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Potential of a dual purpose solar collector on humidification dehumidification desalination system

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HIGHLIGHTS

- Packed bed HDH system is tested with a dual purpose solar collector.
- Effect of turbulators on the system performance is also analyzed.
- Turbulator augments the fresh water production rate of the system.
- Peak distillate of 15.23 kg/m^2.day is collected.

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ABSTRACT

An experimental investigation on a humidification dehumidification (HDH) desalination system integrated with a dual purpose solar collector (DPSC) is reported in this work. The DPSC is used to simultaneously heat the water and air needed for the distillation process. Air flows over the top surface of the absorber plate and the water flows through the riser tubes, attached in the bottom side of absorber plate. The heated air and water from the collector is supplied to the humidifier, where the air gets humidified and moves towards dehumidifier for condensation. The performance of the system is analyzed by providing semi circular turbulators (convex and concave) in the air flow field. The system ability is investigated by varying the flow rate of air, hot water in humidifier and cooling water in dehumidifier. The system distillation capacity enhances with the air and water temperature and flow rate of air, hot water and cold water. The highest productivity of 12.36, 14.14 and 15.23 kg/m^2.day is collected for the without turbulators, convex and concave turbulators in absorber plate respectively. The overall efficiency of the system reaches the value of 67.6% with the concave turbulators in the DPSC.

1. Introduction

Increase in water demand leads to the development different desalination technologies like solar still [1], flash evaporation desalination [2], multi effect distillation, humidification dehumidification desalination, vapour compression desalination, freeze desalination and adsorption desalination [3]. Solar still and solar based humidification dehumidification desalination technology are suitable for low capacity fresh water production. Ability of solar still has been improved by minimizing the water depth, reduction in inclination angle [4], installation of reflectors, coupled with solar collectors, increase in surface area [5] and recovering of latent heat for preheating the saline water [6].

Pin finned wicks [7] and vertical fins [8] were improved the heat transfer rate in the solar still and thereby distillate rate. Energy storing materials increase the basin heat capacity by absorbing the heat during the sunshine hours and release it in evening or cloudy hours. Solar still was augmented by adding the materials like sand, black rubber, gravels [9], phase change material [10], mild steel pieces in basin [11]. Integration of solar still with the parabolic dish concentrator [12], evacuated tube solar collector [13] and parabolic concentrator with cover cooling [14] enhanced the solar still productivity.

The latent heat of condensation was successfully utilized to heat the upper basin water and thereby augmented the solar still productivity [15]. Reduction of water mass in upper basin was increased the distillate output of double basin solar still [16]. Temperature difference between the evaporation and condensation surface is increased by using the thermoelectric module in a solar still. It leads to the higher condensation rate of the system and improved distillate output [17]. A solar still was tested with a thermoelectric module and increased the production rate by 3.2 times greater than the conventional one [18]. A solar still was tested with a separate evaporation and condensation section and a thermoelectric module for increase the condensation rate [19]. A CFD analysis was carried out in a tubular solar still and compared with

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Nomenclature

A_c	area of solar collector, m^2
C_{dw}	distilled water cost, $/kg
h_{fg}	latent heat of evaporation, J/kg
I_s	solar radiation, $W/\cdot m^2$
M	annual yield, kg/year
m	mass of distilled water, kg
t	time, s
T	temperature, °C
u	uncertainty
$q_{electrical}$	heat flux of electrical components, W
TAC	total annualized cost, $
η	efficiency, %

the experimental results [20]. An attempt was made to improve the performance of single basin solar still by installing partition in basin and glass cover [21]. A stepped solar still integrated to a humidification dehumidification process showed better performance with improved distillate output [22]. Performance of a humidification dehumidification desalination system was enlightened by connecting with a cascade solar still [23].

The main reason for lower distillate output in the solar still is the occurrence of evaporation and condensation in the same component. In the HDH system, the humidification and dehumidification process occurs in separate chamber, which ensures the higher distillate compared to the solar still. The inlet water temperature and humidity plays a vital role in the performance of HDH system and the distillate was enhanced with these parameters [24]. Results of the cost optimization analysis were reported that the solar humidification dehumidification desalination is a suitable choice for the small scale fresh water production in the remote arid areas [25]. A two stage humidification desalination system was experimentally analyzed and found that the two stage system reduced the required number of solar collectors and minimized the initial investment [26]. A desalination system was evaluated with the air flows over the hot saline water (heated by solar and electrical energy) and observed that the distillate yield was increased with water temperature [27]. A numerical study to investigate the performance of humidification desalination system with solar air heater was carried out and the result indicated that the presence of solar air heater significantly influenced on the system productivity [28]. A double pass solar air heater was integrated with the humidification desalination system and noticed a considerable improvement in the distillate yield [29]. Higher performance in humidification desalination system was obtained with the integration of evacuated tube solar collector [30]. Performance of a humidification dehumidification desalination system was improved by using a solar air heater [31]. Developments of low cost and high efficient solar air heaters reduce the distilled water cost of HDH desalination system [32]. Experimental study on bubble column HDH desalination was carried out by connecting with the solar air heater [33] and dual purpose solar collector [34].

