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Effect of specific height on the performance of a single slope solar still: An experimental study

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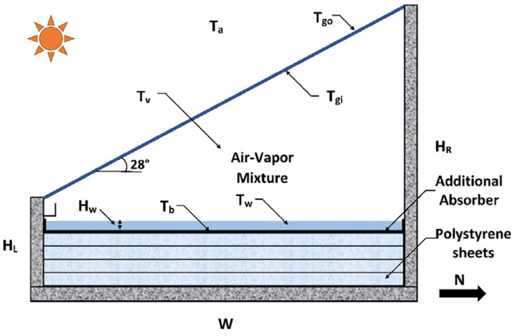
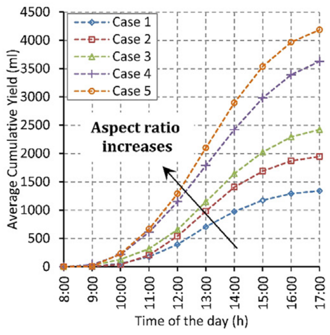
HIGHLIGHTS

- Cavity aspect ratio is varied (1.94 to 2.67) keeping basin area of still constant.
- Productivity of solar still significantly improves by reducing the specific height.
- Nusselt Number is modelled in terms of Cavity Aspect Ratio and Rayleigh Number.
- Daily efficiency of the solar still increased from 11.25% to 39.59%.
- Estimated cost of distilled water is reduced from \$0.074 to \$0.024 per litre.

GRAPHICAL ABSTRACT





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ABSTRACT

A novel experimental approach is presented to study the effect of specific height (defined as the average gap between basin and glass cover) on solar still productivity for a constant water depth. Solar still with an additional absorber was proposed and fabricated for desalination of water. Distillate yields were compared for the same basin area with different specific heights (or Cavity Aspect Ratio from 1.94 to 2.67). Average daily productivity for the period of experimentation improved from 1.341 to 4.186 L/m^2-day. A new correlation based on the experimental data is proposed to estimate Nusselt Number which accounted for the complex interaction of cavity aspect ratio and Rayleigh Number encountered in the solar still. Daily efficiency was observed to increase from 11.25% to 39.59% with reduction in specific height. Water obtained from solar still was found to have improved quality suitable for drinking. It was estimated (based on economic analysis) that cost of distilled water reduced from *\$0.074/L to \$0.024/L*. Payback period of the system was found to decrease from 972 days to 234 days. The water from the solar still had an average cost estimated as \$0.04/L-m^2 along with a payback period of 350 days.

1. Introduction

Water forms an essential part of life on earth and supports numerous domestic and industrial processes. Developing countries like India are among the third world nations that are suffering from dearth of clean water [1]. Population growth, unattended human and industrial waste, and improper implementation of environmental policies have created conditions leading to contamination of water bodies. Consequently, there is an increase in water-borne diseases and human mortality rate [2].

Available processes to clean brackish water (known as desalination or distillation) are technologically complicated and involve high energy

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requirements [3]. These methods are based on oil and gas based fuels which stimulates environmental degradation.

Utilization and application of solar energy in solar-thermal systems have been critically identified for reduction of requirement for oil and gas based energy resources. Availability of solar energy in abundance in many regions of the earth can be exploited to purify water. Utilization of this available solar energy to produce drinkable water is performed through the process known as solar thermal desalination. Desalination of saline water is commonly carried out using conventional solar stills. The main components of a solar still are: absorber plate, condensing cover, insulation, feed water supply and a drainage for removing the basin impurities. These are diagrammatically presented in Fig. 1. Incident solar radiations heat the water in basin which is an enclosed chamber with a tilted transparent cover (usually glass) on the top to receive and entrap the falling radiations. The cross-section of single basin solar still cavity is therefore trapezoidal with front and back wall parallel to each other and supporting the inclined cover. Vapours are formed due to the evaporation of heated water. The vapours rise from the basin to reach the top most part of enclosed chamber, gets condensed by loosing heat to the glass cover and subsequently transforms into water droplets. These water droplets trickle on the condenser (or transparent glass cover) and are collected in distillate channel. Due to the evaporation of water and condensation of vapours in the solar still cavity, the salts and other heavier impurities present in the brackish water are left behind in the basin, and the distillate obtained is highly purified. Also, due to high temperatures achieved in a solar still enclosure, the micro-organisms present in feed water terminate. Solar stills are of great importance in providing clean water in remote and arid areas where complex technological installations are not feasible.

