003) and Kaack and Lyager (2007) were equipped with two lamps, and that used by Jun et al. (2003) had also a blower. By using a blower, a filtered air stream can flow around the lamp serving two functions: dissipating the heat generated by the lamp, and avoiding the accumulation of high levels of toxic ozone produced by the shortest wavelengths. Anderson et al. (2000), MacGregor et al. (1998), and Rowan et al. (1999) used a benchtop experimental facility where two inoculated Petri dishes inclined 450 received equivalent doses. Experimental units with more complicated configurations have also been used. Fine and Gervais (2004) used a fluidized bed to mix powders and to increase particle exposure, and Huffman, Slifko, Salisbury, and Rose (2000) plumbed three PureBright units to treat water continuously. Most of the cited references provide schematic representations of the experimental units.

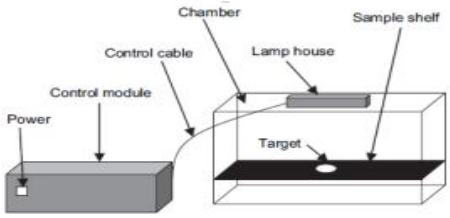


Fig. 2 Schematic representation of a bench top experimental unit of pulse light

A control cable connects the light source with the control module, in which the electric current is modulated to produce a specific prr, pulse width and peak power. The control module has a switch to start the flashing period and a timer to control the exposure time. High peak power is produced by pulse power energization techniques. Information related to this kind of technique can be found in Anderson et al. (2000), Ghasemi, Macgregor, Anderson, and Lamont (2003) and Hancock et al. (2004).

II. MECHANISM OF MICROBIAL INACTIVATION

The lethality of Pulsed Light may be attributed to its rich broad spectrum ultraviolet content, its short duration, high peak power and the ability to regulate the pulse duration and frequency output of flash lamps (Dunn et al., 1995., Takeshita et al., 2003). As a substantial portion of the Pulsed light spectrum covers ultraviolet light, it is considered that ultraviolet plays a vital role in the microbial cell inactivation. It was also found that that there is no killing effect if a filter is used to remove ultraviolet (UV) wavelength region lower than 320 nm (Takeshita et al., 2003). The ultraviolet spectrum comprises of three wave ranges: Long-wave ultraviolet -A (320-400 nm), Medium-wave ultraviolet -B (280-320 nm) and Short wave ultraviolet -C (200-280 nm). Mechanisms that have been proposed to explain the lethality of pulsed light treatment are related to ultraviolet (UV) part of the spectrum which include photochemical and photothermal effect (Anderson et al., 2000; Takeshita et al., 2003; Wuytack et al., 2003).

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However their relative importance depends on the fluence and target microorganism. The primary target cell of pulsed light in photochemical mechanism is nucleic acid as DNA is the target cell for these ultraviolet wavelengths (Chang et al., 1985; Miller et al., 1999). Ultraviolet light absorbed by the conjugated carbon-carbon double bonds in proteins and nucleic acids induces the antimicrobial effect as it changes the DNA and RNA structures.

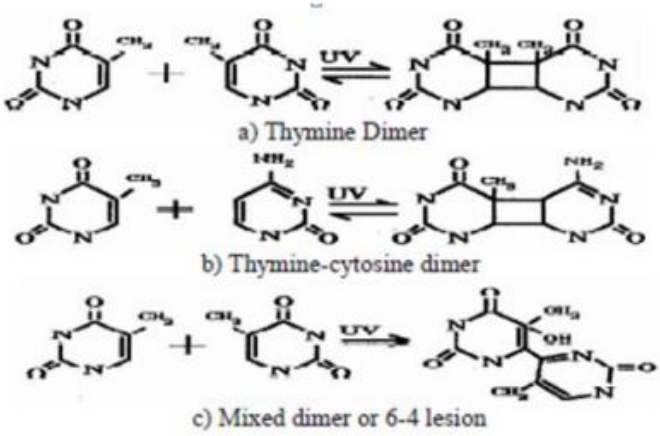


Fig. 3 Formation of Thymine Dimer, Thymine-cytosine dimer and mixed dimer (Setlow *et al*., 1966)

The bactericidal effect is attributed to the high energy short wave ultraviolet-C range. In the ultraviolet-C range of 250-260 nm, alterations in DNA take place due to pyrimidine dimers mainly thymine dimers (Mitchell et al., 1992; Giese and Darby, 2000). Ultraviolet irradiation usually generates thymine dimers in large quantity, cytosine dimers in low quantity and mixed dimers at an intermediate level as shown in Figure 2 (Setlow et al., 1966). These dimers inhibit the formation of new DNA chains in the process of cell replication resulting in the chologenic death of affected microorganisms by ultraviolet (Bolton and Linden, 2003). The ultraviolet-C treatment of bacterial spores may result in the formation of spore photo-product 5-thyminyl-5, 6-dihydrothymine and in single-strand breaks, double-strand breaks and cyclobutane pyrimidine dimers (Slieman and Nicholson, 2000). It was also found by experiments that enzymatic repair of DNA does not occur after damaged by pulsed light. The lethal effect of Pulsed light can also be due to photothermal effect. Wekhof (2000) proposed that with a fluence exceeding 0.5 Joule/cm2, the disinfection is achieved through a rupture of bacteria during their temporary overheating caused by absorption of all ultraviolet light from a flash lamp. This hypothesis become evident by (Wekhof et al., 2001) when they showed electron-microscope photographs of flashed Aspergillus niger spores presenting severe deformation and rupture. The ruptured top of spore become evident of an escape of an overheated content of the spore, which became empty after such an internal ‘‘explosion’’ and ‘‘evacuation’’ of its content took place during the light pulse. Other effects on the cells include, collapse of cell structure, enlargement of vacuoles as found in some microbial studies (Proctor, 2011) as showed by flashed yeast cells. Antimicrobial effects are also manifested due to changes in ion flow, increased cell membrane permeability and depolarization of cell membrane (Ohlsson and Bengtsson, 2002). As Pulsed light causes cell membrane damage, it could be considered as a technique for sterilization (Takeshita et al., 2003, Bialka et al., 2008).

