Solar based water purification

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HIGHLIGHTS

- Over four billion people suffer from serious water scarcity
- 1 m^2 of mirror panel could clean up to 61 litres of water per day
- Cheap solution using satellite dish and aluminium foil

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ABSTRACT

Worldwide, an increasing number of people are facing a shortage of clean drinking water. This issue is especially prevalent in developing countries in Africa and the Middle East. A lack of clean drinking water can lead to a number of issues, such as illness and conflicts between countries and peoples.

The goal of this project was to test the feasibility of a low-cost method of removing biological contaminants from water for developing countries by using the energy from the sun. This would be done by concentrating sunlight and using it to heat up batches of water to 85 degrees Celsius. A calculation model was made to determine the theoretical yield of such a system. For the Mafraq region of Jordan, this came down to a yearly average purifying capacity of 61 litres per day.

The design process was done through rapid prototyping, eventually leading to a system based on a satellite receiver and aluminium foil. In addition, alternative ideas of automated solar tracking and a modular system were proposed and developed.

Introduction

Over four billion people suffer from serious water scarcity and two billion people drink contaminated water worldwide (Mekonnen & Hoekstra, 2016) (WHO, 2018). This number is expected to rise in the future due to the effects of climate change. The main concern in sourcing potable water is faecal contamination in many of these locations, specifically developing countries with poor infrastructure in Africa, Asia and the Middle East (Gadgil, 1998) (United Nations, 2018). These countries often lack modern water infrastructure and sewage networks (Davis & Boehm, 2010). Even when a relatively clean source is located, the water might still have traces of harmful bacteria such as E.coli (WHO & Unicef, 2017).

Besides illnesses, water scarcity can lead to conflicts between countries and populations (Spitz, 2012). That is why the UN (United Nations) wants to achieve universal and equal access to clean and affordable drinking water for all in 2030, as described out in the Sustainable Development Goals (United Nations, 2018).

Solar energy is rapidly emerging as an energy source in developing countries. Solar energy is suitable for developing countries because they are often located in remote regions with large amounts of sunlight. Fuel is scarce and expensive to transport (Saeed, Foroudastan, & Dees, 2006), but the use of solar energy can offer them independence in a sustainable manner. Solar energy, however, is not regularly used for the direct cleaning of water.

An idea was proposed to use concentrated sunlight as a means to remove biological contaminants from water. Literature from the World Health Organisation suggests that most hazards are removed when water is kept at a temperature of 85°C for a minimum of one minute (WHO & Unicef, 2017). The practical applicability of this concept is assessed through the question: How can the cleaning of water through concentrated solar energy be made economically and technically viable for the Middle East and Africa? This specifically refers to remote regions in these areas that lack access to modern infrastructure and are poor. The system is expected to be technically viable considering that similar technology is already applied in the generation of electricity, however it is unknown whether this would be affordable for our four main stakeholders.

Stakeholders

The four main stakeholders for this project are Finpetra, SolarFire, the small communities who will be the end users and the NGO's (Non-Governmental Organisation) and non-profit intergovernmental organizations UNICEF, Oxfam, the Finnish Red Cross and the WHO. Each of them have their own reasons to desire a positive outcome. Keeping this in mind is an important part of the preliminary research.

The small communities often have to collect their water from contaminated sources such as rivers and stagnant water sources (Davis & Boehm, 2010). An affordable and easily maintained system for on-site water purification can reduce health concerns and increase their quality of life. Finpetra wants to support innovation in the sustainable development sector, while NGO's want to support a better quality of life for underdeveloped regions. While the motivations of these parties are different, they all stand to benefit from a low cost solution. Finally, the company SolarFire is developing a technology that provides thermal services with concentrated sunlight. Their concept is similar, but differs in that they use it to dry and cook foods. This project could create an extra service for them to offer their customer base.

Methods

The project was kicked off by preliminary research into similar concepts and the current application of solar concentration technology in energy production. Contact was established with multiple NGO's and the concentrated solar power companies Skyfuel and Rioglass to discuss the requirements and possibilities for the technology. This was further elaborated on through the use of the value proposition canvas concept from Alexander Osterwalder and the consultation of Iraqi refugees regarding their experience with water availability. Expansion of the team's network led to a large amount of outside input regarding the criteria of a successful system. The results of this initial exploration culminated in a social cost-benefit analysis (SCBA) detailing the requirements for a viable and marketable end product.

Calculation model

During the early stages of the project, the team started working on a calculation framework that would estimate the water cleaning potential of different types of mirror setups. The framework was made in Microsoft Excel and was based on the average solar irradiance of the Mafraq region in Jordan, using publically available weather and climate data.

