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Alternative UV Light Sources for Surface Disinfection

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***Abstract* - Mercury UV-C light sources are long known to be efficient for microbial inactivation and have been widely used. At the same time, the radiation, if used in inappropriate doses and spectral regimes, can also cause harmful effects to human tissue. The aim of the study was to evaluate the applicability of the novel UV light sources from thallium – antimony at different UV-C. For the research specially made light sources were produced. The influence of UV-C radiation in the range of 200 - 280 nm was tested on Gramnegative bacterium *Escherichia coli*, both with mercury and thallium. More than 99.99 % inactivation of *E. coli* cells was obtained after 10 min contact time for thallium – antimony UV-C light source, demonstrating the potential of the produced lamps.**

Keywords - disinfection, UV thallium lamp, UV mercury lamp, UV-C, antiviral, antibacterial

I. INTRODUCTION

Ultraviolet radiation in the range of 200 – 280 nm (UV-C) has long been known to have the abilities to cause damage to the cellular material of bacteria or viruses, including their DNA or RNA. The inactivation occurs when the absorption of a photon forms pyrimidine dimers between adjacent thymine bases and renders the microorganism incapable of replicating [1]. As reported [2], at appropriate doses UV-C can selectively inactivate microorganisms while preserving viability of mammalian cells and, moreover, promote wound healing.

The wide application of UV-C for disinfection purposes has been linked with multiple advantages over liquid disinfectants and heat sterilization. It can be performed to disinfect surfaces, liquids, air and rooms, and it is also very energy-efficient [3]. All these factors are of high importance not only in routine disinfection but also during local and global pandemics, e.g., SARS-CoV-2, swine flu, MERS-CoV.

The spectral region used for disinfection is mainly the UV- C radiation in the spectral range of 200 – 280 nm. To produce radiation in the UV-C region, in almost all disinfection experiments mercury low-pressure lamps have been used with a strong emission line at 254 nm what is close to the RNA absorption peak [3]. There are very few experiments applying other wavelengths. Only individual

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experiments with a peak wavelength at 222 nm, and 365 nm (UV-A) [3] or 207 nm [4] have been reported. One of the reasons for the predominant use of Hg 254 nm light is the widespread ability of Hg light sources due to simple manufacturing process and lack of other appropriate UV-C light sources. This has so far been a limitation for exploitation of other UV- C wavelengths.

Thus, the aim of this study was to evaluate the applicability of the novel UV light sources filled with thallium and antimony for their potential to be used in disinfection. Thallium and antimony filling would give more working spectral lines in the same region. These wavelengths of the UV-C spectral region will be compared with mercury resonance line to demonstrate the efficiency.

Institute of Atomic Physics and Spectroscopy, University of Latvia has experience in development and manufacturing of special design high-frequency low pressure metal vapour light sources. Such light sources are widely used as bright radiators of intense spectral lines in different types of scientific devices, for instance, in atomic absorption spectrometers [5,6].

The high –frequency light sources are excited by the electromagnetic field, using electrodes outside the lamp. As the result, the inductive coupled discharge is initiated. It has been proven that such kind of discharge plasma is characterised by both, higher electron temperature and concentration, giving more intense spectral lines in comparison to other type of low pressure discharges.

Multiple high-frequency light sources, radiating in UV region filled with such elements like lead, phosphor, selenium, arsenic, thallium, antimony and mercury have been manufactured [7]. At the moment, these light sources have to be optimized for each particular use, and it is of great importance to use reliable methods for these investigations and further on for improvement of the light sources.

Within this work, we report the results of disinfection experiments with the thallium – antimony light sources in comparison with mercury lamps for neutralisation of *Escherichia coli* as representative Gramnegative bacterium.

MATERIALS AND METHODS

A. UV-ligh sources

For the experiment, special type high-frequency electrodeless light sources were manufactured at the Institute of Atomic Physics and Spectroscopy, University of Latvia. The light sources were made of SiO_2 glass with a diameter of 10 mm, filled with a metal vapour and a buffer gas at low pressure (Fig. 1).

Fig. 1. Typical design of the high-frequency light source.

In this case, thallium and antimony mixture was used for filling to excite more spectral lines in the UV-C spectral region. As a buffer gas, argon was used at the pressure of 3 torr. An outer electromagnetic field of about 100 MHz frequency was applied to initiate a discharge inside the lamp.

Spectra of the manufactured metal vapour light sources were recorded by the high – resolution Jobin Yvon 1000 M spectrometer.

