Pulsed UV to Sterilize Food Packaging and to Preserve Food Stuffs

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Abstract

The report describes how the recently discovered sterilization mechanism with a pulsed UV light [1] and its experimental validation within the independent German government program BMBF [2]. According to these works, at certain pulse powers the major sterilization effect is due to a momentous overheating and rupture of microorganisms under pulsed UV light. This is possible when the heating of a microorganism by a UV pulse far exceeds the cooling rate of UV-subjected microorganisms into the surrounding media or to an underlying surface. A flash lamp with a broad UV spectrum, or a pulsed light from a UV laser of a sufficient power, can be used for this purpose. This sterilization method has the important advantage of using only UVB and UVA light, since the UVC light, 200-280 nm, is filtered out by food packaging. It allows the sterilization food or water through clear PET (polyethylene terephthalate) or PS (polystyrene) packaging. This report offers practical solutions for sterilizing packaging and some foodstuffs directly or through clear packaging foils with very competitive costs.

Introduction

General information on flash lamp usage, spectra, and applications during the last 70 years and on flash lamp manufacturers is given in [3] and is not covered here. The technique of disinfection with flash lamps originated during the late 1970s in Japan and was patented in 1984 [4]. This work suggested that not only UVC band radiation but perhaps also visible radiation are responsible for the disinfection effect. In 1988, the newly formed PurePulse Inc. (California) acquired this patent and since then they have put in considerable effort to prove that the major role in such sterilization belongs to the Pulsed White Light (PWL) -- see their papers [5-7]. During the same period, an alternative approach stressed the exclusive role of the pulsed UV light in achieving effective decontamination from both toxic organic substances and from microorganisms [8-10], and quite a few U.S. journals 10-12 years [e.g., 11] referred to it as “The New Generation of UV technologies. It did, however, take 8 years before the actual disinfection mechanism of the flash lamp action was found and summarized by the same author [1] and then experimentally proved within the German BMBF program [2]:

1. This disinfection mechanism has two components: one is the standard germicidal action of UVC from the flash lamp light, and the other is a rupture and disintegration of microorganisms through overheating after absorption of all the incident UV photons emitted in the light pulse.

2. The calculated temperature rise for a treated microorganism during a single light pulse is an exponential function of the peak power $P_{peak}$. The process has a threshold level for each specific condition, below which level the sterilization is due only to the germicidal UVC action. Above a threshold level of $P_{peak}$, all UV light contributes to rapid heating of microorganisms in excess of 130°C, causing terminal overheating and rupture -- see Figure 1. For that reason it was named Pulsed UV Disintegration (PUVD).

![Figure 1 (from [1]): Calculated dependence of bacterial (E. coli) temperature (°C) and of the UVC dose (in mJ/cm²) as a function of the fluence rate (in W/cm²) on a dry sample (transparent to UV) or in air and for water for two selected pulse durations: 1) 100 μs, 2) 1 msec.](image)
3. The PUVD of a microorganism can be achieved with UVB and UVA light only, and this can be a stand-alone disinfection method (see data with Pyrex™ filter in Figure 2).

4. Visible light plays no major role in flash lamp sterilization (see data with Makrolon filter in Figure 2).

5. The PUVD of microorganisms is terminal and, in principle, is different from the standard UV sterilization, which damages the DNA chain, see Figure 3.

Figures 2 and 3 from [2] support the above premises, including a direct evidence, via electron microscope photography, of the momentous overheating and consequent disintegration of the microorganisms. These data also show how incorrect was the approach perceived by earlier workers [5-7] with their reliance on the visible (white) light action. One of consequences of their approach was that their systems had many technical shortcomings [12], besides being quite expensive.

As one can see from photo B in Figure 3, the spore damage is lethal: all that is left is an empty and deformed shell, while all content has been ejected due to momentous overheating by the pulsed UV light.

Below are practical recommendations on how this technique can be used for packaging and for food preservation of certain foodstuffs packed in PET and other plastic bottles or onto a transparent foil. When considering this method, a potential user has first to find if the use of the UVC light is either allowed or is necessary. It may not be allowed due to possible photochemical damage to food items or to packaging. If this is the case, the UVC band has to be filtered out of the lamp spectrum by using lamps in a Pyrex™ envelope.

