Advantages and Limitations on Processing Foods by UV Light

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Review: Advantages and Limitations on Processing Foods by UV Light

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Fresh food products can be processed using UV light as a germicidal medium to reduce the food-borne microbial load. Water has been treated with UV light to obtain drinking water for quite some time. Pumpable fruit and vegetable products are generally very suitable for processing by UV light to reduce the microbial load. Today, most of these products are pasteurised to obtain microbiologically safe and nutritious products. However, pasteurisation can change the taste and flavour of such products because of the temperature and processing time. Juices from different sources can be treated by exposure to UV light at different doses. On the other hand, variables such as flow rate, exposure time, type of fruit product, juice colour and juice composition, among other variables, need to be studied to obtain fruit products with reduced microbial load, increased shelf life and adequate sensory and nutritional characteristics. Reduction of microbial load through UV light application as a disinfection medium for food products other than liquids is also being studied. Moreover, UV technology could be a source for pasteurisation of liquids, or disinfection of solid foods as an alternative technology, instead of thermal treatment or application of antimicrobial compounds.

Key Words: Ultraviolet radiation, UV processed food, UV light microbial effects, UV dosage, inactivation, disinfection, food preservation

INTRODUCTION

Non-thermal technologies are being applied in food processing as a viable alternative to thermal processing. They include pulsed electric fields, ultraviolet light processing, minimal thermal processes and batch or continuous high pressure processing, among many others. These alternative technologies can deliver food products without hazardous microorganisms and enzymes that may reduce the nutritional and sensory characteristics of foods, which are often changed when thermal processes are applied (Butz and Tauscher, 2002).

Ultraviolet light can be used to inactivate many types of organisms, including viruses, but it is currently known that UV light only works on surfaces or clear liquids such as water. UV light radiation has been used for many years in pharmaceutical, electronic, and aquaculture industries as a disinfection medium (Anonymous, 2002b). A monochromatic UV light (254 nm) is obtained by using low-pressure mercury (LPM) vapour germicidal lamps. The UV light acts as a physical method for microbial disinfection (Anonymous, 2002b). Microorganisms that are exposed to UV light are affected at the DNA (deoxyribonucleic acid) level. Thus, the injured reproduction systems of cells lead to their death. Use of UV light for food disinfection has been wrongly associated with loss of nutritional value and undesirable appearance, which may be true when using very high UV doses (Gardner and Shama, 2000).

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ULTRAVIOLET LIGHT MICROBIAL EFFECTS

Ultraviolet Light

UV light has been used for surface treatment for disinfection (Sizer and Balasubramaniam, 1999). However, today there is a growing interest in using ultraviolet light for food preservation. Radiation from the UV region of the electromagnetic spectrum can be used for the purpose of disinfection of liquid food products. The wavelength for UV processing ranges from 100 to 400 nm (Figure 1) (Sastry et al., 2000; Bintsis et al., 2000), and it may be classified as presented in Table 1.

The UV light, with some precaution, is easy to use and lethal to most types of microorganisms (Bintsis et al., 2000). The wavelength between 220 and 300 nm is considered germicidal against microorganisms such as bacteria, viruses, protozoa, moulds and yeasts, and algae (Morgan, 1989; Sizer and Balasubramaniam,

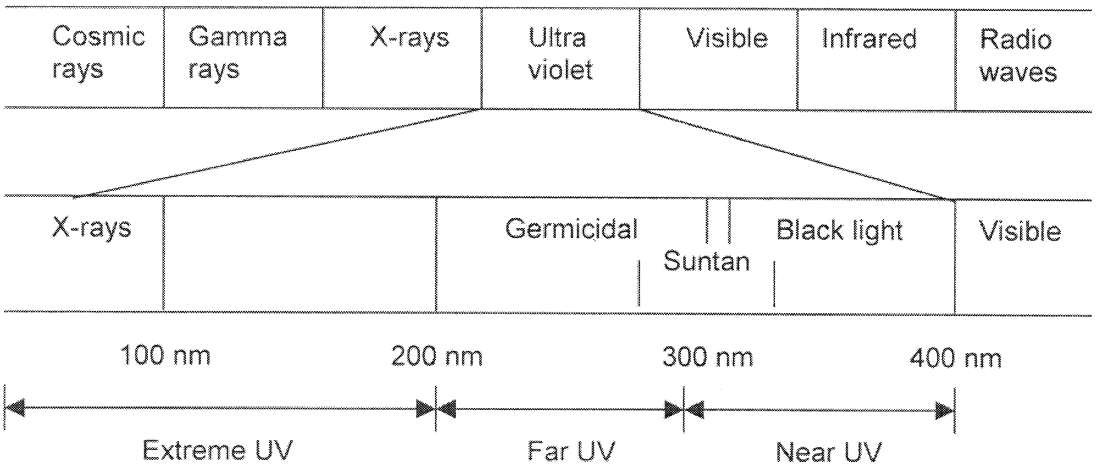

Figure 1. Electromagnetic spectrum (adapted from Snowball and Hornsey, 1988).