A. Photosensitization

It has been proposed as a milder alternative to the emerging non thermal technologies for food preservation. The combination of photo sensitizer and light, in the presence of oxygen results in the destruction of microorganisms. After the work by McDonald, Curry, Clevenger, Brazos, et al. (2000), it is foreseeable that the definition can be expanded to include the UV part of the spectrum. Haematoporphyrin, sodium chlorophyllin, riboflavin and psoralen are examples of photodynamic active plant food constituents that could be used as photosensitizers for foods (Kreitner et al., 2001). As an example of photosensitization, Kreitner et al. (2001) inactivated as much as 3.9 log CFU/ml of S. aureus cells after incubation for 1 h with haematoporphyrin, followed by illumination for 1 h. To date, its potential application in food preservation has only been tested for the inactivation of bacteria, yeasts (Kreitner et al., 2001), and fungal food contaminants in vitro (Luksˇiene, Pe_ciulyte, Jurkoniene, & Puras, 2005; Luksˇiene, Pe_ciulyte, & Lugauskas, 2004). Therefore, more research is necessary to evaluate its future in food preservation.

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B. Susceptibility of Microorganisms

Anderson, Rowan, MacGregor, Fouracre, and Farish (2000) and Rowan et al. (1999) reported the following trend of susceptibility in decreasing order: Gram-negative bacteria, Gram-positive bacteria and fungal spores. The colour of the spores can play a significant role in fungal spore susceptibility. Aspergillus niger spores are more resistant than Fusarium culmorum spores, which could be because the pigment of the A. niger spores absorbs more in the UV-C region than that of F. culmorum spores, protecting the spore against UV (Anderson et al., 2000). In contrast, Go´mez- Lo´pez, Devlieghere, Bonduelle, and Debevere (2005a) did not observe any sensitivity pattern among different groups of microorganisms, after studying 27 bacterial, yeast and mould species.

C. Inactivation Curve

The shape of the inactivation curve for microbial inactivation by CW UV light is sigmoid. Once the maximum amount of injury has been surpassed, minimal additional UV exposure would be lethal for microorganisms and survivor numbers would rapidly decline (Barbosa-Canovas et al., 2000). The end of the curve has a tailing phase that has received several explanations, which have been summarized by Yaun, Summer, Eifert, and Marcy (2003): lack of homogeneous population, multi-hit phenomena, presence of suspended solids, the use of multiple strains that may vary in their susceptibility to UV-C, varying abilities of cells to repair DNA mutations, and the shading effect that may have been produced by the edge of the Petri dishes used in some experiments. Another possible explanation was given by McDonald, Curry, Clevenger, Brazos, et al. (2000) when explaining the tailing of the inactivation curve of Bacillus subtilis treated with PL: the probability of exposing a biological element to the requisite conditions for lethality is reduced with decreasing population density. Anderson et al. (2000) and MacGregor et al. (1998) reported that the higher the number of pulses the higher the lethal effect. The report by Fine and Gervais (2004) on the viability of S. cerevisiae cells dried on a quartz plate, which suggested a threshold level of energy for total destruction. However, complete inactivation of microorganisms and absence of tailing have also been reported (Krishnamurthy, Demirci, & Irudayaraj, 2004; Otaki et al., 2003; Wang et al., 2005.

D. Peak Power Dependence

It asserts that for the effectiveness of radiation it does not matter whether the fluence is reached with high fluence rate and short exposure time or with low fluence rate and long exposure time. An exception to this principle has been found for CW UV light treatment (Sommer et al., 1996). According to McDonald, Curry, and Hancock (2002) several theories predict a more rapid kill of vegetative cells with PL. Rice and Ewell (2001) examined the peak power dependence in the UV inactivation of bacterial spores by comparing the output of a high-peak-power UV source at 248 nm from an excimer laser to a low-power CW UV source (254 nm) used to inactivate B. subtilis spores. It appears that the total number of photons delivered is the important parameter and not the number of photons delivered per unit time (peak power). The results agree with the principle of BunseneRoscoe. Results reported by Takeshita et al. (2003), also supported a violation of the principle of BunseneRoscoe. The authors compared the effect of peak power on S. cerevisiae cells, using 4655 and 2473 kW. Their results revealed that under high-peak-power conditions, the killing effect and concentration of eluted protein were higher than under low-peak-power conditions. Furthermore, the photothermal effect is not in agreement with the BunseneRoscoe law. It seems that under certain extreme conditions, PL causes different kinds of damage than CW UV.

E. Photoreactivation

Photoreactivation means the reversal of ultraviolet damage in bacteria by illumination with visible light (Cleaver, 2003). It is a well known phenomenon in the CW UV treatment field. It is catalysed by the enzyme photolyase, which uses light energy to split UV-induced cyclobutane dimers in damaged DNA through a radical mechanism. ‘‘Photolyase is a flavoprotein and contains two noncovalently bound chromophores. One chromophore is the fully reduced flavin- adenine dinucleotide (FADH_), the catalytic cofactor that carries out the repair function upon excitation by either direct photon absorption or resonance energy transfer from the second chromophore (methenyltetrahydrofolate or deazaflavin) that harvests sunlight and enhances the repair efficiency. The excited flavin cofactor transfers an electron to the cyclobutane pyrimidine dimer to generate a charge separated radical pair. The anionic ring of the dimer is split, and the excess electron returns to the flavin radical to restore the catalytically competent FADH form and close the catalytic photocycle’’ (Kao, Saxena, Wang, Sancar, & Zhong, 2005).

Photoreactivation after a PL treatment, being the photoreactivation rate slower than after a CW UV treatment. The photoreactivation suppression was assumed to have been due to the difference in wavelength. Evidence of photoreactivation in flashed cells has also been given by Go´mez-Lo´pez et al. (2005a). However, future research is needed to better quantify this phenomenon.

