**Photopurification as an Alternative to Milk and Milk Products Processing - An Energy Saving Green Technology**

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**Abstract**

Ultraviolet (UV) light technology is used in dairy and food industry for control of pathogens and spoilage microorganisms for food safety and shelf life extension. The wide studies on application UV light for disinfection of solid surfaces and treating of liquid foods has been carried out. Several recent studies on UV treatment of milk and milk products imply that there is extensive scope of research in the areas of solid food products to control the viable count and extend the shelf of the product. Photopurification process technology is not commonly used in the processing industry, while in future; UV technology could be used to maximize its impact on food borne pathogens and spoilage microflora, however the appropriate design and methods should be taken into consideration. In the aim of replacing the conventional processing technologies with green technologies particularly with UV processing the article is written.

**Keywords:** Green technology, UV, UV-C, Total Viable Count (TVC)

**I.Introduction**

Preservation of food by green technologies is now becoming challenging task for the manufacturing industries. Although various green technologies such as, membrane technology, irradiation, microwave radiation, pulsed electric field, ultrasound processing,high pressure processing, and ohmic heating treatments are available for food preservation. While, conventional technologies likeheating and evaporation can impart physical andchemical changes that may or may not be desired. Hence, preservation of food is critical and complex. Industries can adopt the use the combined technologies with enhanced benefits and shelf life.The alternative technologies are now surfacing the conventional technologies by their promising results and better nutritional quality in food processing.Green Food Processing can be a research thematicthat covers a broad strategy based on the discovery andthe design of processes in order to reduce energy and water consumption [1].

Ultraviolet (UV) radiation covers part of the electromagnetic spectrumfrom 100 to 400 nm and is categorized as UV-A (320 to 400 nm), UV-B (280 to 320 nm), and UV-C (200 to 280 nm). UV-C isconsidered to be germicidal against most types of microorganismssince photons are absorbed by DNA at this specific wavelength [2] Photopurification by UV-C is a non-thermal process that disrupts genome transcription and replication, leading to death of a broad spectrum of bacteria, viruses, molds and protozoa. Photopurification technology is recognized by several regulatory agencies to effectively disinfect liquids such as drinking water, fruit juices, beer, wine, and milk without having any detrimental effect on the nutritional content of the treated products (www.nationalhogfarmer.com). The germicidal effect of UV radiation is mainly result of any of the five mechanisms i.e. dimerization of cellular DNA, photoreactivation, dark repair, inactivation kinetics and UV-C irradiance and UV-C dose [3].

**II.UV: principle of action and mechanisms**

The UV light photons react with thymine and cystine nucleoside bases, producing the cross linked photoproducts, especially cyclobutyl pyrimidine dimers (CPD), which interrupt the transcription, translation, and replication of DNA and lead to cell death [4]. UV with a wavelength of 228 – 265 nm is the most deadly to microorganisms because this is the ideal absorption spectrum of the organisms' nucleic acids [5, 6]

The cells indeed have their own repair mechanisms i.e. photoreactivation and dark repair.Photoreactivation is the formation of a complex between a photoreactivationenzyme (PRE) and the dimer to be repaired. This reaction does not require light, but it is dependent on temperature, pH, and ionic strength [7,8]. Further process is the release of PRE and repaired DNA. The restorationof the dimer to its originalmonomerized form is absolutelydependent upon light energy intensity. The reaction occursin less than a millisecond; consequently, the limiting stepof the whole reactivation process is the formation of the PREdimercomplex. An extended period of exposure to photoreactivatinglight would enable the release of PRE, which wouldthen be available to form new complexes.

In contrast with photoreactivation, dark repair does not require exposure to visible light in order to be reactivated. Under stress conditions, such damage caused to the DNA of the cell following exposure to UV light, the RecA protein in the cell is activated. The activated RecA protein then cleaves the negative regulator, LexA protein, which represses the transcription of the genes involved in the SOS signal in the cell. As LexA are lowered, the SOS system in the cell is activated, which in turn is responsible for the dark repair mechanism [9]. Inactivation of bacteria with heat in pasteurization is based upon the common principle in food safety of a D-value[ [10,11,12]. Inactivation of bacteria by either heat or light will follow first-order kinetics.

