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► **To cite this version:**

Alfredo Gonzalez-Perez. UV-LED water disinfection for small-scale decentralized systems. 3rd IWA Disinfection and Disinfection By-Products Conference, Jun 2022, Milan, Italy. 2022. ⟨hal-03718690⟩

HAL Id: hal-03718690

<https://hal.science/hal-03718690v1>

Submitted on 9 Jul 2022

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UV-LED water disinfection for small-scale decentralized systems

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Motivation

Water disinfection can be achieved with different techniques using chlorine, ozone, ultraviolet light or filtration. Among the different processes ultraviolet has become a technology of choice due to their proven efficiency inactivating protozoa, bacteria, and viruses. Ultraviolet light involves high process safety, ensuring that no harmful byproduct will be formed during the application. The main germicidal UV sources are low-pressure mercury lamps, Excimer lamps, UV-LEDs, and other like medium-pressure mercury lamps and Xenon lamps that allow for pulsed operation (Bergman 2021). Those are used for water, air and surface disinfection among other uses.

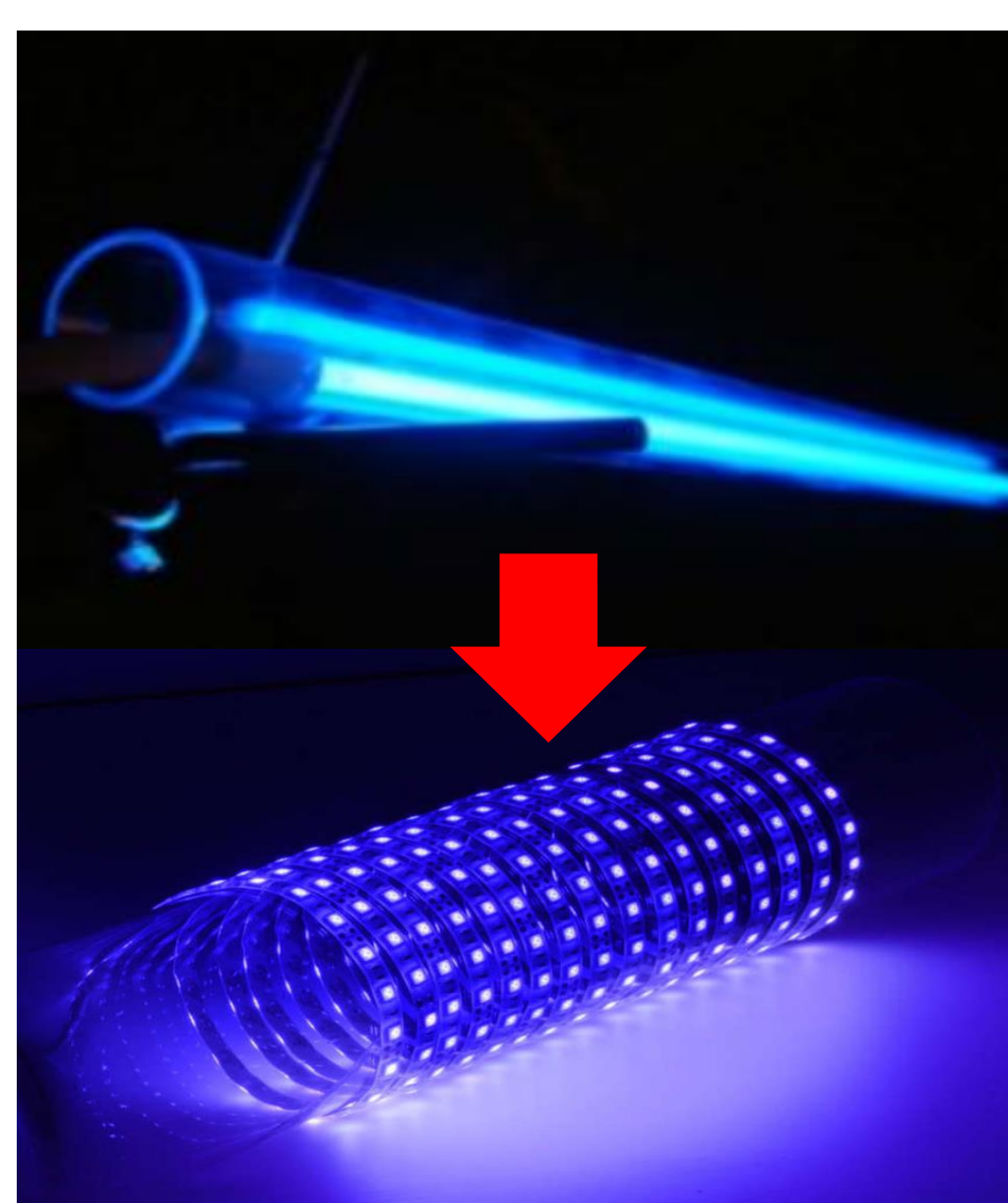
In recent years, a global treaty to protect human health and the environment from the adverse effects of mercury has emerged. With the implementation of the regulation by the [Minamata Convention on Mercury](#) that enforce the elimination of mercury-based technologies and their substitution for alternative ones. Currently water purification plants all over the world depend on mercury-based UV lamps for their disinfection units (allowed by the Minamata convention on Mercury for the water business), which maybe required for replacement when alternative technologies like those on UV-LED become efficient enough for the treatment of large water volumes and regulation incorporate guidance adapted to their operating requirements.