There are two other repair mechanisms for UV damage that might reactivate PL treated cells, One is the dark repair mechanism, which does not require light as photoreactivation does; The other is specifically related to spores. Spores can repair themselves from the spore photoproduct by the common excision repair system, or the spore photoproduct specific repair system (Setlow, 1992).

III.FACTORS DETERMINING THE EFFICACY OF A PL TREATMENT

The most important factor determining the effect of PL is the fluence incident on the sample. The energy emitted by the flash lamp is different from the energy incident on the sample. The inactivation efficacy of PL is higher when treated samples are closer to the lamp (Hillegas & Demirci, 2003; Ozer & Demirci, 2006). An equation to describe the effect of distance taking into account both the photochemical and the photothermal effects was described by Go´mez- Lo´pez et al. (2005a). The effect of distance was modeled by Sharma and Demirci (2003) for inactivation of E. coli O157:H7 on inoculated alfalfa seeds, and by Jun et al. (2003) for A. niger spores in corn meal. The effect of the placement of samples at other positions inside the treatment chamber was studied by Go´mez-Lo´pez et al. (2005a). The authors demonstrated that when a group of samples is placed at a short vertical distance from the lamp, those located directly below the lamp will be decontaminated while the rest will undergo almost no decontamination. When the vertical distance is increased, the decontamination will be less intense in those samples located directly below the lamp but the rest of the samples will be also decontaminated. Sample thickness is another limiting factor for microbial inactivation with PL. Due to the restricted penetrability of the UV light, overlapping opaque samples shield surfaces from decontamination and also light is attenuated during the treatment of fluid samples. That was observed by Sharma and Demirci (2003) for alfalfa seeds and by Hillegas and Demirci (2003) for honey. The decontamination efficacy decreases at high contamination levels, which is also related to light attenuation. At high population densities, microorganisms overlap each other. Therefore, microorganisms placed in the upper layers will become inactivated, but will shadow the rest from the light (Go´mez-Lo´pez et al., 2005a). Food composition also affects the efficacy of the decontamination by PL. Go´mez-Lo´pez et al. (2005b) treated Photobacterium phosphoreum, L. monocytogenes and Candida lambica inoculated onto surfaces of agars supplemented with several food components. The results demonstrated that proteins and oil decreased the decontaminant efficacy of PL, whereas when water or starch was added to the agar, no particular trends were observed. Roberts and Hope (2003) also found that the addition of protein to a buffered saline solution decreased the efficacy of virus inactivation. Therefore, high protein and fat containing food products have little potential to be efficiently treated by PL. Vegetables, on the other hand, could therefore be suitable for PL treatment. With regard to the long term applicability of PL, the possible development of resistant strains should be taken into account. However, Marquenie, Geeraerd, et al. (2003) observed no development of resistance in fungi. This was also found by Go´mez-Lo´pez et al. (2005a) in the case of L. monocytogenes.

A. *Critical Process Factors*

1) Light characteristics (wavelength, intensity, duration and number of the pulses)
2) packaging and food attributes (type, color and transparency)
3) For fluid food, transparency and depth of the fluid column become critical factor
4) The lethality of the pulsed light increases with increasing light intensity or fluence (PurePulse Technologies Inc. 1999)
5) Formulation of a model for dose-response is not currently possible

B. *Factors Affecting The Microbial Inactivation By Pulsed Light*

1) Type of micro-organism Optical properties of cells, for example their degree of scattering and absorption of light are important. The incident beam of light undergoes refraction due to difference in the optical density between the substrate and the surrounding air. There are also some micro-organisms resistant to pulsed light (Ethan, 2009; Rajkovic est al., 2010; Manzocco et al., 2011; Uysal and Kirca, 2011).
2) Interaction between light and the substrate or between light and the microbial cells (micro-organism) This factor is very important from the point of view of the efficacy of the pulsed light treatment. The composition of the medium and the wavelength of the incident light decide the reflection, refraction, scattering and absorbing of the light, the refraction and reflection of light being vital for surface treatments. For transparent and coloured food materials, refraction is particularly relevant, whereas for opaque food materials, reflection is the prevailing phenomenon. Specular or diffused reflection can occur depending on the smoothness or roughness of the surface of the material respectively. For smooth surfaces, the incident light bounces on the surface and comes out at the same angle as the incident beam, with the same spectral distribution of energy, which is termed as specular reflection. For rough surfaces, light travels through the outer layers of the material, where the incident light is partly absorbed, this phenomenon is called diffuse reflection. The absorption at different wavelengths is

different and hence the resulting spectral distribution of incident and the diffused light coming out is in all directions (Duran and Calvo, 2002), and reflection of light can tend to decrease the efficiency of the pulsed light treatment. For translucent materials, some part of the incident light interacts with the internal structures and causes multiple internal reflections, redirections which result into scattering. In the case of biological tissues, absorption and scattering are the most relevant types of light–substrate interaction (Cheong et al., 1990).

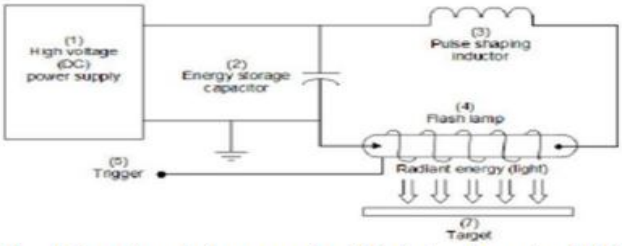


Fig. 4 Functional diagram of a high-intensity pulsed-light system. (Adapted from Xenon Crop., 2005)

3) The distance from the light source As the distance from light source and depth of the substrate increases, the absorption and scattering diminishes. This is because the light intensity decreases as it travels through the substrate. The quantitatively distribution of light dose inside a substrate is described by the term Optical penetration depth, which represents the distance over which light decreases in fluence rate to 37% of its initial value. The optical penetration varies with wavelength, with shorter wavelengths providing deeper penetration into the food than longer wavelengths (Dagerskog and Osterstrom, 1979).

