Journal of Food Protection, Vol. 67, No. 4, 2004, Pages 787–792
Copyright ©, International Association for Food Protection

Efficiency of Pulsed UV Light for Microbial Decontamination of Food Powders

F. FINE[1,2] AND P. GERVAIS[1]*

[1]*Laboratoire de Génie des Procédés Alimentaires et Biotechnologiques, ENSBANA, 1, Esplanade Erasme, 21000 Dijon, France; and* [2]*Unilever Bestfoods France-Amora-Maille, 48 quai Nicolas Rolin, 21000 Dijon, France*

MS 03-368: Received 21 August 2003/Accepted 9 October 2003

ABSTRACT

The aim of this study was to evaluate the efficiency of pulsed light on the destruction of dried microorganisms on fluidized glass beads and to determine treatment parameters (energy level, water activity, final product quality) for process optimization. The applied drying method allowed microorganisms to remain viable on glass beads or dried powdered products with viability yields approaching 100%. The pulsed UV light system enabled an efficient fluidization of food powders, even for granular products (up to 5 mm diameter) and avoided shadowed areas. For *Saccharomyces cerevisiae* decontamination, the dose effect of UV rays was preponderant with glass beads and quartz plate, and in this case, 58 J/cm^2 were required to decrease the microbial population by 7 log. For colored food powders (black pepper and wheat flour), the thermal effect of pulsed light dominated the UV effect.

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022

Most preserved foods have traditionally been thermally processed by subjecting the food to a temperature of 60 to 140°C for a few seconds to minutes. During this time period, a large amount of energy is transferred to the food, causing trigger reactions in the food and leading to undesirable changes or formation of by-products. The need to extend shelf life and improve food quality led to the concept of preserving foods by nonthermal methods that use less energy compared with thermal processes *(1)*.

Among soft decontamination technologies for food products, pulsed UV light process is currently being studied extensively *(6, 18, 20)*. The pulsed-light system is a patented process that submits microorganisms to strong light pulses *(6)*. Electrical energy is accumulated in a capacitor before being transferred, as a result of a discharge gap interrupter, to the flash lamp fitted with a jacket containing xenon gas. As a result of the electric pulse, the gas is ionized and the lamp emits a very short intense flash of white light focused on the treatment area by the lamp reflector *(6, 14)*.

The ability of UV light to inactivate cellular microorganisms (vegetative and sporulated forms) and viruses is well known. However, up to now, such systems only found limited practical application in the pharmaceutical industry *(17)*. Pulsed-light emissions obtain equivalent destruction levels four to six times faster than conventional continuous UV light *(5, 6, 12)*.

The sterilization effect of pulsed light is a result of UV spectrum short-duration pulses (10^{-6} to 0.1 s) and a high energy peak *(5–7)*. The pulsed-light wavelengths consist of low-energy photons, which react with water-forming hydroxyl radicals. For UV wavelengths, energy absorption occurs in aromatic structures that can undergo oxidation reactions (e.g., an activated double bond reacts with an oxygen molecule to form an unstable peroxide radical). For many years, continuous UV light has been used for meat treatments, but oxidation reactions (notably on lipids) resulted in significant color changes. Pulsed-light systems effectively limit oxidation reactions because of the short pulse duration (100 μs) and the half-life of π-bonds (10^{-9} to 10^{-4} s), which prevent efficient coupling with dissolved or free oxygen. Moreover, oxidation reactions are still limited by the low pulse number (1 to 3). Consequently, analysis of treated food products does not show chemical modifications even for high exposures. However, some products, e.g., white potato, can undergo a slight browning.

According to Wekhof *(20)*, the pulsed-light disinfection mechanism includes both the germicidal action of UVC light (notably the formation of lethal thymine dimers on bacterial DNA) and the rupture of bacteria from thermal stress caused primarily by the UV components of the light pulse. It is proposed here that much of flash disinfection at higher flux densities (0.5 J/cm^2) is achieved through a rupture of bacteria during overheating caused by absorption of UV light from the flash lamp. This overheating can be attributed to a difference in the absorption of UV light by bacteria and that of the surrounding medium. The water contained in bacteria will be vaporized, generating a small steam flow that induces membrane destruction *(19)*. Moreover, for certain products, pulsed light inhibits enzymatic activity because aromatic amino acids are able to absorb UV light *(5)*. In order to obtain sufficient decontamination effects, the light must have a sufficient intensity and an exposure time to impair cellular repair mechanisms.

