

LOW-HEAT STERILIZATION SYSTEM ON FRUIT AND VEGETABLE PICKLING LINE PRODUCTION WITH PULSED LIGHTING

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Received: January 25, 2023; Revised: August 24, 2023; Accepted: September 08, 2023

Abstract

Automatic control system for pulsed lighting in sterilization of low-heat fermented food packaging. This paper aims to design and prototype an automatic control system for xenon lamps in pulsed lighting, specifically for sterilizing packages of low-heat fermented foods. The system comprises various components, including lamp holders, lenses, ballasts, heat dissipation mechanisms, power supplies, electronic controller boards, power electronic boards, and touch display control boards. The system's effectiveness is evaluated through the application of a cultured bactericidal test, focusing on *Escherichia coli*. Variables such as control light source distance, the number of pulses, light intensity, and energy per unit area are considered. Results indicate that the application of pulsed light, with variations in frequency, leads to a reduction in the number of *Escherichia coli* colonies observed after the optical test

Keywords: Pulsed Lighting, Low-Heat Sterilization, Fruit, Vegetable Pickling

Introduction

Currently, consumers are placing greater emphasis on healthcare, which leads them to opt for healthier, higher quality, and safer food choices (Bhavaya, and Hebbar, 2017). In the case of pickled vegetables or fruits, manufacturers employ production processes that amalgamate traditional wisdom with modern food technology, ensuring products possess both nutritional value and safety.

The pickled vegetables or fruits processing industry presents promising potential and competitiveness in the future. This potential can be

realized through the adoption of appropriate pickling and storage methods, supported by a broader community of farmers. This collective effort is essential to maintain the quality, cleanliness, safety, and standardization of the end products (Assatarakul, 2015). If a production process is established to effectively control the risk of contamination.

However, improper production, storage, or packaging can lead to a decline in product quality due to the potential risk of contamination by

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Suranaree J. Sci. Technol. 30(5):010254(1-9)

pathogenic microorganisms or spoilage-causing microorganisms (Panyamuangjai *et al.*, 2012).

Numerous microorganism control methods are employed in food processing, including traditional thermal processing. This approach has been used over time to disinfect and ensure the safety of food for consumers. Contemporary applications include the use of high heat through pasteurization and sterilization. Additionally, non-thermal techniques are gaining prominence.

These non-thermal processes encompass methods like irradiation, ultrasound sterilization, and the utilization of electricity, such as pulsed electric field techniques (Wasuri and Chainok, 2022). Other methods like oscillating magnetic fields, high hydrostatic pressure techniques, and high-intensity optical techniques (such as high-intensity light pulses) can effectively inhibit the activity of microorganisms and enzymes without compromising the meat's freshness and flavor—unlike the effects of pasteurization and sterilization, and the level of contamination in the packaging remains consistent before and after the raw materials are packed. This could be attributed to the continued use of traditional production methods or perhaps an overconfidence in the cleanliness of the provided packaging.

Hence, the authors devised a sterilization procedure employing the pulsed light mechanism of a XENON-Lamp with Ultraviolet (UV) light. This approach targets the sterilization of light-permeable packaged foods. By harnessing the production of intense UV light and skillfully regulating pulsed light emissions, the method achieves requisite sterilization energy levels while maintaining low-heat conditions within the packaging.

Materials and Methods

Fermented vegetable and fruits product

Pickled vegetables and fruits have long served as a method of food preservation, effectively retarding the spoilage of these items. Moreover, pickling introduces a distinctive and appealing flavor profile for consumers. In fermented foods, the inherent acidity assumes a role in controlling the growth of microorganisms. During the pickling process, chemical changes transpire within fermented foods, engendering transformations in texture, appearance, and flavor. These alterations, conducive to consumer preferences, often transpire as a result of microbial activity. Enzymes within microorganisms facilitate the breakdown of nutrients like carbohydrates, proteins, and fats into compounds. This enzymatic activity augments the aroma and imparts a novel quality to the food.

