Applications and Efficacy of UV Light for Foods

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ABSTRACT

Ultraviolet light (UV) light holds considerable promise in food processing as an alternative to traditional thermal processing. Its applications include pasteurization of juices, post lethality treatment for meats, treatment of food contact surfaces and to extend the shelf-life of fresh produce. This article will review published studies and commercial applications that utilize UV treatment for solid and liquid foods. Designs of UV reactors that were tested in the author's lab for juice and apple cider treatment are discussed. Future research needed to extend the range of UV light applications in food processing industry is presented.

INTRODUCTION

The use of ultraviolet light (UV) light is well established for water treatment, air disinfection and surface decontamination. With the growing negative public reaction over chemicals added to foods, UV light holds considerable promise in food processing. As a physical preservation method, UV irradiation has a positive consumer image. The US Food and Drug Administration (FDA) and US Department of Agriculture (USDA) have concluded that the use of UV irradiation is safe. In 2000, the FDA approved UV-light as alternative treatment to thermal pasteurization of fresh juice products (US FDA 2000). The performance criterion defined by FDA for fruit and vegetable juice processing is a 5-$\log_{10}$ reduction in the number of the target pathogen of concern (US FDA 2000). In addition, the definition of "pasteurization" for foods was recently revised and now includes any process, treatment, or combination thereof, which is applied to food to reduce the most microorganism(s) of public health significance (Food Chemical News 2004). The processes and technologies examined in the above mentioned report include UV irradiation as an alternative to heat that can be used for pasteurization purposes.

This article will provide a general review of the applications and efficacy of UV light treatment of foods. Consideration will be given to research that describes UV treatment as an alternative preservation method for solid and liquid foods. In addition, the emphasis is given to the future research required to extend the range of UV light applications in the food processing industry.

UV SURFACE TREATMENT: RESEARCH AND FOOD INDUSTRIAL PROCESSES

UV light is used in the food industry for disinfecting surfaces. Applications include decontamination of surfaces of equipment in bakeries, cheese and meat plants, as an adjunct to usual cleaning and sanitizing practices, and for decontamination of conveyor surfaces and packaging containers such as boxes, caps, bottles, cartons, tubes, films and foils. Despite the efficacy of UV light to disinfect smooth surfaces, there are relatively few applications of this technology in the food processing industry. The restricted range of commercially available equipment for disinfecting solids may contribute to its limited use. In addition, most kinetic data of microbial inactivation were obtained in suspension in aqueous media or air. These data are of limited use in predicting the surface disinfection rate. Since complex interactions may occur between microorganisms and surface materials, such as shielding effects from incident UV, efficacy of UV light depends on surface structure or topography.

The recent outbreaks of *Listeria* in Ready-To-Eat (RTE) meats prompted the USDA to implement a regulation to control *Listeria* in facilities producing RTE products (FSIS 2003). Alternatives 1 and 2 of this regulation include the use of a post lethality treatment and/or an antimicrobial agent together or separately to reduce or eliminate the bacterium on the product. The ability of UV light to disinfect surfaces of meat products has been reported in the literature. A few studies have evaluated the use of UV irradiation to reduce levels of *Escherichia coli* and *Salmonella* on pork skin and muscle (Wong et al.1998); *Listeria monocy-*

togenes on chicken meat (Kim et al. 2002), and *Salmonella* Typhimurium on poultry carcasses (Wallner-Pendelton et al. 1994). Despite the known limited ability of UV light to penetrate rough food surfaces such as meats, these studies demonstrated that UV light has the potential to reduce bacterial contamination on food surfaces and therefore has the potential to be used as post lethality treatment to control *L. monocytogenes* and other pathogens of concern in meat and poultry processing facilities.

