Desalination with Solar Stills in Mexico

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Access to freshwater for rural populations is increasingly difficult worldwide. Even in coastal regions with abundantly available seawater, this is not suitable to meet the population's basic needs. Desalination with solar stills represents a simple, inexpensive, and accessible alternative to obtaining freshwater.

solar still desalination

1. Introduction

Population growth, industrialization, and the fast growth of the agricultural sector have led to intensive water use and the contamination of water resources, resulting in less and less available water [1]. In addition, because of climate change, the planet is currently undergoing a significant freshwater shortage that affects almost 20% of the world's population [2][3]. Moreover, demand for freshwater is expected to increase to 6.9 trillion m^3 by 2030, representing an increase of more than 53% compared to the current level [4]. This change will undoubtedly aggravate the scarcity issue the planet has today. This scenario is very noticeable in populations settled in remote and rural areas, mainly in developing countries [5], as well as in coastal populations where seawater has very high salinities that range from 35,000 to 40,000 ppm, making it unsuitable for direct consumption [1].

As a solution to abstract freshwater, the desalination of seawater, brackish water, or groundwater is recommended [6]. A strategy proposed by the General Assembly of the United Nations to achieve the sixth goal of the Millennium Development Goals (SDG) [7] has to do with international cooperation and the creation of technological infrastructure in developing countries for water desalination.

Desalination has been known throughout history, both as a concept and technology. Generally, in the past, and specifically, during the times of ancient China (475–221 BC) [8] and Aristotle (384–322 BC) [9], the possibility of desalination through evaporation and subsequent condensation was already known, and the technique was widely used by sailors. Before the Industrial Revolution, desalination was used mainly on transoceanic ships that needed to be supplied with freshwater. Nonetheless, it was only after WWII that major research was carried out in the US to improve desalination technologies [10].

Water desalination processes can be generally classified into phase change or thermal processes, and processes without phase change or using membranes [11][12][13][14]. The thermosolar water desalination method within the thermal desalination techniques is essentially divided into the following two main categories: (a) direct systems and (b) indirect systems. The key difference between these desalination methods is that in the direct system, solar radiation is absorbed and converted into heat during the evaporation process of the saltwater inside the device, while in the indirect system, separate dual systems are used, i.e., a matrix for solar collection comprising of thermal and/or photovoltaic (PV) collectors, and a discrete conventional distillation plant to eliminate latent heat condensation loss [15].

Solar stills are direct system thermal devices, i.e., they absorb solar radiation and transform it into heat to evaporate saltwater, and then condense it inside the same device. They generally consist of an insulated black container where saltwater is available at a shallow depth. The basin is covered with a hermetically sealed glass lid to reduce steam leakage. Saltwater absorbs solar radiation, heats up, and then evaporates. When air saturated with vapor comes into contact with the fresh inner surface of the clear glass cover, some of the vapor molecules condense. This condensed water slides downward, where it is collected in a channel along the underside of the glass cover before moving through a plastic tube outside the tank. The maximum efficiency of a conventional solar still is generally around 50% in the case of total isolation. Less insulation causes an efficiency reduction of approximately 14.5% [16].

Many factors can affect solar still productivity, such as temperature differences between glass and saltwater basins, basin area, glass cover inclination, device orientation, materials used in manufacture, and local climatic conditions [1][16]. In essence, the productivity of a conventional solar still depends mainly on the climatic conditions of the site where the device is installed, the operating parameters, and the design parameters [16][17][18].

Although solar stills are simple structures, various researchers have gone to great lengths to model the heat and mass transfer phenomena that occur inside. Thermal modeling is very important, since based on theoretical results, the thermal behavior of the solar still can be researched, and a parametric one can be carried out to optimize the system without the need to manufacture it [6].

The first mathematical model proposed for a solar still was the one reported by Dunkle in 1961 [19], where he introduced heat and mass transfer equations for a conventional desalinator based on thermal circuit diagrams. Despite its constraints, this model is the most popular, and it is still used by most researchers in the solar distillation field. Other popular models are those proposed by Chen et al. (1984) and by Clark et al. (1990) to evaluate the heat transfer coefficient [20]. Nonetheless, Kumar and Tiwari’s works (1996) allowed them to formulate a more realistic mathematical model of these heat transfer coefficients for a higher range of water temperatures, based on a linear regression analysis [21]. Likewise, Adhikari et al. (1990) suggested a mathematical expression to estimate the production of distilled water per hour in the solar still as a function of the vapor pressures and temperatures of the water and glass cover [22].

2. Main Hydrological Characteristics of Mexico

Mexico is located between meridians 118°22′00″ and 86°42′36″ of West longitude and between 14°32′27″ and 32°43′06″ North latitude. The country has a rugged topographic relief with a continental extension of 1,959,248 Km^2. It has a great variety of climates. The northwest and center of the country, which covers two-thirds of the territory, are considered arid or semi-arid areas, with an annual rainfall of less than 500 mm. In contrast, the southeast is humid, with average rainfall sometimes exceeding 2000 mm per year. During the 1981–2010 period, the country's average rainfall was 740 mm per year. According to the precipitation estimation from 1981 to 2010, Mexico receives about 1,449,471 m^3 of water in precipitation form. With the latest hydrological calculations available for 2017, it is estimated that 72.15% of water evapotranspires and returns to the atmosphere, 24.77% runs through rivers and streams, and the remaining 6.38% infiltrates and recharges the aquifers. Nonetheless, renewable water per capita nationwide is expected to decline from 3692 m^3 per capita year to 3250 m^3 by 2030, due to population growth. Although Mexico experiences a low degree of pressure on available water resources (19.5%) at the national level, there are areas of the country with a high degree of stress on the water, such as the one located in the Valley of Mexico, which experiences stress of around 141.4%. Similarly, there are densely populated regions in the Mexican state of Veracruz with high levels of social marginality which exert heavy pressure on water resources [23]. In addition, if only the demographic effects are considered, according to the Falkenmark water stress criterion, by 2030 most of the Mexican territory will be in water stress conditions (1000 to 1700 m^3/inhabit/year), scarcity (500 to 1000 m^3/inhabit/year), or absolute scarcity (<500 m^3/inhabit/year) [24].

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