As the light passes from the UV-C lamp through the liquid, it follows the Lambert-Beer law. The irradiance/fluence rate (*I*) falls exponentially with path length (*x*) from its initial value (*Io*) for a given material with absorption coefficient (𝛂) according to equation shown to the right [13,14,15]. The absorption coefficient varies according to the type of liquid being treated and effect of the requirement of UV light dosage will be dependent on the it.

**III.Factors influencing ultraviolet processing**

The inactivation of microorganisms following UV exposure will depend mainly on three factors according to [16]. The resistance of the microorganism to UV radiation and the type of microorganism treated, secondly the absorption properties of the medium treated in which the microorganisms are suspended and thirdly the UV dose applied to the medium being treated. In addition, three factors the process characteristics including the source of UV light, the flow dynamics and flow velocity and resulting exposure time (residence time) is important as well. Reference [2] reported that all parts of the fluid (or liquid being treated) should be exposed to at least 400 J.m-2 of UV-C at 254 nm to reduce initial population to 5-log in order to achieve microbiologically safe end product.

Various other factors influencing UV inactivation of microorganisms are: type of microorganism, process characteristics, sources of UV radiation, flow dynamics, geometric configuration and product characteristics (viz. optical properties, physical properties, chemical and biochemical properties).

According to [17] in order for UV radiation to have the desired germicidal effect on the target microorganism and to preserve the properties of the medium being treated, the medium should be subjected to a minimum lethal UV-C dose. The resistance of the microorganism in relation to lethal UV-C dose should be considered, as various factors will determine resistance of microorganisms to UV radiation. These factors include: the species and strain of the microorganism, the growth media of the microorganism, stage of proliferation of the microorganism and the density or concentration of microorganisms, amongst others [18,19].

As for bacteria, in general bacterial spores are the more resistant to UV radiation, followed by Gram-positive and Gram-negative bacteria. The reason for Gram-positive bacteria being more resistant can possibly be linked to the difference in the bacterial cell wall’s structure. The teichoic acids in the Gram-positive peptidoglycan cell membranes are extremely rigid, and because Gram-negative bacteria do not have such teichoic acids, they are less rigid and therefore more susceptible to UV radiation. Furthermore small coccoid bacteria are usually more resistant than rod-shaped bacteria as the surface-to-volume ratio of the coccoid bacteria allows less absorption of UV radiation in the cellular matrix, compared to rod-shaped bacteria [20].

Sources of UV available at present are Mercury Lamps (low and medium pressure), Amalgam Lamps, Excimer Lamps, Broadband-Pulsed Lamps, Microwave UV Lamps and light emitting diode (LED). The factors that will affect the lamp performance and that should be considered when choosing the correct lamp for the application in question, include: life of the lamp, lamp output and lamp output over lamp life, the temperature of operation of the lamp, reflection, scattering refraction within the system, absorption values required and other general maintenance considerations, such as power supply and cost of the lamps to be used [20].

The type of liquid and the viscosity of liquid would determine the choice of flow and resulting reactor design needed for a particular application.The flow dynamics of the UV operating system is a critical parameter in promoting effective UV-C transfer to the liquid being treated. Various reports and studies have been conducted on different UV systems and UV system configurations. Generally the UV reactor system designs can be divided into three distinct groups, namely laminar flow, turbulent flow and dean flow reactors. In order to get the best out of the UV-dose, the type of flow will determine the system design parameters. Laminar flow UV-systems in general uses extremely thin film flow chamber designs to maximize UV absorbency as the difference in the parabolic flow velocity produces non-uniform conditions that need to be exploited [21]. Further, various researchers have mentioned that the geometric configuration of the UV system in order to achieve maximum germicidal effect when treating liquids. Reference [22] reported even if all the other factors within a system are the same, the resultant lethality of the process will be different if the geometric configuration of the UV system is changed. The FDA also refers to the geometric configuration to be an important parameter when referencing the kinetics of microbial inactivation for alternative processing technologies [23].