Strategies for preserving fermented foods, contingent on salt concentration, can be categorized into two primary groups :

1) Pickling vegetables and fruits using a 2.5-5% salt concentration facilitates the attachment of lactic acid bacteria to agricultural produce, resulting in the production of lactic acid reaching approximately 1% concentration after the fermentation process. This type of product is suitable for immediate consumption, examples of which include pickled bamboo shoots, sour pickled cabbage, and dry salting techniques like sauerkraut and kimchi

2) When pickling vegetables and fruits with a salt concentration ranging from 6% to 12%, this initiates microbial fermentation, resulting in a category of products known as salt-stock pickles. To ensure the desired flavor, fruits and vegetables need to undergo soaking in water or multiple water changes. This process effectively washes off excess salt, reducing overall saltiness. Examples of such pickles include pickled lettuce, pickled olives, and pickled cucumbers.

Several factors contribute to the fermentation process, including acidity-alkalinity, oxygen levels, temperature, salt content, and microorganisms. When these conditions align favorably, microorganisms can thrive and generate ample enzymes to catalyze chemical reactions with food. This optimal interaction expedites the pickling process, ensuring the swift production of high-quality fermented food products, greatly desired by consumers.

Ultraviolet

Ultraviolet light, commonly referred to as UV light, originates from the sun's rays. It encompasses a spectrum of light that is beyond the scope of human vision. Notably, UV light stands out due to its elongated wavelengths, exceeding those of X-rays (Manzocco *et al.*, 2011). This characteristic grants it higher energy, allowing it to penetrate surfaces more readily than regular light.

UV lamps typically consist of silica glass tubes containing an inner layer of mercury and gas. Electrodes, typically composed of an inert substance, are positioned at either end of the tube. The energy source driving a standard UV lamp is an electric current. The UV lamp is positioned apart from the food sample that necessitates exposure to UV rays. Most UV emitters are equipped with a control panel to monitor UV intensity and rate.

Food irradiation serves the purpose of eliminating pathogenic microorganisms, prolonging shelf life, retarding ripening, and curbing the prevalence of parasites (Pollock *et al.*, 2017). Furthermore, it inhibits germination during storage

and disrupts the reproduction of insects. The irradiation process is designed to ensure the minimal amount of absorbed radiation required to fulfill its purpose. Maximum radiation absorption occurs at a level deemed safe for consumers. This approach guarantees that food quality remains uncompromised, while preserving nutritional value, structural integrity, and the sensory attributes of the food.

Inhibition of microbial growth by light

The inhibition of microbial growth through chemical or non-thermal food processing can encompass distinct implications (Chen *et al.*, 2015). When using chemicals like chlorine and iodine for microbial growth inhibition, the approach involves dismantling microorganisms' cellular structures, thereby eradicating them. In contrast, non-thermal food processing techniques, like UV radiation inhibition of microbial growth, operate differently. This method doesn't disrupt microorganisms' cellular structure but rather hampers their ability to reproduce, leading to a halt in microbial proliferation (Saikiran *et al.*, 2016).

UV rays achieve microbial growth inhibition by damaging nucleic acids, crucial components of DNA, which prevents DNA replication. UV rays within the 200-310 nm wavelength range (Oms-Oliu *et al.*, 2010) are particularly effective in this regard. For food processing without heat, the wavelength employed is 254 nm, known as the germicidal wavelength. Nucleic acids absorb this wavelength most effectively (maximum absorption). This absorption triggers harm or damage to cells, curbing their multiplication or potentially causing cell demise.

The effectiveness of this process hinges on various factors, including light intensity, the spacing between light sources, exposure duration, the age of infection, and quantity. Each of these elements significantly influences the outcomes of the process

Pulsed light generation

Pulsed light serves as a non-thermal technique for food preservation (Rodrigues *et al.*, 2016). It involves deploying intense light in short pulses to mitigate microbial contamination on food surfaces and packaging materials. The effectiveness of pulsed light hinges on the intensity and frequency of emitted pulses. Generation of pulsed light employs diverse amplification engineering methods, transforming high-speed electronic pulses into brief yet high-energy light bursts. The manipulation of pulses and lamps allows energy storage in high-power capacitors for fractions of seconds, which is then rapidly discharged into a specially designed xenon lamp unit. This setup

facilitates the generation of high-energy nanosecond to millisecond light pulses that reach the targeted area within microseconds (Do-Kyun and Dong-Hyun, 2018).

