New Water Disinfection Technology for Earth and Space Applications as part of the NPP Fellowship Research

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Background

- Why do we need clean water?

from: Background: Water & Health

*SANDIA Report on UV-LEDs.*
Background

Water in Space?

http://apod.nasa.gov/apod/ap070625.html

- Water Disinfection
- Primary Disinfectant
- Secondary Disinfectant
- U.S. NASA-EPA
Problem Statement

- There is the need for a safe, low energy consuming and compact water disinfection technology to maintain water quality for human consumption

Background

- Chlorination YES or NO?
- Metals
- Other....Chloramines, Ozone
- Ultraviolet Radiation?
UV Disinfection


Background

UV Disinfection

http://www.awwa.org/publications/AWWA/Article.chtml?articleid=26174
Background

- UV-LEDs

- SANDIA Report 2005
  - Escherichia coli ATCC 23229, high sensitivity to UV
  - Escherichia coli ATCC 15596, medium sensitivity to UV
Background

- Vilhunen et al. 2008
  - Escherichia coli (k12)

- Hammamoto et al. 2007, and Mori et al. 2007
  - Vibrio parahaemolyticus
  - enteropathogenic Escherichia coli,
  - Staphylococcus aureus

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Background

- Escherichia coli DH5α

were reduced by greater than 5-log10 stages within 75 min at 315 J/cm² of UVA

- Salmonella enteritis

was reduced greater than 4-log10 stages within 160 min at 672 mJ/cm² of UVA
Background

Birmele et al., 2009
-Sphingomonas paucimobilis,
Pseudomonas aeruginosa,
Burkholderia cepacia,
Methyllobacterium fujisawaense and
Cupriavidus metallidurans

3-log reduction in one hour of UVC exposure in a static test

Background

- UVA Disinfection

http://www.wuoen.com/creative药业.com/734

http://www.comforz.com/uv-lights.html
Background

\[ \text{TiO}_2 \rightarrow \text{TiO}_2 \left( h^+_{\text{vb}} + e^-_{\text{eb}} \right) \]

\[ O_2 + e^-_{\text{eb}} \rightarrow O_2^- \]

\[ O_2^- + e^-_{\text{eb}} + 2H^+ \rightarrow H_2O_2 \]

\[ O_2^- + H_2O_2 \rightarrow \cdot OH + OH^- + O_2 \]

\[ e^-_{\text{eb}} + H_2O_2 \rightarrow \cdot OH + OH^- \]

\[ h^+_{\text{vb}} + H_2O \rightarrow H^+ + \cdot OH \]

\[ h^+_{\text{vb}} + H_2O \rightarrow H^+ + \cdot OH \]

\[ 2 h^+_{\text{vb}} + 2H_2O \rightarrow 2H^+ + H_2O_2 \]

Silver, Ag

- Silver has been used in:
  - Water, vinegar, fruit juices, wine
  - Dental amalgams, composites
  - Topical creams, bandages, catheters, medical devices
  - Polymers, ceramics, synthetic fabrics
Silver, Ag

- Mechanisms of microorganism Inactivation:
  - Accumulates inside cells
  - Binds to:
    - Cell wall/ membranes
    - Proteins (-SH)
    - DNA
    - Electron donor groups

General Objective

- Design and test a reactor to prove the efficacy of a UVA-LED, TiO₂, and nanosilver safe technology to sustain water quality for life support systems.

Microorganisms tested:
- MS2 Bacteriophage
- Pseudomonas aeruginosa
- E. Coli
Experiment Design

<table>
<thead>
<tr>
<th>Experiment</th>
<th>UVA-LED</th>
<th>TiO₂</th>
<th>Nanosilver</th>
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<tbody>
<tr>
<td>Treatment 1</td>
<td>X</td>
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<tr>
<td>Treatment 2</td>
<td>X</td>
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<td>Treatment 3</td>
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<td>Treatment 4</td>
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</tbody>
</table>

Materials and Methods

- Modified DFR
- UVA-LEDS
- TiO₂ coated glass slides
- Nanosilver
Materials and Methods

Drip flow reactor with LED placement on top.

Section view of DFR with gaskets, polyethylene, LED and PCB. Small aperture opening to reduce stray light into neighboring wells.

Section view of DFR with gaskets, polyethylene, LED and PCB with parabolic cut out to redirect radiation.
**Materials and Methods**

TiO$_2$ glass slides preparation was done by slurry deposition in a glass borosilicate slide (1x3 in).

**Materials and Methods**

- Nanosilver
Materials and Methods

Areas of Opportunity

- TiO$_2$ coating
- Nanosilver application and quantification
Materials and Methods

1. Bacteria or Virus
2. Centrifuge
   - If it is bacteria only
3. Adjust Concentration
4. Add Bacteria or Virus Concentration to Reactor container
5. Reactor well
6. Add Nanosilver
7. Neutralize Disinfection Effect
8. Plate
9. Dilute
10. Incubate 24 Hrs
11. Count Colonies or Plaques
Results

Disinfection of MS2 Bacteriophage vs. Time

![Graph showing disinfection of MS2 bacteriophage over time with different treatments: CONTROL, UVA, UVA+TiO2, UVA+TiO2+NANOSILVER, UVA+NANOSILVER. The graph indicates the reduction in PFU (plaque-forming units) over time, with the UVA+NANOSILVER treatment showing the most effective disinfection.]
Disinfection of *Pseudomonas aeruginosa* vs. Time

Disinfection of *E. coli* vs. Time
Conclusions

- The design of the reactor presents no overheating and a constant temperature. A good electrical and optical performance for a UV water treatment system.

- The assessment of this study shows that UVA-LEDs can be used as a good disinfectant in water for MS2 Bacteriophage. The log reduction was sufficient to meet US EPA standards as a secondary disinfectant for maintaining water quality control.

Conclusions

- This study has shown that at the conditions tested there is no inactivation of *Pseudomonas aeruginosa* and *E. Coli* and further testing at different conditions (specifically contact area and time of exposure) have to be performed to use UVA-LED as a secondary disinfectant to maintain water quality.
Further work recomended

- Other contact areas and longer times of exposure should be tested.

- Microorganisms:
  - Cryptosporidium parvum oocyst

- Other research lines such as biocides and reactive oxygen species in the reactor.

Key point

UVLEDs are a viable disinfectant in water that should be further investigated to develop an optimized Water Technology for Earth and Space Applications.
References


2.- Hammamoto et al. 2007; Mori et al. 2007; Vilhunen et al. 2008.

IMAGES ON LEFT SIDE:

2.- apod.nasa.gov/apod/image/9909/water_jsc.jpg
3.- coep.pharmacy.arizona.edu/water/drink2.jpg
4.- www.ryanswell.ca/projects/images/Photo5_Page1
5.- imthi.com/.../2009/09/charity-water-honduras.jpg
6.- NASA Image: Earthrise over the lunar horizon, December 1968.

Acknowledgements
- NASA and NPP administered by ORAU.
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Questions?

* Nasa Image: Earthrise over the lunar horizon, December 1968.
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