University of Toledo

The Development of a LED UV-C Water Purification System

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Chemical Engineering for Good Challenge
2019 Competition Submission

How Chemical Engineering Can Be Applied to Solve World Problems on a Micro Scale

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Lead AIChE Chapter

University Name & Location: University of Toledo, Toledo, OH

Team Lead: [redacted]

Team Lead email: [redacted]

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Collaborating AIChE Chapter - *optional*

University Name & Location: N/A

Team Lead ______________________________

Team Lead email: ______________________

Team Lead phone: ______________________

Partner Organization(s) - *optional* N/A

Title of Submission: The development of a LED UV-C Water Purification System

Submission Type: X underutilized technology ___technology toolkit

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Contest entries must address '**How chemical engineering can be applied to solve world problems on a micro scale**". Three prizes of $3000, $1500, and $1000 will be awarded as unrestricted grants to the winning chapters. If judges determine that there are less than three submissions worthy of award than fewer prizes will be awarded. An additional bonus prize of $500 will be awarded for the best submission by a collaboration of a US AIChE chapter and an international AIChE chapter.

Submissions are directed at problems that could be implemented by engineering service organizations in partnership with communities (often small and rural) in the developing world. Micro scale refers to the size, cost, and sophistication of the project (not molecular size). Typically these partners have limited technical sophistication, capital, and funds to cover operating expenses. Utilizing appropriate, sustainable (in the broadest sense) technology is critical. This competition is open to all AIChE student chapters, and entrants are encouraged to partner with other organizations experienced in doing this kind of work. Teams may be of any size, and may include students, faculty and professional engineers. AIChE chapters may collaborate and submit a joint entry.

Submissions should utilize chemical engineering technology and skills (beyond the hydraulics calculations commonly used in designing water systems). Entries will either focus on one chemical engineering-based technology that is currently underutilized by teams working on international service projects (**ISP**) ***or*** provide a useful toolkit for ISP teams to identify, select, and utilize existing chemical engineering-based technologies to solve specific problems.

Attach to this cover page the information requested below for your type of submission. All submissions to be in electronic format. *Only materials in English language will be considered.*

1. Recommendation of the application of a specific technology, available today, which is not currently utilized in ISP projects.

A. Define the specific community problem being addressed
B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or public links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)
C. Describe what kind of data would be required to design / customize this technology for ISP projects
D. Describe why this technology would be appropriate for implementation in partner communities. . Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

2. Provide a toolkit for the application by ISP teams of a set of existing chemical engineering-related technologies addressing a general technical challenge that are underutilized. General technical issues include but not limited to topics such as water purification, alternate energy sources, energy conservation, and preservation / preparation of crops and foods. The set must include at least three different technologies.

The toolkit will include:

A. Technology Basics Document intended for use by another design team, that includes description of the problem addressed, description of each technology, and discussion of when each technology is most applicable
B. checklists / tables to help an ISP project team identify candidate applications and select between technical options

C. important data required to select and design. Inclusion of general design procedures & considerations will be considered by the judges as additional added value to the toolkit.
D. references to useful source materials
E. Also provide a discussion of why these technologies would be appropriate for implementation in partner communities, including aspects of technical, maintenance, financial, and cultural sustainability.

Important Information

- the latest information for this competition is always available at **https://www.aiche.org/ace4g**
- **submission deadline**: **November 22, 2019**
- Submit this completed form by deadline date to **ace4g@aiche.org**
- All submissions, references, and supporting materials must be in English language
- The contents of all contest submissions may be made public, with appropriate credits given to the original submitters
- You may direct questions to Alan Zagoria at **ace4g@aiche.org**

