Desalination 398 (2016) 151–156

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Inflatable plastic solar still with passive condenser for single family use

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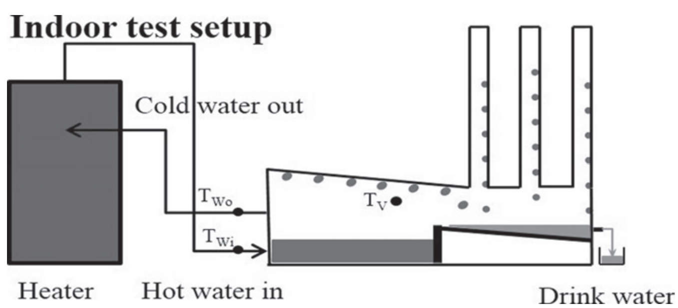
HIGHLIGHTS

- Inflatable plastic solar still with passive condenser demonstrated successfully for the production of water in laboratory conditions.
- 0.75 l/h of water production was achieved when basin water temperature was 75°C.
- Approximately 1 l/h of water production was achieved with use of air flow over the passive condenser.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form 3 July 2016
Accepted 9 July 2016
Available online xxxx

Keywords:
Inflatable
solar still
cooling
family

ABSTRACT

Plastics have been the preferred choice of material for the commercial production of the solar stills. However, most of the currently available solar stills are either too big or too small for satisfying drinking water needs of a single family. Furthermore, methods for increasing the production of water from a solar still are often difficult and costly to integrate in a solar still. Here, we show the effect of adding a plastic channels as passive condenser on an inflatable solar still. The still has a basin area of 1.8 m^2. The tests were performed in lab conditions at different water temperatures. The production of water achieved from the still at a water temperature of 73 °C was 0.75 l/h. Furthermore, the production of water increased to more than 0.95 l/h with use of air flow over the the passive condenser to mimic wind or with use of wet tissue on the passive condenser to mimic evaporation cooling.

1. Introduction

Inadequate quality and quantity of drinking water has adverse effect on health and mortality of the children [1]. In 2010, almost 0.75 million child deaths were caused due to diarrhea [1]. Furthermore, approximately 22.5 million years of life were lost due to ill-health, disability or early death caused by unimproved water and sanitation around the world [1]. The World Health Organization (WHO) in its guidelines for drinking water quality assumes an adult requires approximately 2 l of drinking water per day, although it acknowledges that water intake can vary significantly [2]. Several other authors have suggested a range of 2 to 5 l of drinking water per day to be adequate for survival [3, 4]. Further, approximately 663 million people still lack access to improved sources of drinking water [5]. In 2015, 79% of the population without an access to an improved drinking-water source lived in rural areas [5].

The purification of available brackish or contaminated water in rural communities at a large scale is difficult due to the immense cost associated with the construction and maintenance of the infrastructure necessary to collect, store, purify and deliver water [6]. Furthermore, most large scale facilities need electricity to operate which is also a limitation for these locations. On a domestic scale resource intensive technologies for water purification are not

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http://dx.doi.org/10.1016/j.desal.2016.07.011
0011-9164/© 2016 Published by Elsevier B.V.

feasible. With a growing emphasis on sustainability, an alternative environmental friendly approach to purify water on a micro-scale is via the solar still [6]. Furthermore, in developing regions of the world, it is ideal to provide a device which would enable small family units to have an access to their own, self-made, pure drinking water [7]. In 2014, a big NGO called for desalination devices capable of producing at least 2.5 l /day of drinking water at the technology in action conference in Geneva (internal communications, DrTen B.V.). Such a device can possibly satisfy the demand of drinking water of the infants and small children in a family.

Solar distillation has been found to be the most suitable technology for an application in villages and small islands [8-11]. It presents the best technical solution to supply remote villages or settlements with fresh water without depending on high technology and expertise [8]. They further offer several other advantages [11]. Solar still works on cheap and renewable solar energy. Hardly any use of electricity is made and hence no carbon emissions occur. There is often plenty of solar energy available in regions of scarce drinking water resource. Solar stills are easy to build and operate. Finally, the solar stills can be more economical than other desalination technologies for providing water to the households and small communities. Kumar and Tiwari [10] suggested that a solar distillation plant with a capacity less than 200 kg/day was more economical than other types of desalination plants.