Pulsed–UV light treatment is effective for the inactivation of bacteria (vegetative cells and spores), protozoa,

* Author for correspondence. Tel: +33-03-80-39-66-99; Fax: +33-03-80-39-68-98; E-mail: gervais@u-bourgogne.fr.

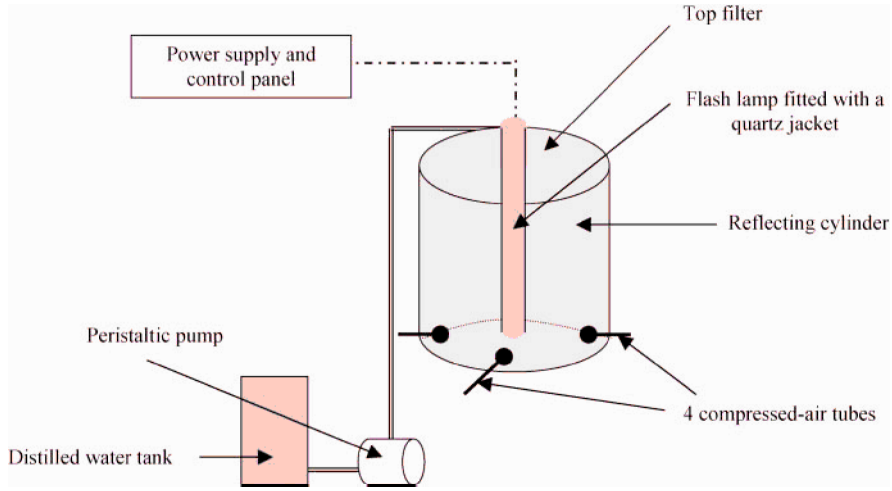

FIGURE 1. *Treatment unit of One-Shot EN2/2143-1 process.*

and viruses in pharmaceutical products (e.g., ophthalmic solutions, blood plasma derivatives, vaccines), medical devices, packaging (e.g., polyethylene, polypropylene), surfaces, food products (meats, eggs, bread, vegetables, fruits), and drinking water *(5, 17, 20).* MacGregor et al. *(12)* showed that 6- and 7-log destruction can be reached with *Escherichia coli* and *Listeria monocytogenes,* respectively, spread onto the surface of tryptone soya yeast extract agar. However, pulsed-light sterilization on damp media (e.g., agar media) was faster than on dry supports (stainless, plastic, polyethylene). Rowan et al. *(18)* showed that gram-positive bacteria were more resistant to the effects of UV light than gram-negative bacteria, whereas pseudomonads and flavobacteria were the most sensitive.

Pulsed–UV light efficiency is dependent on microbial exposure; therefore, shadowing of the target cells must be avoided. Sterilization of packed products is possible if the packaging is UV transparent. Because of the generally opaque and irregular surface of foods, lower kill levels are reached *(5).*

Although the peak power of each pulse is very high because of the short duration, the total energy in each pulse is relatively low, and the average power requirement is modest. As a result, the pulsed-light process, in addition to potentially being effective, is economical.

The aim of this study was to define pulse frequency and energy levels required for microbial decontamination of dried food products and to explain the pulsed–UV light disinfection mechanisms. Factors affecting process efficiency have been identified as (i) the pulse number during an exposure of the whole particle surface; (ii) the particle location and, notably, the distance from the flash lamp, which determine the energy level received by microorganisms; and (iii) the type of product, especially its color.

MATERIALS AND METHODS

Strain and cultivation conditions. *Saccharomyces cerevisiae* strain CBS 1171 cells were maintained on petri dishes with modified malt Wickerham medium *(9)* supplemented with 20 g/liter agar (VWR International, Strasbourg, France). The yeast were grown aerobically, as previously described by Gervais and Martínez de Marañon *(9)* in 250-ml conical flasks containing 100 ml modified malt Wickerham medium made up of 10 g/liter glucose (VWR International), 3 g/liter pancreatic peptone (VWR International), 3 g/liter yeast extract (Institut Pasteur, Paris, France), and 1.5 g/liter NaH_2PO_4 (VWR International). The pH was adjusted to 5.35 by the addition of orthophosphoric acid (Sigma, St. Quentin Fallavier, France) before autoclaving at 121°C for 20 min. The flasks were shaken at 250 rpm on a rotary shaker (New Brunswick Scientific, Edison, N.J.) at 25°C for 48 h. An aliquot (1 ml) of culture was transferred into a conical flask containing the same medium and was allowed to grow to early stationary phase for 48 h to a final concentration of 1×10^9 cells per ml.