General Judging Criteria

- inclusion of chemical engineering-based technologies
- applicability of the proposed solution(s) to micro-scale engineering projects in the developing world intended to improve quality of life (appropriate technology and sustainability). Large industrial-scale projects requiring more capital than could be raised by the volunteer engineering organization and the local partner community will not be considered. We strongly recommend participants view the short sustainability video at https://youtu.be/RmTx-vJKDu0 to better understand the range of sustainability issues we will be judging for.
- discussion of capital and operating costs / sustainability is a must
- supporting material that demonstrates the feasibility, practicality, or previous experience implementing the proposed technology will be highly valued
- originality
- addressing any safety issues
- Type 1: significance of the identified problem and the potential usefulness to an ISP organizations of the proposed solution (relative to what is typically done today)
- Type 2: usefulness of the toolkit

The Problem

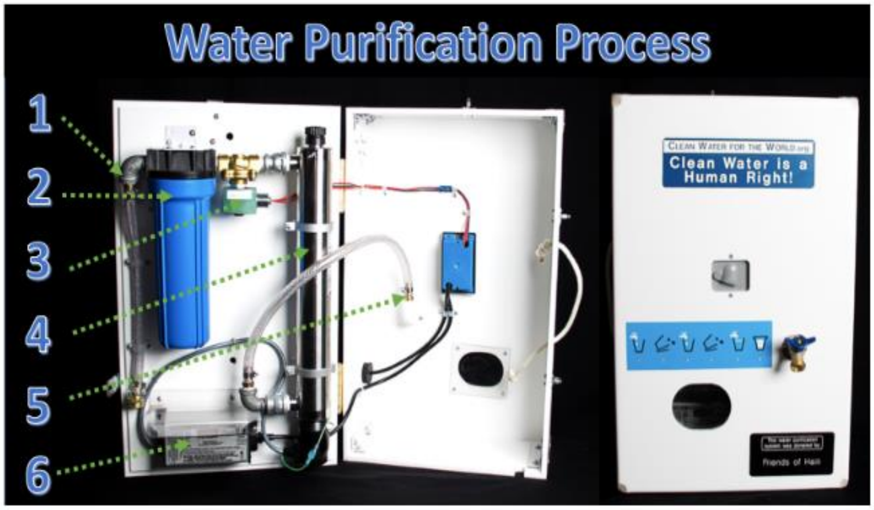
The lack of clean water is a global problem that extends beyond the borders of individual communities. A dire need exists for purified drinking water as 663 million people lack access to an improved source of water and must rely on unprotected wells, unpurified surface/river waters, or water out of an unsanitary tank [2]. Moreover, an astounding 2.5 billion people lack the proper purification processes for waste water. This problem is huge and growing larger as the population grows.

The lack of clean water has a tremendous impact on healthcare and education, especially in the rural communities of Central America. Children can miss school at high rates due to illnesses contracted from the water. When a parent is ill, they may miss work causing a financial hardship for an already impoverished family. In El Salvador, if clean water is priority, families can purchase bottled water. Water costs can approach $400 a month which would take nearly 50% of a typical household income [1]. Consequently, many families use contaminated water. The impact of access to clean water is underappreciated by many people in more well-developed countries.

What is done to help

Clean Water for the World (CWFW) is a non-profit dedicated to the manufacture, installation, and maintenance of point of use (POU) purification units in places of need at no cost to the community. Commonly, the units are installed in schools, clinics, or a community center for everyone to use. CWFW studies indicate a significant decrease in missed school and work can occur after installation of their units – from 2 days per week down to 2 days per month [1].

Application of chemical engineering principles to improving the design of the CWFW device could reduce costs and make the devices more accessible to people around the world. The current design uses UV light to sanitize water by crosslinking the DNA of waterborne pathogens [reference]. Prior to UV exposure, the incoming water passes through a 5-micron paper filter to remove particulates that would block light exposure. The UV photoreactor is powered by electricity if available in the community or solar power if not. A solenoid valve closes to prevent water passage if power is not provided to the unit to ensure water exits only if the UV photoreactor has power. The unit can treat 5 gallons per minute (GPM). Clean Water for the World has installed over 300 of these units throughout the world.