The spectral wavelength of the lamp-generated light spans a wide range, encompassing ultraviolet to near-infrared regions. During pulsed light application, the wavelength spans from 180 to 1100 nm (nanometers): ultraviolet (180-380 nm), visible (380-700 nm), and infrared (700-1100 nm). This spectrum surpasses sunlight intensity on Earth's surface by a factor of 20,000.

Microorganism survival during pulsed light treatment escalates with the increment of light intensity, flicker frequency, the number of lamps, and flashing configuration, with the specifics contingent on the particular application. Key factors impacting the effectiveness of pulsed light include the distance from the light source to the target and the medium between the light and the target object (e.g., air, water, juice). Sample thickness also influences pulsed light's impact on microorganism inactivation. This is due to the limited permeability of ultraviolet light, resulting in shadowing effects when high-density microbial populations overlap. The ultraviolet light system's operational components encompass a high-power, high-voltage power supply to energize capacitors, which in turn store electrical energy for light pulses. The pulse-forming network shapes the pulse characteristics and its spectrum. The discharge of electrical energy through flashing lights, triggered by a start signal, induces xenon ionization, ultimately converting electrical energy into pulsed radiation energy that transmits UV light pulses to the target (Caminiti *et al.*, 2012).

Pulsed ultraviolet radiation boasts higher light intensity compared to mercury vapor lamps, with LED bulbs potentially exhibiting one to twice the intensity at similar wattage (Fang *et al.*, 2020). This enhanced intensity results from the energy storage in high-voltage capacitors, which is subsequently released in short bursts during flashing. This process occurs within a pulse width ranging from 10 microseconds to 300 microseconds. In today's industrial context, this technology can supply power from 300 kilowatts to megawatts. The power supply's ability to achieve full charging is pivotal. The minimum energy level of the power supply can be estimated by multiplying the pulse frequency by the energy per pulse. As an example, a blinking light system operating at 13 joules per pulse with a blink rate of 100 pulses per second (PPS) necessitates a power supply rated at 1,300 watts or higher.

The operational principle of this research is the inhibition of microbial growth through the utilization of UV light, which impedes the

reproduction of microorganisms, thereby restraining their growth. This inhibition is achieved by dismantling nucleic acids, essential components of DNA, rendering them incapable of self-replication. UV rays with wavelengths ranging from 200 to 310 nm are absorbed by nucleic acids, with the commonly used 254 nm wavelength being acidic in nature. Notably, nucleic acids exhibit maximum light absorption at this wavelength.

The parameter employed to depict reduction characteristics is pulse-emitting power per unit area, typically quantified in watts per square meter (W/m^2). Pulse repetition rate (PRR) is measured in hertz (Hz) or pulses per second (PPS). Peak power is denoted in watts (W) and is calculated by dividing pulse power by pulse duration. The energy value can be computed using Equation 1 and Equation 2.

$$E = \frac{1}{2} CV^2 \quad (1)$$

$$W_{\text{avg}} = Ef \quad (2)$$

Where E = energy (watt second, Joules), C = capacitance of storage capacitor (Farads), V = anode voltage (volt), and f = flash rate (hertz, second⁻¹)

Applying the formula, consider a xenon lamp supplied with 13 joules at a frequency of 100 Hz. Operating within a pulse width of 34 μs , this setup can generate an output power of 380 kilowatts (kW). Alternatively, for a xenon gas-based flashing lamp producing ultraviolet C (UV-C) radiation, when energized with 300 J of electrical energy, this energy is stored in a capacitor for a brief moment. Subsequently, it's released within a lamp where xenon is ionized, resulting in plasma formation. This process yields an intensely concentrated white light emission abundant in UV rays. In a mere 300

$\times 10^{-6}$ seconds (0.3 ms), a remarkably high pulse power of around 1 megawatt (MW) is achieved from 300 joules in 0.3 ms. Through capacitor iteration-repeatedly receiving and discharging electrical charges-this device can release several megawatts of power, provided precise control is maintained.