1999; Bintsis et al., 2000). The highest germicidal effect is obtained between 250 and 270 nm, but it may decrease as the wavelength is increased (e.g., above 300 nm, the germicidal effect is negated) (Bachmann, 1975). For this reason, a wavelength of 254 nm (UV-C, generated by LPM lamps) is used for disinfection of surfaces, water, and some food products. Bacteria suspended in air are more sensitive to UV-C light than bacteria suspended in liquids (Bintsis et al., 2000), due to the different penetration capacity of UV light through different physical media.

The photoinactivating process by UV-C is a physical method in which the energy is the germicidal medium. It does not produce undesirable by-products (Chang et al., 1985) that could change the sensory characteristics (taste, odour, and colour) in the final product (Anonymous, 2002b). Also, use of ultraviolet light for sterilisation or disinfection does not generate chemical residues. It is a dry, cold process that can be simple and effective at low cost in comparison with other sterilisation methods (Bachmann, 1975).

Another advantage when applying UV-C radiation is that it does not deliver residual radioactivity as ionising radiation (gamma radiation). However, UV-C light does not penetrate the target very deeply. Thus, it is more frequently used for surface sterilisation (Morgan, 1989). Radiation is more effective on surfaces or transparent materials such as air, water and polyethylene. In addition, the germicidal effect is obtained only by applying direct UV-C light on the target. It is not effective in the shade, in pores, or in orifices (Bachmann, 1975).

Table 1. Ultraviolet light characteristics.

Type	Wavelength	Range	Characteristics
UV-A	Long	320–400 nm	Changes in human skin (tanning)
UV-B	Medium	280–320 nm	Skin burning (cancer)
UV-C	Short	200–280 nm	Germicidal range (microorganisms)
UV-V		100–200 nm	Vacuum UV range

The microbial reduction rate with UV-C light can be obtained by applying low intensity for long periods or high intensity for short periods of time (Bachmann, 1975; Morgan, 1989). Due to the wide variety of organisms, including strains, the dose levels required for disinfection can vary according to the final effect required for each food product. Table 2 displays some examples of low and high dose data for several types of microorganisms.

Microbial Effects

The effect of UV radiation on microorganisms may vary from species to species and, in the same species, may depend on the strain, growth media, stage of culture (Chang et al., 1985; Wright et al., 2000), density of microorganisms and other characteristics, such as type and composition of the food. Fungi and yeasts (large microorganisms) are more resistant during disinfection; however, high microbial levels should be taken into account when using UV-C for disinfection (Bachmann, 1975).

The radiation absorbed by DNA may stop cell growth and lead to cell death (Liltved and Landfald, 2000). The UV-C light absorbed by DNA causes a physical shifting of electrons to render splitting of the DNA bonds, delay of reproduction or cell death (Anonymous, 2002a). This means the UV-C bactericidal effect is mainly at the nucleic acid level (Wright et al., 2000). A cross-linking between neighbouring thymine and cytosine (pyrimidine nucleoside bases) in the same DNA strand occurs because of the UV-C radiation. The most common DNA photoproducts are the cyclobutyl pyrimidine dimers. The resulting effect is that the DNA transcription and replication are

Table 2. Low and high UV-C light dosages (254 nm) needed for inhibiting 100% of several types of microorganisms.

Organism	Microorganism	Low dose (J/m^2)	Microorganism	High dose (J/m^2)
Algae	*Chlorella vulgaris*[a, b, c]	220	Blue green algae[d]	4200
Bacteria (vegetative)	*Bacillus megatherium*[a]	25	*Sarcina lutea*[a]	264
Bacteria (spores)	*Bacillus subtilis*[a, b, c]	220	*Bacillus anthracis*[d]	462
Molds	*Oospora lactis*[a, b]	110	*Aspergillus niger*[a, b, c]	3300
Viruses	Adeno virus type III[b]	45	Tobacco mosaic[a, b]	4400
Yeasts	Brewer's yeast[a, b, c]	66	*Saccharomyces* sp.[a, b, c]	176

[a]Adapted from Legan (1982). [b]Adapted from Cruver (1984). [c]Adapted from Collentro (1986). [d]Adapted from Anonymous (2002a).

blocked, compromising cellular functions and eventually leading to cell death. The cross-linking effects in the DNA are proportional to the amount of UV-C light exposure. UV-C irradiation might also produce DNA mutations in the injured organism (Snowball and Hornsey, 1988; Sastry et al., 2000).

Photoreactivation can occur when the UV-C injured cells are exposed to wavelengths higher than 330 nm (Liltved and Landfald, 2000). The damage occurring at the DNA level could be repaired by protein factors (DNA repair genes) (Yajima et al., 1995). The split nucleic acid by UV-C light treatment may be photoreactivated (fluorescent light) due to the activation of the enzyme photolyase that monomerises the dimer species (splitting of thymine and other pyridines) formed after the radiation process (Stevens et al., 1998). However, a dark environment might avoid photoreactivation of irradiated products (Stevens et al., 1998) or restore cells exposed to UV-C light.