4) Design of pulsed light system Pulsed-light equipment may vary from manufacturer to manufacturer. The system of pulsed light consists of several common components as shown in Figure (4)

a) *A High Voltage Power Supply:* Provides electrical power to the storage capacitor.

b) *A Storage Capacitor:* Which stores electrical energy for the flash lamp.

c) *A pulse-forming Network:* Determines the pulse shape and spectrum characteristics.

d) The gas discharge flash lamp.

e) *A Trigger Signal:* Which initiates discharging of the electrical energy to the flash lamp, which is the key element of a pulsed light unit.

The flash lamp is the important element of any Pulsed light unit that converts 45% to 50% of the input electrical energy to pulsed radiant energy (Xenon Corp., 2005). This is filled with an inert gas such as xenon or krypton. Xenon is mostly preferred because of its higher conversion efficiency and also because it is a gas of choice for most of the microbial inactivation applications. The envelope, the seals and the electrodes are the main structural components of the flash lamp, the envelope being a jacket that contains the filling gas and also surrounds the electrodes.

Figure 4. Functional diagram of a high intensity pulsed-light system. (Adapted from Xenon Corp., 2005) to the radiations that are emitted by the lamp, be impervious to the filling gas as well as air, must be able to withstand high temperatures and thermal shocks and have mechanical strength. Metallic electrodes protrude into each end of the envelope and are connected to the capacitor which 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 is hence an important component. The operational requirements decide the material of making of the electrode. The duty of the cathode is to provide unsputtered and adequate amount 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 by the electrons travelling towards it. A very large current pulse formation occurs and this is sent through the ionized gas, exciting the electrons surrounding the gas atoms, causing them to jump to higher energy levels. The electrons while jumping back to their lower energy levels, release quanta of energy 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. Adjustable one or more flash lamp units, a power unit and a high voltage connection that allows a high electric pulse transfer are used to produce the pulsed light.

The current passing through the gas chamber of the flash lamp unit emits a short intense burst of light. The high current discharge through gas filled flashlights results in millisecond flashes of broad spectrum white light, about 20,000 times more intense than sunlight. Conversion efficiency of electricity to light is about 50%. The spectral distribution is 25% ultraviolet, 45% visible light and 30% infrared. The rate of flashes is 1-20 flashes/sec, a few flashes being generally sufficient for the pasteurizing or sterilizing treatment. This means that the treatment time is very short and throughput is high. Most plastic packaging materials transmit broadband light well, exceptions being Polyethylene terephthalate (PET), polycarbonate, polystyrene and polyvinyl chloride (PVC). 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 (Ohlsson and Bengtsson, 2002). 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 is temperature sensitive (Green et al., 2005). Pulsed light systems can be of either batch or continuous type depending on the usage. In the case of batch processing, such as those developed by Xenon Corp. (Waltham, MA), the packets are placed in a chamber with lamps located along the walls of the chamber. The simplest designs include a single lamp located above the sample and an adjustable tray to hold the samples. More complex designs may incorporate up to eight lamps within a chamber along with a quartz stand to hold the sample and allow a 360^{o} exposure and treatment. In the case of continuous processing, the packaged or unpacked products are placed on conveyor belts, on spool bars and in tunnels and then passed through chamber with lamps (Proctor, 2011). An in-line treatment system is possible with such an assembly. Experiments with continuous pulsed light have been performed. These were for milk decontamination (Krishnamurthy et al., 2007) and for various fruit juices (Palgan et al., 2011; Pataro et al., 2011). For all existing pulsed-light systems, a control system is used to automate the process and control the rate of pulsing. Optical sensors can be installed to record the output of the entire unit.

IV. APPLICATIONS

1) *Pulsed Light Treatment:* Given to eggs for surface decontamination Eggs and egg-based products were frequently associated with salmonellosis outbreaks caused by *Salmonella Enteritidis* in the United States of America (U.S.A.), as well as in the European Union (E.U.) (Braden, 2006; EFSA, 2007). This is a potential consequence of the high frequency at which *Salmonella Enteritidis* colonizes the ovaries of laying hens (Gantois et al., 2008) Eggs were treated with pulsed light of flashes of 2.1 Joule/cm2 and 10.5 Joule/cm2. Exposure to 2.1 Joule/cm2 leads to death of Salmonella cells (5 log colony-forming units (CFU) per egg shell) on the egg surface with slight increase in temperature. Increase to 10.5 Joule/cm2 did not cause penetration of Salmonella cells to the egg contents from the shell. No adverse effect on quality of egg albumin was observed. No effect on sensory and functional properties (Lasagabster et al., 2011). Another study for inactivation of *Salmonella enteritidis* different results were obtained based on the state of the cuticle. In case of unwashed eggs, the highest decontamination of 3.6 log colony-forming units (CFU)/egg was observed and for washed eggs, highest decontamination of 1.8 log colony forming units (CFU)/egg was observed. The integrity of the cuticle is maintained and hence this technique could be used in egg processing (Hierro et al., 2009).
2) *Shelf-life Extension and Inactivation:* of *Listeria monocytogenes* on ready to eat cooked meat products using pulsed light *Listeria monocytogenes* is responsible for severe foodborne disease outbreak. Processed meats are well documented to be a potential vehicle for human listeriosis. Vacuum packaged ham and bologna slices were artificially inoculated with Listeria monocytogenes and then treated with pulsed light with fluences of 0.7, 2.1, 4.2 and 8.4 Joule/cm2. It was found to reduce the microbial load of ham by 1.78 colony-forming units (CFU)/cm2 and of bologna slices by 1.11 colony-forming units (CFU)/cm2 (Hierro et al., 2011). The lower inactivation obtained on bologna could be explained by the distinct microstructural features of both products. It is well known that the surface topography greatly influences the efficacy of pulsed light treatment (Woodling and Moraru, 2005). It tripled the shelf-life of ham as compared to conventional ready-to-eat (RTE) products. 2.1 Joule/cm2 adversely affected the sensory quality of bologna slices (Hierro et al., 2011).
3) *Pulsed Light Treatment for Decontamination*: of chicken from food pathogens High-power pulsed light of 1,000 pulses, treatment duration 200 seconds and total ultraviolet light dose 5.4 Joule/cm2 was found to reduce viability of *Salmonella typhimurium* and *Listeria monocytogenes* inoculated on the surface of chicken by 2-2.4 log10 (N/N_0) colony forming units (CFU)/ml (Paskeviciute et al., 2011). Also, the total aerobic mesophiles on the surface of meat were diminished by 2 log10 (N/N_0) colony-forming units (CFU)/milliliter. Nonthermal conditions were maintained throughout t ($<42^{o}C$). The intensity of lipid peroxidation in control and treated chicken samples differed in 0.16 milligram (mg) malondialdehyde per kilogram of chicken meat. Organoleptic properties of treated chicken did not detect any changes of raw chicken, chicken broth or cooked chicken meat when it was treated under nonthermal conditions in comparison with control (Paskeviciute et al., 2011).