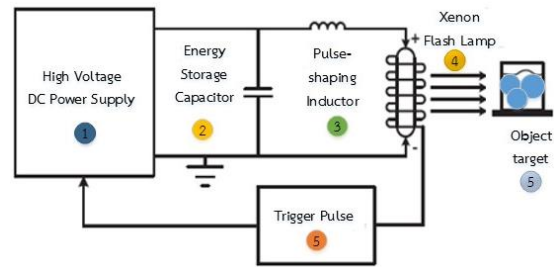


Figure 1. Shows the circuit diagram of the ultraviolet light system

A design of a Low-heat sterilization system for pulsed light packaging

The principle operation of the ultra-violet light system involves using a high voltage power supply to power the capacitors to store energy for supplying pulsed lighting systems. The power is then sent to the preferences pulse and spectrum, whose main components are an inductor connected to the xenon lamp holder. When the trigger signal starts to work as a pulse, it will make the power supply work, causing the xenon ions in the tube to undergo an excitation rhythm, converting the electrical energy into ultraviolet energy to transmit the energy from the aforementioned ultraviolet light to the target, as shown in Figure 1.

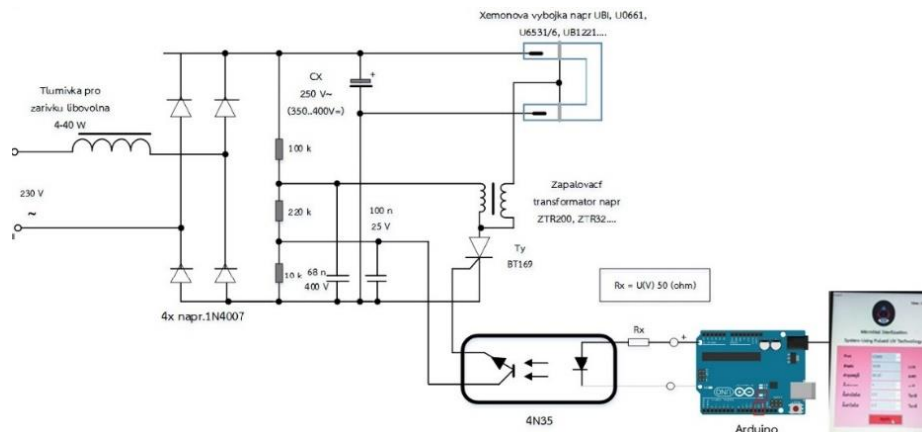


Figure 2. A pulse xenon lamp point circuit with microcontroller control

The authors built a circuit for igniting the xenon lamp and controlling its pulse by using a microcontroller as a controller. This is a design that uses simple, uncomplicated equipment using materials that can be found in Thailand, such as using ballast as a current limiter; using a bridge circuit to convert AC 220 VAC to 250 VDC; the DC voltage supplied to the xenon lamps at the lamp caps of the 170 VDC DC voltage divider is then used as a 1000 V pulse voltage to pulsating the glass bulb xenon lamp at a frequency controlled by the microcontroller via an electronic switch, which can work for the intended purpose as shown in Figure 2.

switch, this configuration achieves its intended objectives, as illustrated in Figure 3.

A performance test results of a low-heat sterilization system for pulsed light packaging.

In the laboratory setting, a performance test was conducted on a prototype of a low-heat sterilization system for packaging using pulsed light. This test involved controlling variables such as the distance of the light source, the number of pulses, and light intensity. Parameters measured included energy per area and power consumption, as illustrated in Figure 4.

