Pulsed vs. Continuous UV for in-line Sterilization or Sanitation.

Dr. Alex Wekhof, White Paper, May 12, 2013:

Summary:

For high speed in-line sanitation of cups, lids etc (max to 99.99%, 3000 cups /h) the optimal UV equipments are U-shaped amalgam low pressure Mercury vapor lamps. Sterilization (6 logs, 99,9999%) at the same or at lower production rates (e.g. ca. 1000 products/h) requires pulsed UV light systems. The selection method is illustrated by results and data from manufactures. Using Pulsed Light for sanitizing cups, lids and packs causes unjustified high capital losses (1 to 25) and high operating losses per cup or lid (1 to 8). Yet pulsed UV (PL) becomes the only non-invasive sterilization choice for infusion solutions, reviewed for packed in 0.25 l UV semi-transparent PE bags, reaching 0.27 c/bag in operating costs INCLUDING 6 logs reduction of B. Pumilus spores, the most radiation and UV resistant spores of all. This result is not possible with amalgam lamps. The use of in-line Pulsed Light is also advantageous to amalgam lamps both for sanitation and sterilization of open or PE packed food or pharmaceutical products. SteriBeam offers both choices of lamps for its UV tunnels.

#1: in-line sanitation of cups and lids at 3000 cups/h.

The task: 4 logs sanitation from common bacteria and spores for a customer from a cosmetic industry at 3000/h. Typical cups are on Fig.1a, from plastic, similar caps are also from glass, Fig 1b below:

Fig 1a.

Fig 1b.

Conveyer speed and available production space:

The largest cup is from a plastic with the opening of 83 mm in diameter, its base is 90 mm diameter, the cup is 80 mm high, has a plastic lid of the same diameter, throughput is 3000/h, or 1 in 1.2 sec. At 9cm footprint diameter of cups the required conveyer speed (with alined cups) is 7.5 cm/sec. The available space on the production line is 80 cm.

Required UVC dose in mJ/cm² to cup´s openings:

A UVC dose in mJ/ cm² at the cup´s opening is distributed inside the cup through reflections on its bottom to side walls and by direct "slid" UV flux from a UV lamp. The inner surface of this sample cup is 272 cm², and the surface of its opening is 51 cm², their ratio is 1/5.3. Therefor, the min dose for cup´s opening has to be x5.3 as much as for inner walls.

This ratio is to be increased by correcting on losses during UV reflections, which for glass surface is ca. 20% and for plastic -at least 50%. This correction increases the compensation coefficient for this sample cap from 5,3 to 7.6.

The average UVC dose for 4 logs reduction is around 250 mJ/cm² (1), making the necessary UVC dose at the cup entry of 1900 mJ/cm². This dose is to be accumulated during the cup movement on the conveyer under a UV lamp. At the available conveyer length of 80 cm and its speed of 7.5 cm/sec the illumination time for each cup is 10.7 sec. Therefore the UVC flux at the reflector plane has to be 178 mw/cm² for a continuously emitting UVC lamp. For a pulsed UV lamp one has first to calculate the total energy which depends on the length of a flash lamp. Both two choices are reviewed further.

Choice #1: 71 cm amalgam low pressure Mercury vapour lamp:

U-type amalgam lamp UVI 170 U 2GL 11 C P 15/755 with 71.5 cm active length, the total lamp module length of 75.5 cm (with sockets: 80 cm), UVC power 60 w (2). The reflector plane surface of 72x8 cm=576 cm². At the collection efficiency of 95%, the actual lamp UVC flux to cups is 60wx0.95/576 = 99 mw/cm². Having these two lamps in parallel will assure a sufficient UVC flux of 189mw/cm², which meets the dose requirement of 178 mJ/cm². The lamp electrical power is 170 w (340 w for both), both costs 440 Euro, reflector is €50, two electronic ballast-controller is 260 Euro (2), total “capital investment” is €750.

Choice #2: the same sanitation with Intense Pulsed Light.

Let us use a PL module from Xenon Corp.(3), retained in EU at 19,000 Euro (in USA at 19,000 USD, data from 2011). The max lamp output per pulse is 500 J, pulse rate is 1 to 4 Hz, the lamp active part is 40 cm long, the full module length is close to 72 cm (28", (3).

At 500 J/pulse the UVC output per a pulse is on average 12% to consuming el power, or 60 J/pulse. UVC dose /pulse under the reflector plane (40x8=320 cm³) is 187 mJ/cm²/pulse. At the reflector collection of about 95% to cups (taken the same as for the amalgam lamp), this dose will be 178 mJ/cm².

To accumulate a required dose of 1900 mJ/cm² requires 11 pulses. The time available under the module is the ratio of the lamp length to the conveyer speed, or 40/7.5=5.33 sec. So the pulse rate has to be 2 Hz. Cups shift under such a lamp between 2 Hz pulses is 7.5 cm/sec x 0.5 sec=3.8 cm, which is a half of the cup. Another possibility is to move the conveyer by steps, like using 3 .5 sec for moving and 4 sec for pulsing with a conveyer remaining still. The pulse rate in this case has to be 3Hz. We continue with the least energy option of 2Hz, having consuming pulsed power of 1kw, plus 0.5kw for the lamp´s cooling blower (3) .