4) *Pulsed Light Treatment:* For freshly cut mushroom Pulsed light treatment for freshly cut mushroom Fresh slices of mushrooms were exposed to pulsed light treatment by flashing at 4.8, 12 and 28 Joules/cm2 and it was found to increase the shelf life by 2-3 days in comparison to untreated samples. The native microflora reduction ranged from 0.6-2.2 log after 15 days of refrigeration. 12 and 28 Joule/cm-2 treatment affected the texture due to thermal damage by treatment. It induced enzymatic browning due to increase in polyphenoloxidase activity. Some phenolic compounds and vitamin C content were found to be reduced. But 4.8 Joule/cm2 increased shelf-life without affecting the texture and antioxidant properties (Oms-Oliu et al., 2010).
5) *Continuous flow Pulsed Light System:* For bacterial inactivation in fruit juices and milk Apple juice (pH of 3.49) and orange juice (pH of 3.78) were inoculated with gram positive (Listeria innocua 11288) and gram negative (Escherichia coli DH5-α) bacteria. These were then subjected to continuous pulsed light system. It was concluded that the lethal effect of pulsed light processing depends on the type of microorganism and the absorption properties of the liquid food. With treatment of 4 Joule/cm2, the microbial load reductions in apple and orange juices for *Escherichia coli* were 4.00 and 2.90 Log-cycle respectively and for Listeria innocua were 2.98 and 0.93 Log-cycles respectively (Pataro et al., 2011). Continuous flow pulsed light technique was also used for inactivation of *Staphylococcus aureus* in milk and has a potential in treatment of milk pathogens (Krishnamurthy et al., 2007) carried out measurements of the temperature increase during the pulsed light treatment of milk in a continuous flow system. Milk temperature increased up to 38°C, depending on the residence time as well as the distance of the product from the light source. This temperature increase caused a fouling effect as well as possible changes in milk quality.
6) *Decontamination of food Powders:* Using pulsed ultraviolet (UV) light Food powders were decontaminated using pulsed ultraviolet (UV) light and the treatment parameters were optimized. 58 Joule/cm2 of pulsed light was required for *Saccharomyces cerevisiae* decontamination and reducing the microbial load by 7 log. It was found that the thermal effect rather than the Ultraviolet (UV) effect of pulsed light worked for decontamination of coloured powders (Fine and Gervais, 2004).
7) *Decontamination of Packaging Material:* Paper-polyethylene was artificially inoculated with spores such as Cladosporium herbarum, Aspergillus niger, Aspergillus repens and Aspergillus cinnamomeus and then exposed to pulsed light with fluence ranging from 0.244 to 0.977 Joule/cm2. The highest level of inactivation of 2.7 log reduction was achieved. The colour of the spores affected their resistance to pulsed light. Different spores required different fluences for their inactivation (Turtoi and Nicolau, 2007).
8) *Application on Food Processing Equipment Pulsed Ultraviolet (UV):* Light treatment was studied for its applicability in decontamination of the stainless steel surface contacting meat from *Listeria monocytogenes and Escherichia coli* O157:H7. The study was performed on stainless steel slicing knife. The type of meat product in contact with the treatment surface and the time between contamination and intense pulse treatment decide the effectiveness of the microbial inactivation. When the knife surface was in contact with meat product containing lower fat and protein content and the time between contamination and treatment was 60 seconds, highest effectiveness of inactivation of 6.5 log colony forming units (CFU)/side of knife was achieved. It was also observed that even though the number of flashes was increased to compensate for the extended time between contamination and treatment, the lost effectiveness of microbial inactivation could not be restored (Rajkovic et al., 2010).
9) *Effects of PL on Foods of Vegetable Origin:* The inactivation of microorganisms naturally present on vegetable surfaces by PL has been demonstrated by Hoornstra, de Jong, and Notermans (2002). The authors treated five vegetables, namely white cabbage, leek, paprika, carrots and kale with two pulses of wide spectrum PL that amounted to a fluence of 0.30 J/cm2. The reduction in aerobic count at the surface of the vegetables varied from 1.6 log CFU/cm2 for carrots to >2.6 log CFU/cm2 for paprika. No significant increase in the inactivation was observed after using a third pulse. Moreover, no adverse effects on sensorial quality were observed after treating the vegetables with three pulses and storage at 7 and 20 ^{0}C for up to 7 days with one exception, iceberg lettuce showed some discoloration after 48 h at a storage temperature of 20 ^{0}C. Their own calculations demonstrated that a reduction of 2 log CFU/cm2 increases the shelf-life at 7 ^{0}C of cut vegetables by about 4 days, which is remarkable given a treatment of only 0.4 ms effective duration. The efficacy of PL to inactivate vegetable spoilage microflora was again proved afterwards. Mesophilic aerobic counts were reduced between 0.56 and 2.04 log CFU/g after treating with more than 2000 pulses several minimally processed vegetables (spinach, radicchio, lettuce, cabbage, carrot, green bell pepper) and soybean sprouts (Go´mez- Lo´pez et al., 2005b). Counts of S. cerevisiae cells inoculated onto carrot slices were reduced by more than 4 log CFU/g after 24 pulses. The inactivation of microorganisms present on food surfaces does not necessarily result in an extension of shelf-life. PL treatment failed to prolong the shelf-life of shredded Iceberg lettuce and shredded white cabbage, stored under modified atmosphere packaging at 7 ^{0}C. For Iceberg lettuce, a 0.46 log reduction was achieved in

