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A technical–economical study of solar desalination

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HIGHLIGHTS

- New multiple tray solar distillation process described.
- Equipment output versus temperature follows Arrhenius model.
- Solar desalination is financially competitive for arid remote area in desert.

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ABSTRACT

Multiple tray solar distillation offers an interesting alternative for small scale desalination of brackish or sea water to produce high quality distilled water at a competitive cost. This work provides summaries of indoor/outdoor trial results of a multiple tray solar distillation model as well as a cost analysis.

1. Introduction

For the last couple of years, the experimental approach was used for continuous improvement of the design features of solar multiple tray distillation equipment for the sake of maximizing output at the lowest possible cost. The equipment could be useful for small scale desalination of brackish water and/production of high quality distilled water at a competitive cost especially for remote and arid areas in the Sahara desert. In previous works [1–5], the potentials and limitations of the tray distillation process were explored. The investigations showed that temperature was the critical variable with the highest impact on equipment output. Temperature here is meant to represent the temperature of the stock water in the evaporator of the equipment and that of the condensation surface of the trays. As a general and perhaps intuitive rule to achieve maximum output, the distillation apparatus should be operated at the highest possible evaporator temperature while maintaining the lowest possible tray surface temperature. Research interests in alternative, pollution free, clean and energy self sufficient desalination technologies are aimed at providing customized and simple solutions to meet specific needs for fresh and/ high quality distilled water at the lowest cost for communities in the desert regions where brackish water is available.

Over the last decade, the world witnessed a sharp increase in large scale sea water desalination facilities spread all over coastal areas to feed ever expanding cities with continuously, or maybe exponentially increasing demands for fresh water. Many of these types of facilities necessitate large capital investments and costly maintenance programs to keep them running effectively. Nations with insufficient fresh water supplies thus devised plans to educate populations and to implement various water management strategies, recycling and conservation programs for a better and more rational use of whatever fresh water resources are available, be they surface water, underground aquifers or processed water.

In the arid regions of the vast expanses of the Algerian Sahara desert, the availability and needs for potable water are specific to the location. Because of the remoteness and size of these Saharan communities, a local, low cost, simple and sustainable solution may offer a competitive edge over more technically involved/expensive, high output

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alternatives. Therefore, this experimental program was initiated to devise, build and evaluate small scale solar powered equipment for water desalination and production of distilled water. Ground water is available in some areas of the Algerian Sahara desert but contains high enough levels of salt as to cause significant damage to crops and date palm trees in particular, eventually leading to their demise.

Unlike other technologies – as stated in previous works – such as reverse osmosis, electrodialysis and others… which are relatively much more technologically advanced, complex and possibly restricted in their domains of applicability, distillation can be simple and does not have any limitations with regards to the composition of the water feedstock. Furthermore, due to the fact that the distillation process offers a great deal of design flexibility, the equipment can be custom engineered to meet fixed performance — cost criteria. For instance, in the case of a family living in a remote area, the solution may be a solar distillation kits designed to be simple, compact, robust, light weight, portable and inexpensive.

Literature research revealed that different designs of tray/multiple-tray distillation models with varying levels of complexity have been investigated over the last decade as were reported for example in the works of Yuan et al [6], Jubran et al. [7], A. Khedim [8], B. Bouchekima [9], and Shatat et al. [10]. However, these investigations and others [11] focused on modeling of the pan or trough type distillation models, with stagnant water in the troughs with no flow of cooling water. This study presents a different distillation process whereby condensation takes place on inclined flat trays that are cooled and temperature controlled with water flowing at adjustable rates.

2. Experimental

2.1. The apparatus

The solar desalination equipment is made of two components, the distillation enclosure and the solar heating system as shown in Figs. 1 and 5, respectively. The distillation unit is thermally insulated and designed with the capability to hold 6 levels of trays plus the ceiling of the box capable to collect condensate. The inside dimensions of the distillation unit are 89 cm in height, 55 cm in depth and 34 cm in width. The dimensions of the evaporator trough are 50 cm by 30 cm with a depth of 13 cm. The unit operates at ambient pressure. Level 1 trays of the distillation apparatus are positioned at a height 9 cm above the water bath level and tilted at 14° with respect to the horizontal as shown in Fig. 1.