An example of a commercially available system to decontaminate surfaces of foods is the UV tumbling process that was developed by C&S Equipment Company (www.cs-equipment.com) (Chapman 2003). The company incorporated either a rotating drum or screw conveyor that lifts and tumbles the product to ensure exposure to the UV source. The unit can be used to treat fresh products (vegetables, fruits, meats, etc.), frozen products (vegetables, fruits, meats, seafood, bakery products, etc.), and cooked, refrigerated products (pasta, cheese, etc.). The C&S Equipment Company designs solutions for these problems using the patented technology of Steril-Aire™ UV Emitters. These emitters are sleeved in plastic to meet the food safety requirements of food processing facilities. The patented design allows emitters to work efficiently in the cold environment of refrigerated or chiller coils, where competitive units lose their effectiveness. Examples of UV units currently used in commercial processing facilities include: a) UV tumbling drum in operation for chicken and beef fajita strips (cooked and IQF frozen) with a capacity 6,000 – 7,000 lb/h; b) cooked and IQF frozen hamburger patty treatment (hooded conveyor with turn over), with a capacity 3,000 lb/h; and c) a deli meat system (custom conveyor with UVC hood) for formed deli ham logs, with a capacity of 10,000 lb/h.

UV treatment has also been applied to prolong shelf life of wrapped partially baked baguettes to minimize post baking contamination (Doulia et al. 2000). UV light has been documented be effective in reducing various bacterial populations on egg shell surfaces including total aerobic plate count (Chavez et al. 2001), *S. Typhimurium* and *E. coli* (Coufal et al. 2002), and *Yersinia enterocolitica* (Favier et al. 2001). Despite the urgent need to improve egg safety, UV treatment of eggs has not been yet commercially implemented.

LIQUID FOODS AND BEVERAGES

UV light has considerable promise to reduce the levels of microbial contamination for a wide range of liquid foods and beverages. Due to the presence of color compounds, organic solutes and suspended matter, liquid foods such as fresh juice products and beverages transmit relatively little UV light, and this low transmission lowers the performance efficiency of the UV pasteurization processes. Comparison of absorption coefficients (Figure 1) indicates

that the absorbance of fresh juices is significantly higher that that for water. In addition, the absorbance and turbidity of clear fresh juices and juices with pulp varies considerably. Clear apple juice has a low absorbance, with absorption coefficients about 11 cm^{-1}, whereas orange juice can have absorbances close to 50 cm^{-1} (Koutchma, Keller et. al. 2004). The turbidity of juices arises from the presence of suspended solids and can be in a range from 1000 NTU for apple and other clear juices to > 4000 NTU for opaque varieties such as carrot, orange and pineapple juices. The juices also have different Brix (soluble solids content) and pH levels, as well as varying viscosities (Figure 2). An increase in viscosity significantly increases the power requirements to maintain the unique and desirable fluid flow characteristics of the individual reactor designs. This means that the combination of physical properties, such as liquid density and viscosity, must to be considered to meet the required pasteurization standard of a 5-log$_{10}$ reduction in the number of the target pathogen of concern for fresh juices. Exposure of microorganisms to UV-light or residence time in the UV reactor should be sufficient to achieve the required level of inactivation.
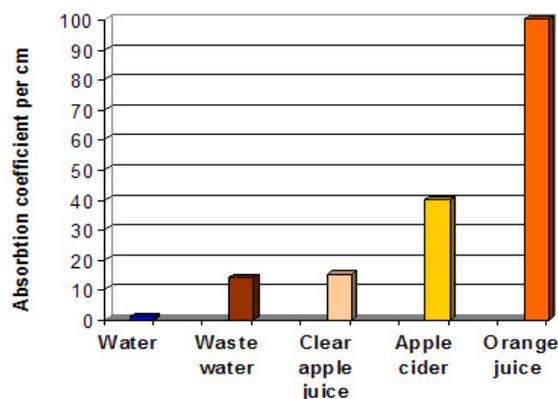

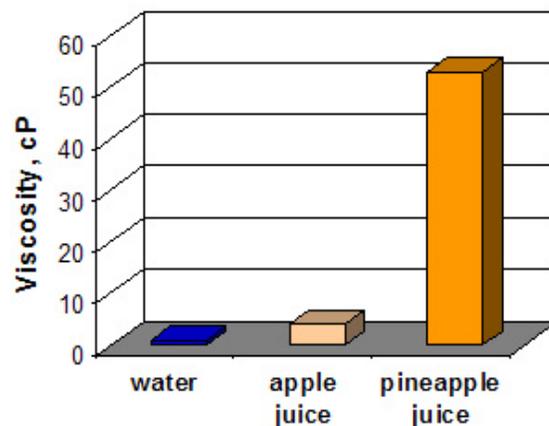**Figure 1**. Comparison of the absorption coefficients of water and fresh juices.