Drying method. Cell cultures in early stationary phase were harvested by centrifugation (2,000 × *g,* 10 min), and cells were washed twice in a binary water-glycerol solution at a water activity (a_w) level of 0.992. The pellet was mixed with 30 g of glass beads (average diameter 2 mm; Fisher-Bioblock, Illkirch, France) that had been sterilized previously by autoclaving at 121°C for 20 min. The mix was dried in a climatic chamber (type 320H60/1.5; Climats-Sapratin, St. Médard d'Eyrans, France) coupled with an air dryer (type MLC450; Munters, Colombes, France) for various periods of time, depending on the a_w to be reached, as previously described by Poirier et al. *(16).* The a_w values of samples were checked with a dew point osmometer (Decagon Devices Inc., Pullman, Wash.).

Other experiments used quartz plates (76 by 26 mm), on which 25 μl of cellular suspension was pulverized and dried in a desiccator for 24 h.

Pulsed–UV light treatment. For treatment of food powders, the One-Shot EN2/2143-1 unit, a 3-liter fluidized bed, developed by the society Solsys (Marseille, France) was used to mix powders and to increase particle UV-exposure. Tangential blowing was performed with four adjustable air nozzles and compressed air, which allowed powder fluidization in a vortex configuration at an adjustable pressure of 2 to 6 bars and a maximal flow rate of 100 liters/min. The One-Shot EN2/2143-1 system is divided into two separate units: the electrical unit and the treatment unit, as shown in Figure 1. Samples were introduced into a glass cylinder (diameter, 200 mm; height, 180 mm) in order to set compressed air flow rate and to avoid product accumulation in the shadow area (notably the top filter). Before light pulses, the glass cylinder was replaced by an aluminum cylinder, which allows light reflection.

In contrast to conventional continuous UV light, the One-Shot EN2/2143-1 system uses high-intensity broad-spectrum white light delivered in short bursts. The wavelengths cover 200 to 1,100 nm, i.e., similar to that of sunlight but with the inclusion of greater exposure to wavelengths below 300 nm (Fig. 2). Indeed,

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022

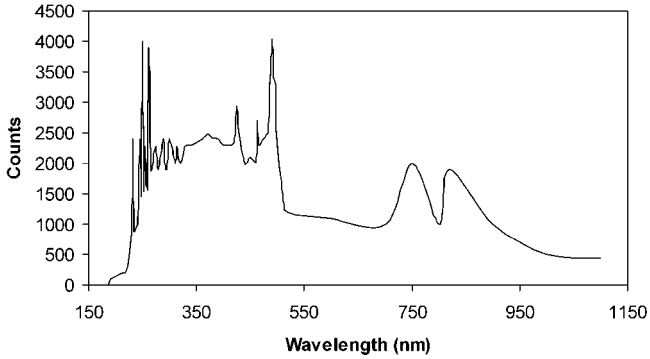

FIGURE 2. *The light emission spectrum produced by the pulsed power system.*

a much higher peak power with respect to greater UV content was beneficial for flash disinfection *(20)*. The emitted spectrum is composed of approximately 21% UV light (8% with a wavelength in the range 200 to 300 nm, and 13% with a wavelength in the range 300 to 380 nm), approximately 49% visible light (from 380 to 700 nm) and approximately 30% infrared light (700 to 1,100 nm). Each flash is of a very short duration (close to 300 μs) but has an intensity of at least 1,000 times that of conventional UV light and 20,000 times that of sunlight reaching the earth. The electrical unit exhibits a working power of 125 W and an adjustable energy level in the range of 24 to 551 J per pulse. Around the flash lamp, a quartz jacket allows water circulation to limit lamp overheating. The energy absorbed by water and the quartz jacket was regarded as negligible.

During trials in one instance, glass beads were fluidized by compressed air and exposed to various light energies (from 24 to 220 J per pulse) for 25 to 400 pulses. In another trial, dried yeast spread on quartz plates were vertically exposed to light pulses on a plate holder. In this case, light energy was adjusted in the range 220 to 551 J and the pulse numbers were in the range of 1 to 100.