Table #1 - PL vs. amalgam lamp at the same UVC dose for 99.99% sanitation of fast moving open glass cups (3000/h, diameter 80 mm, height 80 mm):

	1 Pulse Light 40/70cm module	2 parallel 71.5 cm long U-type amalgam lamps	Advantages by amalgam lamp to pulsed light
capital costs	€19,000	€750	1 to 25
el. consumption/h	1.5kw	0.34 kw	1 to 5
el- costs per h (0.2€/kwh)	0.3 €/h	0.068 €/h	1 to 5
lamp cost	€690	€440	1 to 1.6

lamp life	1000 h	9000 h	1 to 9
lamp costs/h	0.69 €/h	0.049 €/h	1 to 9
Operating costs/h	0.99 €/h	0.117 €/h	1 to 8.5
O. price per sterilized cup	0.033 cent/cup	0.004 cent/cup	1 to 8
depreciation of hardware (5y, 16000 wh)	1.25 €/h (pulsing controls, reflector)	0.019/€/h(2 lamp drivers, reflector)	1 to 65
Depreciation per cup	0.042 cent/cup	0.00063 cent/cup	1 to 67
Full price for a cup sanitation	0.075 cent/cup	0.0046 cent/cup	1 to 16
Safety after lamp breaking	safe	safe (*)	same

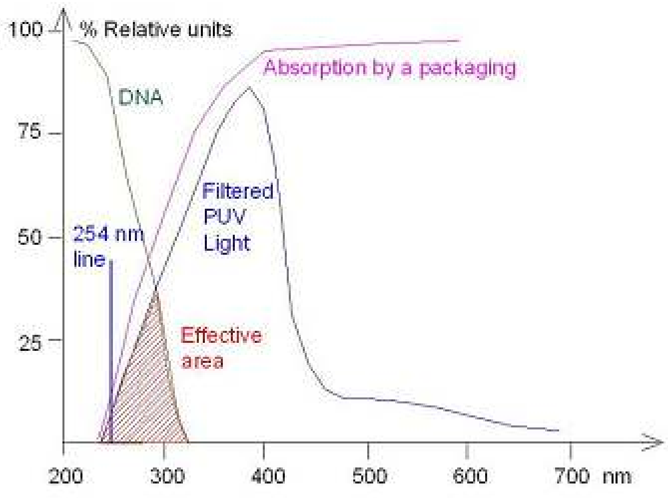
(*) The advantage of Xe-filled lamps having no Mercury is fully diminished since amalgams on open (when a lamp breaks) immediately solidify on lamps walls, thus releasing out no Mercury vapours. See in details on amalgam lamps in (4) and on pulsed UV in (5).

Tests data: these calculations have been supported by results of comparative evaluation tests, conducted for spores of B. Subtilis for 4 logs reduction, made for customer plastic cups on UV equipment from SteriBeam. Similar tests can be conducted at a customer request on their own products, please, see details on our website at INFO.

Conclusion: fast in-line sanitizing of cups, lids etc with amalgam low pressure Mercury lamps is on average 10 times as much more cost-effective than with the Pulsed Light.

#2: Sanitation and Sterilization of products through UV semi-transparent packaging:

in this case both sanitation and sterilization can be done only with pulsed light, unless packaging is at least 30 to 40% transparent to the Mercury line of 254 nm. Yet is often not the case. The real situation is as on the Fig. 2 (5):



Pulsed light can also sterilize in the area of 260-300 nm.

In this case the fixed position of the Mercury 254 nm line is a disadvantage which makes it not possible to use at all.

Moreover, current FDA regulations require to put labels on food or pharmaceutical products which were subjected to invasive treatment creating hazardous for health chemicals or diminishing its nutrient or medication properties. Invasive sanitation or sterilization are gamma radiation, electron or ion beams, heat, and/or Ozone and alike. Many data show that gamma sterilization induces sever damages to nutrients and vitamins in foods, and specifically in meats, plus induces many carcinogenic substances. Gamma sterilization was shown as not always reliable, causing a few dozens of deaths in USA and respective legal actions see at (6).

Yet one of main disadvantages of gamma sources is its inability to be installed for the in-line sterilization.

Mercury lamps can be incorporated as in-line treatment for some food staffs (e.g. salads), yet for protein rich foods the 254 nm Mercury line is labelled by FDA as ionizing radiation since it decompose some proteins, bleaches some products even creates odours on meats and on other protein rich products.

Pulsed light, including its Pulsed UV band, has the broad spectral emission which does not cause same negative effects as a single line of 254 nm. In this range anyway causes negative effects, Pulsed UV module can use the spectral range of 260 nm to 290 nm, also effective in de-activating micro-organisms. This range has much lesser an ionizing action or not at all.