The performance of different types of panel was calculated using reflectivity data published by manufacturers for both aluminium and silver based mirrors (1). The efficiency was calculated using the equation $C_y=S_r * \eta_K * \eta_{sys}$ (Weiss, 2019), where C_y is the useful yield of a mirror setup, S_r is the total solar irradiance, η_K is the net efficiency of the selected panel type and η_{sys} is the net efficiency of the remaining infrastructure for the system.

The η_{sys} was calculated based on the expected ΔT and thermal losses found in a vacuum receiver tube commonly used in large scale solar thermal energy plants (Günther, Joemann, & Csambor, 2017) and the efficiency found by using different modes of solar tracking.

Rapid prototyping

With the calculations and SCBA as basis, fast prototyping started using the sketching software *Krita* to iterate on sketches. Rapid prototyping was chosen because of its ability to quickly make changes to designs and explore different concepts. Consultation with the client and a potential partner shaped one of the proposed development tracks. Solarfire, a company developing affordable solar ovens and dryers for small communities in Africa, has shown interest in an additional solar water purification solution. The second track was the independent development of a cheap-as-possible solution using only household materials. This concept was realised using a 110x120 cm satellite dish as the basis for a parabolic shape. The dish was covered with a layer of flattened aluminium foil to produce a reflective surface and polished lightly. The prototype was tested in sunlight to see if this low cost approach would offer a close enough approximation of a parabolic mirror to be suitable for real world application. Automation of this design is possible using a simple Arduino based solar tracker (Bruce, 2019) to always keep the dish at the optimal angle.

Results and conclusions

Products

The first findings were focused on economic and technical viability. According to our calculations, one square meter of reflective mirror surface could heat up to 61 litres of water per day in Jordan. The investment costs of 1,5 to 2 million dollars were considered too high for the selected regions given the political and socioeconomic situations, based on pricing of similar systems for use in energy generation (Kurup & Turchi, 2016). Based on this, smaller scale solutions were considered the most suitable and developed further.

The established criteria for a workable solution were as follows:

A solution has to be easily maintained and a person without technical education should be able to operate it safely, as discussed with SolarFire. Furthermore, reliability is a big factor that was emphasized by the potential end users. The remote nature of the living situation of the users makes automation largely unnecessary and unattainable at low price points and the available workforce should be easily capable of maintaining the system's functionality. The systems potential to offer added value to local communities helps break the poverty cycle by alleviating the need to search for fresh water. The investment costs can be lowered further by bundling the technology with existing systems, such as SolarFire's solar oven. This new system would then provide three different services with a single mirror setup.

To this end, a design was proposed which would fit the solar oven system provided by SolarFire. The proposed solution fits in front of the oven module, therefore eliminating the need to modify the unit. An illustration of the concept can be found in Figure 1.

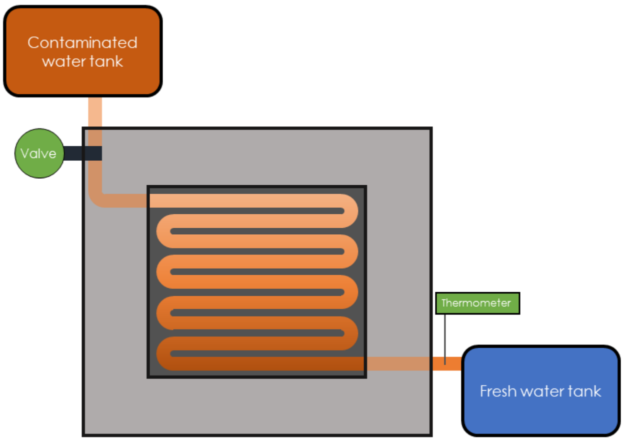

Figure 1: SolarFire implementation concept

The height difference of the two water reservoirs provides the water flow. This way there is no need for computerized solutions. The flow rate can be controlled by a valve located near the top reservoir. The flow rate changes the residence time of the water and therefore the amount of energy that it takes in. This way the end temperature of the water can be controlled. If the output temperature is too high it can be decreased by opening the valve further, which increases flow rate and lowers the residence time.

The second concept, the cheap-as-possible solution, was developed in tandem using readily available materials and tested in Doetinchem, the Netherlands on the 24th of December, 2018. The test was conducted to find the focal point and test the reflective potential of the prototype. The test setup can be found in Figure 2.

Figure 2: Satellite dish prototype

The focal point was spherical and roughly 10x10 cm, removed about 50 cm from the centre of the dish. The diffusion of the focal point is likely caused by the imperfect reflection and application of the aluminium foil. A wooden stick placed directly in the focal point ignited within the first ten seconds. The average solar irradiance for the month of December is 15 kWh/m^2/year, according to weather station Hupsel (KNMI, 2019). Using the calculation framework developed earlier, this is sufficient for a performance of 0.2 litres/m^2 of solar panel per day. The test setup successfully demonstrated the feasibility of using a satellite dish and aluminium foil to produce a reflective surface capable of focussing sunlight. Production of the design was done using on hand materials, but pricing of similar materials found in local hardware markets and scrapyards indicates a total cost of roughly €35, excluding labour. Additionally, the advent of streaming has led to the mass abandonment of satellite based television, resulting in an abundance of receiver dishes. These dishes can be used for solar reflectors. This concept therefore satisfies both the economic and technical requirements for a workable solution.