B. Bacterial culture and growth conditions

Escherichia coli ATCC®10536 was used as the test bacterium. Overnight culture in Tryptone soya agar (Oxoid Ltd, UK) were thrice washed with sterile peptone water (0.1%) by centrifugation (6000 rpm for 2 minutes, Minispin, Eppendorf). The final bacterial pellet was re-suspended in sterile peptone water (0.1%) to obtain a stock solution of approximately 10^7 colony forming units (CFU) mL^{-1}. For cell enumeration 0.002 mL of the stock suspensions were filtered through a 25–mm-diameter 0.2–µm-pore–size filter (Polycarbonate Track- Etch Membrane, Sartorius, Germany) and fixed with 3–4% formaldehyde for 10 minutes, washed with sterile distilled water and stained with 10 µg mL^{-1} DAPI (4',6-diamidino-2-phenylindole, Merck, Germany) for 5–10 minutes. Cell concentrations were determined with epifluorescence microscopy (Ex: 340/380; Em: > 425, dichromatic mirror 565 nm, Leica DM6000B, Germany) by counting of 20 random fields of view.

C. Disinfection experiments

To test the inactivation efficiency, 3 mL of *E. coli* stock was inserted in sterile 30 mm borosilicate Petri dish and placed under the lamp at the distance of 11 cm. The SiO_2 lens was used to create parallel light rays. The measurements were performed in several series, changing the irradiation time form 1 min to 10 min.

Fig. 2. Experimental set-up for irradiation tests.

Immediately after irradiation, the sample was removed from the light source and decimal dilutions of the sample were inoculated onto Tryptone soya agar (Oxoid Ltd, UK) plates and incubated for 24 hours at 37°C. The result (reduction in cultivable *E. coli*) is expressed as negative log reduction of colony forming units after treatment divided by colony forming units before treatment.

II. RESULTS AND DISCUSSION

A design of a high – frequency thallium – antimony light source is shown in Fig.3.

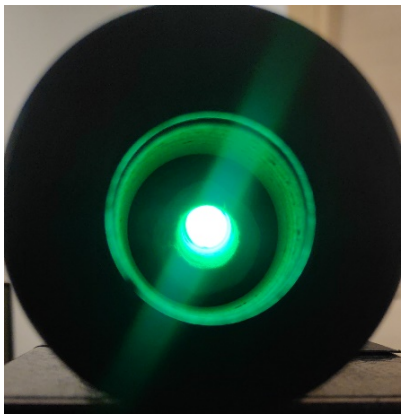

Fig. 3. Design of a high-frequency thallium - antimony metal vapour light source

UV- C spectra of thallium-antimony and mercury light sources are shown in Fig.4 and Fig. 5, respectively. As can be seen, the mercury UV- C spectrum contains only one strong emission line, however thallium – antimony spectrum have many spectral lines, giving a possibility to irradiate broader region of the RNA absorption band [4].

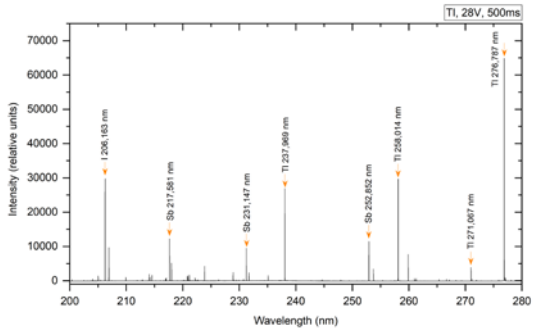

Fig.4. Spectrum example of thallium - antimony light source in the region of 200 – 280 nm.

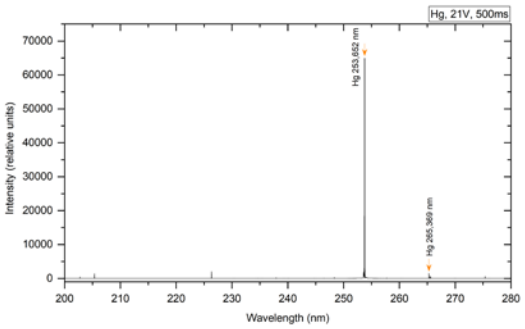

Fig. 5. Spectrum example of mercury light source in the region of 200 - 280 nm.

To evaluate and compare the performance of both UV-C light sources, bacterial inactivation tests with Gramnegative bacterium – *E. coli* have been performed to mimic faecal and surface contamination. In general, higher inactivation efficiency was observed with mercury light source, yielding 99 % reduction within 2.26 min of irradiation (Fig. 6, Fig. 7).

At the same time thallium - antimony produced 99 % reduction within 6 minutes and followed a linear reduction pattern all through the irradiation tests (Fig. 7, Fig. 8).

Till some extent this can be explained by different spectral compositions of both light sources. As a result thallium demonstrated comparable efficiency for reduction of cultivable *E. coli* to mercury UV-C.