A very important concern should be the application of the appropriate dose to ensure delivery of safe food products and to avoid the possibility of spoilage due to photoreactivation. If the UV-C light-treated cells are exposed within the light range of 330 to 480 nm, photoreactivation of the cells may increase the number of viable microorganisms. The reparation of cells has been correlated with the exposed light intensity (Liltved and Landfald, 2000). Hoyer (1998) reported photoreactivation of some microorganisms when they were exposed to visible light in the blue spectral range (Table 3). To avoid this disadvantage, the product should be maintained under refrigeration and/or dark packages should be used to store the product. Table 3 presents the doses required to obtain a 4-log reduction for several species of microorganisms after UV-C application. When less than $400\ J/m^2$ was applied to test microbial reduction, photoreactivated microorganisms were more resistant to UV-C light than non-reactivated microorganisms, which is in agreement with previous research (Hoyer, 1998; Sastry et al., 2000).

EVALUATING DOSES AND SURVIVAL MICROORGANISMS

Survival Microorganisms Modelling

When monochromatic UV-C light is transmitted through a medium, the attenuation of the intensity is described by the Lambert-Beer law:

$$I = I_o . e^{ad} \quad (1)$$

Table 3. Ultraviolet 254 nm exposure for 4-log microbial load reduction for drinking water disinfection (source: Hoyer, 1998; Sastry et al., 2000).

Microorganism	Exposure required without reactivation (J/m^2)	Exposure required with reactivation (J/m^2)
Escherichia coli ATCC 23958	50	200
Vibrio cholerae wild isolate	50	210
Citrobacter freundii	80	250
Escherichia coli ATCC 11229	100	280
Enterobacter cloacae	100	330
Yersinia enterocolitica	100	320
Klebsiella pneumoniae	110	310
Pseudomonas aeruginosa	110	190
Salmonella Typhimurium	130	250
Serratia marcescens	130	300
Salmonella Typhi	140	190
Enterocolitica faecium	170	200
Mycobacterium smegmatis	200	270

Table 4. Coefficient of absorption for liquid foods for UV-C at 254 nm (Shama, 1999).

Liquid food	α (cm^{-1})
Distilled water	0.007–0.01
Drinking water	0.02–0.1
Clear syrup	2–5
White wine	10
Red wine	30
Beer	10–20
Dark syrup	20–50
Milk	300

where I is the attenuated intensity, I_o is the incident monochromatic UV intensity, d is the depth reached by the UV light and α is the absorption coefficient of the liquid. Table 4 shows various absorption coefficients for liquid foods (Shama, 1999). The greater the colour or turbidity the liquid is, the greater the absorption coefficient, which means less penetration of light through the system.

UV intensity flux or irradiance is usually expressed in W/m^2, and the dose or radiant exposure is expressed as J/m^2 (Bintsis et al., 2000). The UV-C dose (D) is defined as:

$$D = I_{254} * t \tag{2}$$

where D is the dose (J/m^2), I_{254} is the intensity or dosage rate (D_r, W/m^2) and t is the retention time in seconds (Chang et al., 1985; Morgan, 1989; Stevens et al., 1999). In a flow system, the retention time is obtained as:

$$t = \frac{Volume\ of\ chamber}{flow\ rate} \tag{3}$$

A number of authors have used the first order kinetics model to describe the relationship between survival microorganisms and doses. Chick's law can be used for measuring the survival microorganisms after UV-C radiation:

$$\log\left(\frac{N}{N_o}\right) = -kD \tag{4}$$

where N_o is the initial concentration of microorganisms and N is the concentration of microorganisms after the UV-C treatment, k is a constant and D is the dose (J/m^2) (Chang et al., 1985). Nevertheless, other mathematical models can be used to describe the curve of the microbial reduction after applying different UV-C doses. For example, Stermer et al. (1987) used the relationship for survival microorganisms when using UV disinfection as:

$$\ln\left(\frac{N}{N_o}\right) = -kIt \tag{5}$$

where N is the number of survival microorganisms after UV-C radiation, N_o is the initial load of microorganisms, k is a constant that depends on the type of microorganisms and environmental conditions, I is the intensity (W/m^2), and t is the exposure time (s). The product of intensity and time of exposition is referred to as the 'fluence' (F), commonly known as 'doses' (Shama, 1999).