Light energy received by the target cells is strongly dependent on the distance from the lamp. Consequently, the energy level, corresponding to the total light emission spectrum, is expressed according to exposure surface; that is, at 80 mm from the lamp, the calculated exposure surface is 905 cm^2. One hundred flashes at 551 J supply a total energy of 55,100 J. So for this treatment, each point location at 80 mm from the lamp was exposed to approximately 60.88 J/cm^2. This calculation is probably below the real energy quantity received by the sample because reflected light is not taken into account.

Viability measurements. After light-pulse treatment, dried cells on glass beads or quartz plates were resuspended by washing on a rotary shaker (New Brunswick Scientific) with 9 ml of the water-glycerol solution (a_w = 0.992) for 30 min to reconstitute the cellular suspension. Decimal dilutions were spread on malt Wickerham–agar medium. Viability was determined by counting colonies (CFUs) and comparing with the controls, which were samples that had been dried in the same conditions but not exposed to light pulses. Experiments were performed at least three times, and mean values as well as 95% confidence intervals were calculated. These confidence intervals were found to be less than 15% of the mean variability.

Colorimetry measurements. Colorimetric analyses of treated samples were performed with the use of a Minolta CR-200 colorimeter (Dietikon, Switzerland). This system converted colors into numerical data according to international norms in the L*a*b system. In Hunter *Lab* Color Space, L corresponded to the degree of lightness or darkness. The chromatic portion of the color space is based on rectangular Cartesian coordinates (a, b), with red represented by +a, green by −a, yellow by +b and blue by −b. The L-value gives a spectrum ranging from 0 (black) to 100 (white). The a-value represents the spectrum with a range from −60 (green) to +60 (red), and the b-value ranges from −60 (blue) to +60 (yellow) *(4)*. Color difference between treated and untreated samples can be quantified by the following relationship.

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

The effect of process on product quality has been evaluated in wheat flour type 65 (Les Grandes Minoteries Dijonnaises, Dijon, France) and black pepper (UBF-Amora-Maille, Dijon, France). Color coordinates of untreated samples were L = 79.4, a = 0.329, b = 0.338 for wheat flour and L = 22.9, a = 0.342, b = 0.347 for black pepper. Powders were spread in monolayers between two quartz plates located 20 mm from the lamp, and each face was submitted to 2 to 64 light pulses at 220 J. Residual viability was also determined after dilution plating on plate count agar (Grosseron, St. Herblain, France). Each measurement was performed in triplicate, and mean viability values and 95% confidence intervals for the means were calculated. The black pepper essential oil, called piperin, also was dosed by a spectrophotometric method (ISO norm no. 5564:1982).

RESULTS

Decontamination of *S. cerevisiae* dried on glass beads with the pulsed-light fluidized bed. Glass bead fluidization was accomplished using compressed air with flow rate adjusted for each sample; 5 bars and 80 liters/h were required to optimize bead light exposure. The glass particles stayed in a vortex 110 or 115 mm from the lamp. Four hours of drying allowed the mix to reach an a_w of 0.07 with a cellular concentration close to 2.6×10^8 cells per g of beads. The a_w level was adjusted respectively to 0.3 and 0.6 by adding water-glycerol solution ($a_w \sim 0.992$) to the dried beads. Glass beads were then exposed to light pulses; residual viabilities are summarized in Table 1.

For an energy in the range 0.46 to 16.92 J/cm^2, destruction level remained below 1 log regardless of the a_w level. Results indicated that cell death was directly correlated with energy received by the microorganisms. Residual viability remained unchanged when beads received 5.33 J, whereas for an energy level of 195.27 J, a decrease of 0.5 log was recorded.

Contrary to thermal treatment, results did not show a strong influence of a_w on microbial destruction. Indeed, residual viability after light pulses was roughly similar; that is, for an energy level of 4.23 J/cm^2, microbial counts were 1.57×10^8 and 1.70×10^8 CFU/g of beads for a_w levels of 0.3 and 0.6, respectively.

From these results, dynamic treatment of glass beads did not reach high decontamination levels. Therefore, static treatments on quartz plates were performed in order to understand this low efficiency and improve the pilot characteristics.