The presence of rib grooves with different angles in absorber plate showed the higher performance compared to the conventional system [35]. Impinging of air into the solar collector augments the heat transfer rate between the air and absorber plate and the higher outlet air temperature was observed [36]. A solar collector was tested and augmented the outlet air temperature by providing the aluminum cans in absorber plate [37]. The presence of transverse and inclined ribs on absorber plate of solar air heater was resulted in the higher effective efficiency [38]. Presence of conical cut out turbulators in the air heater flow field enlightened the system ability [39]. A packed bed HDH desalination system was tested by using the different ratios of twisted tape inserts, conical cut out turbulators and half perforated circular turbulator in the air heater. The production rate of the modified system enhanced by 45% compared to conventional system [40]. Energy and exergy efficiency of the dual purpose solar collector was found to be higher than the single purpose solar collector, due to effective utilization of thermal energy [41]. Three different fluid flow channels have been used in a dual purpose solar collector and the higher potential is observed with the rectangular fin channel [42]. The efficiency of the single purpose collector has been noted that the 3 to 5% lower than the dual purpose collector [43].

The literature shows that the humidification dehumidification desalination system has greater opportunity for the decentralized fresh water production over solar still. It is observed that the distillation capacity of the system enhances with the humidifier inlet temperatures. Also the presence of turbulator enhances the ability of solar collectors and the dual purpose solar collector is efficient. In most of the previous works, humidification dehumidification desalination system is integrated with the different solar collectors (Flat plate solar collector, evacuated tube collector, parabolic trough collector) to heat the water and air separately.

Thus an attempt is made in this work to analyze the effect of integrating a dual purpose solar collector with a packed bed HDH desalination system. The dual purpose collector supplies the required hot water and hot air for desalination system. Also semi circular turbulators (concave and convex) are used in the air flow passage of a dual purpose solar collector. It augments the humidifier inlet air temperature by means of creating the turbulence in air flow field. The performance of the system is analyzed by varying the mass flow rate of air (0.84 to 1.08 kg/min), hot water (1 to 3 kg/min) and cooling water (1.5 to 3.5 kg/min).

2. Experimental setup

Schematic and photographic view of the solar packed bed humidification dehumidification desalination system is shown in the Figs. 1 and 2. It consists of a dual purpose solar collector humidifier and dehumidifier. The outer cover of a dual purpose solar collector is constructed as a rectangular hollow box in the size of 0.95 m × 0.75 m × 0.12 m and extended as duct on both sides. The dual purpose solar collector setup is kept in a stand with the inclination of 10° which is equal to the latitude

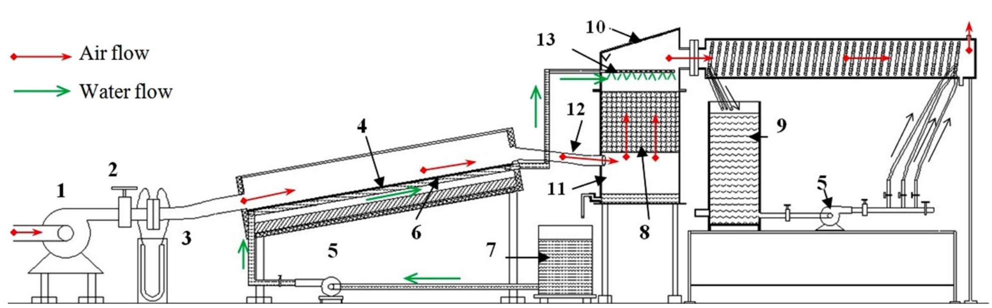

Fig. 1. Schematic diagram of HDH system with dual purpose collector. (1) Blower, (2) flow control valve, (3) orifice arrangement, (4) absorber plate, (5) pump, (6) riser tube arrangement, (7) feed water tank, (8) packed bed, (9) cooling water tank, (10) condensing cover, (11) humidification chamber, (12) hot air inlet, (13) hot water spray pipe.