Figure 2. Comparison of the viscosity of water and fresh juices.

REACTOR DESIGNS FOR THE UV TREATMENT OF LIQUID FOODS

The correct UV reactor design can reduce the interference of high UV absorbance and viscosity associated with some food products and therefore improves the inactivation efficiency. The flow pattern inside the UV reactor strongly influences the total applied UV dose, since the position and the residence time of the microorganisms in certain regions of the irradiance field can vary significantly. Currently, different continuous flow UV reactor designs are being evaluated for use in fresh juice pasteurization. The first design approach uses an extremely thin film UV reactor to decrease the path length and thus avoid problems associated with lack of penetration. Thin film reactors are characterized by laminar flow with a parabolic velocity profile. The maximum velocity of the liquid is observed in the center, which is twice as fast as the average velocity of the liquid; this results in non-uniform processing conditions (Koutchma and Parisi 2004). The two laminar flow designs shown in Figure 3 are a thin film CiderSure reactor (FPE Inc., Macedon, NY) and the Taylor-Couette flow UV reactor (Forney and Pierson 2004). In the CiderSure unit (Figure 3a), low-pressure mercury arc lamps are mounted within a quartz sleeve running centrally through the reactor. Juice is pumped from a reservoir through a 0.08 cm annular gap between the inner surface of the chamber and the outer surface of the quartz sleeve. Forney and Pierson (2004) developed a UV reactor
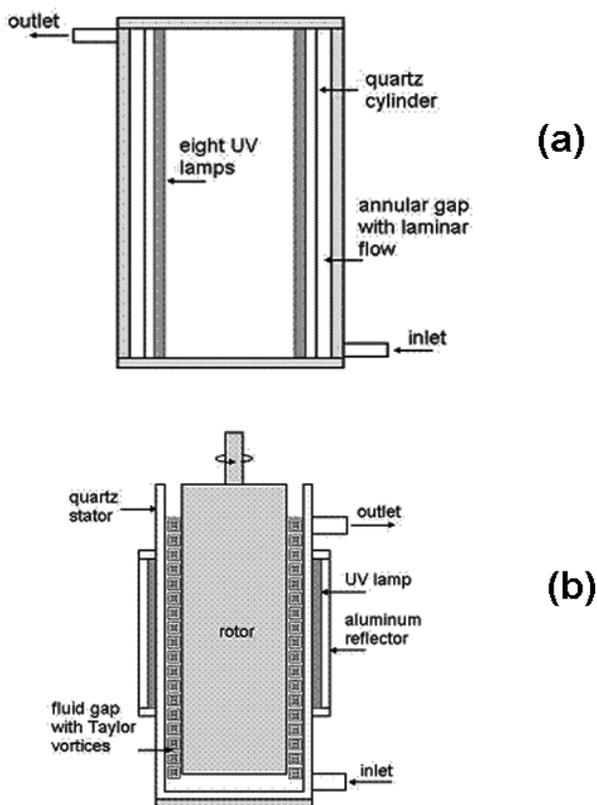

(a)

(b)

Figure 3. Schematics of (a) a laminar thin film reactor (Cider Sure) and (b) a laminar Taylor - Couette UV reactor..

that pumps fluid through the annular gap between two concentric cylinders, as shown in Figure 3b. To provide sufficient exposure and to reduce the fluid boundary layer thickness next to the UV radiation source contained within the outer stationary cylinder, the smaller inner cylinder (called Taylor-Couette flow) consists of laminar vortices that both fill the annular gap of several millimeters and circumscribe the inner cylinder.