psychrotroph counts. However, no-flashed and flashed samples were rejected at the third day of storage due to excessively high psychrotroph counts and bad sensory quality. For white cabbage, a 0.54 log reduction was achieved in psychrotroph counts. But after 2 days of storage, no-flashed and flashed samples had the same psychrotroph counts; therefore, the benefit of the decontamination was readily lost (Go´mez-Lo´pez et al., 2005b). It should be mentioned that the failure in shelf-life prolongation does not necessarily imply the inefficacy of PL, but can also be a consequence of the storage conditions. Regarding fruits, Marquenie, Geeraerd, et al. (2003) reported a maximal inactivation of 3 and 4 log units for conidia of B. cinerea and M. fructigena in vitro, which are fungi responsible for important economical losses during postharvest storage and transport of strawberries and sweet cherries. PL however had no effect on strawberries or on the development of B. cinerea inoculated on strawberries. The treatment did not induce resistance against fungal infection (Marquenie, Michiels, et al., 2003). This could be due to insufficient dose or inadequate exposure. PL has also been tested to decontaminate food powders and seeds. Jun et al. (2003) reported a 4.96 log reduction of A. niger spores inoculated in corn meal, but Fine and Gervais (2004) achieved less than 1 log reduction in S. cerevisiae cells inoculated onto wheat flour and black peppers. For seeds, Sharma and Demirci (2003) showed >4 log reduction in E. coli O157:H7 inoculated on alfalfa seeds. The colour of foods can be modified by PL. Fine and Gervais (2004) compared the effects of light pulses on the inactivation of S. cerevisiae on black pepper and wheat flour. Colorimetric results indicated a rapid modification of product colour well before the decontamination threshold was reached and this was clearly more rapid for black pepper than for wheat flour. This colour modification was attributed to overheating combined with oxidation. The difference in colour modification between wheat flour and black peppers was explained by the difference in initial colour, dark products absorb more light energy than pale products. On the other hand, Lammertyn et al. (2003) found that PL treatment did not significantly reduce strawberry sepal quality decay rate during storage for 10 days at 12 ^{0}C. PL can affect the enzymatic activity of flashed vegetables as well as cause physiological changes also observed due to application of CW UV. Since proteins have a strong absorption at about 280 nm (Hollo´sy, 2002), broadspectrum pulsed light could be useful to inactivate enzymes and as such inhibit adverse effects due to enzymatic activity. Dunn et al. (1989) claimed that by using two to five flashes of light at a fluence of 3 J/cm2, it is possible to inhibit potato slice browning. The polyphenol oxidase extract recovered from the treated slices exhibited less activity than that from the untreated slices. PL can also increase the respiration rate of vegetables. Go´mez-Lo´pez et al. (2005b) reported an 80% increase in the respiration rate of shredded Iceberg lettuce, but no significant effects on the respiration rate of shredded white cabbage treated under the same conditions.

10) *Continuous flow Pulsed Light System:* For bacterial inactivation in fruit juices and milk Apple juice (pH of 3.49) and orange juice (pH of 3.78) were inoculated with gram positive (Listeria innocua 11288) and gram negative (Escherichia coli DH5-α) bacteria. These were then subjected to continuous pulsed light system. Xenon-flash lamp emitting light in the range of 100-110 nanometre (nm) and with the flashes at constant frequency of 3 Heartz and lasting for 360 microseconds (μs) was used. It was concluded that the lethal effect of pulsed light processing depends on the type of microorganism and the absorption properties of the liquid food. With treatment of 4 Joule/cm2, the microbial load reductions in apple and orange juices for Escherichia coli were 4.00 and 2.90 Log-cycle respectively and for Listeria innocua were 2.98 and 0.93 Log-cycles respectively (Pataro et al., 2011). Continuous flow pulsed light technique was also used for inactivation of Staphylococcus aureus in milk and has a potential in treatment of milk pathogens (Krishnamurthy et al., 2007) carried out measurements of the temperature increase during the pulsed light treatment of milk in a continuous flow system. Milk temperature increased up to 38°C, depending on the residence time as well as the distance of the product from the light source. This temperature increase caused a fouling effect as well as possible changes in milk quality.
11) *Decontamination of other Foods:* Besides its application on foods of vegetable origin, PL has been tested for efficacy to inactivate microorganisms in a very limited number of other foods. As much as 0.97 log reduction was obtained for spores of Clostridium sporogenes inoculated in honey. When the depth of the honey was decreased the spore kill increased. It appeared that the UV light has a limited penetration in the honey. The heat generated does not appear to have a synergistic effect on the inactivation of C. sporogenes in honey (Hillegas & Demirci, 2003). For E. coli O157:H7, the maximum log reduction was 1.09 on the muscle side and 0.86 on the skin side, while for L. monocytogenes, the maximum log reduction was 0.74 on the muscle side and 1.02 on the skin side. Some fish fillets were overheated at shorter distances and longer treatment times. The higher inactivation on the skin side was attributed by the authors to a higher temperature in comparison with the muscle side. CW UV light has been used for meat treatments, but oxidation reactions (notably of lipids) resulted in significant changes. Other applications are described in the US patent of Dunn et al. (1989), such as disinfection of curds of dry cottage cheese, hard crusted white bread rolls, cake, packaging materials, and shrimps.