Results and Discussion

A prototype of a low-heat sterilization system for pulsed light packaging

The authors have meticulously designed a supporting framework to accommodate the prototype cabinet. Within this cabinet reside xenon lamps alongside temperature sensors. Electronic devices necessary for control and processing are integrated into the control cabinet, firmly attached to the main structure. A specialized circuit has been constructed to initiate and regulate xenon lamp ignition through pulsed emissions. This design prioritizes simplicity, utilizing materials readily available in Thailand.

For instance, the utilization of ballasts as current limiters and a bridge circuit to convert 220 VAC to 250 VDC for the xenon lamps showcases this approach. Following this, a DC voltage divider generating 170 VDC serves as a pulse generator, providing a 1000 V pulse to ignite the xenon lamp's glass bulb. The microcontroller governs the rhythm or frequency of these pulses. Via an electronic



Figure 3. A prototype of a low-heat sterilization system for pulsed light packaging

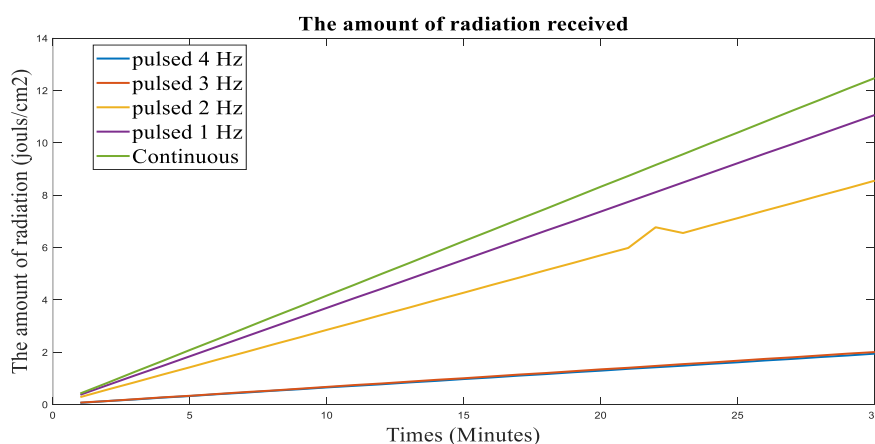


Figure 4. The radiation dose and time from turning on the xenon lamp on various frequencies

Sterilization test for *Escherichia coli* bacteria

A prototype test was conducted on the *Escherichia coli* disinfection system, with comprehensive experimentation encompassing variable control of the light source distance, the number of pulses, light intensity, and energy measurement per area. This rigorous testing procedure generated detailed insights, and the test results are as follows:

1) *Escherichia coli* was incubated at 37°C for 24 hours. Suspension cells were then prepared, yielding a concentration of 1.5×10^8 , determined by absorbance measurement. This concentration was adjusted with NSS to attain $OD_{625} = 0.08$, followed by dilution to 104 with a 20 ml volume. The solution was placed in a petri dish, with a magnet inserted for subsequent testing.

2) The system and UV light were activated for a duration of 15 minutes. Subsequently, testing commenced by introducing a magnetic stirrer into the petri dish cabinet. The petri dish was positioned 7 cm from the lamp. During the test, the magnetic stirrer was activated to maintain agitation. The petri dish lid was then opened, initiating the testing phase. The experimental procedure is illustrated in Figure 5 and Figure 6.



Figure 5. The sterilization test for *Escherichia coli* bacteria

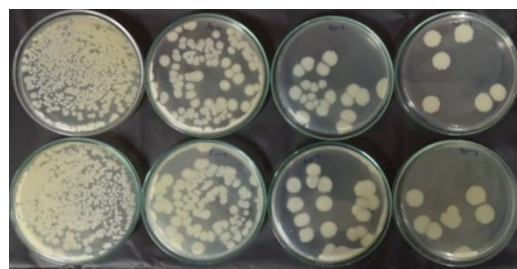


Figure 6. Amount of *Escherichia coli* treated with pulsed light

From Table 1, it is found that the percentage of *Escherichia coli* after the pulse light test at 3 minutes, frequency 2 Hz, the number of *Escherichia coli* decreased by 3.40%, the frequency of 0.5 Hz, and the number of *Escherichia coli* was reduced by 5.30. % and 1 Hz frequency, the number of *Escherichia coli* decreased by 6.06%, as shown in Figure 7

