AIChE
The Global Home of Chemical Engineers

Chemical Engineering for Good Challenge
2018 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: _______Miami University in Oxford, OH, USA______________

Team Lead ___[redacted]

Team Lead email:

Team Lead phone:

Collaborating AIChE Chapter - *optional*

University Name & Location: __________N/A____________________

Team Lead _________________N/A__________

Team Lead email: ___________N/A_________

Team Lead phone: ________N/A____________

Partner Organization(s) - *optional* ___Engineers Without Borders Miami University Oxford, OH, USA___

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Title of Submission: __Continuous Flow Solar Sterilization Module for a Water Treatment Plant in Kabingo, Uganda___

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, that 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 (pers, 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 23, 2017**
- 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

Option 1: Recommendation of the application of specific technology, available today, that is not currently utilized in ISP projects.

A. Project Description

Hope for Kabingo (HFK), a nonprofit nongovernment organization (NGO) seeking to improve the living conditions for the Kabingo community in Uganda through financial and medical aid, saw many of the same health issues arising from poor water quality and asked Engineers Without Borders' Miami University (EWB-MU) and Engineers Without Borders' Greater Cincinnati Professionals (EWB-GCP) chapters to design and implement solutions to these issues. The community had no water supply or distribution system and collected water from stagnant sources in different locations. EWB-MU began its five-year water resources implementation plan for Kabingo in January 2018. The primary goal is to provide potable water meeting Ugandan National Standards for quality at an acceptable taste for ~2100 people by developing year-round water sources, targeting 20 liters/person/day. The water will be pumped from boreholes to a central hilltop for storage before treatment to remove iron/manganese. The filtered water is then gravity-fed to tanks and taps at schools, a dispensary, and population centers where the water will be disinfected with chlorine tablets.

Buying and distributing chlorine tablets to the community will cost both time and money. Incorporating a water sterilization system into the sanitation plant would significantly reduce long-term costs as well as make cleaning the water less of a burden on the community. The United States Center for Disease Control and Prevention (CDC) recommends using solar sterilization (SODIS) by filling water bottles with low-turbidity water and leaving them on roofs for two days [1]. A simple, cost-effective solution that centralizes water cleaning efforts would be a solar sterilization module appended to the current iron and manganese removal systems. The solar sterilization module would be built in two parts: a solar preheater and a primary sterilization trough.

Since MU's and GCP's February-March 2019 trip will focus on expanding the current turbidity treatment plant, the SODIS project is targeted for the 2019 - 2020 project year. Any issues with the current treatment plants that arise can be dealt with and allow for adequate planning of the SODIS system implementation. The following paper will describe the steps and calculations necessary to design a functional system combining the preheater technology with similarly implemented SODIS reactors.

B. Solar Disinfection Technology for Water Treatment

Devices and systems have already been designed advocating for the irradiation and pasteurization of water using only SODIS [2-8]. The technologies utilize photon-driven reaction kinetics; therefore, heat transfer and civil engineering are used in this project. The preheater has shown to reduce the exposure time of water to UV radiation (sunlight) from a couple days to a few minutes [2]. Rather than using individual bottles, this unit is responsible for making continuous flow SODIS a possibility.

According to literature, sunlight must be focused using parabolic troughs for continuous flow systems to take full advantage of radiation and thermal effects [6,9]. The trough focuses all incident rays into a pyrex glass tube along the requisite exposure length. The light is able to reduce biological activity in water to safe levels, damaging the viability of the microorganisms enough to allow for months-long storage [10-13]. The ultraviolet photons are able to damage every part of bacteria by facilitating hydrogen oxidation in the DNA and organelles, effectively causing cell lysis [12]. Protozoa and fungal spores/mycelium have been shown to be more resilient to the treatment; however, the destructive effects of sunlight also carry over to these organisms when exposed to the correct amount of energy [13]. The thermal effects imparted on the water by preheating and the optical treatment denatures the working enzymes in the cells enough to halt all life functions, combining with the ionizing effect of the radiation to sterilize the solution.