Decontamination of *S. cerevisiae* dried on quartz plate. To determine lamp energy requirements, quartz plates containing 2×10^7 CFU/ml were successively lo-

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022

TABLE 1. *Viability of* Saccharomyces cerevisiae *dried on glass beads according water activity and light energy received by microorganisms*

Flash energy (J)	Flash number	Energy (J/cm^2)	Energy received on bead area (J)	Bead microbial content (CFU/g)[a]	
				$a_w \sim 0.3$	$a_w \sim 0.6$
0	0	0	0	2.66×10^8	2.68×10^8
24	25	0.46	5.33	2.56×10^8 ($\pm$2.0)	2.60×10^8 ($\pm$3.2)
24	50	0.92	10.65	2.40×10^8 ($\pm$2.3)	2.50×10^8 ($\pm$5.2)
24	100	1.85	21.30	2.04×10^8 ($\pm$4.4)	2.35×10^8 ($\pm$4.3)
72	25	1.38	15.98	2.14×10^8 ($\pm$2.9)	2.37×10^8 ($\pm$4.8)
72	50	2.77	31.95	1.83×10^8 ($\pm$4.1)	2.31×10^8 ($\pm$5.1)
72	100	5.54	63.91	1.30×10^8 ($\pm$5.2)	1.67×10^8 ($\pm$4.9)
220	25	4.23	48.82	1.57×10^8 ($\pm$5.5)	1.70×10^8 ($\pm$3.5)
220	50	8.46	97.63	9.27×10^7 ($\pm$2.3)	1.30×10^8 ($\pm$7.4)
220	100	16.92	195.27	4.95×10^7 ($\pm$5.8)	6.72×10^7 ($\pm$6.9)

[a] Viability confidence intervals at the 95% level are given in parentheses.

cated 80 mm from the lamp without compressed airflow. Table 2 summarizes decontamination results obtained for lamp energies in the range 220 to 551 J.

A 1-log destruction was recorded for an energy level of 24.31 J/cm^2. Microbial decontamination increased progressively to 43.76 J/cm^2 and produced greater than a 2-log reduction. Above this energy level (e.g., 54.81 J/cm^2), no viable microorganisms were detected.

The influence of lamp distance on pulsed-light efficiency and the pulse number required to obtain complete sterilization of the quartz plate with the maximal lamp power (551 J) were also determined. Table 3 shows residual viability obtained after 1 to 25 pulses and an energy level from 2.44 to 60.95 J/cm^2. A progressive 2-log reduction was recorded from 1 to 23 pulses. The energy corresponding to the 24th pulse (58.51 J/cm^2) performed a complete inactivation of microorganisms spread on the plate.

After the determination of lamp energy requirements, the influence of lamp distance on *S. cerevisiae* destruction was determined. The quartz plate was located 65 to 10 mm from the flash lamp. A treatment of 24 pulses at 551 J was performed and results are presented in Figure 3. From 65 to 20 mm, a progressive destruction reaching 2 log was recorded that was correlated to an increase in energy level from 18 to 58 J/cm^2. This energy seemed to be a threshold from which total destruction was obtained at 58 to 117 J/cm^2. Other experiments showed that glass plate height has no influence on *S. cerevisiae* destruction (data not shown).

To obtain information relative to food powder decontamination, wheat flour and black pepper were studied. The treatment effect on microbial viability and product colorimetry (ΔE) was evaluated. Initial counts were 1×10^7 CFU/g for wheat flour and 4×10^6 CFU/g for black pepper, primarily sporulated forms (i.e., *Bacillus* sp.). At an energy level of 31.12 J/cm^2 (64 pulses at 220 J, 20 mm from the lamp), residual viability remained close to 89.9% and 55.5% for wheat flour and black pepper, respectively (Table 4). On glass beads, residual viability was approximately 4.1% for the same energy level 20 mm from the lamp. Moreover, a visual modification was recorded from $\Delta E = 4.3$ for wheat flour and $\Delta E = 4.5$ for black pepper. Flour and black pepper became progressively burned, and the piperin content decreased from 5.12% to 3.40%. These product degradations took place at 15.56 J/cm^2 for wheat flour and at 3.89 J/cm^2 for black pepper. Visual and flavor qualities were thus significantly altered even before an efficient

TABLE 2. *Viability of* Saccharomyces cerevisiae *dried on quartz plate according to light pulse energy for 100 pulses 80 mm from the lamp*

Flash energy (J)	Energy (J/cm^2)	Plate microbial content (CFU/ml)[a]
0	0	2.00×10^7
220	24.31	2.29×10^6 ($\pm$5.2)
296	32.71	1.28×10^5 ($\pm$2.8)
396	43.76	9.67×10^4 ($\pm$6.2)
496	54.81	<10 ($\pm$0)
551	60.88	<10 ($\pm$0)

[a] Viability confidence intervals at the 95% level are given in parentheses.

