Application of Pulsed Light Technology in Dairy Industry

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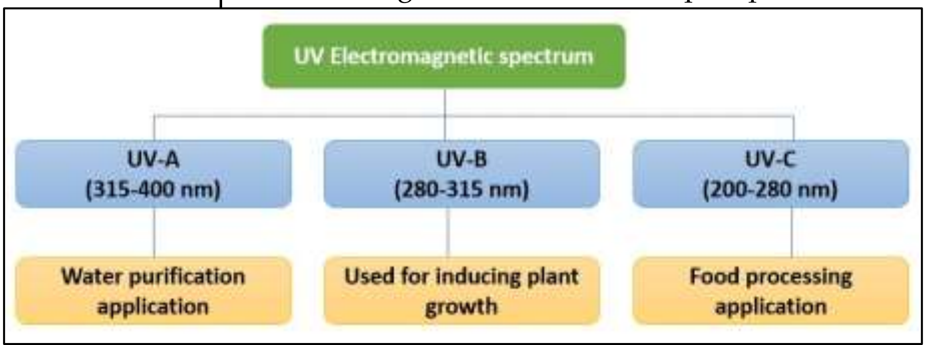
Pulsed Light Technology (PLT), known as high-intensity pulsed light (HIPL), is a novel non-thermal technique used in food processing. It utilizes short, intense pulses of broad-spectrum light to deactivate and decontaminate microbes. Pulsed light technology offers several advantages such as minimal impact on product quality, fast processing times, versatility in applications, and reduced reliance on chemicals. It has gained significant attention due to its ability to effectively eliminate microorganisms, improve food safety, and extend product shelf life. With its versatility spanning various industries, including dairy, it plays a crucial role in surface disinfection and ensuring food safety.

Sources of PLT

PLT incorporates various types of electromagnetic radiation, including UV rays (λ = 200–400 nm), visible light (380-700 nm) and infrared (IR) rays (λ = 700–1100 nm). UV rays are further classified into UV-A, UV-B and UV-C (Mandal *et al.,* 2020). The pulses generated by pulsed light technology have a short duration, typically ranging from 1 μs to 0.1 s. These pulses are characterized by their high intensity, and in the context of decontamination, UV-C light with a peak wavelength of 253.7 nm has been found to be the most effective.

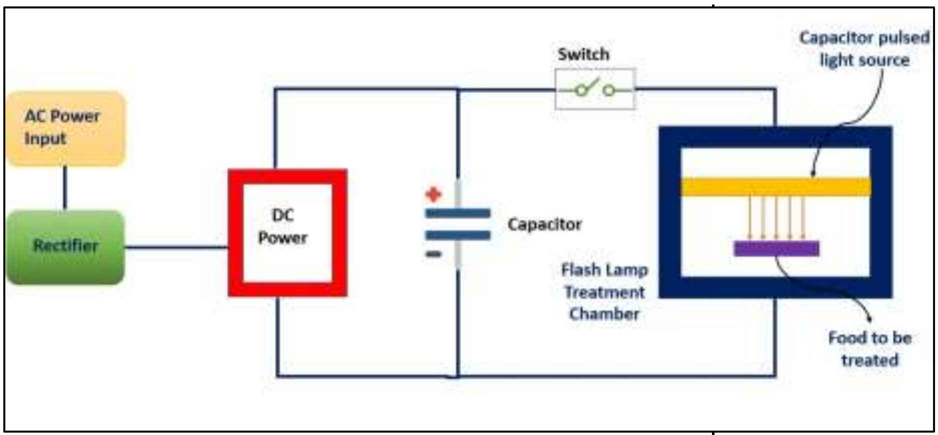
The dose of Pulsed Light (PL) treatment is measured by its 'fluence,' which represents the total radiant energy of PL exposure on the surface of the food. The intensity of PL is typically measured in J/cm², and the energy of PL is determined using actinometry techniques. Commercial PL units designed for food processing are available in both batch and continuous treatment modes, offering effective microbial elimination capabilities.

The effectiveness of UV treatment in the dairy industry depends on several critical process factors. which include the UV light absorption capacity of the dairy product, the geometric design of the UV reactor, the characteristics of the light (intensity, wavelength, power, and duration), the physical arrangement of the UV sources, and the flow profile of the milk or dairy products being treated. These elements collectively play a significant role in determining the success of the UV treatment process. As per FDA, to achieve a microbial load reduction of at least 5 logs in a well-mixed liquid product, it is recommended to apply a minimum treatment dose of 400 J/m² of UV radiation (Datta et al., 2015).



Equipment

The low-power, low-voltage AC continuous current from the line source is transformed into low-power, high-voltage DC continuous electric current through a converter or rectifier. This converted



current is then stored using capacitors. Electric pulse forming network (switches) further convert the stored energy into high-power, high-voltage pulsed DC electric current. This pulsed current is directed to a pulsed light source, typically inert-gas flashlamps. The resulting high-power pulsed light is then utilized for the intended application.