Surrogate microorganisms (non-pathogen) are needed in some processes to evaluate the effect of the treatment without introducing pathogens. PA 3679 and *Listeria innocua* are surrogate microorganisms used in place of *Clostridium botulinum* and *L. monocytogenes*, respectively (IFT, 2000) or *Escherichia coli* ATCC 25922 in place of *E. coli* 0157:H7 (Sastry et al., 2000). Inoculated samples with surrogate microorganisms can be exposed to UV light. The survival load of microorganisms counted at different levels of UV doses can be used to determine D_{UV}-values (decimal reduction time). The D_{UV}-values can be computed from the negative reciprocal of the slope ($m = -k$) when plotting ln (N/N_o) vs. time. D_{UV}-values have been obtained for *E. coli* 0157:H7 inoculated in apple cider (Sastry et al., 2000).

Shama (1999) pointed out that a simple straight line may be described by a first order kinetics model. However, many survival microbial curves present 'shoulders' or a 'plateau region'. If the plateau region displayed for some survival microorganisms vs. dose is large, then the kinetics should be described with more complex mathematical models. On the other hand, a sigmoid-shaped curve for microbial inactivation is obtained using UV-C light for disinfection. Three phases are observed from the survival microbial load vs. dose representation. The initial plateau region indicates that the microbial load is injured in response to the UV-C light. In the second phase, the number of injured microorganisms increase and the survival microorganisms continue to decline because of the additional UV-C exposure. The end of the curve is the tailing phase of the surviving microorganisms. Those remaining are due to solids in suspension that block the UV light through the system (Hoyer, 1998; Sastry et al., 2000).

Dosage Measurement

The UV-C dose emitted from a lamp is usually measured using UV sensors in W/m^2 units. Radiometers (thermal or photonic) are instruments used to measure UV irradiance. Chemical actinometry is also used to measure the amount of the dose. Actinometers are used for measuring concentrations of products (with well-characterised energies) that come from photochemical reactions; these concentrations are directly related to the amount of UV light absorbed by the treated product (Shama, 1999). All sensors must be standardised for irradiance, taking into account a spectral selectivity radiation (240–290 nm) to obtain

reproducible measurement. The calibration is usually done by actinometry. However, the most consistent technique for monitoring irradiance is biodosimetry, which consists of inoculating a surrogate microorganism and measuring the log reduction after UV-C treatment of the fluid under specific conditions (Sastry et al., 2000).

EFFECT OF UV LIGHT IN FOOD SYSTEMS

UV-C radiation (non-ionising radiation) has the advantage in that it does not produce chemical residues, by-products or radiation. Also, it is a simple dry and cold process (Bachmann, 1975; Morgan, 1989) requiring very low maintenance (Anonymous, 2002a) and low cost, as it does not need energy as a treatment medium. For this reason, there is an increasing interest in using UV-C light for food disinfection (Sastry et al., 2000). However, every food product, liquid or solid, has its own composition, and this may determine the effect of the UV-C dosage. The only disadvantage in using UV-C light for disinfection is that the UV-C unit or equipment must be placed as close as possible to the target in the process system (Anonymous, 2002b).

Liquid Foods

It is known that UV-C light only penetrates a very short depth into the surface of liquids other than clear water (Shama, 1999). For instance, the penetration of UV light into juices is about 1 mm for absorption of 90% of the light (Sizer and Balasubramaniam, 1999). This is the main reason for using a turbulent flow during liquid food processing (Anonymous, 1999). The penetration effect of UV-C radiation depends on the type of liquid, its UV-C absorptivity, soluble solutes in the liquid and suspended matter. Increasing the amount of solids will diminish the intensity of penetration of the UV-C radiation; large suspended particles may also block the incidence of light on the microbial load (Shama, 1999; Bintsis et al., 2000). It is necessary for all parts of the fluid to be exposed to at least 400 J/m^2 of UV light at 254 nm to ensure an adequate reduction of 5 log cycles of a surrogated microorganism, in order to obtain a microbiologically safe food product. The UV-C doses should be applied to the entire food system to ensure that the liquid food is treated equally (Anonymous, 1999).

Hoyer (1998) pointed out that photoreactivation of cells may occur when cells are exposed to visible light in the blue spectral range. These photoreactivated cells can be more resistant to UV-C light when a second UV treatment is applied (Sastry et al., 2000). Hoyer (1998) observed that greater UV-C doses are required to obtain a 4-log reduction of photoreactivated cells previously UV-C treated in water (Table 3).

UV-C has been applied to reduce the microbial load of several types of microorganisms in some liquid foods. Wright et al. (2000) used a thin film UV-C disinfection unit (10 individual chambers in series) to treat inoculated unpasteurised apple cider with a mixture of five strains of *E. coli* 0157:H7. They evaluated the log reduction of *E. coli* using various flow rates, ranging from 0.999 to 6.48 L/min, corresponding to a range of 610 to 94 J/m^2, and found a 3.81 log (cfu/mL) reduction in apple cider. However, this reduction is not enough to achieve the recommended 5-log microbial reduction in liquid foods. Harrington and Hills (1968) obtained a 2.673-log total microbial reduction in apple cider with a good shelf life during 35 days at 2.2 °C. Farid et al. (2001) treated a thin film of orange juice falling over the wall of a UV system at 214.2 W/m^2 and found that the UV-treated orange juice doubled its shelf life without changes in colour and taste.