TABLE 3. *Viability of* Saccharomyces cerevisiae *dried on quartz plate according to light flash number for an energy level of 551 J per pulse 20 mm from the lamp*

Flash number	Energy (J/cm^2)	Plate microbial content (CFU/ml)[a]
0	0	2.00×10^7
1	2.44	5.48×10^6 ($\pm$2.4)
5	12.19	3.64×10^6 ($\pm$3.7)
10	24.38	1.20×10^6 ($\pm$7.2)
15	36.57	8.27×10^5 ($\pm$4.8)
20	48.76	8.01×10^5 ($\pm$5.9)
21	51.20	5.66×10^5 ($\pm$4.1)
22	53.64	2.80×10^5 ($\pm$3.2)
23	56.08	1.30×10^5 ($\pm$6.0)
24	58.51	<10 ($\pm$0)
25	60.95	<10 ($\pm$0)

[a] Viability confidence intervals at the 95% level are given in parentheses.

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022

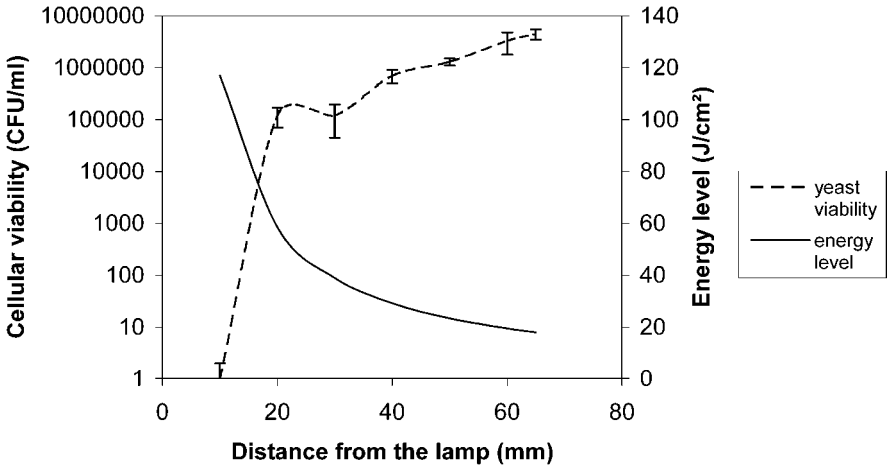

FIGURE 3. *Influence of lamp distance on* Saccharomyces cerevisiae *viability after 24 pulses at 551 J. Vertical bars correspond to confidence intervals at the 95% level.*

decontamination level was reached (at least 58 J/cm^2 is required to significantly decrease a dried yeast population).

DISCUSSION

Microbial distribution is a critical parameter for the use of pulsed-light technology in the food industry. Indeed, microorganisms are not always located in the periphery, in which case they do not receive all of the light energy (UV component) delivered, but rather an amount correlated with the low penetration ability of light *(7)*; consequently, no or low microbial destruction is recorded. Moreover, for powders with only external contamination, the One-Shot process developed by the society Solsys and tested in our laboratory allowed an efficient fluidization of food powders and even of granular food products (up to 5 mm diameter).

However, as shown in Table 1, decontamination levels remained insufficient for an industrial development of the technology. Indeed, dynamic treatment of glass beads did not reduce microbial levels more than 0.5 log units (100 pulses at 220 J and 110 mm) regardless the a_w level. Microbial destruction was strongly dependent on the energy quantity received by yeasts and in the fluidized bed. Therefore, the UV dose remained insufficient to decontaminate glass beads efficiently, and the thermal effect of pulsed light was significantly attenuated by air flow. With actual process configuration, greater microbial inactivation levels could be reached only by increasing the pulse number, to the detriment of the useful life of the lamp.