Design and fabrication of a solar still together as well as its working and maintenance is simple due to the fact that it does not incorporate any moving parts. However, its low productivity and efficiency are among the main disadvantages that restricts its use in large scale commercial applications (average productivity and efficiency are 2–3 L/m^2 day and 20–30%, respectively) [4,5]. This is because of simultaneously water evaporation and vapour condensation within the solar still cavity. Thus, there is scope of improvement in solar still performance to achieve higher yields and efficiencies through optimization of still design.

1.1. Solar still performance factors

Several factors affect the performance of a solar still which can be classified into three main categories [6,7]:

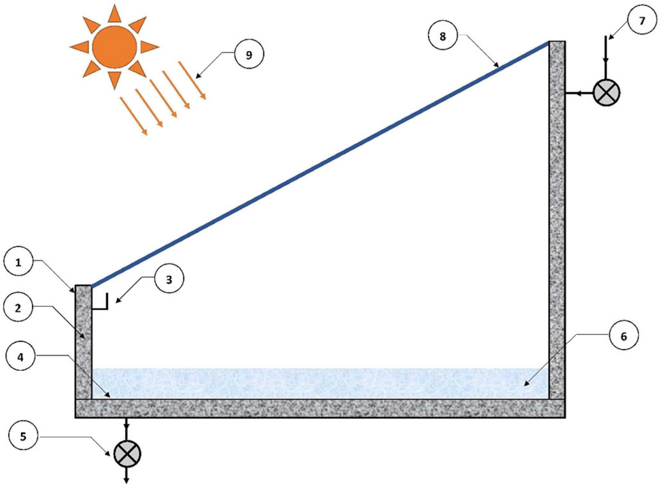

Fig. 1. Main components of a conventional solar still: 1. Outer box 2. Insulation 3. Distillate channel 4. Absorber plate 5. Drainage 6. Basin water 7. Feed water supply 8. Glass cover 9. Solar radiation.

a) Meteorological parameters:

Solar radiation, ambient temperature, wind velocity, atmospheric pressure and humidity, and sky clearness etc.

b) Design features:

(i) *Absorber*: Length of basin (L), material & thickness, and basin aspect ratio ($=L/W$)
(ii) *Condenser*: inclination and thickness of cover, material of cover, single or more glazing;
(iii) *Insulation*: type (mineral, natural and synthetic), thickness of insulation etc.; and,
(iv) *Cavity Aspect Ratio* (A_R): distance between the absorber and cover (specific height, H_s), and distance between the front and back wall of the solar still (width of solar still, W).

c) Operational parameters:

Feed water temperature, saline water depth in basin, location and orientation of still.

Although, the performance of solar still is greatly affected by the meteorological parameters, however these cannot be controlled. Better yield and efficiency of the solar still can therefore be obtained by optimization of the parameters that comes under the other two categories i.e. design features and operational parameters.

An account of factors due to which the evaporation and condensation is affected in the passive solar still was given by Manokar et al. [8]. They stated that condensation process is considerably influenced by wind speed and configuration of the glass cover. The wind velocity variation plays an important role in the rate of condensation and yield. Also the evaporation rate was found to depend on few other factors (i.e. level of water in basin, thermal capacity of the system and initial condition of supply fluid). Similar findings were reported by Dimri et al. [9] that the convective heat transfer is greatly affected with a rise in the velocity of the ambient air.

Murugavel et al. [10] presented a study describing the optimum inclination of condensing cover for a solar still. They reported a relationship between the tilt of glass cover and output of the solar still. Khalifa [11] proposed correlation for optimum inclination based on the latitude of the location and established seasonal variation of productivity. Based on the study it was reported that value of optimum inclination of glass covers should be closer to the latitude of location for better exploitation of incident solar energy.

Heat transfer rate is also influenced by the cover material of solar still. Jones et al. [12] tested three cover materials i.e., plain glass, plexiglass, and thin polyethylene sheet. They reported that best performance with overall higher water temperatures and yield of distilled water were found for glass covered solar still. A large number of studies in literature have reported the influence of depth of water in basin and suggested that minimum depths have higher efficiencies and distillate outputs [13,14]. Taghvaei et al. [15] indicated that yield of a solar still increases with the decrease in water depth. Therefore, water depth optimization can achieve reasonable performance without further cost investment, and is therefore an economical method. Ahmed et al. [16] also reported similar findings presenting strong dependence of depth of water on the quantity of distillate yield. Similar other numerous investigations [17–20] have been carried out to compare the outcome of water depth in single basin passive solar stills. Therefore, it is confirmed that with an increase in the amount of basin water (or water depth), output of the passive solar still reduces.

Recently a number of researchers have proposed approaches for obtaining high yields and efficiencies from solar desalination systems. A common approach is to couple the solar still with an additional device