1. Hose to Water Source: Contaminated water enters from source, under pressure or gravity-fed, through a hose or PVC pipe into a 5-micron filter.
2. Filter: The 5-micron filter removes all particulates that are present in the water.
3. Solenoid: As a safety device, the solenoid is designed to permit water to flow through only when the UV lightbulb is on and working to completely purify the water.
4. U-V Light Chamber: Housed in a glass sleeve (quartz tube) to keep it dry, the UV light destroys bacteria and viruses present in the water as it passes through the chamber.
5. Faucet: The water then flows through the faucet, purified and safe to drink.
6. Ballast: Functioning as the counter, the ballast energizes the UV lightbulb, signaling when something is not functioning correctly with the purifier.

Figure 1: CWFW's Water Purification Process

Source: https://cleanwaterfortheworld.org/how-the-unit-works/

UV Technology

UV technology has been used in health care and water purification since the early 1900s [3]. UV light penetrates the cell walls of bacteria and viruses and fuses their DNA together preventing reproduction and illness. UV light also causes protein damage.

UV light is most effective for inactivation at a wavelength of 265 nm. However, UV absorption occurs over a range of 255-280 nm and can sanitize water with appropriate exposure. Figure 2 illustrates the sensitivity of common organisms that cause disease. The data from the graph demonstrates the potential for UV light to purify water.

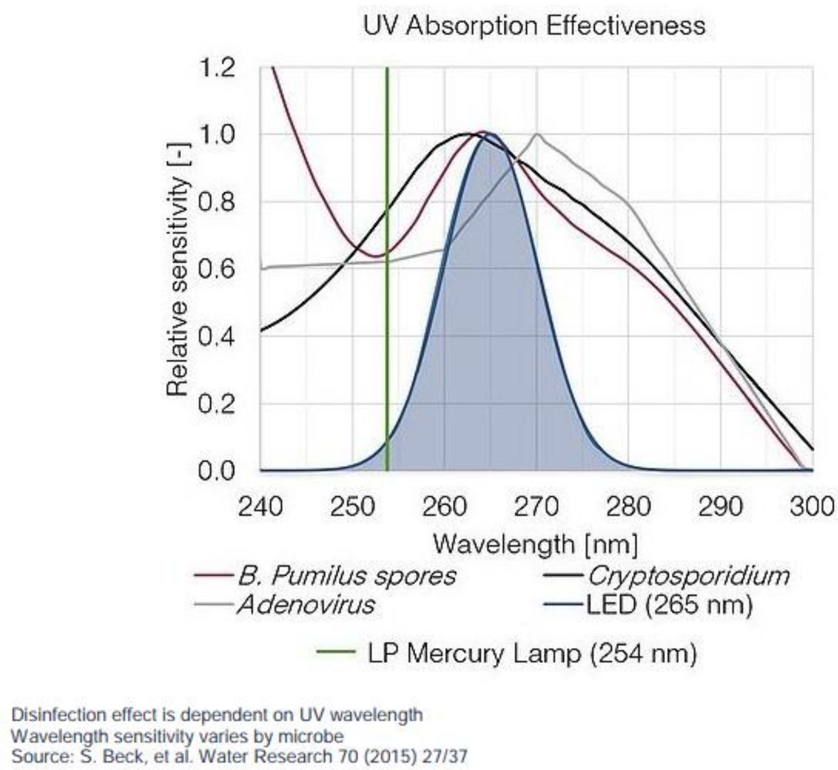


Figure 2: UV Absorption in Common Organisms

Source : https://www.aquisense.com/wavelength-selection

Disadvantages of the fluorescent bulb

The CWFW unit provides clean water but concerns exist related to UV bulb lifetime, power consumption, and environmental and health impacts. The fluorescent bulb lifetime is approximately one year. Replacement is a financial burden borne by the community and requires distribution network and installation labor. Bulb power consumption has been a concern to some communities and is especially problematic in solar installations that require battery storage. Reduction in power consumption is desirable. Another issue with fluorescent bulbs is the environmental impact of disposal. The bulb contains a small amount of mercury and disposal options that safely recover mercury do not exist in most developing countries.