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12) *Mitigation of Allergen using Pulsed Ultraviolet Light:* Peanut allergy is a severe Immunoglobin E mediated reactions with food. Peanut allergy can be prevented by complete avoidance. But pulsed ultraviolet light treatment of peanut extracts and peanut butter showed to deactivate Ara h 2, the most potent allergic protein present in peanut. Protein band intensity for Ara h1, Ara h2, Ara h3 reduced at energy levels ranging from 111.6 – 223.2 Joule/cm^2 (Yang et al., 2011). Pulsed ultraviolet light treatment of soy extracts has found to decrease the levels of soy allergens (glycinin, β conglycinin). But clinical data are needed for development of products from such treated soy extracts (Yang et al., 2010).

V. 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 non thermal technologies studied were, ultra-violet light (5.3 Joule/cm2), high intensity pulsed light (3.3 Joule/cm2), pulsed electric field processing (34 kilovolt/cm, 18 Hertz, 93 microsecond) and manothermosonication (5 bar, 43oC, 750 Watt, 20 kilohertz). A blend of apple and cranberry juice in the ratio of 90:10 (volume/volume) was taken and stored at -20oC pre- and post processing. The juice was filtered through 425 micrometre (μm) steel sieve and then processed. The above mentioned processes were paired, their combinations were analysed. A light based technology (ultra violet or high intensity light pulses) in combination with pulsed electric field or manothermosonication was applied. It was concluded that ultraviolet and pulsed electric field combination or high intensity light pulses and pulsed electric field combination was found to maintain product quality better than any combination with manothermosonication under the applied conditions which lead to adverse effects on product quality (Caminiti et al., 2011a). High intensity light pulses in combination with pulsed electric field were used to inactivate Escherichia coli in apple juice. The optimum combination was obtained and sensory analysis was performed as well for quality effects. The optimum combination did not affect the quality (Caminiti et al., 2011b). High intensity light pulses in combination with thermosonication were experimented for inactivation of Escherichia coli in orange juice could be developed as hurdle technology.

VI. ADVANTAGES AND DISADVANTAGES

The intensity of light, that lasts for only a second, is 20,000 times brighter than sunlight, but there is no thermal effect, so quality and nutrient content are retained (Brown, 2008). The xenon-flash lamps used in pulsed light treatment are more eco-friendly than the mercury vapour lamps used in ultraviolet (UV) treatment (Gomez-Lopez et al., 2007). Pulsed white light is not strictly a non-thermal, but the thermal action, due to its very short duration, it doesn't show much adverse effect on the nutrients (Ohlsson and Bengtsson, 2002). A possible problem of this preservation method is that folds or fissures in the food may protect microbes from being exposed to the pulsed light (Brown, 2008). There might be some strains of micro-organisms which are resistant to the pulsed light treatment, for example Listeria monocytogenes (Caminiti et al., 2011a). This technique for decontamination of micro-organisms is useful mostly in case of liquid foods and surface of solid foods and hence limiting its application. The short pulse width and high doses of the pulsed UV source may provide some practical advantages over CW UV sources in those situations where rapid disinfection is required (Wang et al., 2005). For example, Rice and Ewell (2001), in the aforementioned experiment, needed 3 h to deliver 104 J/m2 using a CW UV lamp and 40 s to deliver the same total fluence using a laser with a repetition rate of 10 Hz. Other advantages of PL treatment are the lack of residual compounds, and the absence of applying chemicals that can cause ecological problems and/or are potentially harmful to humans. Xenon flash lamps are also more environment friendly than CW UV lamps because they do not use mercury. Sample heating is perhaps the most important limiting factor of PL for practical applications. Heat can originate Another disadvantage of PL treatments is the possibility of shadowing occurring 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 (Hiramoto, 1984), although the use of relatively high peak powers can overcome the shadowing effect. In order for a PL treatment to inactivate microorganisms, contact between photons and microorganisms should occur. Therefore, any body between the light source and the microorganism that absorbs light will impair the disinfection process. This restriction is different when flashing solid foods, and when flashing fluid foods or microorganism suspensions. For the decontamination of solid foods, the situation can be divided into three cases. The first and most important case is that food components absorb light. Therefore, opaque solid foods can only be decontaminated superficially. The most important implication of this fact is a food safety concern. It has been demonstrated that pathogenic microorganisms can be internalised in produce tissues (Beuchat, 2006). PL cannot inactivate those microorganisms because the light will be absorbed at the surface, and the more opaque and thicker the food item, the lower the inactivation below the surface.

This drawback should not be overestimated since the superficial character of PL treatment is also common with washing solutions such as chlorinated water and its substitutes, applied to decontaminate raw fruits and vegetables. The superficial absorption of light should be regarded in view of how deep the light can penetrate into the food, i.e. the superficial character of the PL decontamination process should not be considered limited to an infinitesimal superficial layer of the food because some degree of inactivation can occur below it.

Although it has been claimed that PL has a big penetration power, independent experiments have not been reported. The second case is that the entire surface of the food piece should be flashed in order to achieve the decontamination of its whole surface, where irregularities of the food surface complicate the achievement of the goal. case is that food pieces can shadow each other when treated together. Both cases require engineering solutions that need sometimes equipment with radically new designs (Gardner & Shama, 2000).

Regarding fluid foods and microorganism suspensions, the liquid will absorb light depending on its absorption coefficient and depth. The challenge consists in promoting the flow of the fluid in an adequate way to drive microorganisms close to the light source in order to achieve a uniform exposure.

Coping with this problem also requires engineering solutions, and a possibility has been offered by Forney, Pierson, and Giorges (2005) for CW UV applications. PL is safe to apply but some precautions have to be taken to avoid exposure of workers to light and to evacuate the ozone generated by the shorter UV wavelengths.