A second design approach increases the turbulence within a UV reactor to bring all material into close proximity of the UV light during the treatment. The higher flow rates achieved under turbulent conditions provide improved homogeneity of the flow when the fastest flowing particle travels 1.1-1.2 times faster than the volume averaged particle, and each volume of the product will be exposed to UV light due to better mixing. Unfortunately, as turbulence increases, the pressure drops across the reactor, and the high flow rate to ensure turbulent flow is coupled to a reduced fluid residence time which can lead to complications scale-up. In the Aquionics UV reactor (Hanovia Ltd, Slough, England), treatment is achieved by passing liquid through a stainless steel chamber containing UV emitting low-pressure arc-tubes (Figure 4a). Each single arc-tube is mounted in a quartz sleeve and fitted within the chamber allowing the liquid to pass the sleeve on all sides (Koutchma et al. 2004). The UV module (Salcor Inc, CA) shown in Figure 4b contains a coiled Teflon tube with 24 ultraviolet lamps and reflectors. The coiled tube promotes additional turbulence and causes a secondary eddy flow effect, also known as a Dean effect, and results in a more uniform velocity and residence time distribution. The lamps and reflectors are placed both inside and outside the coiled tube, increasing not only UV irradiance of the flowing liquid, but its uniformity as well.

The current 21 CFR 179 food additive regulation recognizes these distinctions and stipulates the use of turbulent flow for UV light reactors used to treat fresh juices. The presence of dead spaces in the reactor may affect the average residence time of the fluid in the reactor and requires tracer analysis to measure the residence time distribution. A desirable design for UV reactors is pure plug flow, which indicates that every element of liquid resides in the reactor for the same time period and all microorganisms would receive an equivalent UV dose, if the UV irradiance were equal at all points. However, it is important to recognize that treatment of some high viscosity fluids or fluids with pulp will be incompatible with some of the reactor designs.

UV LIGHT SOURCES

Several alternative UV sources types, such as continuous UV low-pressure and medium-pressure mercury lamps, pulsed-UV, and excimer lamp technologies have been developed and can be applied to foods. However, the effi-

cacy and specific characteristics of common UV light sources that are used today for water treatment have not been evaluated for food applications. Traditional low pressure mercury UV lamps at 254 nm were used for applications for disinfection of food surfaces and food liquid treatments discussed previously.

There are no reports available, except for the study made by Warriner et al. (2002), of applications of excimer lamp technology for foods. UV–excimer lamps can produce monochromatic output that can be tuned to the wavelength of interest by the combination with gases. Excimer lamps also have an advantage of extremely low output and are able to operate at much lower surface temperatures. Thus they can provide an advantage by avoiding fouling behavior by liquid foods. Warriner et al. (2002) demonstrated that UV-excimer light was effectively used for sterilization of the packaging carton surfaces.

A few studies recently reported an application of UV pulsed light for foods. A pulsed xenon UV-light treatment was applied to inactivate spores of *Aspergillus niger* in corn meal. However, low penetration power and excessive heat buildup inside the chamber was reported (Jun et al. 2003). Pulsed UV light was found to be effective in inactivation *Saccharomyces cerevisiae* (Takeshita et al. 2003). In addition, the pulsed UV light was used to control microbial levels on fresh processed lettuce. Allende and Artes (2003) reported that pulsed UV light was effective for

Figure 4. Schematics of turbulent channel reactor and Dean flow reactor.

reducing the levels of psychrotrophic and coliform bacteria as well as yeast without adversely affecting the sensory quality of lettuce. Sharma and Demirci (2003) demonstrated that pulsed UV light holds promise for eliminating pathogens such as *E. coli* O157:H7 from alfalfa seeds.