Solid Foods

Fruits and Vegetables

UV-C light is also applied to fresh fruits, vegetables and roots before being stored to accomplish two objectives. One is to reduce the initial count of microorganisms on the surface of the product and the other is to induce host resistance to the microorganisms. The beneficial effect of UV-C light on fresh food products is called 'hormesis' and the agent (UV light) is called 'hormetin' or 'hormetic effect' (Stevens et al., 1997, 1999). The hormetic effect of UV-C light may stimulate the production of phenylalanine ammonia-lyase (PAL) that induces the formation of phytoalexins (phenolic compounds), which may, in turn, improve the resistance of fruits and vegetables to microorganisms (Table 5). For instance, PAL induces the resistance of sweet potato roots to the fungus *Fusarium solani* (Stevens et al., 1999). The production of scoparone and scopoletin has been reported in flavedo of citric fruits after UV-C treatment. These phytoalexins enhanced the resistance of citrus to pathogens (D'hallewin et al., 2000; Ben-Yehoshua et al., 1992). Stevens et al. (1997, 1998) applied UV-C light to peaches and found an augmented PAL concentration and a diminishing of the ethylene synthesis that improved the shelf life of the fruit by delaying ripening.

Stevens et al. (1997) applied low UV-C light doses as a hormetic agent to reduce the brown rot caused by *Monilinia fructicola* on peaches, green mould caused by *Penicillium digitatum* on tangerines, and Rhizopus soft rot caused by *Rhizopus stolonifer* on tomatoes and sweet potatoes during storage.

Table 5. UV-C light dosage on fruits, vegetables and roots applied with different hormetic purposes.

Fruit	Microorganism/hormetic effect	Dosage (kJ/m^2)	Source
Strawberries	*Botrytis cinerea* (control decay)	0.25–1.0	Baka et al. (1999)
Tomatoes	*Alternaria alternata*, *Botrytis cinerea*, *Rhizopus stolonifer*	1.3–40.0	Liu et al. (1993)
Lemons	*Penicillium digitatum* (phytoalexins prod.)	5–15.0	Ben-Yehoshua et al. (1992)
Peaches and apples	Reduction of rot and delayed ripening	0.84–40.0	Lu et al. (1991)
Tangerines	*Penicillium digitatum*	1.30	Stevens et al. (1997, 1998)
Peaches	*Monilinia fructicola*	7.50	Stevens et al. (1997)
Tomatoes and sweet potatoes	*Rhizopus stolonifer*	3.6	Stevens et al. (1997)
Grapefruits (Ruby Star)	Production of phytoalexins	0.50	D'hallewin et al. (2000)

Fish, Poultry and Meat

Several types of meat may be UV-C treated on the surface for reduction of microbial load before refrigeration. Fresh meat irradiated with UV-C light reduces the microbial load in two or three log cycles, depending on the dose. By increasing the dose, the microbial reduction improves. However, the radiation does not penetrate opaque materials (Stermer et al., 1987). The UV-C light used for disinfection does not change the colour or general appearance of fresh meat. Djenane et al. (2001) continuously irradiated beef steak packaged in polyethylene pouches with modified atmosphere (70% O_2, 20% CO_2, 10% N_2) stored at 1 °C. They pointed out that the shelf life of the fresh meat was extended from 12 to 28 d. Wallner-Pendleton et al. (1994) applied UV light (825.6–864.0 W/m^2 doses) to chicken carcasses to reduce the amount of *Salmonella typhimurium* (61% reduction), and pointed out that the carcass colour was not negatively affected. Kuo et al. (1997) used UV radiation at various doses to reduce the population of *Salmonella typhimurium*, aerobes, and moulds on eggs shell, observing a significant reduction in the microbial population.

UV PROCESSING AND EQUIPMENT FOR LIQUID FOODS

UV Processing

The simplest way to build a UV-C system for treating liquid foods is using concentric tubing systems with a UV-C lamp, containers for the liquids, plastic tubing or sanitary pipes, refrigeration systems, and pumps (Figure 2). An ultraviolet lamp surrounded by a jacket (or sleeve) made of quartz (Shama, 1999), as in a heat-exchanger system, may be placed inside the concentric system. The liquid will flow through the annular part. The UV-C lamp standing in the centre of the system will provide the amount of light dose required for disinfection. Thus, the jacket requires tubing connectors on the ends of the system for use as the circulation system. The liquid passing through the system can be re-circulated or treated continuously through the annular part to achieve the required germicidal effect. However, more than one concentric tubing system can be connected in a series array to increase the germicidal effect on the liquid food without being re-circulated. A refrigeration system at the inlet or outlet of the concentric system can be attached to cool the liquid food before or after UV light treatment. Using pumps to apply the required doses can control the flow rate of the liquid.