Empirical engineering equations exist to determine the trough and piping dimensions for the solar reactor [6,8]. Preheater dimensions, however, have not yet been parameterized. Amsberry et. al. (2015) have designed a preheater to work in a location with 16.8 $\frac{kWh}{m^2 \times day}$ during only the summer months; our location will have approximately 24 $\frac{kWh}{m^2 \times day}$ throughout the year [14]. Nevertheless, further experimentation needs to be done to understand the scale-up mechanics and limitation of this operating unit. Construction materials will be locally sourced and transported to the community site. This research project will start with initial pilot modules being installed on two of the four water sanitation trains, allowing water to continue to the community for chlorination during testing.

C. Design of Solar Disinfection System for Kabingo, Uganda

The data required to customize this technology for the community in Kabingo will require analysis of the current biological activity at the current outlets to understand how much bacteria is eliminated after the SODIS module. The turbidity of the water has already been eliminated by the pilot plants installed during previous trips such that it does not negatively affect the sterilization. These four points will be characterized by the number of colony-forming units (CFU/mL): pre- and post-preheater, pre- and post-SODIS reactor. Measuring the CFU's will yield an accurate measurement of the bacterial and fungal activity present in the water at each point.

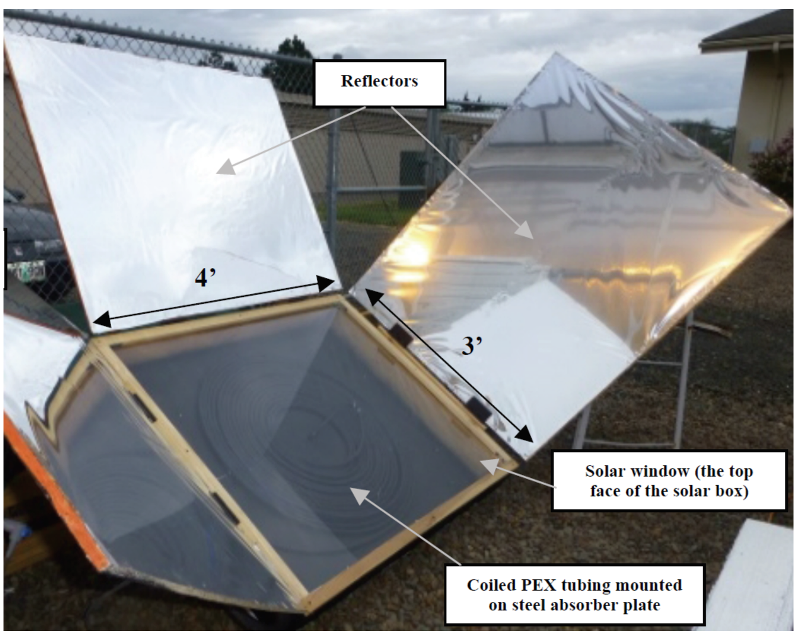

Figure 1: the solar preheater built by Amsberry et. al. [2]

System Design: Solar Preheater

Amsberry et. al. built a thermal concentrator to operate at 44° latitude in Corvallis, Oregon, USA. Copying the same design would yield exceptional results at the 0°-latitude location. The maximum throughput in the research location was 220 L/day to preheat the water from 20°C to 45°C. The same flow rate would yield a higher temperature if the same dimensions were used; alternatively, the flow rate could be increased for the same temperature. The dimensions of the preheater need to be determined. Figure 1 shows the preheater built by Amsberry et. al. It is a 33.3-meter length of coiled PEX tubing mounted on a 1m x 1.3m black-painted steel plate framed with wood and sealed with a window. The reflectors are angled to focus all light into the box. The air inside the box is heated by the sun and the steel plate, creating a small oven.

The throughput of the default device is not enough to supply an entire village of over ~2100 people. The proposed solution is to use a linear modification to the original design. The preheating unit would be linearized across a length determined by heat transfer analysis, using lengths of pipe rather than a coil in a box. The device will be divided into subsections for ease of assembly and heat separation. General design characteristics IE a black-painted steel bedplate, PEX tubing, and a glass window will form the preheating trough. The walls will need to be made of a longer-lasting, insulatory material other than wood. Locally-sourced plastic would be optimal for the sub-70°C target temperatures. Alternatively, seared bricks made by the community could be incorporated into the design to create a well-insulated system.