UV LIGHT FOOD PROCESSING RESEARCH AT NCFST

The National Center for Food Safety & Technology (NCFST) is a unique research consortium carrying out research addressing issues in the area of food safety and technology. In this facility, located at the Illinois Institute of Technology's Moffett Campus, Summit-Argo, Illinois, scientists from industry, academia and the FDA work cooperatively to analyze and solve problems related to the safety aspects of novel food processing and packaging technologies. The NCFST has unique capabilities in UV light food processing and, with support from the FDA, has previously evaluated both laminar thin film and turbulent flow reactors for the pasteurization of juices. To conduct process validation studies and to ensure the successful scale-up of UV light for applications in liquid food and beverage processing, the UV reactors can be set up in a biosafety level 2 pilot plant laboratory. An annular singular lamp reactor is currently used for microbial inactivation studies to determine the dose needed to achieve the required level of microbial inactivation. The lessons learned at the NCFST in the course of the studies of UV light for processing of juices and beverages will undoubtedly illuminate areas for further research for food applications. The findings should lead to the identification of new opportunities to make UV processing more consistent and effective, therefore allowing for further commercialization of this technology in the food industry.

SUMMARY

The recent advances in the science and engineering of UV light irradiation have made it a viable option for commercial application in food processing. As a nonthermal alternative to traditional thermal processing, UV light has a potential to be used for pasteurization of juices and beverages, as a post lethality treatment in controlling microbial contamination on meats and shell eggs surfaces, and as a means for the shelf life extension of fresh produce. UV light processing can improve safety of selected solid and liquid foods without appreciable loss in quality or nutrient content.

However, to improve the efficacy of UV light for food application, the following areas of research need to be conducted. To predict UV disinfection rates on food surfaces, more kinetic inactivation data need to be obtained for pathogen and spoilage microorganisms, taking into account interactions between microorganisms and surface
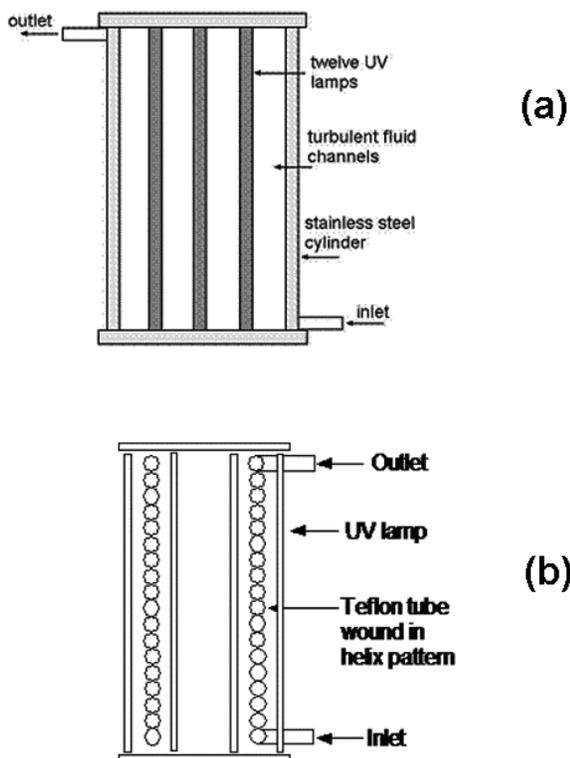
materials, such as shielding effects from incident UV and their dependency on surface structure or topography. In addition, novel methods and models need to be developed to measure the inactivation rates or dose–response behavior of food pathogens in highly absorptive and viscous food liquids, such as juices and beverages. The correct choice and/or design of the UV reactor, its flow characteristics and UV source can reduce the interference of high UV absorptivity and viscosity associated with some liquid food products and improves inactivation efficiency. The development of validation methods for food processing facilities requires identification of surrogate microorganisms or suitable actinometers for pathogens. Research in the indicated areas can ensure the effectiveness of UV light for microbial inactivation, stimulate the growing interest in the nonthermal technologies, and assist in the successful commercialization of UV light for food processing applications.

REFERENCES

Allendre, A., and Artes, F. 2003. Combined ultraviolet –C and modified atmosphere packaging treatments for reducing microbial growth of fresh processed lettuce. Food Sci. Technol. /LWT , 36: 779-786.

Chapman, S. 2003. New machines use tumbling process to decontaminate food. Food Chem. News, 10: 20.