Mixing devices are needed before and after the UV-C unit to ensure appropriate mixing of microorganisms in the system and to obtain a representative sample to assess residual microorganisms after processing (Sastry et al., 2000). Turbulent flow is necessary during UV light processing to ensure that the whole product has received the same UV light dose (Anonymous, 1999). It is also advised that the (well-mixed) liquid product be exposed to at least 400 J/m^2 of UV-C radiation to accomplish at least a 4-log reduction of the microbial load (Sastry et al., 2000). Sastry et al. (2000) pointed out that two important considerations when using a UV-C light system for disinfection of liquid foods are: a) the unit should be programmed to deliver the same energy to the food material; and b) the exposure time must be adjusted to achieve the proper energy levels.

Several arrangements have been used for UV liquid treatment. For example, water disinfection supplier companies throughout the world have built UV-C disinfection units for drinking water. However, most liquid fruit products are not transparent or colourless. This means that some specific characteristics are needed when applying UV as a disinfection medium to liquid food products.

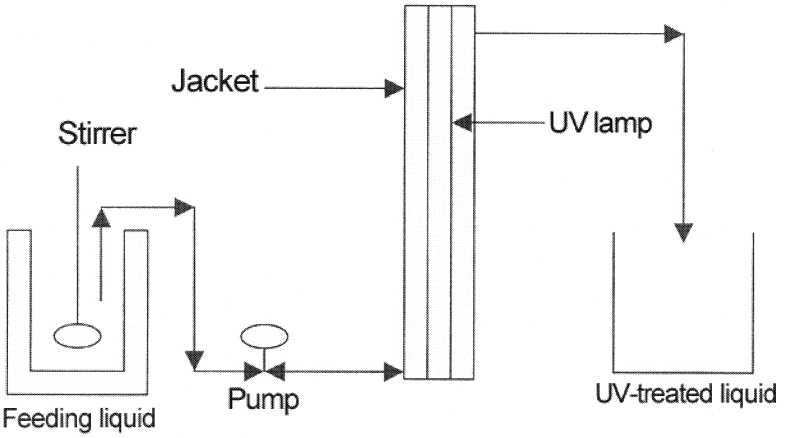

Figure 2. Simple UV-irradiation liquid system.

The most common approach to disinfecting liquids by UV-C light is by running the liquid through an annulus, as in those used for drinking water disinfection. However, the disinfection may not be effective if the thickness of the layer of liquid is not small enough, since UV penetration depends on the absorptivity of the liquid (Shama, 1992). Thin films of liquid are recommended to increase the effectiveness of UV-C penetration into liquids to ensure a lethal dose against bacteria (Shama, 1992).

Salcor, Inc. (Fallbrook, CA) has manufactured a prototype ultraviolet juice treatment with transparent Teflon™ tubing in a coiled manner surrounded by UV-C lamps. According to the manufacturer the system has two advantages: a) the pathogenic load is reduced significantly; and b) flavour, colour, texture and enzyme activity are preserved. Other observed advantages include: a) the amount of UV-C light and flow pressure are monitored during processing; and b) written information is given by the system, ensuring that all juice is treated successfully (Anonymous, 1999).

Shama (1992) and Shama et al. (1996) developed a thin film photoreactor that had a nozzle with a special design that could spray the liquid by forming a liquid bell. The equipment had a UV-C lamp positioned axially inside the falling liquid bell and four UV-C lamps circumferentially located outside of the liquid bell to improve the UV germicidal effect. Each lamp was held at a distance of 10 cm from the liquid bell. Shama et al. (1996) recirculated 32 L of *E. coli* (1.2×10^7 CFU/mL) suspended in water or humic acid at a rate of 13.5 L/min. They found that the initial load was reduced to survival fractions of 1.88×10^{-5} and 1.84×10^{-4} for absorptivities of 0.18 cm^{-1} (water) and 4.0 cm^{-1} (humic acid), respectively, after 30 min of treatment. The dosage delivered was between 20.3 J/m^2 and 48.4 J/m^2 for one and five sources, respectively.

Key Parameters in UV Processing of Foods

The effectiveness of UV penetration on liquid foods is affected by factors such as light source, product composition, flow profile and geometric configuration.

Light Source

The light source is restricted to UV-C light or, more specifically, to 254 nm because of its germicidal effect on microorganisms. As the UV-C radiation passes through the liquid, its intensity is reduced (Shama, 1999). For instance, UV radiation loses 30% of its intensity at 40 and 10 cm below the surface of distilled water and sea water, respectively (Bintsis et al., 2000). For this reason, exposure time, dosage and flow profile are critical in accomplishing the required effect on microbial load in liquids to deliver microbiological safe food products.