VII. NUTRITIONAL AND TOXICOLOGICAL ASPECTS

Neither the effect of PL on nutritional components of vegetables nor the potential formation of toxic by-products has been studied yet. Since the wavelengths used for PL are too long to cause ionisation of small molecules and are in the non-ionising portion of the electromagnetic spectrum (Dunn et al., 1995), the formation of radioactive by products is not expected. PL treatment of foods has been approved by the FDA (1996) under the code 21CFR179.41. According to Dunn et al. (1997), in assessing the safety of foods treated with all forms of radiation, the agency considers changes in chemical composition of the food that may be induced by the proposed treatment, including any potential changes in nutrient levels. The legal status of PL in the European Union has a different approach, since the legislation is not technology oriented but food and food ingredient oriented. This technology would fall in the scope of regulation 258/97 on novel foods and novel food ingredients, article 1, item f (European Union, 1997). Among other categories, this legislation applies to foods and food ingredients to which a production process not currently used has been applied, and evaluates possible changes in nutritional value, metabolism and level of undesirable substances. The EU therefore would not approve PL technology as such, but specific foods and food ingredients treated with PL. It has been proved that CW UV treatment can increase the concentration of phytochemicals in fruits. Cantos, Espı´n, and Toma´s-Barbera´n (2001) found that UV treatment can increase by more than 10-fold the levels of resveratrol in grapes. Given the similarities between both techniques, PL might also have the same effect.

VIII. RESEARCH NEEDS

A. Identification of critical process factors and their effect on microbial inactivation.
B. Suitability of the technology for solid foods and non clear liquids where penetration depth is critical.
C. Potential formation of unpalatable and toxic by products.
D. Resistance of common pathogens or surrogate organisms to pulsed light treatments. Differences between this technology and that of the more conventional UV (254 nm) light treatment.
E. Mechanisms of microbial inactivation to determine whether they are significantly different from those proposed for UV light.
F. Understanding of the mechanism and quantification of the benefit attributed to the pulse effect

IX. CONCLUSIONS

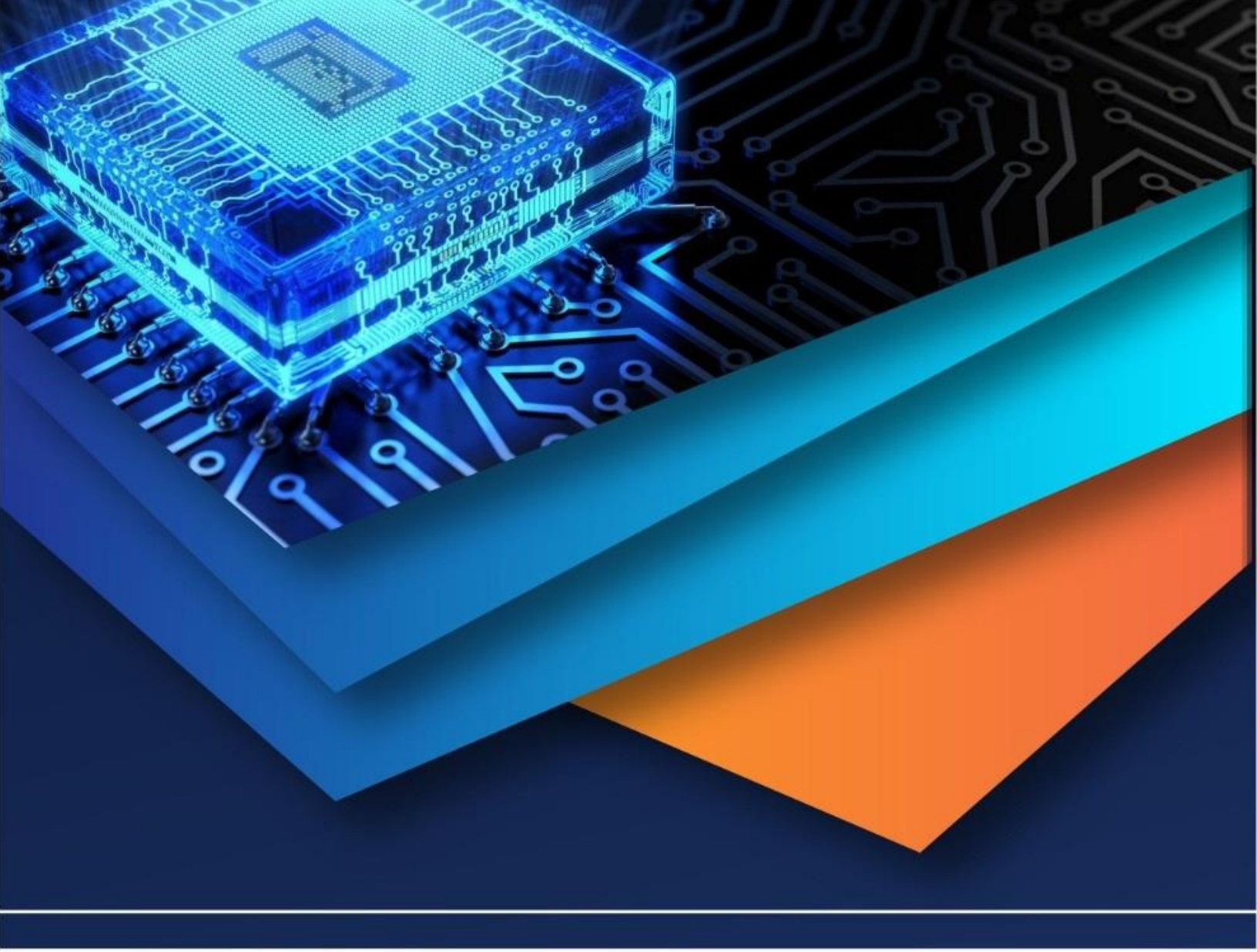
The use of Pulse Light can be a boom for food processing and preservation knowing the complete physical and bio chemical aspects of its complete system and operation and its effects.

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