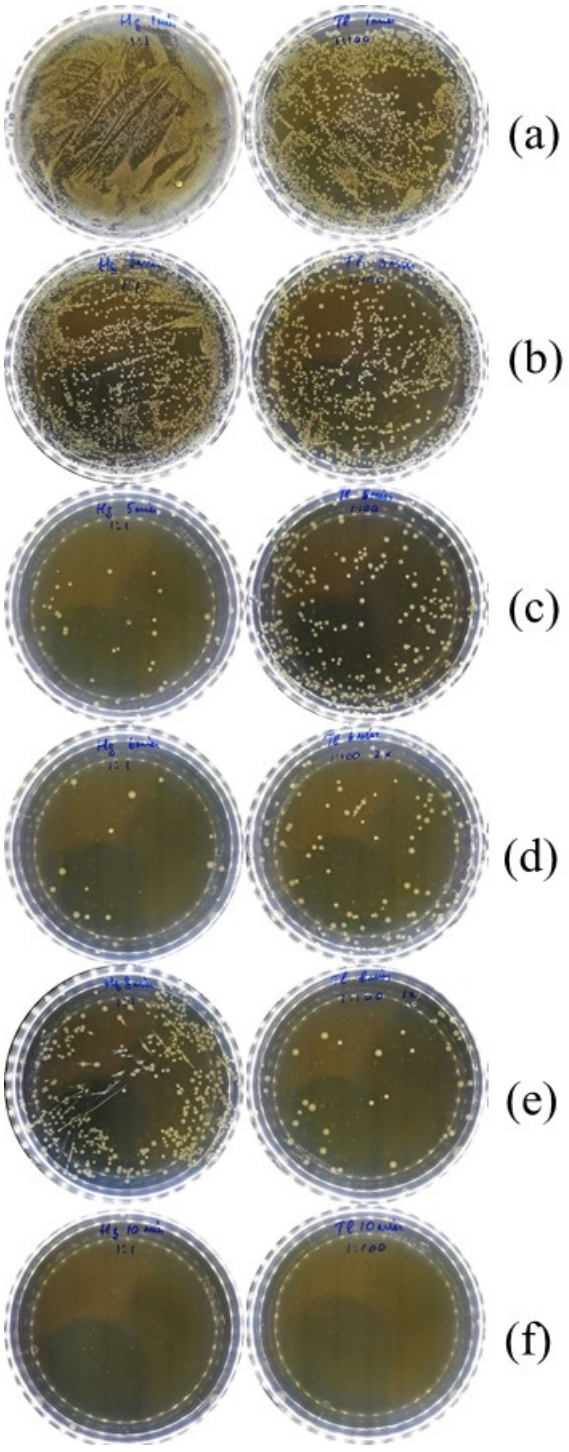

Fig. 6. Decrease in cultivable *E. coli* (CFU per plate) at various treatment times with mercury (left, no sample dilution) and thallium – antimony (right, 10^2 dilution) UV-C light source.(1 min (a), 3 min (b), 5 min (c), 6 min (d), 8 min (e) and 10 min (f))

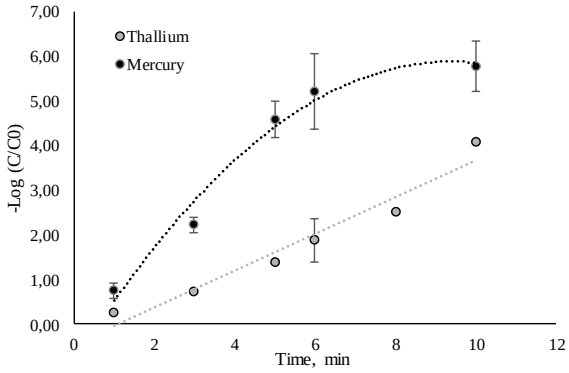

Fig.7. Log-reduction of *Escherichia coli* CFU as a function of exposure time for thallium – antimony and mercury light sources by equal irradiation conditions.

To date, mercury 254 nm spectral line irradiation has been demonstrated as efficient source to inactivate both microbial cells and viruses [8, 9]. Within this study even low irradiation doses of thallium - antimony UV-C at spectral region of 200 – 280 nm containing many spectral lines showed to be efficient to obtain 99 % reduction of *E. coli* within 6 minutes of contact time. The obtained results demonstrate the potential application of thallium as alternative UV-C light source for microbial and viral contaminant inactivation on surfaces.

III. CONCLUSIONS

Mercury UV light source at 254 nm spectral line demonstrated 99,99 % reduction in less than 5 minutes. The thallium – antimony light source demonstrated lower but still comparable efficiency in tests with *Escherichia coli*. Thus, UV-C irradiation with non-mercury light sources can be a promising tool for surface and room disinfection.

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