TABLE 4. *Viability and colorimetry variation of wheat flour and black pepper according to light flash number at 220 J per pulse and 20 mm from the lamp*

		Wheat flour		Black pepper	
Pulse number	Energy level (J per cm^2)	Residual viability (%)[a]	ΔE	Residual viability (%)[a]	ΔE
2	0.97	99.0 (±1.1)	0.9	98.0 (±1.8)	3.0
4	1.95	98.4 (±2.4)	0.9	97.5 (±1.5)	3.2
8	3.89	98.2 (±1.3)	2.8	96.0 (±2.2)	4.5
16	7.78	97.5 (±.3.5)	2.5	93.3 (±1.7)	5.1
32	15.56	97.3 (±3.2)	4.3	83.5 (±4.8)	6.6
64	31.12	89.9 (±1.1)	6.1	55.5 (±4.1)	8.5

[a] Viability confidence intervals at the 95% level are given in parentheses.

Contrary to heat stresses *(11, 13)*, initial a_w level did not show a strong correlation with the destruction of dried microorganisms subjected to light pulses and with the efficiency of powder decontamination by this technique. Indeed, during heat stress, a thermotolerance increase of microorganisms dried on glass beads was recorded for an initial a_w level from 0.3 to 0.4. However, as shown in Table 1, no difference in microbial inactivation between $a_w \sim 0.3$ and $a_w \sim 0.6$ can be detected with the pulsed-light process.

Trials that used the quartz plate underscored the importance of the distance from the flash lamp on microbial destruction. For 24 pulses at 551 J, the results showed a distance threshold (between 10 and 20 mm) from which a total sterilization of the plate was performed. At 20 mm from the lamp, total destruction was obtained at between 23 and 24 pulses. It is worth noting that microbial destruction is very rapid and could be correlated to the mutagenic dose effect of UV rays (such as formation of single-strand breaks and pyrimidine dimers). Indeed, the decontamination threshold should correspond to an irreversible UV dose effect from which nucleic acid repair is no longer possible.

On the basis of these results, the mean energy level threshold required for an efficient decontamination was around 58 J/cm^2, whereas in liquid or damp media, 4 to 12 J/cm^2 produced effective decontamination *(7, 20)*. Our results clearly showed that 58 J/cm^2 was required to obtain high destruction (~7-log reduction) in dry media. As for thermal treatments, dried cells seemed to have developed resistance mechanisms (e.g., membrane adaptation, solute accumulation, stress protein synthesis) which resulted in more stringent treatments to obtain the same destruction level *(2, 3, 8, 10)*.

To reach 58 J/cm^2 and obtain efficient decontamination, the low lamp power needs a high flash number in order to accumulate energy doses; consequently, the energy is given sequentially to the cells (at 20 mm, each flash delivers an energy level of 2.44 J/cm^2). Therefore, it is essential to measure the size of the reflecting cylinder by taking into account lethal power and to increase the UV energy given to the product by adding several flash lamps

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022

in the periphery or by choosing a lamp with higher UV content in the spectrum. A new continuously working pilot plant will be developed by taking into account the data and results obtained in this study.

Food powders (black pepper and wheat flour) were treated with pulsed light to evaluate the influence of color on the efficiency of the process. Colorimetry results (Table 4) indicated a rapid modification of product color in addition to low amounts of microbial destruction (10.1% for wheat flour and 44.5% for black pepper at 31.12 J/cm^2). It is important to note that color change occurred well before the decontamination threshold of 58 J/cm^2 was reached and was clearly more rapid for black pepper than wheat flour: for an energy level of 31.12 J/cm^2, wheat flour ΔE was 6.1, whereas black pepper ΔE reached 8.5. This color modification can be attributed to overheating combined with oxidation. The difference in color modification between wheat flour and black pepper could be explained by the difference in initial color: indeed, it is well known that dark products absorb more light energy than lighter products; consequently, heat level will be higher in dark products. In this case, the thermal effect of pulsed light seems to be dominant relative to the UV effect.

The microbial destruction results obtained with UV transparent supports (quartz, glass) underscore the finding that pulsed-light efficiency depends on UV dose received by the microorganisms. Consequently, the corresponding mean energy threshold for the lamp used was set at 58 J/cm^2. From this threshold, nucleic acid damage from UV rays is too extensive for repair. Conversely, for black pepper and wheat flour, the difference in initial product color affected the final thermal effect of the pulsed light. Indeed, the treatment resulted in undesirable color alterations of the products well before microbial inactivation was completed.