Figure 2 (from [2]): the reduction in the population of Aspergillus niger spores on PS and PET foils as a function of applied peak power of a single pulse. Tests with a Pyrex™ filter demonstrate that the sterilization can be achieved without the UVC component, since Pyrex™ absorbs all photons below 305 nm.

Figure 3 (from [2]): Left: Untreated spores of A. niger; Right: Spores of A. niger treated with two pulses at 33 kW/cm².

Thus it is really important first to check that the targeted microorganisms absorb UVB and UVA at a rate sufficient for the selected PUVD system to perform the required work in order to justify higher costs of disinfecting only with UVB and UVA light.
Some practical aspects of sterilizing packaging with pulsed UV

Based on tests with spores of *Aspergillus niger* and of *Bacillus subtilis*, this technique has the following advantages for packaging [2]:

1. A minimal thermal stress for PVC or other plastic foil packaging since the energy deposition is no larger than 10 J/cm². Such a small energy can increase the surface temperatures by only a few degrees °C.
2. A high throughput since the sterilization takes only a fraction of a second.
3. The ability to sterilize inside packaging by U-shaped lamps. In this case, either the packaging is advanced to the lamp or a lamp is inserted into the packaging.
4. An ability to sterilize through a clear foil used for packaging. For this to perform effectively, such a wrap-foil must pass at least all photons with wavelengths above 280 - 310 nm (a full UVB) and preferably some UVC light.

Figure 4 provides the example of a potential use of the technology by sterilizing the inside surface of containers (bottles, plastic jars, paper packs for milk and juices, etc). Such sterilization can effectively reduce requirements for sterilizing the food items or water packaged in such containers.

![Figure 4: Sterilizing of the inside surfaces of packaging, or jars with a diving U-shaped flash lamp. (1) a jar is positioned under the lamp; (2) the lamp dives into the jar and flashes; (3) the lamp returns to its initial position above the jar and the jar is moved on a conveyer belt.](image)

Some practical aspects of sterilizing food items with pulsed UV:

This technique can be successful for sterilizing surfaces of food items just before its packaging or before being rolled in cans.

In this case, only a very thin layer of an external surface can be treated for bacterial spore contamination. The efficiency of such a treatment depends on the ability of the surface to absorb the UV and other light. For example, protein-rich foods, such as meat products, have UV absorptions just as good as those of microorganisms. In turn, this limits the effect of the thermal rapture (momentous thermal disintegration). The heating (just as frying) of the top layer can be accomplished with all light photons and has been described in [5].

Since flash lamps can emit considerable (up to 15-20%) UVC light, it can cause effects similar to that from a standard mercury UV lamp (at 254 nm). This harmful consequence of the UVC action can be easily avoided with the present technique by simply using flash lamps made from Pyrex™ tubes; UVC photons will be absorbed by the lamp walls. The momentous heating effect from the light pulse would remain due to UVB photons and also due to the rest of the light spectrum, as soon as these photons are absorbed by a thin top layer of a sterilized food item.

Since much of food contamination spreads from the surface, food spoilage can be significantly reduced by this method. It can prolong the useful shelf time of food stuffs sterilized by this method.

Figure 5 shows the sterilization of a food items for two cases:

**Case 1:** Here flash lamp provides a pulse with a power sufficient to fry a very thin (~0.5 mm) layer of the surface. Such a frying eliminates all microorganisms in this layer.

**Case 2:** If this “frying” cannot be applicable (e.g., because of a possible visual change of the surface), than one should use the case with a pulse having a much smaller energy power, however with a sufficient content of UV light. This UV light would deactivate microorganisms without any visible damage to the top layer of a food. Such a process would have a lower efficiency than in Case 1 because organic cells of food items absorb the UV light just as effectively as microorganisms. It creates a competition for consuming the pulse UV energy leaving less energy for inactivating of microorganisms. A selection between cases 1 or 2 depends on customer requirements and can only be determined in tests.