Alternative types of technology used

Other technology that can be used in a community or family setting include: Sawyer filters, boiling water, and chlorine treatment. These all have downsides including lifetime, maintenance, flow rate, practicality and primarily cost. These types of technology just do not meet the needs of the family or community and will not be used in an everyday setting.

Proposal of a UV-C Reactor

The development of an LED UV-C photoreactor to replace the existing fluorescent bulb photoreactors used by Clean Water for the World and others for water treatment would address many of the concerns of fluorescent bulbs. The LED reactor prototype would be constructed of UV-C LED light bars incorporated into a flow chamber. The flow chamber would be designed to provide the exposure required for inactivation and provide the required usage lifetime. Figures 3-5 show how the light bars and the quartz tube would look inside the stainless-steel casing.

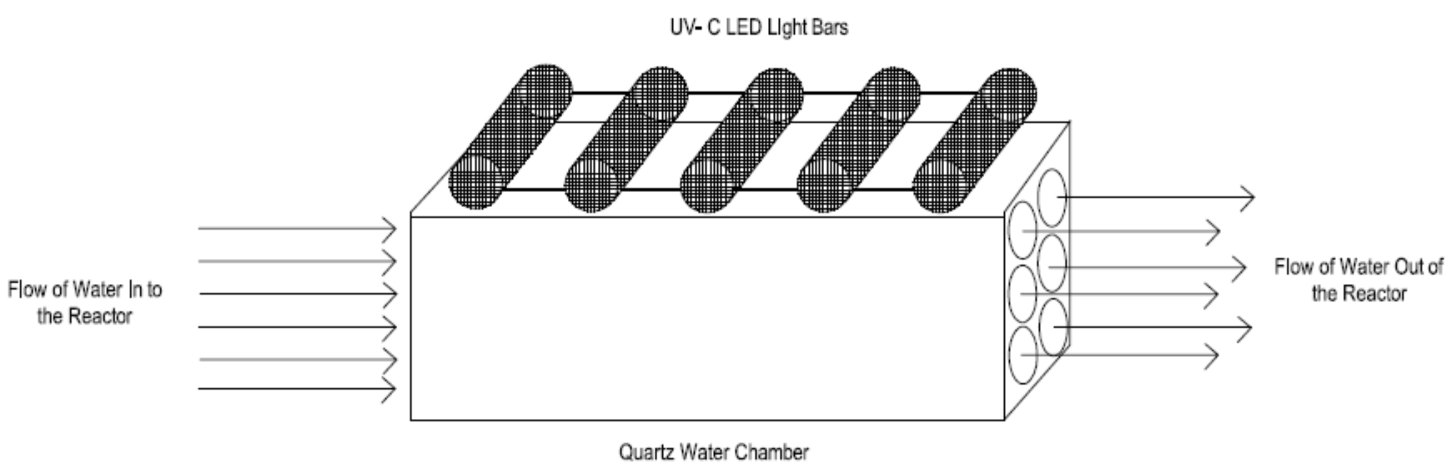


Figure 3: Prototype Design of Photoreactor

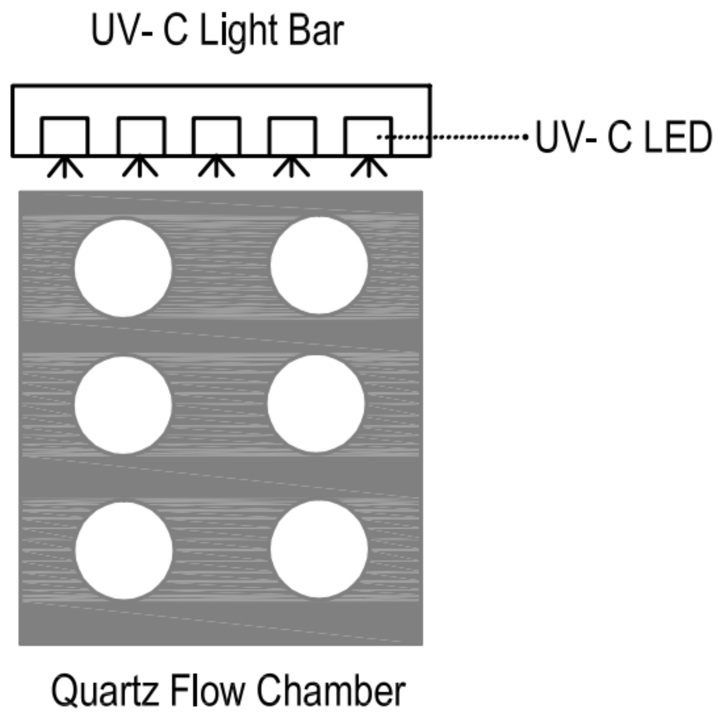


Figure 4: Prototype Design of Photoreactor from in Coming or Out Going Water