Technology replacement

Small and medium-size water treatment units can already benefit from the use of UV-LEDs lamps for their water disinfection units. This alternative is optimal for decentralized water treatment units (Lui et al 2014).

UV-LEDs provide with new advantages not present in traditional mercury-based UV lamps. The use of several individual wavelengths, flashing modes and new reactor designs are some of the advantages that will drive the transition to UV-LED standardization on water treatment. (Song et al 2016).



UV-LED Challenges and opportunities

- UV LEDs of higher output are needed and more efficiency.
- Studies indicate that combined wavelengths of 280/365nm and 280/405nm are the best for disinfection. Use of dual-wavelengths for efficient disinfection and flashing modes.
- Reactor designs with new geometries. Some excellent designs away from traditional mercury-lamps are already commercially available.
- New regulations need to be developed taking into account the characteristics of UV-LED technology to facilitate the use on municipality owned water treatment plants.

Key References

- (1) Lui, GY., et al. 2014 Point-of-use water disinfection using ultraviolet and visible light-emitting diodes. Science of the total environment 493, 185-196.
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- (3) Song, K., et al. 2016 Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: A review. Water Research 94, 341-349.
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- (5) Chevremont, A.C., et al. 2012. Effect of coupled UV-A and UV-C LEDs on both microbiological and chemical pollution of urban wastewaters. Sci. Total Environ. 426, 304-310.
- (6) Song, K., et al. 2019. Microorganisms inactivation by wavelength combinations of ultraviolet light-emitting diodes (UV-LEDs). Sci. Total Environ. 665, 1103-1110.
- (7) Woo, H., et al. 2019. Efficacy of Inactivation of Human Enteroviruses by Dual-Wavelength Germicidal Ultraviolet (UV-C) Light Emitting Diodes (LEDs). Water 11, 1131.
- (8) Xiao, Y., et al. 2018. Impact of UVA pre-radiation on UVC disinfection performance: Inactivation, repair and mechanism study. Water Res. 141, 279-288.
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Decentralized water treatment

Centralized water treatment systems can treat large volumes of water at high rates to accommodate all residential, business, and industrial uses and are mostly used in urban areas. A centralized approach has multiple advantages; effectively remove practically any range of raw water turbidity along with harmful pathogens, including bacteria, virus, and protozoa. Some disadvantages like the capital cost as well as operating and maintenance costs for a centralized system can be significant. In addition, the fast growth of many cities makes a centralized approach unsuitable leading to some suggestions for a shift towards decentralization have been proposed. *This approach opens for the possibility to treat and reuse water at the local level as well as testing different technologies without affecting the entire city providing a more sustainable approach with increasing resilience.*