**Treatment Costs per Sterilized Item**

From published data on sterilizing surfaces, it follows that energy costs are very competitive with existing sterilization techniques. Below is Table 1, which illustrates associated costs for a system with a standard life of two months (non-stop operation). Costs with far longer and far shorter lasting lamps have to be considered on a case-by-case vasis, since costs are dependent also on the type of production goals, etc. In any case,
the use of Pulsed UV Technology should not be considered only by the lamp life, but more by the overall price-to-performance factor. This factor is calculated in Table 1 below and shows how competitive the method is.

![Flashlamp 1 and Flashlamp 2](image)

Figure 5. Two modes of the sterilization irradiation of a food items: 1. By frying the whole thin Top Surface Layer (TSL = 0.5 mm) with up to 100% of bacteria reduction; 2. By inactivating microorganisms only through UV germicidal and partially by the pulse thermal action only on the Top Sterilized Surface (TSS).

**Conclusions**

The data presented here and published data sited give solid assurances that systems with pulsed UV light have a very good chance to be accepted as a method for sterilization by packaging and food industries. The basic reason for such optimism is the system’s high processing speed, cost-effectiveness and ability to be incorporated into future production lines. The principal development phase is over, and the next step is to get customers willing to pay for implementation of this technology at their production lines. This work already has been started.

**References**


(Table 1 is on next page)

I am indebted to Dr. J.R. Bolton for his very excellent editing and critical reading of this manuscript.
Table 1: Breakdown costs for sterilizing plastic caps with pulsed UV systems, for a PUVD system with one flash lamp (2 kW power and 8 weeks lamp life). The estimate is for sterilizing 10-packs of plastic caps with a diameter of 70 mm before filling or for sterilizing of food filled into similar caps just before its sealing.

<table>
<thead>
<tr>
<th>Type of Costs / Data</th>
<th>1000xEuro (k€)</th>
<th>Clarifications:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Capital cost</td>
<td>88</td>
<td>without robotics</td>
</tr>
<tr>
<td>2 Bank interest (8 %) per year</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3 Depreciation per year (over 8 years)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>4 Capital Costs / year (2+3):</td>
<td>15</td>
<td>approximate</td>
</tr>
<tr>
<td>5 Working hours per year</td>
<td>5000 h</td>
<td>24 h x 5 work days</td>
</tr>
<tr>
<td>Working seconds per year</td>
<td>18 x10^6 sec</td>
<td>x 45 work weeks</td>
</tr>
<tr>
<td>6 Lamp pulsing</td>
<td>10.000 (kWh)</td>
<td>at € 0.09 / kWh</td>
</tr>
<tr>
<td>7 Lamp support (simmer + cooling)</td>
<td>20.000 (kWh)</td>
<td>at € 0.09 / kWh</td>
</tr>
<tr>
<td>8 Energy costs [(7) +(8)]</td>
<td>2.7</td>
<td>(7) is ±50% system dependent</td>
</tr>
<tr>
<td>9 Maintenance + lamp change</td>
<td>0.75</td>
<td>±25% to a purchase contract</td>
</tr>
<tr>
<td>10 Running costs (8+9)</td>
<td>3.5</td>
<td>Approximate – see below</td>
</tr>
<tr>
<td>11 Total yearly costs (4+10)</td>
<td>18.6</td>
<td></td>
</tr>
<tr>
<td>12 Total caps sterilized</td>
<td>180</td>
<td>10 or 50 caps/sec.</td>
</tr>
<tr>
<td>13 Steril. cost (€ / million caps)</td>
<td>105</td>
<td>See note</td>
</tr>
</tbody>
</table>

Note: Each lamp is to sterilize a pack of 10 caps per pulse. These are calculations only, as no actual data on real processing exist.

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*Photochemical Purification of Water and Air*
by Thomas Oppenländer

Information on photoinitiated advanced oxidation technologies has been dispersed among the literature until now. This authoritative and comprehensive handbook fills the gap in covering both the photochemical fundamentals and practical applications, supported by various real-world examples. Numerous references facilitate access to pertinent research topics, while over 140 detailed figures visualize photochemical and photophysical phenomena and help interpret important research results.

Further information at [http://www.wiley-vch.de/publish/en/books/subjects/ch00/ISBN3-527-30563-7/?srid=97d955e135609a8a7f1655f14d57cece]<br />

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