The products characteristics play an important role to ensure an effective UV dose response from UV radiation. The liquids have a diverse range of physical, chemical and optical properties, the latter especially relevant when assessing the use of UV technology in the treating of liquids as it is directly related to UV light transmission and germicidal efficacy. Physical properties include the viscosity and density of the liquid being treated, and whether the liquid in question would be regarded as Newtonian or Non-Newtonian. The chemical and biochemical composition would include the dissolved solids including macronutrients (such as fat, proteins and carbohydrates) and micronutrients (such as vitamin C and D) as well as organic compounds and enzymes that could ultimately influence the germicidal efficacy of UV radiation. In addition other chemical parameters that will affect UV efficacy possibly include insoluble solids, pH and the redox potential of the liquid being treated [24].

**IV.UV dose for solids and liquids**

UV light was initially used to disinfect surfaces; therefore the irradiance is generally expressed as W m-2, while the radiant exposure (UV dose) is expressed as W s m-2 or J m-2 and characterizes the energy delivered per surface area of the treatment device. On the other hand, UV dose (*D*) is determined as Time (*t*) multiplied by Irradiance (*I*) for the liquids. As the UV-C energy penetrates into the medium, working with volume rather than surface area is advisable. An alternative method to characterize UV as dose per volume of liquid was proposed by [25]. For liquids, the UV dose is expressed as J L-1.

**V.UV reactors**

A UV reactor design can reduce the interference of UV absorbance and viscosity and improve the inactivation efficiency. The flow pattern inside the UV reactor strongly influences the total applied UV dose, as the position and residence time of the microorganisms in certain regions of the irradiance field can vary significantly. Recently, in 2020, artificially inoculated donkey milk was performed in pilot-scale equipment. The low-power UV unit named SP-1 (SurePure) contained with a UV bulb enclosed in an optically pure quartz sleeve that separates milk from the light source. The “SurePure Turbulator™” device can use for continuous flow inactivation of turbid fluids such as milk which creates turbulent flows [26]. Further, continuous flow UV system developed by [27]. wherein a vertical UV reactor equipped with 6 low-pressure mercury UV lamps (total power 30 W, light emission at 254 nm) positioned around a protective quartz tube (diameter, i.e. UV path length, 5.08 cm) for processing of clear and turbid grape juice.

A stainless steel barrel-shaped chamber was constructed to perform the experiments with twelve UV-C lamps (6 of 30 W and 6 of 55 W). They were placed longitudinally around the chamber’s inner surface where packaged chicken meat samples placed at the geometrical center of the chamber using the aid of nylon net. Samples were evaluated various intensities and the values were measured using an UV radiometer [28].

Also, bench-scale UV apparatus was designed by [28] for standardization of methods for fluence determination in waste waters matrix. The apparatus equipped with collimated beam with a spatially homogeneous irradiation field at place and the tube should be ‘‘roughened’’ and painted with a ‘‘flat black’’ paint to prevent reflection from the sidewalls. The low or medium pressure mercury vapor monochromatic lamp at 253.7 nm UV light was used for waste waters matrix.

**VI.Dairy and Food Applications**

UV light is used in the dairy and food industry for various purposes. The applications includes decontamination of surfaces of equipment in food plants, as an adjunct to usual sanitizing practices, decontamination of conveyor surfaces and packaging containers. The research on the application of UV light to reduce microbial contamination on the surfaces of solid foods is growing. However, in liquids the presence of colour compounds, organic solutes and suspended matter transmits relatively low UV light and hence the performance efficiency of UV processes is limited.

Recently, [29] investigated the effect of UV light irradiation on food contact surfaces and the subsequent effect on the shelf-life of the raw diced beef being processed within a red meat processing facility. It was reported that the shelf life of the final packed product was increased to greater than 10 days. The study implicated of determining the Total Viable Count (TVC) of four food contact surfaces involved in the processing of diced beef.