To move the lamp output into this region is possible by selecting its pulse current, plus by using filters to absorb UVC below 260 nm (5).

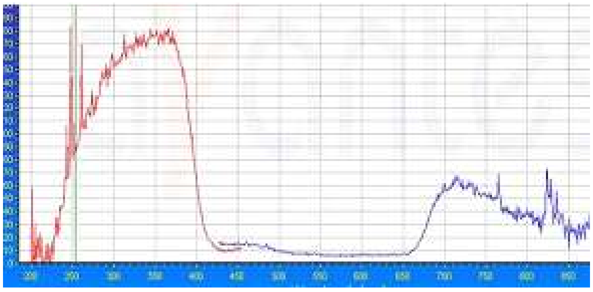


Fig 3: A spectra of a flash lamps with a water cooling jacket from a filter material absorbing visible light and IR light (5).

FDA recommends Pulsed Light as a non-radiation method for deactivating micro-organisms, and does not require to label products treated with PL. The reduction rate here depends on customer requirements and can be either sanitation or sterilization.

#3. In-line fast sterilization of in-fusion solutions and vaccines, packed in UV transparent bags or syringes.

A High need for sterilization of in-fusion solution comes from facts that for now it is sterilized by exclusively gamma rays. The requirements is to find the in-line solution.

Recently SteriBeam performed tests to reach 6 logs reduction for the most UV resistant micro-organism: <u>spores of Bacillus Pumilus.</u> This is the only known micro-organism to survive space conditions: NASA explorers found an abundance of these spores on external surfaces of ISS-International Space Station(7). Yet external surfaces of this station are exposed to high doses of cosmic rays, solar wind (which are energetic electrons and ions), X-rays and deep UV light, which otherwise are absorbed by the Earth atmosphere. Therefore full radiation doses for these spores far exceed anything which can be delivered by standard UVC low pressure Mercury vapour lamps. Article shows that B. pumilus is resistant also to H2O2, heat etc (7,8).

Available publication data have shown that the does of 3J /cm2 is sufficient only to get 4 logs (with a standard UV light(9). Our data have shown the ability to get 4 and respectively 6 logs at following UVC doses (using our semi-automatic PUV system XeMaticA- SA-1L (5),

Table 3: PL action on B. pumilus spores in 100 ml (15x5x1.4 cm) 70% UV transparent PE bags

Illumination conditions:	Test #1	Test #2
pulse energy J/pulse	750 J	500 J
% of UVC from the pulse energy	35%	20%
number of pulses	5	10
Full UVC dose	13 J/cm²	10 J/cm²
reduction in logs	6	5
Number of samples	5	5

At 1200 bags /h 250 ml is 3 sec /bag will require 2 lamps at 6 pulses at 750 J/p, at 2 Hz or 1500 J/sec in UVC, or at 4.3 kw pulsing. The full system is 6 kw, such a tunnel could cost ca. 120,000 Euro. Cost per sterilized bag will be around as per the Table 4 below:

Table 4: projected costs for in-line sterilizing infusion bags with PUV Tunnel

SteriBeam PUV Tunnel	data base	€
capital costs		€120,000
Power consumption	6 kw	€1.2/h
lamps 2 x20 cm, 200h life, price /h	2 x 200 €	€2/h
Total operating costs per hour		€3.2/h
Number of bags per hour	1200	
operating costs/bag		€0.0027/bag
depreciation (5 y, 16,000h)/h		€7.5/h
operating plus depreciation/hour		€10.7/h
operating plus depreciation/bag		€0.09/bag

This is very competitive price providing that it is in-line operation, impossible for gamma treatment.

Fig 4: SteriBeam offers in-line UV Tunnel systems with pulsed UV or with amalgam continuous UVC lamps to food and pharmaceutical companies.

It provides the 360° UVC exposure both from top and bottom of products with up to 3000 p/h rate. It can be also equipped with pulsed UV or with continuous UVC amalgam lamps.

Cited reference materials, web links:

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#3: website of Xenon Corp: www.xenoncorp.com

#4: On Amalgam lamps: www.spectralinnovations.com/uv_technologies/ultraviolet_lamps.htm

#5: fhttp://www.steribeam.com/technology/SBS-PUV-principles.pdf

#6: John M. LaForge / Z Magazine Oct2000 “Safe-guarding the public from human-made radiation” see at http://www.mindfully.org/Food/Irradiated-Food-Nuc-Weapon.htm

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#9: L. Link, J. Sawyer, K. Venkateswaran and W. Nicholson1:“Extreme Spore UV Resistance of Bacillus pumilus Isolates Obtained from an Ultraclean Spacecraft Assembly Facility” at 3J/cm^3 got 4 logs. Microbial ecology, Received: 29 April 2003 / Accepted: 23 June 2003 / Online publication: 17 September 2003.

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