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Enhancement of integrated solar still using different new absorber configurations: An experimental approach

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ABSTRACT

Solar stills yield only lower amount of fresh distillate, when compared to other conventional based desalination systems. In the present work, in an intention to increase the solar still productivity, a new hybrid solar desalination system was developed by combining an inclined solar still with a single basin solar still and hot water storage tank. This integrated system was fabricated and tested with different geometry of new absorber plate configurations (flat, grooved and fin shaped absorbers) under actual climatic conditions. The different new absorbers used in this experiment, increases the surface area of water available for evaporation inside the inclined still. In this experimental study, the integration of these stills was done to recover the waste heat energy from the un-evaporated output (hot waste water) drained from the inclined still. Based on the experimental analysis, it was observed that for the conventional inclined still, 25.75% productivity increased, when it is coupled with fin shaped absorber and 74.5% productivity increased, when it is integrated with basin still. The overall productivity (distillate output) in the integrated still with fin shaped absorber configuration was 5210 ml/day and the efficiency of the integrated desalination system with hot water thermal storage was 46.9%.

1. Introduction

Clean water is essential for good health, which influences the social and economic development of any nation. Without potable or fresh drinking water, human life is not possible. Industries and agriculture also needs fresh water without which, they cannot function. Around 97% of earth's water resources are salty, 2% of water resources are frozen in the form of polar ice bergs and the remaining 1% of water resources is only available for humans. Fresh water available from rivers, lakes and ponds is becoming scarce because of industrialization, climatic change and population explosion [1]. The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. Therefore, it would be attractive to tackle the water-shortage problem by desalinizing of this water. Thermal desalination techniques like Vapour Compression (VC), Multi Effect distillation (MED), Reverse Osmosis (RO), etc. are applicable for large metro cities and they require a huge input of electrical power, mostly from fossil fuels that contribute to environmental degradation [2]. But, these technologies are not suitable for villages, islands, deserts, coastal and remote areas.

Large scale desalination plants using fossil fuel are in use in few oil-rich countries. But the other countries, in which the availability of fossil fuel is limited and are economically backward, prefer solar energy for desalination process. Solar desalination systems are the sustainable solution for this problem, but the major drawback is their low productivity compared to the other conventional desalination systems [3]. In desert and semiarid areas, where the availability of pure water is scarce, solar stills are used to produce fresh potable drinking water. In solar still, impure saline water is taken in a well-insulated air tight basin covered with transparent glass cover and is evaporated using solar energy. Solar stills are cheap in design and may be used in places where, there is abundant of solar energy and less fossil fuel supply. Solar stills can be categorized into two types: Passive solar stills (Direct collection systems) and Active solar stills (Indirect collection systems). The direct collection systems are the systems which absorbs solar radiation directly through only one medium, whereas the indirect collection systems, absorbs solar radiation indirectly through more than one medium, by adding some external devices to the existing collection systems [4].

Numerous efforts have been made by the researchers to enhance the productivity of passive stills. Passive stills can be classified into two categories: basin and inclined still types. In a basin still, water will be stagnant on a flat absorber plate, whereas in an inclined still water flows down along an inclined absorber plate. The primary and most

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Nomenclature

A	area (m^2)
C	specific heat (J/kgK)
I	average solar flux (W/m^2)
L	latent heat (J/kg)
M	mass (kg)
Q	heat energy (J)
QH	percentage of heat energy utilized (%)
QL	
t	percentage of heat energy losses (%)
T	time (s)
ΔT	temperature (°C)
η	temperature difference (°C)
efficiency (%)	

