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Ultraviolet Pasteurization for Food Industry

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Abstract This article reviews the status and scope of ultraviolet (UV) light technology in food processing industry for control of foodborne pathogens and spoilage organisms for food safety and shelf life extension. The literature suggests that there have been extensive studies on application of ultraviolet light for disinfection of apple ciders. FDA acceptable reduction of pathogens and spoilage organisms were reported by UV treatment of for apple cider. Several recent studies on UV treatment of milk suggest that there is more work needed to improve design of UV reactors for raw milk processing. Fresh produce industry will also benefit from UV processing so that occurrence of frequent outbreaks can be avoided. A brief review of recent applications in produce industry has also been reported. Finally a recommendation was made for future direction of UV application research in food processing industry.

Keywords Ultraviolet processing, nonthermal processing, food processing, UV, UV-C

1. Introduction

Deterioration of foods by pathogenic and spoilage microorganisms can be minimized by food processing and preservation techniques. Frequent outbreaks of foodborne pathogens are associated with fresh produce, milk and fruit juices. Currently, produce industry uses chemicals and fumigants to control pathogens in packing and handling industries. The liquid foods and dairy industry uses thermal pasteurization methods to disinfect food pathogens and extend the shelf-life of products. Though thermal methods are effective in inactivating microorganisms, thermal processing negatively affects foods through losses in vitamins; and changes in sensory properties, such as color, flavor and wholesomeness (Montenegro et al. 2002). Moreover, thermal processing is not practical in fresh produce industry. Thermal pasteurization also affects enzyme inactivation, lipid oxidation, protein denaturation and non-enzymatic browning. Therefore nonthermal processing methods are being studies as alternative food processing techniques. Currently several nonthermal technologies are under research. Some of these technologies are ultrasound (US), high-pressure processing (HPP), pulsed electric fields (PEF), pulsed light treatment (PL), ultraviolet light (UV), and non-thermal atmospheric pressure plasma (NTAP). These novel non-thermal methods may be useful in inactivating foodborne pathogens and spoilage microorganisms from a range of solid and liquid foods (Montenegro et al. 2002; Pereira and Vicente 2009; Song et al. 2009; Ekem and Akan 2006; Purevdorj et al. 2002; Critzer et al. 2007; Deng et al. 2007). UV irradiation is considered one of the effective means of disinfection, which excludes the necessity of heat to get rid of microorganisms (Sastry et al. 2008).

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2. Ultraviolet Light

There are three regions of ultraviolet light within the electromagnetic spectrum. These are the UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (200–280 nm). UV light exhibits germicidal properties in the UV-C region. The inactivation efficiency follows a bell-shaped curve where maximum inactivation occurs approximately at the range of 254 to 264 nm. However, typical mercury UV lamps deliver at 254 nm maximum. Therefore, it is usually mentioned that UV inactivation is at 254 nm. Several studies suggest that the destruction of microorganisms occurs due to the penetration of UV-C light into the outer membranes of the cells leading to tremendous damage of the DNA owing to the formation of thymine dimers, which prevent the microorganism from undertaking DNA transcription and replication, eventually leading to cell death in the UV-C light disinfection process (Bank et al. 1990; Bintsis et al. 2000; Miller et al. 1999).

3. Penetration and Absorption of Ultraviolet Light in Food

UV light penetrates food materials only up to several millimeters depending upon the optical properties of the food. UV light can easily penetrate water since it is transparent to the wavelengths produced. UV light cannot penetrate milk and other turbid foods as well, so opaque foods need to be presented to the system as a thin layer. Guerrero-Beltran and Barbosa-Canovas (2004) stated that the color or the turbidity

of the liquid influences the optical absorption coefficient of the liquid. The penetration capacity of the UV light reduces as the absorption coefficient increases. Therefore, it is essential to understand that enhancing the penetrative depth will be beneficial for UV light treatment of foods with higher coefficients of absorption. Presentation of food in a thin film may result in an increase in the efficiency of microorganism inactivation.