Product Composition

Liquids that have high light transmissivity can easily be treated by UV-C radiation, but liquids with low transmissivity, which is associated with particulate materials or organic compounds, may present difficulties. Initial microbial populations, particles and organic matter are factors associated with low transmissivity of UV-C radiation (Shama et al., 1996). Yeast cells are larger than bacteria cells and this may cause turbidity of the medium. Small particles in liquids can reduce UV penetration and the UV germicidal effect may be greatly reduced (Shama et al., 1996; Wright et al. 2000). Thus, liquids with suspended particles must be treated by first forming a thin film to improve the UV light penetration (Shama et al., 1996). The UV-C light penetration into juices is about 1 mm with light absorption at 90%. Thus, a turbulent flow is recommended to improve the germicidal effect on most of the juice flowing

through a UV system (Sizer and Balasubramaniam, 1999). Colour, soluble solids content and composition of liquid foods may also cause reduction in the transmissivity of the UV light through the liquid. Pure water, as a colourless and transparent liquid, has the highest transmissivity rate; however, the radiation is lost as the UV light passes through the water.

Geometric Configuration and Flow Profile

Geometric configuration is critical to ensure adequate disinfection in the food system. For this reason, some researchers have been working with different geometric configurations of equipment to produce: a) a thin film throughout pipes (Wright et al., 2000); b) a liquid bell formed by spraying the liquid with nozzles (Shama, 1992; Shama et al., 1996); or c) turbulent flow throughout the pipes (Anonymous, 1999). This means the UV system should be arranged to produce a flow profile that best renders the desired germicidal effect.

CURRENT APPLICATIONS OF UV LIGHT

Applications

The most common application of UV-C light is for disinfection of air, surfaces and water (Bintsis et al., 2000). UV light disinfection is also a current procedure for sanitation in commercial businesses (resorts, hotels, restaurants), institutions (hospitals, schools, nursing homes, fish hatcheries, laboratories) and industries (food packagers, brewers, bottling, cosmetics).

Air

Sterile air is necessary in some specific places or buildings to avoid microbial contamination. Sterile air can be obtained by using UV germicidal lamps placed in ducts before introducing air to a room or building in which sterility is required (Shama, 1999). However, the appropriate geometry of the duct should be well designed to ensure the correct germicidal dosage and, hence, the sterility required (Morgan, 1989). UV-C radiation is used as a barrier to sterilise air in hospital areas where patients sensitive to infection are housed. UV-C radiation is also used in theatres in the United States to diminish the load of air-borne bacteria (Bintsis et al., 2000). Bailey et al. (1996) applied UV light for air sanitation of egg hatching cabinets to reduce *Enterobacteriacea* and *Salmonella* species.

Surfaces

The amount of microorganisms on surfaces can be reduced or eliminated by applying the appropriate UV light doses. The sterilisation of packaging materials (Shama, 1999) by UV-C light is necessary when the materials do not resist heat sterilisation (autoclave) (Bachmann, 1975). These materials include containers, wrappers, bottle caps, foil caps and cartons for liquid products when using aseptically filled UHT processing (Bintsis et al., 2000). Processing equipment, medical devices, and many other surfaces are also UV-light sterilised (Barbosa-Cánovas et al., 1998). Microorganisms can be protected from radiation if dirt on surfaces is not well removed. For this reason, surfaces must be sanitised and free from debris to avoid absorption of UV light by organic materials (Bintsis et al., 2000). Also, the effectiveness of UV treatment is better on smooth surfaces (Shama, 1999) since irregular surfaces may retain traces of matter and the UV light cannot reach all corners because of shadowing (Shama, 1999).

Water

UV-C light has been used to disinfect water for several years and has become a successful process that eliminates several types of microorganisms (Bachmann, 1975; Wright et al., 2000). Disinfection of water by UV-C light does not produce changes in colour, flavour, odour, or pH (Anonymous, 2002b). The application of UV technology to water disinfection includes potable water, cooling towers, manufacture of pharmaceuticals, rinsing of microchips and other areas where chemical-free disinfection of water is required (Cruver, 1984; Anonymous, 2002b). In the brewery industry, for instance, UV disinfection is used for water to ensure a final product without altered taste (Bintsis et al., 2000; Morgan, 1989).

UV light has been used for many years to reduce the microbial count in drinking water, which was previously accomplished with chlorine. Chlorine may be hazardous because of handling and storage of cylinders (Morgan, 1989) and dechlorination is required to avoid residual taste, odour and colour in the final product (Legan, 1982; Cruver, 1984). Chlorination may deliver toxic by-products such as trihalomethanes (THMs), and the dechlorination process by sulphur dioxide or carbon adsorption may be expensive (Anonymous, 2002b). However, in the food-processing industry, chlorination is a medium for disinfecting equipment and tubing systems. Ionised water may be an alternative, but the ionisation process is an expensive substitution for the chlorination process normally used to sanitise equipment (Anonymous, 2002b). For this reason, UV light has become an alternative approach to disinfecting water and wastewater (Liltved and Landfald, 2000).

