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RECENT TRENDS IN SOLAR DESALINATION SYSTEMS

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Abstract: *Clean water is an essential requirement of any country for drinking, domestic use and other industrial, agricultural purposes for which a large quantity of clean water is required. The increasing demand for water is basically due to the increase of population and rapid growth of industries. About 97% of available water sources are saline and/or consist of harmful bacteria and 2% are in the form of frozen glaciers and polar ice. Thus, only 1% of the earth's water can be used conveniently for drinking and domestic applications. The solar desalination system has the advantage of low maintenance and operational cost. Despite the solar stills have high investment cost, they are environment friendly. The solar still is simple in construction and can be fabricated easily by locally available materials even with the help of unskilled man power. They are largely used for water purification in rural and remote areas with limited demand and low population when abundant amount of solar energy are available. In the present article a review has been presented in the field of recent trends in solar desalination system.*

Keywords: *solar still, desalination, brackish water, saline water, distillation, solar energy*

[I] Introduction

One of the prime requirements of any civilization is clean water. Water for drinking, domestic use and other industrial, agricultural purposes requires a large quantity of clean water [1]. The rising demand for water is essentially due to the increase of population and fast growth of industries [2]. Among the 6.3 billion people living on earth, 400 million people are living in the areas which have shortage of clean water and this will rise to four billion by mid-century [3]. About 97% of available water sources are saline and/or consist of harmful bacteria and 2% are in the form of frozen glaciers and polar ice. Thus, only 1% of the earth's water can be used conveniently for drinking and domestic purposes [4]. Among the various methods of producing clean water, the solar desalination system has the advantage of low maintenance and operational cost. In spite of the fact that solar stills have high investment cost, they are environment friendly [5]. The solar still is simple in construction and can be fabricated easily by locally available materials and unskilled labourers. Solar stills are widely used for getting fresh water at small scale [6]. They are largely used for water purification in rural and remote areas with limited demand and low population when abundant amount of solar energy are available [7].

[II] Recent innovations in the field of solar stills

There has been a lot of work in the past in the field of solar stills to enhance its performance. Researchers used various means such as change in geometry, employment of mirrors in various orientation, use of waste heat etc to improve the performance of solar stills. Arunkumar et. al [8] categorized the different solar still designs with productivity exclusively more than 5 l/ m^2/day and identified efficient high productivity stills with a discussion on their novel modifications and heat transfer mechanism.

Bahrami et al. [9] presented a novel design of a solar still with solar parabolic dish collector system mounted at its focal point for distillation. The performance was investigated experimentally as well as theoretically and a mathematical model was developed for the system. The model includes two main parts: the modeling of saline water heating in the evaporator before evaporation process starts, and the other one is the modeling of water vaporization in the evaporator and condensation of vapor produced in the condenser. Validation and verification of the model were also done with experimental data, and the results of errors analysis prove the reliability of the model. The results revealed that the collector optical efficiency, absorber reflectivity, dish aperture diameter, and absorber plate size have a significant effect on the production of distilled water. For a dish with an aperture of 2 m, when the absorber plate reflectivity reduces from 0.7 to 0.4 and parabolic dish optical efficiency increases from 0.5 to 0.8, the production of distilled water rises up to 120 and 80%, respectively. On the other hand, the influence of initial water salinity, temperature and its amount in the evaporator on distilled water produced is less than 10%. For a dish concentrator with an aperture diameter of 3 m and for specified conditions, about 75 kg distilled water was produced in a day while operating from 8:30 to 17:30.

Cheng et. al [10] conducted experiments and presented a simulation model to evaluate the performance of a solar still by applying a new shape-stabilized phase change material (SSPCM). The SSPCM have the characteristics of stable shape, high thermal conductivity (1.50 W/mK) and high solar absorption (0.94). The comprehensive heat transfer model for the solar still analyzed the effect of melting temperature and thermal conductivity of the SSPCM on the performance of the solar still. The experimental results showed that the daily distillate with SSPCM was 3.41 l/m^2, and was 43.3% higher than that of conventional solar still without SSPCM. The simulation results revealed that the daily distillate increased from 42% to 53% as compared to conventional solar still when thermal conductivity of SSPCM increased from 0.2 W/m K to 4.0 W/m K. Increasing the melting temperature of SSPCM from 34 °C to 50 °C, increases the percentage of distillate from 21.5% to 57.5%.