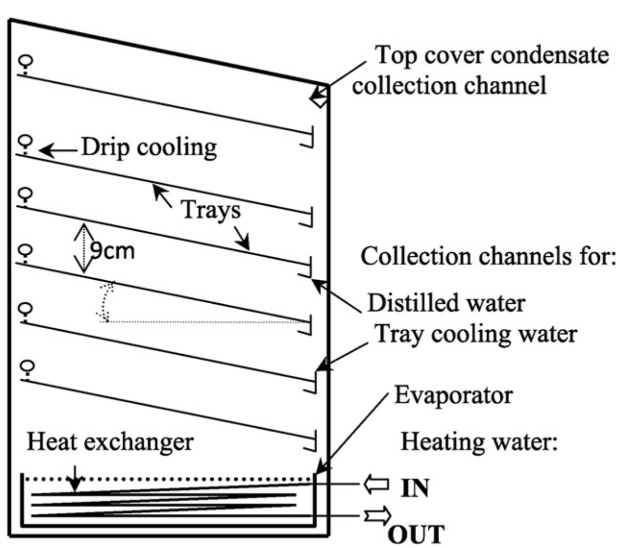

Fig. 1. Schematic diagram of the distillation unit.

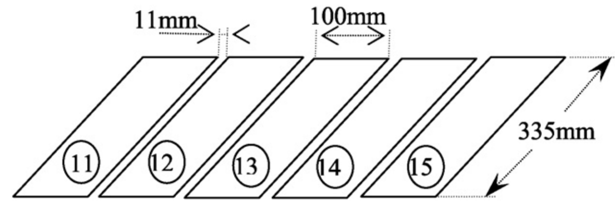

Fig. 2. Configuration and layout of level 1 trays.

Level 1 consists of 5 trays, 100 mm wide, evenly spaced at approximately 11 mm as shown in Fig. 2. The outside edges of trays number 11 and 15 rest against the inside walls of the distillation box.

Level 2 consists of 4 trays. Their dimensions and specific positioning are schematized in Fig. 3. Similarly, the outside edges of trays 21 and 24 touch the inside walls of the distillation unit. Furthermore, the width of the 2 outer trays 21 and 24 are 157 mm, while the other 2 – the inner trays, 22 and 23 – are 100 mm. Spacing between the trays is 11 mm.

The configuration and layout of trays of levels 3 and 4 are the same as those of levels 1 and 2, respectively. Level 5 is constructed with trays similar to those of level 2. There is however a difference in the layout, in that the wide trays are moved inwards while the narrow ones are moved outwards adjacent to the distillation inside walls as shown in Fig. 4. Naturally, the reason for choosing this kind of layout is to ensure that openings between trays of one level to those next to it are in a staggered configuration so as to maximize the condensation process and thus increase productivity.

Level 6 which consists of one single tray with the outer edges of the tray in contact with the inside walls of the distillation unit. The top of the distillation unit is tilted at 14° and serves the role of an additional tray capable of collecting condensate from the roof. Heating of the distillation unit is provided by a solar water heater. The solar heat collector used in this work is a commercial model with the dimensions of 2 m long and 1 m wide, as shown in Fig. 5. The solar heat collector is connected in a closed loop configuration to a heat exchanger sitting inside the evaporator of the distillation unit.

The heating fluid is distilled water with an appropriate amount of antifreeze added for frost protection. The solar heat collector, Fig. 6, is mounted in a fixed position, oriented to the south and inclined at an angle of 19° which is a good trade off for maximum heat collection during the spring, summer and fall seasons.

The design guidelines are to maximize the solar heater efficiency without using complex or expensive sun tracking systems. To further simplify the design and operation of the solar distillation system, there are no pumps used for circulation of the heating fluid. In fact, flow of the heating fluid through the solar heater into the heat exchanger of the evaporator is driven by the thermosiphon effect which starts and stops automatically depending on the sunshine conditions. Performance evaluation trials of the heating system showed that the distillation unit should be placed at a level higher than the top edge of the solar heater such that the bottom surface of the evaporator is about 40 cm above the hot water outlet – top side – of the solar heat collector. To monitor temperature, thermocouples are placed in appropriate areas in the evaporator, on the trays and other relevant points inside and outside the distillation unit.

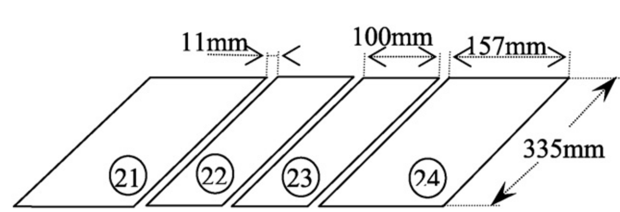

Fig. 3. Size and layout of level 2 trays.