The flat reflectors will be made oblong and stretch the length of the tube, focusing light down into the preheating trough. Each set of reflectors will focus on its subsection. Dividers - made of the same material as the walls - will separate sections to allow for focused heating, increasing the efficiency of heat transfer into the water.

Alternatives analysis will yield alternative designs like using parabolic troughs or including multiple pipes through a single trough. Each possibility must be carefully assessed for efficiency and effectiveness.

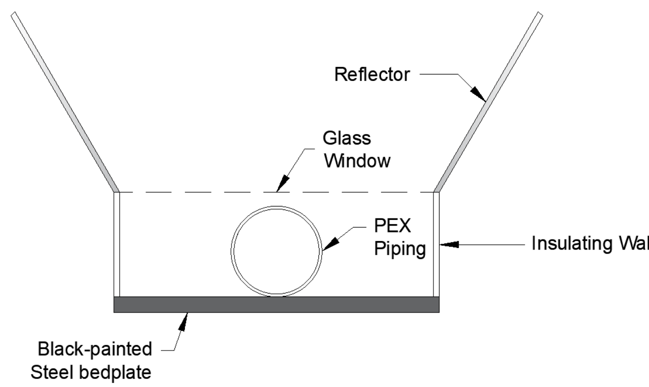

Figure 2: cross-section of the linear modification of the solar preheater shown in Figure 1.

Once the preheating module has been designed and built, scale-up analysis must then commence. Design calculations would have already taken the water's starting head into account, so flow mechanics cannot be a problem. The pre- and post-treatment temperatures need to be observed. The water can then be put through serial dilutions for CFU measurement. Agar plates and sampling rods will need to be delivered or transported with team members for these measurements. Colony counting can be done easily in ImageJ using a picture snapped on a digital camera brought along by a team member. Since the target temperature is only between 45°C and 60°C [2], there should be little reduction in the biological activity at this stage.

System Design: SODIS Sterilization System

Compound parabolic collectors (CPCs) will focus the sun's rays efficiently into the reaction tube. Reviews and research suggest using flat-based trough (FBT) design by rotating the reflector parabolas in the design until a flat base is created. This design is superior to the double-parabolic trough for focusing rays into the reactor as indicated by the ray-tracing simulations in Figure 3[15,16]. It is also easier to design and build a U-shape with the pipe resting at the bottom than a W-shape with the pipe perched at the center peak.

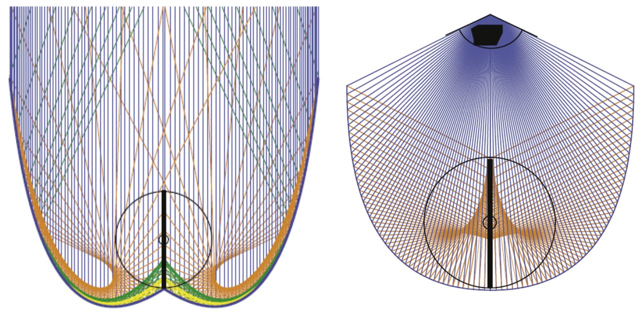

Figure 3. Ray tracing simulations of double-parabolic troughs (left) and flat-bottom troughs (right). Note how the DPT loses more rays out the entrance [16,17].

The reflecting surfaces need to reflect a high percentage of ultraviolet light $(10nm \leq \lambda \leq 400nm)$. Using an aluminum foil sticker with a reflectivity of approximately 0.95 on an aluminum base is sufficient, as this keeps the material costs low [8]. More expensive solutions include using the aluminum base as a substrate and treating it with four alternating layers of SiO_2 and TiO_2 [17]. This route would only be considered if a square piece of aluminum foil sticker were unobtainable. A Google search shows cheap silver aluminum tapes which will suffice for this application.

Sizing needs to be determined through further analysis. Based on the available head and outlet temperature from the preheater, empirical equations can be utilized to determine the pipe and reflector dimensions [8,18]. The area concentration ratio - defined as $C = \frac{A_a}{A_r}$ where A_a is the aperture area and A_r is the receiver area (the pipe surface) - must be 10 or greater [18] in order to take advantage of the absorbed radiation per unit area equation $S = I_b \rho (\gamma \tau \alpha)_n K_{\gamma \tau \alpha}$.