Dumka et. al [11] studied conventional solar still (CSS) and CSS augmented with permanent ferrite ring magnets (MSS). Mathematical model proposed by previous researchers were used for evaluating the internal heat transfer coefficients, internal efficiency, exergy efficiency, and exergy destruction. While conducting experiments for 13 h, the mean partial pressure difference between basin water and inner condensing cover surface for MSS was found to be 77.99% higher than CSS. The maximum value of evaporative heat transfer coefficient of MSS leads over the CSS by 28.65%. The productivity for MSS was found to be 49.22% higher than CSS. The overall internal efficiency and exergy efficiency of MSS over CSS was enhanced by 49.17% and 110.26% respectively. The distillate was also found to be enhanced remarkably for MSS.

Hammadi [12] presented a simplified model of heat and mass transfer for an integrated solar still with an underground heat exchanger (GHEX). The model included a theoretical analysis in the transient mode for the solar still as well as underground heat exchanger. The system uses solar energy to saturate the air in the solar still, which is conducted into a buried pipe. A numerical method was employed to solve the governing equations of heat and mass transfer characteristics. The maximum distillate was 4.7 (kg/m day) in the year. Jania and Modib [13] carried out the experimental performance evaluation of a double slope single basin solar still with circular and square cross-sectional hollow fins. The distillate was evaluated for the variation of water depth (10 mm, 20 mm and 30 mm) in basin. The results reveal that 10mm water depth is more productive basin water depth for the both solar stills. The maximum productivity of 1.4917 kg/m^2-day was obtained from the circular finned solar still for the 10mm basin water depth, whereas for the square finned solar still it was 0.9672 kg/m^2-day.

Kabeel and Abdelgaied [14] developed and investigated a hybrid system of photovoltaic (PV) panel with reflectors and cooling coupled solar still with air injection. The water cooling was used to reduce the PV surface temperature. Reflectors were used to reduce reflection loss and increase the rate of solar radiation absorbed by PV panels. Five operating cases were studied, viz. case-A (conventional PV panel), case-B (PV with reflectors), case-C (PV with reflectors and air cooling technique), case-D (PV with reflectors and water cooling technique), and case-E (PV with reflectors, water and air cooling techniques). The improvement in the electrical power of the PV panel was found to be 16.81, 21.62, 35.13, and 39.69% for cases B, C, D, and E, respectively, as compared to case-A. Further, the air injection system improved the freshwater production by 40.98% and 21.96% for cases C and E, respectively, compared to the case without air injection system. The average overall efficiency of the hybrid system was found to be 21.2, 22.1, 30.55, 22.95, and 27.15% for cases A, B, C, D, and E, respectively. The economic analysis estimated that the cost of kWh and fresh water production vary between 0.076-0.083 $/kWh and 0.01-0.014 $/L, respectively.

Modi and Modi [15] evaluated the performance of a single-slope double-basin solar stills with the use of small pile of wick materials in lower basin of stills. Two similar solar stills were developed with the small pile of two different wick materials viz. jute cloth and black cotton cloth. The experiments were conducted for the two different water depths i.e. 0.01m and 0.02m in lower basin. The improvement of 18.03% and 21.46% in yield was found at 0.01m and 0.02m water depth for the still with small pile of jute cloth compared to the still with small pile of black cotton cloth. It was concluded that the still with small pile of jute cloth achieved the overall higher productivity compared to the still with small pile of black cotton cloth. Abdessemed et. al [16] studied a solar distiller with four floors which can operate by three different energy sources viz. electrical resistance (power grid or photovoltaic panel), photo thermal solar collector or vegetable and animal waste. The tested trays of the still had two different forms: "V" and "Λ". It was found that "V" shaped trays are the most efficient at producing distilled water because it is cheaper and more cost effective than the "Λ" floor that requires two collectors.