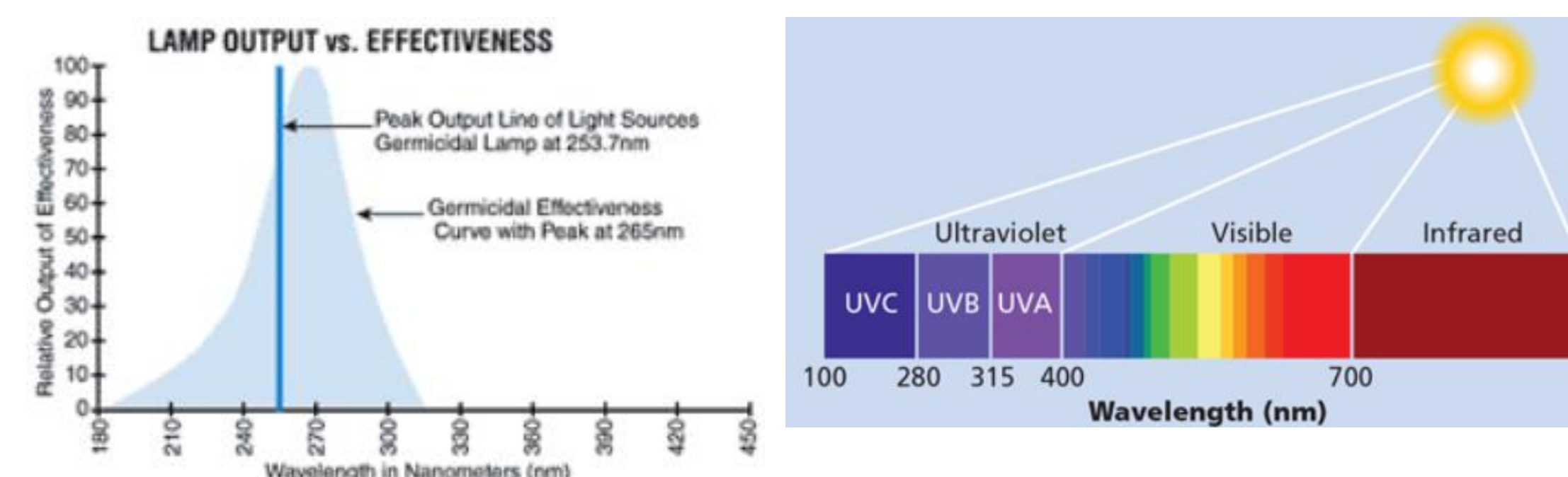
In rural areas as well as remote areas away from traditional municipality services a small to medium size decentralized water supply and treatment is preferred. A decentralized system that could be point-of-entry (POE) or point-of-use (POU) a treatment unit can be installed at the individual home, small community, or business to provide drinking water and wastewater treatment. *The advantage of a low initial capital investments and reduced operating and maintenance costs is a plus. In general, the shift towards decentralization have advantages for both small-medium size water treatment as well as large scale water treatment at the economic, operational and technology level adding the possibility to use emerging technologies like the UV-LED based one, and potentially more efficient, that are not ready for large scale utilities.*

Germicidal Activity Wavelengths

The table show a selection of multiple wavelengths combinations (UV-C, UV-B and UV-A) targeting different microorganisms on different mediums.

Reference	Microorganism	Media	UVC/ UVA	UVB/ UVA	UVC/UV B-UVC
(A. C. Chevremont et al., 2012)	E. coli and CIP 6224, Enterococcus faecalis	buffered solutions	Yes	Yes	N/A
(Song et al., 2019)	E. coli, MS2 coliphage	Sterile phosphate buffered saline	No	No	No
(Woo et al., 2019)	Human enteric species (Enterovirus A-D)	Water	N/A	N/A	No
(Xiao et al., 2018)	E. coli	Distilled water	Yes	N/A	N/A

A recent review by Matafonova and Batoev (Matafonova et al. 2022) summarize the state of the art on disinfection using dual-wavelength light radiation. Below we show some key parameters for uv disinfection on using UV-mercury lamps.



Low-Pressure (low-output):
Small/Compact systems low doses

Low-Pressure (high-output):
Small/Compact systems greater doses

Medium-Pressure (high-output):
High doses and high flow volumes

Parameter	Low-pressure	Low-pressure high-output	Medium-pressure
Germicidal UV light	Monochromatic at 254 nm	Monochromatic at 254 nm	Polychromatic, including germicidal range (200 to 300 nm)
Mercury Vapor Pressure (torr)	Optimal at 0.007	0.76	300 – 30,000
Operating Temperature (°C)	Optimal at 40	130 – 200	600 – 900
Electrical Input (W/cm)	0.5	1.5 – 10	50 – 250
Germicidal UV Output (W/cm)	0.2	0.5 – 3.5	5 – 30
Electrical to Germicidal UV Conversion Efficiency (%)	35 – 38	30 – 40	10 – 20
Arc length (cm)	10 – 150	10 – 150	5 – 120
Relative Number of Lamps Needed for a Given Dose	High	Intermediate	Low
Lifetime (hrs)	8,000 – 10,000	8,000 – 12,000	4,000 – 8,000

Acknowledgement

The author wants to acknowledge the Water Centre for Innovation (UCV - Utvecklingscentrum för vatten) at Campus Roslagen AB (Norrtälje Municipality) for support and discussions on water decentralization and regulation.