Subscripts

w	water
g	glass
i	inclined still
b	basin still
int	integrated still
ew	evaporated water
$e_{(w-g)}$	evaporation
$e_{(w-g)i}$	evaporation- inclined still
$e_{(w-g)b}$	evaporation- basin still
gi	glass-inclined still
gb	
hws	glass-basin still
hot water storage tank	
whr	waste heat recovery
o	overall
s	sensible

important advantage of the inclined still over basin still, that it can produce fresh water distillate and hot water simultaneously. Lot of research works have been carried out to enhance the productivity of inclined type solar stills [5]. Aybar et al. [6] tested an inclined solar distillation system with different mass flow rates and wick materials. Kabeel et al. [7] studied the theoretical performance of a steeped solar still by using water cooling over the glass cover. Khalifa et al. [8] studied the effect of inclination of external reflector on a simple inclined solar still in winter. Omara et al. [9] studied the effect of inclination of both internal and external reflectors on a stepped solar still. Badran et al. [10] studied the performance of an inverted tickle solar still based on simulation and experimentation. Sadineni et al. [11] conducted an experimental and theoretical study on a weir-type inclined solar still. Radhawan et al. [12] studied the theoretical analysis of a steeped solar still used for heating and humidifying the green houses. Velmurugan et al. [13] conducted experiments for desalinating industrial effluents using a steeped solar still. El-Zahaby et al. [14] incorporated a reciprocating spray feed mechanism to enhance the productivity of a corrugated steep solar still. Anburaj et al. [15] studied the experimental performance of a new type inclined solar still with rectangular grooves and ridges in absorber plate. Hansen et al. [16] conducted experiments in an inclined solar still with different new wick materials on various absorber configurations. Some researchers enhanced the efficiency, by integrating the inclined still with some other solar thermal energy systems. Velmurugan et al. [17] enhanced the distillate productivity by integrating a stepped and single basin solar still with a mini solar pond. Abdullah et al. [18] studied the performance of a steeped solar still by coupling it with a solar air heater. Minisan et al. [19] studied the performance of an improved wick basin type integrated solar still. Mohammed et al. [20] conducted experiments on a new hybrid desalination system which constitutes of wind turbine and inclined solar still integrated with a main solar still.

Based on the above literature study, it is understandable that for an inclined solar still, mass flow rate of water, residence time of water for evaporation, waste hot water usage, reflector usage, wick material usage, absorber design and integration of the still with some other energy systems are the important factors which can increase the day time productivity. Among these factors, residence time of water for evaporation, hot waste water (un-evaporated output) usage, and integration of the still with some other energy systems, plays a very important role in enhancing the overall productivity of inclined solar still. In this work, an integrated hybrid solar desalination system was designed for water purification and heating purpose, by constructing an array of inclined solar still with a single basin solar still and a hot water storage tank. The proposed configuration produces simultaneously evaporated distilled water and un-evaporated hot water outputs. In this integrated system, there are two outputs of distilled water, one from the inclined still and the other from the basin still. Also, there are two outlets for the hot water storage tank, one from the inclined still and the other from the glass cover of the basin still.

2. Objective of the work

The objective of the present work is to improve the inclined solar still distillate and hot water productivity by the following methodologies:

1) Selecting an adequate geometry of new absorber plates (flat, grooved and fin shaped absorbers) and using inside the inclined still to improve the residence time and surface area of water available for evaporation.
2) Integrating inclined still with a single basin solar still to recover the waste heat energy from the hot water drained from the inclined still and thereby increasing the overall distillate productivity of the integrated desalination system.
3) Integrating the hybrid solar desalination system with a hot water storage tank for hot water productivity and thereby enhancing the overall efficiency of the integrated solar thermal energy system.

3. Experimental system description

The outdoor experiments were conducted at the campus of Francis Xavier Engineering College, Tirunelveli, (8°44′N, 77°42′E), Tamil Nadu, India, with test facility located at the roof of Mechanical Engineering Department, during the months of March–April 2016. The schematic drawing of the integrated solar still setup used in this experimental study is shown in Fig. 1. The photograph of the integrated type solar still is shown in Fig.2.

3.1. Inclined solar desalination system

The basin body of the inclined solar still was fabricated with mild steel of 1 × 1 × 0.15 m dimension. The inclined solar desalination system consists of 3 different absorber plates (flat plate, grooved plate & fin shaped plate), in which the saline water from feed water tank, flows from one end of the still to the other end. The feed water was supplied to the absorber through a distribution pipe fixed on the top portion of the basin with 15 small holes. A glass cover of 1 m^2