I_b is the solar irradiance on the plane of the collector. In the case of the flat-bottom trough, this is the area between the top ends of the trough. This will be the monthly average throughout the year in Kabingo, which hovers around $22 \pm 2\frac{kWh}{m^2 \times day}$ according to geographical data [14]. With such a small variance, the option to vary flow rate can become unnecessary if designed correctly. ρ is the specular reflectance, the 0.95 value determined for the silver aluminum tapes described earlier.The remaining variables branch into more complicated calculation dependent on various factors, so will not be described in detail here. Refer to *Solar Engineering of Thermal Processes* for more information.

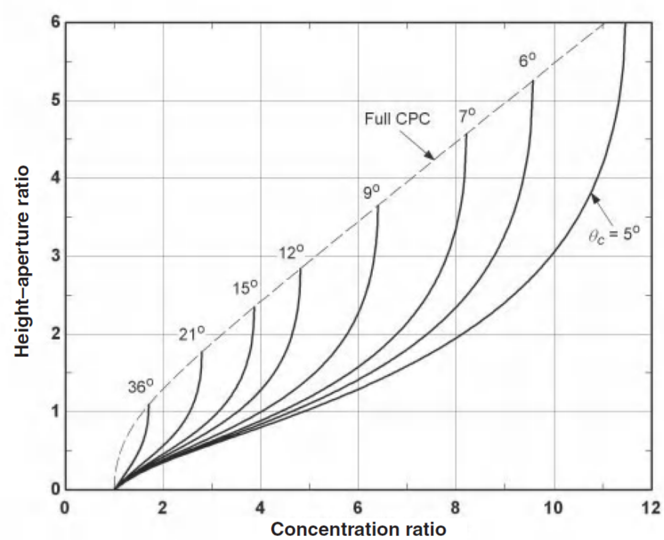

Figure 4. Ratio of height to aperture for full CPCs as a function of C and θc (maximum aperture angle) [18].

The dimensions of the trough will be determined by drawing operating lines in Figure 4. The system has then been fully specified and an implementation project can proceed. Previous experience reported by Dayem et. al. indicates another thermal step after the irradiation step significantly reduces biological activity. However, it is unclear if this is because of the combined effect of optical then thermal treatment, or if the preheater described in this system will suffice

The biological activity at the inputs and outputs need to be determined by the same CFU tests run at the inlet and outlet of the preheater. The outlet of the SODIS reactor should show little to no biological activity after a x10 serial dilution. Undiluted water can also be tested for a higher-resolution measurement if the diluted CFU test yields no activity. This water can hopefully be stored in sealed and well-cleaned tanks and/or immediately tapped by Kabingo denizens.

D. Suitability of Project for Kabingo, Uganda

The goal of this project is to eliminate the biological activity in filtered groundwater. Incorporating a solar disinfection system in the filtration system already present on site would alleviate the need for the community to buy chlorine tablets and distribute them to their ~2100 citizens. Since cheap materials, the sun, and occasional cleaning are the only requisites of this project, it meets very high sustainability standards.

Research and prior experiences have shown that solar disinfection works in similar communities. All the tools necessary for design of both the preheater and the SODIS system can be consolidated from various papers and textbooks. Once the system is built, the technical aspects of maintenance and operation will be addressed. Miami University has a good record with educating the community how to make the most of their filtration system, an experience that will carry over well to this implementation as well. The targeted implementation window is sometime during the 2019-2020 academic year.

Cultural and financial considerations will be taken into account by incorporating community voices into the design process. During the upcoming trip in February-March, an assessment will be made for implementation location and how to incorporate the SODIS into the present system. The community wholly owns the filtration system and appending to is manageable contract work between EWB, local governments, and the NGOs. The community and EWB would agree to a set monitoring and evaluation period such that we are sure the system can be tweaked and handled correctly. Adequate planning will ensure the community is able to replace parts as the years continue. The data collected from this implementation could be reduced and summarized into a later paper to help improve implementation plans elsewhere.

References

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