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Solar stills: A comprehensive review of designs, performance and material advances

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ABSTRACT

The demand for fresh water production is growing day by day with the increase in world population and with industrial growth. Use of desalination technology is increasing to meet this demand. Among desalination technologies, solar stills require low maintenance and are readily affordable; however their productivity is limited. This paper aims to give a detailed review about the various types of solar stills, covering passive and active designs, single- and multi-effect types, and the various modifications for improved productivity including reflectors, heat storage, fins, collectors, condensers, and mechanisms for enhancing heat and mass transfer. Photovoltaic–thermal and greenhouse type solar stills are also covered. Material advances in the area of phase change materials and nanocomposites are very promising to enhance further performance; future research should be carried out in these and other areas for the greater uptake of solar still technology.

Contents

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1. Introduction

Water scarcity is a major global challenge. By the year 2025, it is estimated that 1/4 of the world population will be affected by water scarcity, and 2/3 will experience water-stressed conditions. By 2030, 1/2 of the world population will experience high water stress [1]. Presently, African regions are experiencing high water stress affecting up to 31% of the population, followed by Asia, America and Europe with 25%, 7% and 2% of high water stress respectively [2–5]. Desalination has a growing role to play in meeting the demands for fresh water.

There are various methods of desalinating sea and brackish water. These include flash distillation, multi-effect distillation, membrane distillation, reverse osmosis, forward osmosis, ion exchange, capacitive deionisation, electrodialysis and seawater greenhouse technology [6,7]. The energy for desalination can be obtained from fossil fuel or alternate energy sources such as biomass, wind, solar, geothermal energy, or industrial waste heat. Among the various methods of solar desalination, solar stills have several advantages including simplicity, low cost, ease of maintenance, and low environmental impact. However, they also have disadvantages, such as low performance, that hinder their commercial uptake.

Generally, solar still works on evaporation and condensation process. The brine inside the solar still is evaporated using solar energy and the condensate is collected as the distilled water output. In a double- or multiple-effect solar still, this process is repeated such that the heat of condensation is used to drive a subsequent evaporation process. Use of multiple effects tends to increase the performance but with a cost penalty associated. Use of active components, such as pumps and fans, is another way to boost performance, but it also introduces penalties with regard to cost and complexity.

The performance of a solar still may be quantified by efficiency and productivity. For a single-effect still, efficiency is defined as the ratio of latent heat energy of the condensed water to the total amount of solar energy incident on the still. Instantaneous efficiency specifies the efficiency over a short period (typically 15 minutes) whereas overall efficiency specifies for the whole day. Productivity is the water output per area of solar still per day. The productivity for a basic passive solar still is only about 2–5 L/m^2 day; thus at least 1 m^2 of area is required to supply the essential needs of one person [8]. This review focuses on the existing and emerging techniques to improve the performance of solar stills.

Many reviews of solar stills have been written, especially with respect to design and development [9–12], performance enhancement [13–17], wick type [18] and modelling [19]. Nonetheless, recent advances including new materials (such as phase change materials and nano-composites) promise significant improvements in performance, thus introducing the need for a fresh review. Here we present an up-to-date and comprehensive review of the state of the art in solar stills. An overview of the studies covered by this review is given in Table 1.

Both efficiency and productivity depend on many operating and design parameters which are discussed in this review. Some general parameters such as climate and water depth affect both passive and active solar stills in comparable ways, and are therefore discussed under common headings in Section 2 below. Then in Sections 3 and 4 we discuss separately parameters affecting the performances of passive and active stills respectively. In Section 5, we discuss greenhouse-type solar stills (which may be of both passive and active type) and in Section 6 we outline the trends in emerging materials that are likely to affect solar still development in coming years. Section 7 covers economic aspects. Finally, Sections 8 and 9 contain the conclusions and recommendations for future work.

2. General parameters affecting the performance of solar stills

2.1. Climatic conditions

Solar radiation intensity is the main climatic parameter affecting productivity. At constant efficiency, daily productivity will be proportional to solar irradiation (kJ/m^2 day). However, wind speed and ambient temperature also affect performance. An experimental study by Sebaii showed that the productivity of a solar still increases with wind speed only below the critical speed of 4.5 m/s [20,21]. Tiwari et al. modelled the effects of various climatic conditions in active and passive distillation systems, and found that wind increased performance up to this same critical