4. Effect of UV on Food Components and Quality

UV light exposure initiates free radical oxidation and catalyzes other stages of the oxidation process. Lipid radicals, superoxide radicals (SOR), and H2O2 are formed due to UV light (Kolakowska 2003). SOR can further induce carbohydrate cross linking, protein cross linking, protein fragmentation, peroxidation of unsaturated fatty acid, and loss of membrane fluidity function. Denaturation of components such as proteins, enzymes, and amino acids (especially amino acids with aromatic compounds) in milk may occur with UV radiation, thereby also bringing about textural changes. Water also absorbs UV photons and produces OH- and H+ radicals, which in turn aids changes in other food components. Kolakowska (2003) reported that there are obvious changes in the chemical composition of food components and product quality deterioration when the UV light treatment is applied in high doses. Therefore, it is mandatory to properly optimize the disinfection process so that the quality of the food products is maintained and its safety is ensured. Normally, microbial inactivation can be achieved within seconds to minutes depending upon the opacity of the food products and microorganism type.

In general, using UV light treatment for food has been found not to cause any adverse effects, especially if UV light is applied in moderate amounts (Krishnamurthy 2006). However, the modification and optimization of the UV light treatment might be necessary for successful implementation of the process with regard to some foods.

5. UV Disinfection of Liquid Foods

New regulations imposed by FDA stipulate the implementation of Hazard Analysis and Critical Control Point (HACCP) in fruit and vegetable juice processing operations (66 FR 6137). This regulation requiring 5-log reduction of pathogens has necessitated the development of affordable technology. The efficacy of UV irradiation to control pathogens in apple cider has been the focus of recent studies (Hanes et al. 2002; Wright et al. 2000; Basaran et al. 2004).

Wright and colleagues (2000) inoculated apple cider with a cocktail of five *Escherichia coli* O157:H7 strains to an approximate level of 106 CFU/ml and placed the stained apple cider in thin films through the Cider-10uv model (Ideal Horizons, Poultney, VT) UV disinfection unit through an UV radiation at 254 nm (Wright et al. 2000). The flow rates ranged from 60 to 90 l/h to generate UV doses between 9.4 and 61 mJ/cm^2. The mean log reduction was 3.8 log CFU/ml (Wright et al. 2000). They suggested that if the apparatus was modified to increase the intensity of UV irradiation in addition to a maximal flow rate, *E. coli* reduction would be higher and at faster rates. The levels of yeast and mold counts in the cider also influenced the reduction of microbial counts (Wright et al. 2000).

Choi and Nielsen (2005) demonstrated that UV pasteurized apple cider were superior in color and overall sensory scores compared to thermally pasteurized apple cider. UV-irradiated samples were lower in soluble solids for the first 7 days and showed no significant difference in consumer acceptability (Choi and Nielsen 2005).

Studies using apple cider that utilized the CiderSure 3500 UV apparatus (FPE, Inc., Rochester, NY) confirmed the ability of the apparatus to achieve a 5-log reduction of *Cryptosporidium parvuum* and *E. coli* (Hanes et al. 2002; Basaran et al. 2004). The apparatus was designed to allow the apple cider to pass through a series of eight germicidal UV lamps in thin films. The wavelength and intensity inside the CiderSure apparatus was 254 nm and 14.3 mJ/cm^2 of UV irradiation, respectively, with exposure times between 1.2 and 1.9 sec (Hanes et al. 2002). A computer-monitored UV sensor was placed within the apparatus to adjust the flow rate in accordance with the sensor readings to ensure that all of the cider received the correct amount of UV light.

In a study conducted by Basaran et al. (2004), ciders with different solid compositions and concentrations were subjected to different filtration treatments that produced lighter and darker ciders. These variables were deliberately included to test the UV apparatus for its ability to overcome such differences and still achieve a 5-log reduction in *E. coli* O157:H7. Three strains of *E. coli* O157:H7 were used in the study (ATCC 43889, 43895, and 43933). The apple cider samples were inoculated with each of the three strains and then passed through the CiderSure UV-irradiation unit at 4°C. The results showed a 6.12 ± 0.36, 5.83 ± 0.11, and 5.87 ± 0.11 log reduction for the three *E. coli* O157:H7 strains, respectively (Basaran et al. 2004). They also found >5 log reduction of a surrogate organism *E.coli* ATCC 25922 in a validation test at a cider mill production setting. Quintero-Ramos et al. (2004) showed that apple cider's pH did not have a significant influence on reduction of *E.coli* 25922 in apple cider. The results showed existence of a nonlinear relationship between *E. coli* survival rate and UV dose.