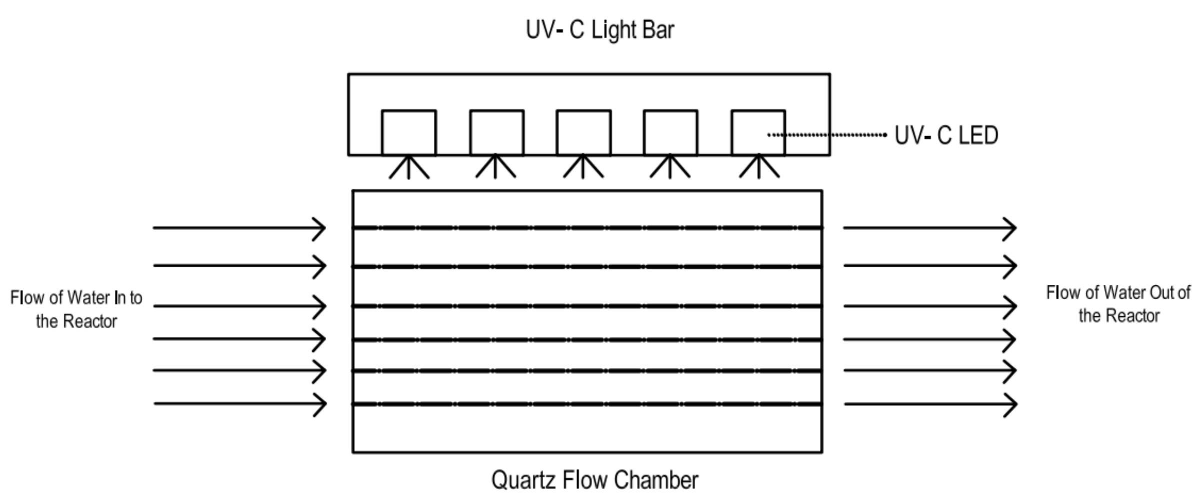


Figure 5: Prototype Design of Photoreactor from Side of Photoreactor

The developing technology of light-emitting diode (LED) practically in the use of UV-C in the disinfectant sector of healthcare and other industries is very promising. Using the LED UV-C bulbs to replace the fluorescent bulbs in water purification would be a great solution to many of the downsides of the fluorescent bulbs. The LED UV-C lights use the same mechanism as the fluorescent bulbs to purify the water. The LED bulbs could improve the issues that occur with the fluorescent bulbs. The LED bulbs have long lifetimes, smaller power consumption, and less of an environmental impact.

Irtronix has developed a light bar that will be used in the prototype of the LED reactor. The LED light bars consist of tube containing the LED bulb, circuit board, and heatsink that would directly connect to a power supply, either from an AC outlet or solar panel battery storage system. The LED light bars can also be connected to be in series together forming a Square Light Bar. A potential configuration is shown in Figure 7.