Coufal, C.D., Chavez, C., Knape, K.D., and Carey, J.B. 2003. Evaluation of ultraviolet light sanitation of broiler hatching eggs. Poul. Sci., 82: 754-759.

Doulia, D., Katsinis, G., and Mougin, B. 2000. Prolongation of the microbial shelf life of wrapped part baked baguettes. Intl. J. Food Propert. 3(3): 447-457.

Favier, G., Escudero, M., and De Guzman, A. 2001. Effect of Clorine, Sodium Chloride, Trisodium Phosphate and Ultraviolet Radiation on the Reduction of Yersinia enterocolitica and Mesophilic Aerobic Bacteria from Eggshell Surface. Journal of Food Protection 64, 10: 1621-1623.

Forney, L., and Pierson, J.A. 2004. Ultraviolet disinfection, Resource, 11, 7.

FSIS. FSIS rule designed to Reduce Listeria monocytogenes in Ready to Eat Meat and Poultry Products. April 2003. http://www.fisi.usda.gov/OA/background/lmfinal.htm

Jun, S., Iruddayyaaraj, J., Demirci, A., and Geiser, D. 2003. Pulsed UV-light treatment of corn meal for inactivation of Aspergillus niger spores. International J. Food Sci. Technol., 38: 883-888.

Kim, T., Silva, J., and Chen, T. 2002. Effects of UV irradiation on selected pathogens in peptone water and on stainless steel and chicken meat. J. Food Protect., 65 (7): 1142-1145.

Koutchma, T., and Parisi, B. 2004. Biodosimetry of E. coli UV inactivation in model juices with regard to dose and RTD distribution in annular UV reactors. J. Food Sci., 69:14-22.

Koutchma, T., Keller, S., Parisi, B., and Chirtel, S. 2004. Ultraviolet disinfection of juice products in laminar and turbulent flow reactors. Innovat. Food Sci. and Emerg. Technol., 5, 179-189.

Pasteurization redefined by USDA committee. Food Chemical News, 2004, 46(3).

Sharma, R.R., and Demirci, A. 2003. Inactivation of Escherichia coli O157:H7 on inoculated alfalfa seeds with pulsed ultraviolet light and response surface modeling. J. Food Sci., 68(4): 1448-1453.

Takeshita, K., Shibato, J., Sameshima,T. 2003. Damage of yeast cells induced by pulsed light irradiation. Intl. J. Food Microbiol., 85: 151-158.

U. S. Food and Drug Administration. 2000. 21 CFR Part 179. Irradiation in the production, processing and handling of food. Fed. Regist. 65, 71056-71058.

Wallner-Pendleton, E.A., Sumner, S.S., Froning, G., and Stetson, L. 1994. The use of ultraviolet radiation to reduce Salmonella and psychrotrophic bacterial contamination on poultry carcasses. Poul. Sci. 73: 1327-1333.

Warriner, K., Kolstad, J., Rumsby, J., and Waites, W. 2002. Carton sterilization by uv-C excimer laser light: recovery of Bacillus subtilis spores on vegetable extracts and food simulation matrices. J. Appl. Microbiol., 92: 1051-1057.

Wong, E., Linton, R., and Gerrard, D. 1998. Reduction of Escherichia coli and Salmonella senftenberg on pork skin and pork muscle using ultraviolet light. Food Microbiol., 15: 415-423.

Erratum

Equations 11 and 12 in the article by Dr. Charles Sharpless in IUVA News, Vol. 7, No. 3 contained a typo in which square brackets were used instead of parentheses. The correct equations are:

$$[11] \qquad k_f^w = \frac{k_t^{'}}{E_{avg}^{'}(P)}$$

$$[12] \qquad R_{OH}^{w} = \frac{R_{OH}}{E_{avg}^{'}(H_2O_2)}$$

Here, $E'_{avg}(P)$ and $E'_{avg}(H_2O_2)$ refer to the average fluence rate weighted by the pollutant and H_2O_2 action spectrum, respectively.