By subjecting xenon gas within the flash lamp to a high voltage electrical pulse, the gas is ionized, leading to the formation of plasma and the generation of a substantial current. As this high current pulse passes through the ionized xenon gas, the electrons within the gas are energized, transitioning to higher energy levels. The emission of pulsed light occurs when these excited electrons release their energy by transitioning from higher to lower energy levels, resulting in the production of photons.

Mechanism of action

The germicidal efficacy of UV light primarily stems from its ability to modify microbial DNA through the formation of cyclobutyl pyrimidine dimers, which cross-link the pyrimidine bases. The degree of cross-linking is directly proportional to the dose of UV light administered. These dimers impede DNA transcription and replication, compromising essential cellular functions and ultimately leading to the death of microbial cells. Three mechanisms by which microbial inactivation occurs are:

- Photo-chemical effect: By formation of pyrimidine or thiamine dimers
- Photo-thermal effect: Heat generation by the IR rays effectively eliminates pathogenic organisms on the surface
- Photo-physical effect: High energy pulses are capable of destructing the cell membranes of microorganisms

Advantages

- Non thermal process
- Operation at ambient temperature
- Less detrimental effects on colour, flavour
- Suitable for batch and continuous process
- No chemical residue after treatment
- Vitamin D enrichment in milk by UV
- Low maintenance cost
- Low installation and operational cost
- Minimum usage of energy
- Reduced use of chemicals
- Time efficiency: Process is extremely fast and treatment time ranges from fraction of seconds to a few seconds
- Can be easily incorporated into the existing setup

Applications in Dairy Industry

Commercial applications of PLT includes disinfection of water, sanitization and sterilization of equipments, enhancement of shelf life and microbial load reduction in food industry, photodynamic therapy for cancer treatment, waste water treatment and control of industrial emissions.

Package and surface disinfection

As this technology possess lower penetration power, it is commonly used for the surface disinfection of products as well as package. In the dairy industry, UV technology is highly recommended for microbial disinfection of solid packaging surfaces, as it effectively extends the shelf life of dairy products. This application encompasses the reduction of microbial counts on various packaging materials used in the dairy industry, such as tubs, bottles, cans, lids, covers, and foils for yogurt, milk, butter, cheese, and other dairy products. By subjecting these solid surfaces to continuous UV radiation at appropriate doses and durations before filling them with dairy products, the growth of food spoilage microorganisms is significantly reduced. As a result, the product's shelf life is prolonged, and the risk of contamination is minimized.

Problems with PLT treatment

- Sensory defects arise in whole milk and skim milk when proteins undergo oxidation as a result of exposure to UV light
- Decrease in the amount of vitamin present in milk in the order of C>E>A>B2
- Not ideal for milk packed in translucent packaging
- Efficiency of the treatment reduces in cloudy and opaque liquids
- UV exposure can lead to burns, skin cancer, damage to human eyes

The stage of photo-reactivation serves as a damage control mechanism in injured microorganisms by utilizing repair enzymes, known as photolyases. This process enhances the survival capacity of microorganisms, but also reduces the shelf life of UV-treated products. Photo-reactivation mainly occurs when the treated food is exposed to light and so it is utmost important to control the light exposure by the treated product in order to maintain the quality and safety of foods (Mandal *et al.*, 2020).

Conclusion

Pulsed light technology serves as a valuable asset to the dairy industry, offering a potent tool to strengthen food safety measures, extend the shelf life of products, and uphold stringent quality standards. By efficiently decontaminating surfaces and mitigating the risk of microbial contamination, this technology plays a crucial role in safeguarding dairy products and ensuring their freshness and integrity. Consumer acceptance of Pulsed Light (PL) technology in the food industry is rapidly increasing due to multiple factors. Firstly, PL treatments are non-invasive, preserving the natural state of the food and aligning with the demand for minimally processed options. Secondly, PL technology offers versatility in various applications like surface disinfection, shelf-life extension, and reduction of spoilage microorganisms, leading to improved product appearance and consumer confidence. Additionally, PL treatments are comfortable for consumers as they involve no heat or chemicals. With well-established safety credentials, regulatory approvals, and growing accessibility, PL technology is becoming more feasible for food manufacturers to implement and offer PL-treated food products to consumers.

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Table 1: Application of Pulsed Light Technology in Dairy Products

Food Products	Pulse energy/ Dose	Treatment time (μs)	Log_{10} Reductions	Reference
Milk	25.1 J/cm^2	114s	>2.0 of *Serratia marcescens*	(Smith et al., 2002)
Packaged cheese	53.4 J/cm^2	40s	2.98 of *Listeria monocytogenes* and 1.25 of *P. roqueforti*	(Can et al., 2014)
Concentrated milk (45% TS)	8.4 J/cm^2	-	<1 for *E. coli ATCC 25922*	(Miller et al., 2012)
Infant milk powder	-	9500	3 for *L. monocytogenes*	(Choi et al., 2010)
Raw whole milk	-	-	4 for *E. coli W*1485	(Choudhary et al., 2011)
Skimmed milk	700 J/m^2	-	3.3 for *E. coli* 25922	(Milly et al., 2007)

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