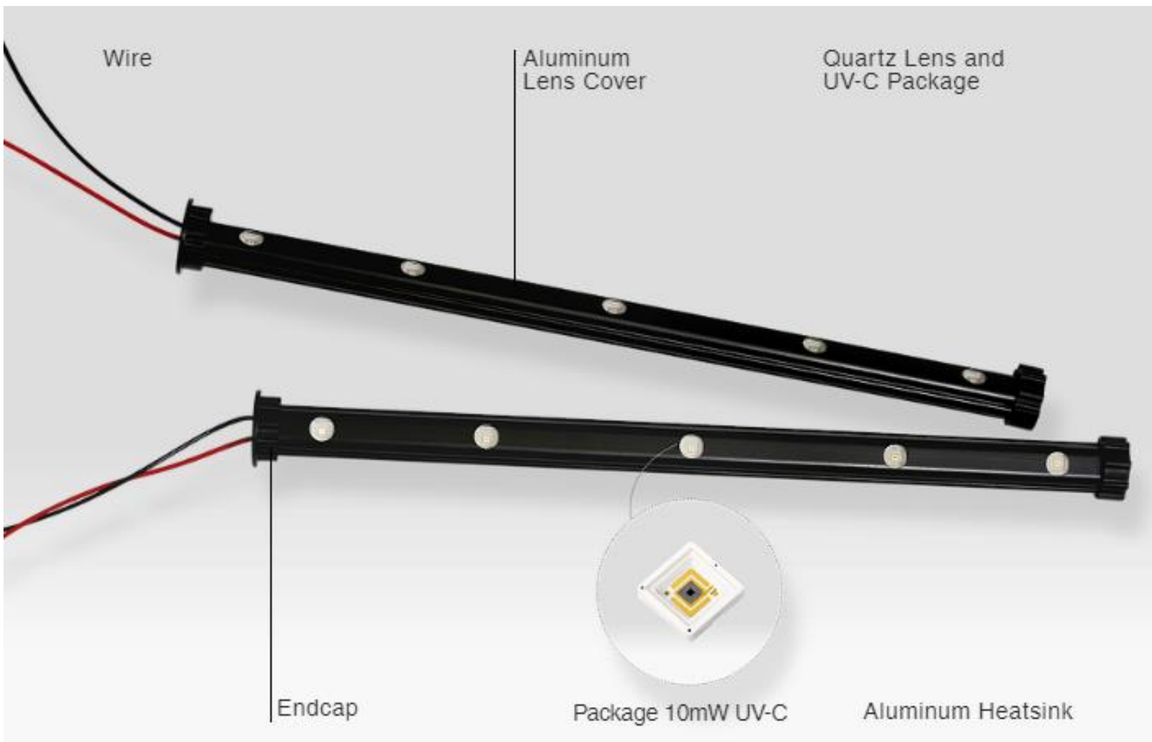


Figure 6: Light Bars Manufactured from Irtronix

Source: https://www.irtronix.com/uvc-light-bar

Figure 7: UV-C Square Light Bar

Source: https://www.irtronix.com/uvc-light-bar

The optimum wavelength for water is 265nm. The lightbar utilizes five 276nm LED bulbs. Multiple lightbars can be arranged to form the best light intensity and productivity of the system.

The heat produced by the LED bulbs is a challenge to utilization of this technology. Without proper heat removal, UV-C LED bulbs would generate sufficient heat to melt the circuit board. The light bars possess aluminum heatsinks as casing that holds the bar together. The high rate of heat transfer in the aluminum prevents thermal damage and enables use of the LED bulbs.

The quartz flow chamber will be optimized to ensure the water flowing the system will have the sufficient residence time and irradiation to ensure pathogen inactivation. The light bars and the flow chamber will be placed in a stainless-steel casing. Computer simulation will be used to simulate the flow through the reactor. This would be used to help better understand the characteristics of the reactor including size, fluid flow, residence time, and light intensity. Stainless steel is used to increase the efficiency of the reactor by using the reflective surface to reflect the light into the flow chamber.

