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A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices

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A R T I C L E   I N F O

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A B S T R A C T

Wholesome drinking water is a vital requisite of human being. Solar desalination is one of the simplest methods utilized for the purification of saline water and the device used for that is known as solar still. The desalination through single slope solar still has very low yield of potable water. Hence, the notion of double or dual slope solar still has been created to boost the productivity of solar stills. Over the years, the studies of different glass cover geometries have been carried out for availing the maximum solar radiation to the absorber plate. For conveying the solar energy available at the absorber plate to the basin water, the heat transfer has to be effective as much as practically possible. The various ways to improve the rate of heat transfer from the absorber plate to the basin water are: consumption of Nanofluids, use of corrugated absorber plate, augmentation of fins upon the absorber plate etc. Nanofluids act as an efficient heat transfer medium for utilizing the thermal energy in solar applications. The addition of various shapes of fins attached to absorber plate increases water evaporation rate which results in a higher yield. The present paper reviews the diverse means of boosting the heat transfer rate in solar-thermal desalination devices and to be precise, solar stills.

1. Introduction

Water is the most abundant and important substance on earth [1]. Purified water is the basic necessity for all the breathing entities to survive in nature. Over 97% of planet's water is saline, 2.6% of remainder is sweet water and below 1% of fresh water is inside human reach [2]. Also the industrial and anthropogenic activities have their contribution in the degradation of fresh water resources. Hence, the availability of pure drinking water is reducing progressively. Currently, the hike in clean water demand is a terrifying problem faced by mankind due to the swift advancement in the world inhabitants and contamination of available environmental water reserves [3]. Most of the globe's populace does not have access to harmless and hygienic drinking water which is the main cause of waterborne diseases that are responsible for the death of more than 6 million children every year [4]. Contaminated water generally contains viruses, bacteria, parasitic entities, liquefied and anonymous constituents, physical and chemical impurities which are responsible for severe harm to human hygiene. Therefore, the water available from the various aquatic sources (such as rivers, lakes, oceans, rain etc.) has to be refined. Such adulterations can be isolated using solar distillation. It is greatly anticipated that the water decontamination equipment must hold the proficiency to safeguard the ecosystem containing dependability and renewability [5]. There are various techniques that have been served for purification of water such as Reverse Osmosis (RO), Vacuum Distillation, Vapour Compression (VC), Multi Effect Distillation (MED) and Multi Stage Flash Distillation (MSF) [6]. Solar Desalination is the simplest technology which employs solar energy as an ample and renewable energy source for distillation of saline water [6].

Tiwari et al. [2] reviewed the condition of solar desalination systems used all over the globe along with the upcoming perspectives. Various water resources, water exigency, drinking water accessibility and refinement procedures were considered in their review. Authors have concluded that the double (dual) sloped Fiber Reinforced Plastic (FRP) solar stills are utmost cost-effective for domestic applications and active solar stills are supplementary appropriate for industrial purposes. Eibling et al. [7] commenced the study with the discussion on the potential of solar still as community application. In the article, authors have reviewed the effects of atmospheric variables, effects of still design, and effects of operational techniques on the performance of solar stills. Researchers have also discussed the economics of solar stills and concluded that the acceptable range for the cost of clean water is $3 to $4 per 1000 gallon (3785.412 l) for the long term application.

Garg et al. [8] presented a technical note on the effects of climatic conditions and operational as well as design parameters on year round performance of single slope and dual slope solar stills under the Indian

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dry region surroundings. It has been concluded that the long axis conventional dual slope solar still should be facing east-west directions for receiving greater amount of solar radiation specifically at higher latitude locations. The single slope solar still collects greater amount of solar radiation as compared to the dual slope solar still at lower and higher latitude locations. The performance of solar still improves with increment in solar radiation, ambient air temperature and wind speed. The productivity remains intact during the variation in vapour pressure of surrounding air. Both the channels of dual slope solar still collect equal quantity of condensed water. The performance of solar still gets boosted while using lower water depth in basin (i.e. small quantity of water) and higher initial water temperature (i.e. preheated water).

Asadi et al. [9] conducted an analysis on the processing of sanitary and industrial waste water with the help of solar still under the climatic condition of Malaysia. The stepped solar still was experimented and found that the still was tremendously fruitful in eliminating inorganic and organic impurities and harmful bacteria from waste water. Tiwari et al. [10] assessed the recent advances in solar desalination. Moreover, Tiwari et al. [11] explored the influence of variation in water depth on the yearly and seasonal productivity of single slope passive type solar still under the condition of New Delhi (28°35′ N, 77°12′ E), India and concluded from the experiment that the lower water depth leads to higher yield. The influence of variation in basin water depth observed was same as that of the study conducted by Garg et al. [8]. In further study, Tiwari et al. [12] elaborated the solar distillation practice for water desalination systems.