Koutchama et al. (2004) studied the efficacy of UV light on the destruction of *E. coli* K-12 in apple juice using laminar and turbulent flow UV reactors. They concluded that increase in flow rate of UV radiation increases the inactivation of *E. coli* in apple juice when turbulent flow UV reactors are used because of better mixing conditions inside the UV reactor. On examining the physical and chemical parameters of the apple juices, they found that absorbance consistently affected inactivation of *E. coli* K 12 in the apple juice.

Matak (2004) studied the efficacy of UV light in inacti-

vating *E. coli* K 12 for different fat percentages of milk at different temperatures (4℃ and 20℃) using CiderSure 3500 apparatus. They found that a 0.73 to 2.29 log reduction of *E. coli* in different fat percentages of milk. *Listeria monocytogenes* was inactivated to non-detectable levels from 107 CFU/ml in goat milk when UV light at cumulative UV dose of 15.8 ±1.6 mJ/cm^2 was used for an exposure time of 18 sec (Re- 5187) (Matak et al. 2005).

Reinemann et al. (2006) achieved 3-log reduction of natural flora in raw cow milk with UV dose of 1.5 J/ml using UV reactors pure version 1 and 2 in their laboratory. These reactors contain low pressure mercury UV lamp inside the quartz glass sleeve and this enclosed in a stainless steel chamber.

Most recently our group (Choudhary et al., 2011a; Bandla et al., 2012) examined efficiency of Dean flow UV reactors on inactivation of *E.coli* W 1485 and *Bacillus cereus* endospores in raw cow milk, commercially processed skimmed milk, and soymilk. We found >7 log reduction of *E.coli* W 1485 in skimmed milk and >5 Log reduction of the same organism for soymilk using a Dean flow reactor with 1.6 mm diameter with a UV dose of 0.05 J/ml. With raw cow milk using the same reactor at the same UV dose, we found a 4 log reduction of *E.coli* W 1485. A higher UV dose for raw cow milk than skimmed milk and soymilk was recommended due to the lower UV transmission of raw cow milk.

6. UV Treatment of Fresh Produce

There are several non-thermal pathogen reduction techniques for fresh produce. These alterative treatment processes may be chemical or non-chemical in nature. Most chemical treatment techniques include chlorine, bromine, iodine, trisodium phosphate, hydrogen peroxide, or ozone. Non-chemical treatments include microwave, ultrasound, ionizing radiation and ultraviolet (UV). UV is a promising technology of surface decontamination because it is safe and does not leave any residual effect in treated food products. In addition to being germicidal, UV treatments have been found to induce desirable changes in health constituents of fruits and vegetables such as increased antioxidant capacity and increased shelf life (Wang et al., 2009). UV systems are affordable as they require low initial investment and a lower operating cost of treatment (Yuan et al. 2004).

Several studies on UV treatment of fruits and vegetables were conducted for increasing shelf life and improving product quality (Lu et al. 1991; Bialka and Demirci 2007, Pombo et al. 2009). Lu et al. (1991) studied the effect of low levels of UVC radiation (130-4000 mJ/cm2) on the shelf life of peaches and tomatoes, and reported reduced post-harvest rots and delayed ripening.

Bialka and Demirci (2007) reported using UV treatments for decontamination of *E. coli* and *Salmonella enterica* on blueberries. After 60 s of pulsed UV treatment, they reported a maximum reduction of 4.3 and 2.9 log CFU/g for *Salmonella* and *E. coli* respectively. Pulsed UV is more expensive than continuous-wave UV. The low initial cost of continuous-wave UV as well as the lack of extensive safety equipment may benefit those with little capital to invest, which applies to most commercial blueberry packinghouses.

7. Conclusions

Promising opportunity exists for adopting ultraviolet processing in a small or large scale food and dairy processing industry. With the approval of FDA, several new applications of UV processing are being tested and validated by the dairy and food industries in the United States of America. With potential for offering superior organoleptic qualities of food products at lower initial investment and operating costs, the authors foresee a great success for adoption of UV processing technology by the food processing industry.

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