Table 1. The percent of reduction of E.Coli

Time	0.5 Hz	1 Hz	2 Hz
1	6.43±0.01	8.71±0.01	10.60±0.07
2	4.92±0.00	9.46±0.01	10.22±0.08
3	4.92±0.00	6.06±0.00	3.40±0.00
4	6.06±0.00	7.57±0.01	3.93±0.00
5	15.15±0.01	15.53±0.01	15.30±0.43

Sterilization test for *Bacillus cereus*

Bacillus cereus sterilization test with details as follows:

1) *Bacillus cereus* was cultured at 37 °C for 48 hours until the bacteria reached the desired growth stage. The cultured bacteria were then placed into a sterile petri dish, preparing it for the subsequent irradiation test.

2) The sterile petri dish was positioned at the center of the setup. The pulsed light system was activated, emitting light pulses. The testing process involved sampling at intervals of 0, 5, 10, 20, and 30 minutes. After each interval, the samples were analyzed to determine the number of surviving organisms. This procedure is visually depicted in Figure 8 and Figure 9.

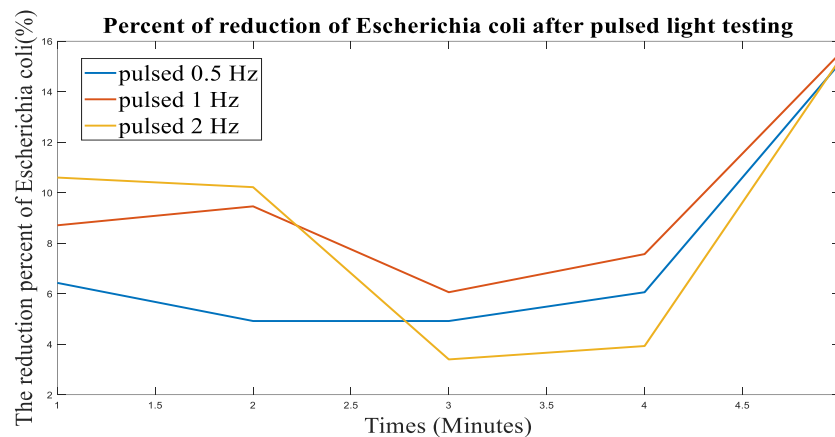


Figure 7. Percent of reduction of Escherichia coli



Figure 8. Sterilization test for Bacillus cereus bacteria

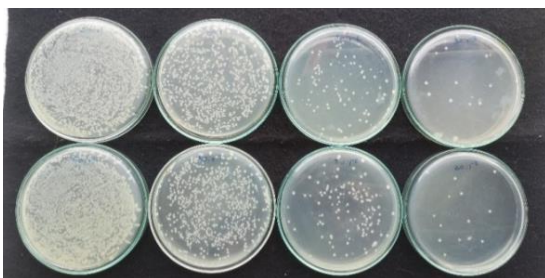


Figure 9. Amount of Bacillus cereus bacteria treated with pulsed light

The results from the pulsed light irradiation experiments conducted at 5, 10, 20, and 30-minute intervals to test the inoculation of *Bacillus cereus* are as follows:

The initial bacterial concentration was prepared at $1.64 \pm 0.04 \times 10^6$ cfu/ml (t_0). After

irradiation for 5, 10, 20, and 30 minutes, the surviving percentages were determined as follows: $46.78 \pm 4.76\%$, $72.48 \pm 3.46\%$, $90.61 \pm 0.76\%$, and $94.45 \pm 0.76\%$, respectively. This demonstrates the efficacy of the pulsed light treatment in effectively reducing the *Bacillus cereus* population, as illustrated in Figure 10.