In the UV-light water disinfection process, the dosage levels are commonly given by manufacturers of the equipment, which will depend on the flow rate and water quality required. The only concern regarding the

water treatment is the flow rate and transmissivity of the water treated (Anonymous, 2002b). In wastewater treatment, the flow rate should be low to ensure a good UV treatment (Liltved and Landfald, 2000) since the turbidity of the liquid may reduce the germicidal effect because of low diffusion of light throughout unclear liquids.

Some disadvantages when treating water by UV light are the amount of suspended solids and salts of calcium, magnesium, iron and manganese (Snowball and Hornsey, 1988). Suspended solids can produce blockage of the UV light, thereby reducing the germicidal effect. Solid materials can be deposited on the inner surface of the flow tubing system (Shama, 1999). Calcium and magnesium may form a hard build-up on the inner surface; iron and manganese may stain the sleeves, which in turn will reduce the light emitted by the lamp. Temperature, on the other hand, may improve the germicidal effect when the working temperature is between 40.0 and 49.0 °C (Anonymous, 2002b).

Regulatory Aspects

The Food and Drug Administration is considering the use of UV-C radiation for fruit juice disinfection. The UV irradiation process on fruit juices should be accomplished with a rigorous HACCP programme to deliver safe and nutritious food products to consumers (FDA, 1997; Bintsis et al., 2000). Liquid foods should indicate a 5-log reduction of microorganisms after UV-C light treatment; however, the product should be maintained under refrigeration (Anonymous, 1999) to ensure appropriate shelf life. The FDA has also requested a warning statement be placed on the labels of all fruit or vegetable juices to alert consumers when a product does not meet this 5-log reduction (Anonymous, 1999; Sizer and Balasubramaniam, 1999).

Future Applications

Ultraviolet radiation has been used for several years as a physical disinfection medium for air, surfaces and drinking water. It has been applied for several purposes in buildings, hospitals, institutions and industries. Drinking water, rinse water for materials, industrial wastewater and water used in breweries are examples of liquids that are UV-C treated to reduce the load of microorganisms. Since UV light is a cold disinfection medium, it might be used in the food industry for purposes other than water disinfection: a) for pasteurisation of liquid foods instead of thermal pasteurisation in the juice industry (fruit and vegetable juices), dairy industry (raw, low-fat and skim milk), wine industry and cheese industry (whey); b) for use on surfaces of packaged meals ready-to-eat before storage under refrigeration or during storing, as well as on fresh fruits and vegetables; and c) for treatment of rinse water to clean food preparation contact surfaces, and rinse water to clean fresh fruits and vegetables prior to packaging or storage. Since UV light penetrates differently depending on the type of liquid, as explained above, further studies about UV radiation regarding dosage, colour and appearance, flavour, microbial quality, and nutritional quality of the final product are required.

FINAL REMARKS

UV technology is an emerging non-thermal process technology for disinfection of foods in the food industry. Ultraviolet processing can potentially provide more ideal food products with fresh-like characteristics. Short wave UV-C radiation is lethal to most microorganisms and can be applied to render safe food products. At present, the application of UV light for disinfection of food products is no longer used, but it could easily be applied to liquid and solid food products. Each food processing method is indeed different, and the performance of UV lamps for treatment of liquids or solids should be studied to obtain basic information regarding microbial disinfection. In addition, sensory evaluation, nutritional quality and shelf life should be considered. All new processes must be tested at low scale before being scaled-up at the industrial level, but validation of methods to ensure microbiological effectiveness and the optimisation of critical process factors must be studied. Ultimately, UV-treated products should satisfy FDA requirements along with HACCP programmes to deliver safe food products to consumers.

GLOSSARY

Fluence Rate (E')

'The radiant power of all wavelengths passing from all directions through an infinitesimally small sphere of cross-sectional area dA, divided by dA (W/m^2).' UV fluence rate is an appropriate term used for disinfection. The microbial load can receive UV power from any direction when exposed to several lamps (Sastry et al., 2000; Bolton, 2001).

Irradiance (E)

'The total radiant power of wavelengths incident on an infinitesimal element of surface area dS containing the point under consideration divided by dS' (Sastry et al., 2000; Bolton, 2001). Irradiance is expressed in W/m^2 and also called intensity flux or UV radiation (Bintsis et al., 2000). The term is frequently used in water disinfection (Sastry et al., 2000).

Radiant Exposure (H)

'It is defined as the total radiant energy incident from all upward directions on an infinitesimal element of surface of area *dS* containing the point under consideration divided by *dS*', and is expressed in J/m^2 (Bolton, 2001).

UV dose or fluence (H')

'The light dose or fluence is the total radiant energy of all wavelengths passing from all directions through an infinitesimal small sphere of cross-sectional area *dA* divided by *dA*' (Sastry et al., 2000; Bolton, 2001). The fluence or dose is a function of the intensity (W/m^2) and time (s) exposure, and is expressed in J/m^2 (Sastry et al., 2000; Bintsis et al., 2000).

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