ACKNOWLEDGMENTS

This work was financially supported by the Contrat de Plan Etat-Région Bourgogne and NOVELECT and by a grant-in-aid by the National Association of Technical Research (ANRT) and the Unilever Bestfoods group.

REFERENCES

1. Barbosa-Canovas, G. V., M. M. Gongora-Nieto, and B. G. Swanson. 1998. Nonthermal electrical methods in food preservation. *Food Sci. Tech. Int.* 4:363–370.
2. Corry, J. 1971. The water relations and heat resistance of microorganisms, p. 1–42. *In* Scientific and technical surveys, vol. 73. The British Food Manufacturing Industries Research Association, Bartholomew Press, Dorking.
3. Crowe, J. H., L. M. Crowe, and D. Chapman. 1984. Preservation of membranes in anhydrobiotic organisms: the role of trehalose. *Science* 223:701–703.
4. Demir, A. D., J. M. F. Celayeta, K. Cronin, and K. Abodayeh. 2002. Modeling of the kinetics of color change in hazelnuts during air roasting. *J. Food Eng.* 55:283–292.
5. Dunn, J. 1996. Pulsed light and electric field for foods and eggs. *Poultry Sci.* 75:1133–1136.
6. Dunn, J., A. Buschnell, T. Ott, and W. Clark. 1997. Pulsed white light food processing. *Cereal Food World* 42:510–515.
7. Dunn, J., T. Ott, and W. Clark. 1995. Pulsed-light treatment of food and packaging. *Food Technol.* 49:95–98.
8. Fine, F., and P. Gervais. 2003. Décontamination des poudres alimentaires: revue bibliographique et nouvelles perspectives. *Sci. Aliment.* 23:367–394.
9. Gervais, P., and I. Martínez de Marañon. 1995. Effect of the kinetics of temperature variation on *Saccharomyces cerevisiae* viability and permeability. *Biochim. Biophys. Acta* 1235:52–56.
10. Iwahashi, H., S. Kaul, K. Obuchi, and Y. Komatsu. 1991. Induction of barotolerance by heat shock treatment in yeast. *FEMS Microbiol. Lett.* 80:325–328.
11. Laroche, C., and P. Gervais. 2003. Unexpected thermal destruction of dried microorganisms immobilized on glass beads as a function of water activity. *Appl. Environ. Microbiol.* 69:3015–3019.
12. MacGregor, S., N. Rowan, L. MacIlvaney, J. Anderson, R. Fouracre, and O. Farish. 1998. Light inactivation of food-related pathogenic bacteria using a pulsed power source. *Lett. Appl. Microbiol.* 27:67–70.
13. Murrel, W. G, and W. J. Scott. 1966. The heat resistance of bacterial spores at various water activities. *J. Gen. Microbiol.* 43:411–425.
14. Palmieri, L., D. Cacage, and G. Dall'Aglio. 1999. Non-thermal methods of food preservation based on electromagnetic energy. *Riv. Ital.* 27:5–11.
15. Perez-Galvez, A., and M. I. Minguez-Mosquera. 2002. Degradation of non-esterified and esterified xanthophylls by free radicals. *Biochim. Biophys. Acta Genet.* 1569:31–34.
16. Poirier, I., P. A. Marechal, S. Richard, and P. Gervais. 1998. *Saccharomyces cerevisiae* viability is strongly dependant on rehydration kinetics and the temperature of dried cells. *J. Appl. Microbiol.* 86: 87–92.
17. Roberts, P., and A. Hope. 2003. Virus inactivation by high intensity broad spectrum pulsed light. *J. Virol. Methods* 110:61–65.
18. Rowan, N., J. Anderson, R. Fouracre, L. MacIlvaney, and O. Farish. 1999. Pulsed-light inactivation of food related microorganisms. *Appl. Environ. Microbiol.* 65:1312–1315.
19. Takeshita, K., J. Shibato, T. Sameshima, S. Fukunaga, S. Isobe, K. Arihara, and M. Itoh. 2003. Damage of yeast cells induced by pulsed light irradiation. *Int. J. Food. Microbiol.* 85:151–158.
20. Wekhof, A. 2000. Disinfection with flash lamps. *PDA J. Pharm. Sci. Technol.* 54:264–276.

Downloaded from http://meridian.allenpress.com/doi/pdfplus/10.4315/0362-028X-67.4.787 by guest on 26 May 2022