The performance test of a prototype low-thermal sterilization system for pulsed light packaging was conducted using sealed plastic bottles of salted lime products, specifically the 'Mae Perm' brand. The aim was to evaluate the system's efficiency by subjecting the sealed plastic bottles of salted lime products to the disinfection process.

This evaluation encompassed the control of variables such as the distance of the light source, the number of pulses, and light intensity. Additionally, energy per area and power consumption were measured.

Subsequent to the disinfection process, the remaining germs were examined. Energy consumption per infection control was calculated based on these variables. The evaluation extended to the detection of total plate count, yeast and mold count, lactic acid bacteria, coliform, and *Escherichia coli*. The primary focus was on assessing the reduction in the number of microorganisms.

When comparing high-voltage electric and ozone disinfection methods, it becomes evident that constructing such systems demands multifaceted engineering techniques. This is primarily due to the involvement of critical components, including the generation of oxygen from the air (Air modification) and the creation of ozone through the corona discharge technique using high-voltage electricity. Ensuring a specific level of electrical safety within the system is imperative.

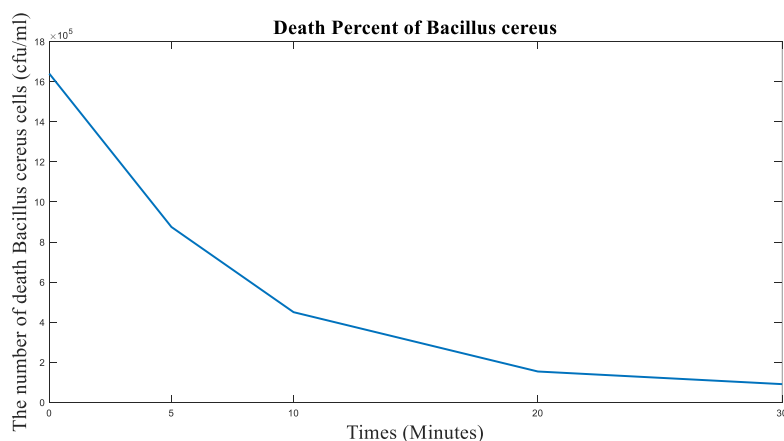


Figure 10. Amount of *Bacillus cereus* bacteria treated with pulsed light

Furthermore, it's worth noting that ozone could potentially pose adverse health effects on users, particularly if proper throttling or a controlled transition from ozone to oxygen is lacking. Thus, it's crucial to implement a measurement process both before and after usage to guarantee the safety of operators.

Conclusions

In the *Escherichia coli* sterilization test, precise control of variables including light source distance, number of pulses, light intensity, and energy per area was conducted. It was observed that the count of *E. coli* colonies notably decreased in response to the pulsed light system's preliminary sterilization process. Interestingly, the reduction in *E. coli* colonies was more prominent with higher frequencies of pulsed light.

Turning to the *Bacillus cereus* sterilization test, the effect of pulsed light irradiation was examined across study periods of 0, 5, 10, 20, and 30 minutes. Results indicated a progressive sterilization impact, with destruction rates of 0.00%, 46.78±4.76%, 72.48±3.46%, 90.61±0.76%, and 94.45±0.76%, respectively. Notably, a customized light source generating an intensity of approximately 5,000-9,000 lux, while maintaining temperatures below 35 degrees Celsius, was utilized.

Microorganisms within the food samples were exposed to light radiation at roughly 2.0 joules per square centimeter. The dosage decreased by over 50% following irradiation periods of around 5 minutes (for continuous light) and approximately 30 minutes.

The innovation lies in the utilization of electrical technology to store energy within

a capacitor bank, allowing for the selection of stored energy based on the intended capacity, and it incorporates computer technology to precisely regulate the release of energy needed for a specific purpose. This regulation involves controlling factors such as energy density (w.t/cm², j/cm²) through frequency modulation and timing for igniting the xenon lamp.

Acknowledgement

This research was funded by the income budget of Nakhon Pathom Rajabhat University.

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