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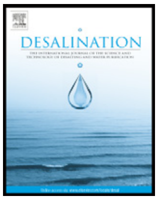

Novel and low cost designs of portable solar stills

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ABSTRACT

On a micro/domestic scale resource intensive technologies for water purification are not feasible. With a growing cultural emphasis on sustainability, an alternative environmentally friendly approach to purify water on a micro scale is via the solar still (solar distillation). To date the solar still has not been embraced due to high capital costs, low yields, high maintenance and low portability. The project sought to address the aforementioned issues via utilising light weight plastics and mass manufacturing technology. The first stage of the project involved the development of a simplistic computational simulation primarily used to optimise the design parameters. Two prototypes were designed, constructed and tested; a 0.2 m^2 Poly Vinyl Chloride (PVC) Pyramidal still (1) and a 0.6 m^2 triangular-prism PVC solar still (2). The stills yielded an average of 0.5 l/day and 0.9 l/day of distilled water respectively, with turbidity levels not exceeding 3 NTU. The average cost per litre of water over an estimated useful life of 4 years was $0.046 per litre for the pyramidal still and $0.063 per litre for the triangular prism still. When compared to the cost per litre of bottled water, the results are encouraging for further development of the proposed solar stills.

1. Introduction

Unfortunately during the political turmoil and civil unrest, there are many people unable to access potable water due to the immense cost associated with constructing and maintaining the infrastructure necessary to collect, store, purify and deliver water. Approximately 67% of the global population has access to potable water [1], with only 46% of people in Africa able to access potable water. Thus there is a need for cheaper and innovative solutions to providing potable water.

The world is in abundance of salt water, and naturally occurring purified water is not in profusion. Water purification techniques are employed to cater to the demand for potable water. With the abundance of solar radiation, a feasible mode of water purification is distillation.

The distillation process is a widely adopted technique for converting seawater into potable water. This is evident with more than 90% (as at 1986) of worldwide seawater desalination capacity being a product of the fuel fired distillation process [2]. Fuel fired desalination is not feasible on a domestic scale, due to the associated financial and resource demands.

Solar distillation is a natural process, much like the hydrological cycle, which relies on the evaporation and condensation of water. A solar still, which employs solar distillation functions as such: Contaminated feed water (sea water, or brackish water) is positioned in the bottom of the still. Sunlight (solar radiation) penetrates a transparent angled surface, causing the water to heat up and subsequently evaporate leaving contaminants and impurities (salts, minerals and microbes) at the bottom of the still. The vapour ideally condenses on the underside of the transparent cover allowing the condensate to flow into a collection trough and eventually into a storage container.

Solar desalination has long been considered a viable water purification method with it being initially utilised by Arabian alchemists' in as early as the sixteenth century [3]. The first modern solar still was constructed in Las Salinas, Chile, in 1872, by Charles Wilson. The still (approximately 4700 m^2 in size) was in operation as late as 1912. During the 1950s, there was a great interest in solar distillation with the common objective of designing large solar distillation plants. However large solar distillation plants were unable to compete with fuel-fired plants, particularly due to the high maintenance, the low efficiencies and the sparse areas required.

In understanding the current barriers preventing solar distillation becoming a prevalent technology, the aim of this project was to design and construct two solar stills, one small, and one relatively larger. Both stills were to be light, portable and cost effectively mass-manufactured. Thus an investigation into the potential of cost and weight reduction of a solar still via a design for mass-manufacture and portability using extrusion technology was conducted. This entailed research into alternative light weight plastics and mass manufacturing processes such as extrusion manufacturing and extrusion moulding. Prior to engaging in a design of such a solar still, one must consider the market factors which influence product demand and ultimately tailor the design to address feasible and lucrative opportunities.

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2. The solar still market analysis

Having conducted a rudimentary industry analysis, the following was ascertained:

> Barriers to entry of the solar distillation industry are low due to low economies of scale, minimal switching costs, ease of access to distribution channels, Low bargaining power of suppliers, High bargaining power of buyers, Low threat of substitute products, and Low intensity of rivalry amongst competitors.