Amongst the various types of solar still tested and manufactured till date, plastic based solar stills have been the preferred choice of solar still for commercial production [12-16]. Plastic based solar still present several advantages. Plastic materials are easy to machine and manufacture for large scale production. They presents the advantage of being light in weight and collapsible or foldable into very small space, making it easy to store and transport. Use of thermoplastic material makes the heat sealing and bonding of parts easier and quicker for mass manufacturing. Further, plastics present an ideal solution for the mass manufacturing by injection or extrusion molding [2]. Additionally, plastics are cheap and globally available. Thus, easier to locally mass manufacture and sell. All these properties, make plastics an attractive material for large scale production of solar stills. However, most of the commercially available plastic solar stills like the water cone or the water pyramid are either too small or too large for a family [6, 17] .

Lower production of water from the solar stills has been a major limitation in its commercialization [11]. Higher production of water can be achieved by including design features like a pump to create a thin water film that rapidly heats up in the sun [18] or a V-through solar concentrators that heat up water before entering the solar still [19]. However, most of these methods are costly, complex and involve regular monitoring. Easier methods for for increasing the production of water in solar stills has been evaluated by several authors [20-24]. Madhlopa and Johnstone [20] reported that the theoretical productivity of a passive solar still with a separate condenser was 62% higher than that of a conventional still. Fath and Elsherbiny [22] added an external condenser to a single slope simple still. They reported an increase in production of water of up to 50% by addition of a passive condenser inside a solar still. The condenser acts as a heat and mass sink which continuously sucks water vapour from the still, condenses it and maintains the still at low pressure and temperature. The uses of condenser limits vapor leaks and losses of energy from the solar still [22]. Application of simple and easily operable methods for increasing the output of water from the plastic solar stills can make them attractive to be used by families in a large number of rural locations.

Without claiming that we present the exact solution to fulfill the needs of everybody in need of drinking water, we demonstrate a family scale inflatable plastic still for solar distillation. The inflatable still has additional condensation channels for improving the passive cooling. All the tests were performed in controlled laboratory conditions. As noted previously by several authors [25–29], indoor tests eliminate the climatic factors on the efficiency of the solar still and help to standardize its performance at steady state conditions. The prototype was completely made out of plastic and produced more than 0.75 l /h of purified water. Additionally, the effect of placing an external fan, internal fan and evaporation cooling on the production of water from the inflatable plastic still is tested and presented. In the presence of a fan, the inflatable plastic still produced more than 6.2 l of water in 6.5 h at an average water temperature of 70 °C. The tests presented in this study were performed in the lab to test the feasibility of such a setup in controlled conditions. In future, experiments in the sunny conditions can be helpful to establish the feasibility of such a setup in the field.

2. Materials and methods

Fig. 1 shows the CAD drawing of the inflatable plastic still. The still consists of two sections. The front section or basin has a transparent top and a black bottom. The basin holds the contaminated water. The back portion consist of three hollow channels connected on the base of the still. Each inverted channel has two condensing sheets glued on both sides of the post. A water collection tray is kept below the hollow channels. The air duct is located at the right corner of the channel at the base. These three channels constitute the inflatable parts of the still. At the back of the still, the water collection tray is at a higher elevation in comparison to the basin in the front. A tube is attached to the bottom of the collection tray. The water from the still is taken from the back section via the tube.

The dimensions of the still are depicted in Fig. 1. In its completely air-filled condition, the total area of the base of the still is approximately 5.5 m^2. The total area includes the wet area and the inflated area of the channel. The wet area at the base of the still is divided in two sections of approximately equal area of 2 m^2. The base of the still is surrounded by an inflatable U-channel. The diameter of the U-channel at the base was 0.3 m. The diameter of the inverted channels at the back is 0.25 m. The condensing sheet has an approximate dimension of 1.25 m by 0.52 m. In total, there are six condensing sheets at the back side of the still. The distance between two channels is 0.1 m. At the base of the back section, there is a water collection tray connected with a water pipe at the back. The isometric view of the still depicts it in the completely blown condition. Poly vinyl chloride (PVC) was used as a material of construction for the inflatable still. The air occupies the space in the sides and the top posts of the still. In its deflated from the still was fitted in a bag with dimensions of approximately $0.7 \times 0.5 \times 0.3$ m^3.

2.1. Procedure

Fig. 2 (b) shows the schematic of the setup used for the experiments. It consists of a water heater and the inflatable solar still. The water heater was used to provide heat for the experiments instead of solar heat to present standardized results. As noted previously by several authors [25–29], indoor tests eliminate the climatic factors on the efficiency of the solar still. The hot water from the heater was continuously circulated, to the still and back from the still, using a pump. The water vapor in the still condenses at the top part of the still. The condensed water rolls down from the inclined top and the inverted channels to the water collection tray at the back. The following section lists the procedure for the experiments.

1. The heater was switched on and the water inside is heated to a fixed temperature.
2. The still was then inflated with air and placed on an insulating mat.