Discussion

Applicability

The proposed solution only removes the biological contaminants from the water. To purify the water from other possible contaminants, the system can be coupled with filters or other purifiers. On a similar note, application of the concept to the existing system used by SolarFire has the unintentional side effect that this design can only be used in combination with the existing solution of SolarFire. This can limit the number of end users.

Since the scope of the project spans many different countries and cultures, the system will not be equally applicable everywhere. Regions with large amounts of solar irradiance are required for a properly functioning system, but availability of construction materials and existing infrastructure is also a limiting factor. This is somewhat alleviated through the use of common materials such as the satellite receiver dish.

Even though the system still requires a water source and does not increase the amount of sources available, it can potentially provide clean water for regions with high solar irradiance and plentiful contaminated sources. Considering this, the project contributes to SDG6: Clean drinking water for all.

Calculation model

The calculation model is based on the Mafraq region of Jordan, as this was the original target region for the project. Later stages of the project saw the decision made to switch target regions due to the original user case no longer being valid. Because of this, the yield of the water system will differ from those in the model and updated climate data of a new target region should be applied before using the results elsewhere. Functionality has been added to the model to allow for this.

The reliability of the calculations in the model was confirmed by means of consultation through two independent professionals. All calculations used were based on existing literature. It should however be noted that this is a theoretical model and real world results may be different.

Prototype

The prototype has been tested in the Netherlands during the winter. The average solar irradiance in this period is substantially lower than that in the target region. Due to this, it is expected that performance will be better in the target region. Time and weather constraints made further testing in a more suitable environment impossible. On a similar note, no time was available to test the durability of the design and effects of prolonged exposure to the elements. Before a similar solution is implemented, further research must be performed in this area.

Rapid prototyping has been very useful to the team and led to quick improvements in the design of a solar based water purification system. The nature of this technique, however, also means that many concepts have not been developed further and could still be viable. This includes a concept for automated solar desalination using a cooling feedback loop, the use of umbrella frames to approximate a parabolic shape and solar tracking through the use of two light dependant resistances.

References

Bruce, G. (2019, 01 16). *Instructables*. Retrieved from Instructables: https://www.instructables.com/id/Arduino-Solar-Tracker/

Davis, J., & Boehm, A. (2010). Water, Health and Development: Challenges and Solutions in the Developing World. *Woods Institute for the Environment Solution Breef, Stanford University* , 5.

Foroudastan, S. D., & Dees, O. (2006). *Proceedings of the International Conference on Renewable Energy for Developing Countries.* Engineering Technology and Industrial Studies College of Basic and Applied Sciences Middle Tennessee State University.

Gadgil, A. J. (1998). Drinking Water in Developing Countries. *Annual Revieuw of Energy and the environment*, 286.

Günther, M., Joemann, M., & Csambor, S. (2017). *Parabolic Trough Technology.* Hamburg: Enermena.

KNMI. (2019, 01 16). *KNMI Baseline surface radiation network measurements*. Retrieved from KNMI: https://www.knmi.nl/research/observations-data-technology/projects/baseline-surface-radiation-network-bsrn

Kurup, P., & Turchi, C. S. (2016). *Parabolic Trough Collector Cost Update for the System Advisor Model (SAM).* National Renewable Energy Laboratory.

Mekonnen, M. M., & Hoekstra, A. Y. (2016). *Four billion people facing severe water scarcity.* New York: American Association for the Advancement of Science.

Saeed, D., Foroudastan, P., & Dees, O. (2006). *Solar power and sustainability in developing countries.* Murfreesboro: Middle tennessee state university.

Spitz, G. (2012). Water bron van ontwikkeling, macht en conflict. *NCDO Globaliseringsreeks*, 43.

United Nations. (2018, January). *water-and-sanitation*. Retrieved from Sustainable Development Goals: https://www.un.org/sustainabledevelopment/water-and-sanitation/

Weiss, W. (2019, January 16). *CRSES.* Retrieved from CRSES: https://www.crses.sun.ac.za/files/services/events/workshops/03_Design%20ST%20Systems_Calculation%20methods.pdf

WHO. (2018, Februari 17). *Drinking water*. Retrieved from WHO: https://www.who.int/news-room/fact-sheets/detail/drinking-water

WHO, & Unicef. (2017). Safely managed drinkingwater. *WHO Library Cataloguing- in- Publication data*, 52.