Bait [17] suggested a tubular solar collector assisted solar still for desalting saline water. Its exergy performance, enviro–economic and economic analyses were carried out. The annual production of the traditional and modified solar stills was found to be ~405.04 and ~549.77 kg/m^2. The hourly exergy efficiency and global exergy efficiency of the passive system attained ~7 and ~30% and similarly for the active system ~11 and ~41%, respectively. It was estimated that the distilled water cost is minimum when the interest rate and the lifespan are 5% and 30 yrs, respectively, for the simple solar still (i.e. ~0.018 $/L), while under same conditions, it reaches ~0.036 $/L in case of modified still. The payback period of the passive and active solar distillers was estimated to be about 7.7 yrs and 21 yrs, respectively, based on the lowest interest rate (5%) when the selling price of pure water is taken as 0.04 $/L. Dumka and Mishra [18] carried out experimental and theoretical evaluation of solar-earth water still for coastal areas or swamps. Relative analysis of energy and exergy solar stills were carried out using Dunkle, Clark, Kumar & Tiwari, Tsilingiris and modified Spalding's mass transfer theory. Also, Dumka and Mishra [19] studied two newly developed Modified single slope solar stills integrated with earth (MSSIE) viz. MSSIE(I) and MSSIE(II), using Dunkle, Kumar & Tiwari, Clark, modified Spalding's mass transfer theory and Tsilingiris models.

Nazari et. al [20] studied the performance of copper oxide (Cu_2O) nanofluid in a single slope solar still fitted with an external thermoelectric condensing channel. The results revealed that the productivity, energy and exergy efficiencies of solar still equipped with the external thermoelectric condensing channel increased by about 38.5%, 38.9% and 31.2%, respectively. Further, by adding 0.08% volume fraction of the Cu_2O nanoparticles in basin water, the productivity, energy and exergy efficiencies are enhanced about 82.4%, 81.5% and 92.6%, respectively. The cost analysis estimated the cost of distillated water as 0.021 $\$/L/m^2$. Shanmugan et al. [21] studied incorporating (Al_2O_3) nanoparticles of wick materials in the solar still. It is a novel technique which uses a drip button to decant saline water drop by drop on absorbing materials in the basin. Diurnal variations of drip button temperature and mass of the output were verified. Vitality equilibrium equations for the moist air inside the still, glass cover and wick material were solved to get the analytical expressions for the instantaneous efficiency. Mortazavi and Ameri [22] performed conventional and advanced exergy analyses on a simple flat plate collector and a flat plate collector with thin metal sheet. Mathematical models were developed using energy balance equations developed for each of the components. The effects of Reynolds number, channel depth and radiation intensity on the exergy annihilation of each component and process were investigated by conventional exergy analysis.

Park et al. [23] investigated a multiple-effect diffusion (MED) hybrid solar still with dual heat sources of solar thermal energy and waste heat. El-Agouz [24] investigated a stepped solar still using a storage tank for salt and sea water with continuous water circulation. Arunkumar et al. [25] studied the compound parabolic concentrator-concentric tubular solar still united with a single slope solar stills performance. Phase change material was used to increase the distillate at night hours. Chong et al. [26] worked on a multiple-effect diffusion solar still with a bended-plate design in multiple effect diffusion units (MDU) to solve the peel-off problem of wick material. Dashtban and Tabrizi [27] developed a weir-type cascade solar still, combined with latent heat thermal energy storage system, for improving the productivity. Elango and Murugavel [28] carried out a study on the basin material to improve productivity of still. Hansen et al. [29] performed investigations on an inclined type solar still using different wick materials on different absorber plate configurations. Kabeel et al. [30] developed a stepped basin used to enhance the performance of solar still.

[III] Conclusion

Due to the population explosion and rapid industrial growth any nation requires a large quantity of clean water for drinking, domestic use, industrial and agricultural purposes. The present article reviews the latest development in the field of solar desalination which leads for its better performance. The use of wick material, PCMs, concentrators and other geometrical changes in solar still are various methods that improves the working and productivity of solar stills. In the near future, due to unavailability of traditional energy sources, the solar still would come out to be a very feasible option for getting pure water.

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