In undertaking an external environmental analysis of the potable water industry it was apparent that amongst well-developed countries, there exists sufficient infrastructure to supply households, businesses and agriculture with sustainable levels of water. Hence the target market of natural solar distillation would most logically apply to:

a) Developing and emerging countries lacking the resources to create sufficient infrastructure,
b) A demographic situated in remote areas which require significant investment in establishing a connection to water infrastructure
c) A demographic intent on nomadic practices and travellers amongst remote areas, including but not limited to army, navy and air force personnel (for the purpose of survival packs).
d) A demographic intent on showing a corporate social responsibility via the use of sustainable products (such as PV- panels and solar stills) which provide a positive image
   In considering the results of the market analysis, the solar still designs were to incorporate the following characteristics to address the existing market opportunities whilst targeting the identified demographic:
   - A simple shape to streamline the manufacturing process and decrease manufacturing costs,
   - Light weight to enhance portability), and
   - Flexibility as to enable the packaging of the still into back pack or suitcase).

In summary, a simplistic design capable of being produced at a low cost and a high capacity was a key goal of this project. In addressing this goal, characteristics of mass manufactured plastic and rubber products were investigated, and consequently incorporated into the design process. This involved an investigation into the highly popular mass manufacturing techniques of extrusion and injection moulding and their respective technologies.

3. Design optimisation

3.1. Critical parameters

The yield of a solar still is contingent on numerous factors and properties. Table 1 lists the key parameters considered in the design process.

Table 1
Critical design parameters.

Geometrical	Material	Environmental
• Length • Material Thickness • Width • Height (and thus water depth)	• Level of Solar Radiation • Absorption • Emissivity • Transmittance • Thermal Conductivity • Density • Specific Heat Capacity	• Solar Radiation • Sun Hours • Wind Velocity • Temperature (Ambient and Surface)

3.1.1. Geometrical parameters

The geometrical parameters dictate the area of the solar still exposed to solar radiation. In considering the area alone it is possible to obtain a maximum theoretical yield via multiplying the exposed area by the fraction of the daily solar radiation over the latent heat of vaporisation of water:

$$Daily\ Yield = Area \times \frac{Daily\ Solar\ Radiation}{Latent\ Heat\ of\ Vaporisation\ of\ Water}. \tag{1}$$

The water depth of a solar still has been proven to affect the pure water yield. Abdelkader et al. [4] have experimentally shown a decrease of 14% in productivity as a result of an increase in depth from 2 cm to 7 cm. The result of the experiment can be seen in Fig. 1.

A greater water depth translates to a greater thermal mass. As the thermal mass increases the amount of thermal energy required for evaporation increases, which prolongs the time taken for evaporation to occur. Conversely, the greater thermal mass would retain thermal energy overnight (with small inputs of solar radiation from the moon) and enable the solar still to perform at a greater competency during that period of darkness, which increases productivity by 2% to 3%. Evidently, according to Fig. 1, the cons associated with a greater depth do not compare to the benefits of a shallower depth.

3.1.2. Material parameters

The material parameters have been identified as important inputs due to their impact on the heat flux and heat balance equations. The material parameters mentioned contribute to a materials capability of sustaining, insulating and transmitting heat.

There are three modes of heat transfer: conduction, convection, and radiation. These three modes contribute to latent heat and sensible heat transfer in the cyclical operation of a solar still. The three modes of heat transfer are subject to several material properties.

The ability of the internal environment of the solar still to absorb and maintain heat is vital in determining the ultimate pure water yield. To analyse this one must look at the transmittance of the material (the level of radiant heat that passes through the material), the absorption factor (the amount of heat absorbed by the material) and the emissivity (the power of a surface to emit heat radiation).

Once these factors are considered, one must determine the thermal capacitance (the ability of a material to store heat). The thermal capacitance is directly proportional to the amount of material present (which depends on material geometry such as length width, thickness and density) and the specific heat capacity. The specific heat capacity illustrates the energy required to increase the temperature of a unit quantity of a substance by a unit temperature quantity.

It is important to consider the thermal conductivity of the material (a material property which is an indicator of a materials ability to conduct heat), as the solar still will be in contact with numerous surfaces. Unlike the convection coefficient, thermal conductivity is solely dependent on a materials chemical structure.

3.1.3. Environmental parameters

The key environmental climatic factor is the incoming solar radiation. Solar radiation is the driving heat source enabling the functionality of the solar still. The intensity of the solar radiation is theoretically proportional to the maximum pure water yield over an area. To adequately determine daily yield it is imperative to acknowledge the sun hours, such that a daily solar radiation figure can be attained.

It is vital for the estimation of still yield to consider ambient and different surface temperatures in the still.

A significant contributor to heat loss is wind velocity. A higher wind velocity will act as a cooling mechanism to the solar still, thus drawing heat critical to the distillation process. In Fig. 2, Malik et al. [5]