Application of UV technology can have many advantages in the dairy and food industry, including increased shelf life and microbial protection of products, as well as energy savings due to the non-thermal technology. Nowadays, consumers prefer food manufactured in an environmentally friendly manner, so sustainability and environmental issues are becoming highly relevant. UV processing can provide more desirable food items with fresh-like qualities.

Many authors reported that UV light can be used effectively for the reduction of certain bacterial pathogens in milk. Similar level of microbial efficacy obtained in milk processed with pasteurization (high temperature short time), UV light and their combination. Similarly, [30]investigated the effect of UV-C light on the inactivation of pathogenic bacteria such as *Listeria monocytogenes*, *Serratia marcescens*, *Salmonella senftenberg*, *Yersinia enterocolitica*, *Aeromonas* *hydrophila*, *Escherichia* *coli* and *Staphylococcus aureus*.

Out of the seven milk borne pathogens tested, *L. monocytogenes* was the most UV resistant, requiring 2000 J/L of UV-C exposure to reach a 5-log reduction, and the most sensitive bacteria was *S. aureus*, requiring only 1450 J/L to reach a 5-log reduction. Referance [31] reported that UV-C treatment could be used for the reduction of *L. monocytogenes* in goat’s milk and application of a cumulative UV dose of 15.8- 1.6mJ/cm2 to goat milk led to more than 5 log reduction in *L. monocytogenes*. In 2012, [32] reported the UV irradiation was as effective against certain microorganisms as heat treatment. The authors applied the UV light as an alternative to heat treatment to bovine milk using a custom-made UV system and the growth of *coliform* bacteria, *E. coli* and *Staphylococcus* *spp*. was completely reduced by UV treatment. Similar results were found for inactivation of *S. aureus* in milk using pulsed UV light treatment by [33]. It was shown that the pulsed UV light can be used as an alternative method to inactivate *S. aureus* in milk. Referance [34] showed that *E. coli* W1485 was reduced by 7.8 log in skimmed milk, but 4.1 log in full-fat raw milk with UV light treatment by using coiled tube reactor. They also reported that Bacillus cereus endospores were more resistant than E. coli W1485 and that these endospores were reduced by only 2.72 and 2.65 log in skimmed milk and full fat milk, respectively. In another study, inactivation of *E. coli* O157: H7 in bovine milk exposed at 254 nm was higher than at 222 and 282 nm at the same UV doses. The reductions in E. coli O157:H7 at 254 nm using the doses of 5, 10 and 20 mJ/cm2 were 1.81, 2.38 and 2.95 log respectively [35].

Authors concluded that this treatment showed an interesting surface microbial decontamination and prolonged cheese shelf-life with minimum transmittance inside the product. Similarly, [36] used different UV doses on the surface of Kashar cheese and application of UV-C (1.926 kJ/m2) was able to achieve approximately 2–3 log reduction in mold population. Reference [37] investigated the efficacy of pulsed UV light for inactivation of inoculated *Penicillium roqueforti* and *Listeria monocytogenes* of hard cheeses packaged and unpackaged. The reduction of *P. roqueforti* was 1.32 log and 1.24 log in packaged and unpackaged cheeses, respectively. *L. monocytogenes* was reduced by over 2.8 log for packaged and unpackaged cheeses. They reported that pulsed UV light has potential to inactivate *P. roqueforti* and *L. monocytogenes* on the surface of hard cheeses. Reference [38] examined the effectiveness of pulsed-light (PL) treatment on the inactivation of the spoilage microorganisms on cheese surface in order to determine the effects of inoculums level and cheese surface topography and the presence of clear polyethylene packaging. Inoculated cheese samples were exposed to PL doses of 1.02–12.29 J/cm2.

**VII.Conclusion**

In current scenario, UV light processing have made it a feasible option for commercial application in dairy and food processing. As a non thermal alternative to conventional heat processing, UV light has a large potential to be used for pasteurization of liquids, as a post lethality treatment in controlling microbial contamination on surfaces of solid foods like meats and cheese surfaces, and as a means for the shelf life extension of fresh produce. UV light processing can improve safety of solid and liquid foods without appreciable loss in quality or nutrient content.

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