Stainless steel will also be used due to resistance to high humidity and lifetime of the material.

The Advantages of UV-C LED technology

The lifetime of the LEDs produced today is over ten years. This decrease required financial investment and maintenance. Reduced maintenance will increase the probability the technology will not go into disrepair and decrease capital costs associated with bulb replacement over the lifetime of the unit. With an LED photoreactor the Clean Water for the World unit would require only paper filter replacement as routine maintenance.

LED bulb power consumption is significantly less than any other type of lighting technology today. LEDs power efficiency is between 40-50% while fluorescent power efficiency is 20-30% [3]. Increased efficiency will reduce community concerns over electricity consumption and cost of solar systems as battery storage requirements will decrease. Both systems represent an improvement in energy sustainability.

The LED reactor is better for the environment as well. The environmental impacts of the LEDs are less because there are no toxic materials, like mercury, that would be exposed to humans if the LED was to break. There would also be less waste due to the longer lifetime - reducing the 10 fluorescent bulbs that would be used in the single life of the LED.

Challenges the UV-C LED technology

The biggest challenges in implementing the LED reactor are the flow rate and the cost. To either produce clean water at a rate of 5 GPM or succeed the flow rate, in-depth simulation and design will have to be completed. Other types of LED reactors are on the market such as Klaran's UV-C LED light reactor [4]. The Klaran UVC LED Reactor is a point of use application. This is a simple plug and play design, but the disadvantage is the maximum flow rate is less than a half-gallon per minute making it unusable for use in a family or community. Figure 8 illustrates the Klaran UVC LED reactor, showing the simple design. The advantage of the Klaran purifier is the cost, at only $39.00. Also, these units are not able to be sold in the U.S. yet. This shows that there are advancements that can be made in the industry.

Figure 8: Klaran UV-C LED

Source : https://www.klaran.com/products/disinfection-modules/klaran-wr-series

The other disadvantage is the cost of the UV-C LED bulbs. Individual UV-C LED bulb can cost from $30-$250 depending on the power and the wavelength produced. Additional costs are incurred for the materials to mount and wire the LED bulbs. The LED light bars are a simple, cost-effective design the LED reactor. Each light bar costs $200.00, including the heatsink and circuit board [6]. If a unit is going to be produced with a larger UV chamber, it will add to the production costs of the unit. With the developing technology around the use of UV-C LED in healthcare and sterilization, the costs of the LEDs are predicted to go down as need and production for the technology goes up. The high costs of the LEDs are due to the low quantity of production and the advancing technology in manufacturing them. Soon, the costs of the LED bulbs will become an advantage to the implication of the LED reactor rather than a downside.

Conclusion

With the advancing technology, the LED reactor is a strong solution to the water crisis in communities like the ones in El Salvador. The LED reactor connects the gaps between the disadvantages of the fluorescent bulbs and the current technology to create an improvement that could last years. The LED reactor will last more than ten years, is more sustainable and is better the environment. As the fast-moving pace of manufacturing continues, the downsides of the UV-C technology of the LED reactor will become an advantage. The strong evidence supporting the development of UV-C LED technology will open new opportunities to improve people's lives.

References:

[1] Admin. "How the Unit Works." *Clean Water for the World*, https://cleanwaterfortheworld.org/.

[2] "Drinking-Water." *World Health Organization*, World Health Organization, https://www.who.int/news-room/fact-sheets/detail/drinking-water.

[3] "How It Works." *How UVC Works*, https://uvtechnology.co/howitworks.html.

[4] "Klaran WR Series Disinfection Module Offers Plug n Play UVC Disinfection - Klaran.com Crystal IS, Inc." *Klaran*, https://www.klaran.com/products/disinfection-modules/klaran-wr-series.

[5] "UV LED Benefit: Wavelength Selection." *Aquisense*, https://www.aquisense.com/wavelength-selection.

[6] "UVC Light Bar." *Irtronix*, https://www.irtronix.com/uvc-light-bar.