Tsilingiris [13] accomplished research work on the impact of binary mixture (water vapour and dry air) properties and thermo-physical properties of air during the heat and mass transfer process on solar still. The observed results depict that the usage of dry air properties presents a noteworthy overestimation of convective heat transfer coefficient, specifically at higher operating temperature. The effect deviation on the mass flow rate was less and corresponded to maximum errors merely of 10% as compared to the saturated mixture properties. Rajamanickam et al. [14] analyzed the influence of basin water depth on the heat and mass transfer in dual slope solar still and obtained the same results as that of obtained by Garg et al. [8] and Tiwari et al. [11]. Prakash et al. [15] presented a review on the parameters like absorber area, lowest water depth, temperature gap among water and glass cover, temperature of inlet water, appending heat storage material, phase change material (PCM), wick material, vacuum provision and other approaches such as use of reflector, external condenser, multi-effect distillation etc. for the enhancement of the performance of solar still.

Kalidasa Murugavel et al. [16] reviewed the advancement in upgrading the effectiveness of the passive type solar still. From the review, authors have concluded that the alignment and inclination must be adjusted to obtain highest solar energy. To increase the heat capacity and absorption of the solar radiation, different materials like rubber, gravel, glass sand, saw dust and sponge can be used in the basin. Among them rubber was proved to be the superlative for improving absorption, storage and evaporation properties. Velmurugan et al. [17] have reviewed the factors affecting the productivity of still such as free surface area of water, water - glass cover temperature gap, absorber plate area, inlet water temperature, slope of glass cover, basin water depth and appending additional accessories like reflectors, condenser, energy storage material, vacuum, integrated stills, asphalt basin liner and sprinklers. Kabeel et al. [18] assessed the diverse approaches and modifications to enrich the performance of single basin type solar still. Authors have concluded from the review that (1) inclination of glass cover nearer to latitude angle receives the normal radiation throughout the year, (2) productivity increases with decrease in the thickness and increase in the thermal conductivity of glass cover, (3) productivity of solar still also gets affected by the basin material, (4) daily production can be increased with the use of sponge, PCM, fins, steps, external reflector, solar collector, hot water tank etc. Kaushal et al. [19] elaborated distinctive forms of solar still and suggested that the selection of correct type of solar still completely depends upon the local surrounding and operating circumstances. In depth examination of active type solar distillation system was carried out by Sampathkumar et al. [20]. The study comprised of numerous sorts and expansions in active type solar distillation approaches, theoretical investigation and upcoming possibility. Authors have concluded from the investigation that the active type solar stills are more productive and present higher thermal and exegetic efficiency as compared to passive type solar stills.

Xiao et al. [21] presented a review on the desalination of brine solution using solar still. For the comparison, the study was carried out with the six different arrangement based on design guideline such as regular solar still, solar still containing reflectors, solar still integrated to a solar collector, solar still incorporating an enhancing condensation device, solar still having increased free surface area, solar still with recovering vapour latent heat and solar still coupled with heat storage. Installation of reflectors and solar collectors were suggested for the locations having lower solar radiation and surrounding temperatures. Increment in free surface area, recuperating latent heat of vapour, inclusion of heat storage and improvement in condensation were suggested for locations with relatively higher solar irradiation. Nevertheless, the performance of solar still primarily relies upon the rate of evaporation of basin fluid and condensation of vapour [22].

The performance of solar still is evaluated on the basis of certain parameters also known as performance indicators which are: temperatures of different components of solar still, heat transfer rate between absorber plate and basin water, quantity of desalinated water collection and thermal efficiency. The lower or minimal temperature difference between basin water and absorber plate results in the better performance which is achieved through higher amount of heat transfer among them. Higher temperature difference between basin water and glass cover consequences in faster condensation of evaporated basin water. Above both the cases result in the higher amount of distilled water output. Greater distilled water yield at lower solar radiation depicts better thermal efficiency which is desirable. Further, the design parameters such as area of still, depth of water, orientation of still, inlet temperature of water and meteorological parameters such as solar radiation, ambient temperature and wind velocity affect the performance of solar still. In order to enhance the performance of solar still, above mention parameters must be optimized. The selection of solar still also depends upon the availability of materials and economics, location and quality of water.

The core intention of the authors is to elaborate the numerous means of enhancing evaporation rate by increasing the heat transfer rate among the absorber plate and basin water for the single slope and double (dual) slope solar stills. In the present paper, authors have attempted to review the techniques such as use of nanofluid and fin to enhance the productivity of single and double slope solar still. The layout of paper is as follows: introduction is presented in Section 1. Section 2 represents the basics of solar still, Sections 3 and 4 represent the literature review of solar still using nanofluid and augmented solar still with fins respectively. Section 5 presents the summary. Future scope and recommendations are presented in Section 6. Section 7 states the conclusion of study.

2. Basics of solar still

Solar still uses solar irradiation as an energy source. The thermal radiation absorbed by the absorber plate increases the temperature of basin water. Due to the simplicity of the device, it has various applications in the industrial as well as in domestic sectors. The water filled in the basin gets evaporated by absorbing solar radiation and generates water vapour which comes in contact with the glazing cover and leads to the condensation. The condensate (condensed water) is accumulated at the down end of the inclined glazing cover.

The ideal basins used for the distillation have shallow and wide structure with the black painted inner surface; wide structure for larger