Solar Energy 164 (2018) 370–381

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Single slope solar distillator productivity improvement using phase change material and Al_2O_3 nanoparticle

Miqdam Tariq Chaichan[a,*], Hussein A. Kazem[b]

[a] Energy and Renewable Energies Technology Center, University of Technology, Baghdad, Iraq
[b] Faculty of Engineering, Sohar University, Sohar, Oman

ARTICLE INFO

Keywords:
Al_2O_3nano-particles
Paraffin wax
Solidification
Latent heat
Thermal storage
Distiller

ABSTRACT

The improvement of heat transfer in any system stores latent heat as a thermal energy enhances the system's efficiency. In this study, nanoparticles were dispersed in paraffin wax (as a phase change material) to increase the thermal conductivity of the latter compared to the base material. The mixing of nanoparticles with the wax changes the thermophysical properties of the used wax. The thermophysical properties as density, viscosity, and thermal conductivity showed increasing values in contrast to the specific heat where it reduced relatively. Three distillers were made to study the effect of adding these nanoparticles to simple solar distillers. The first of which was without any modification and the second had paraffin wax as additional material. In the third distiller, a combination of paraffin wax with a nano-Al_2O_3 spread on it that was used to promote thermal conductivity. The addition of nanoparticles to paraffin wax increased significantly the rate of heat transfer, resulting in higher yields of the solar distiller. Paraffin wax addition caused an increase in the daily distillation yield up to 10.38% while the addition of nano-Al_2O_3 to paraffin wax improved distillate yield up to 60.53% compared to the simple distiller yield due to continuous distillation after the sunset.

1. Introduction

The Earth is suffering from all its population and its specters of several critical problems and challenges that may affect its future existence. Some of these problems are, global warming due to the increase of CO_2 rates due to combustion of fossil fuels in the air (Al-Maamary et al., 2016). Climate change is becoming a reality and has begun to alter the conditions of the game for many countries around the world (Al-Maamary et al., 2017a). In addition to the fluctuation of oil prices, which affected the global economy and called on the governments of the world to deal effectively on the diversification of energy sources to get rid of pollutants and to protect national economic security (Al-Maamary et al., 2017b).

The provision of potable water and human resources is another challenge that must be addressed in vast areas of the world, and the Arab region can be considered one of the most critical areas. To achieve development goals, achieve prosperity and reach a sustainable human development future that can be achieved only by addressing the challenge of water supply. Achieving this goal reduces the risk of many possible crises that can be faced by these countries such as economic collapse, unplanned migration, or regional conflict over water (UNDP, 2013).

Solar energy is a different alternative to fossil fuels and has entered the arena, and global attention in it is growing. Many important applications have been entrusted to them because of the efficiency of the solar systems used. In heating water for housing purposes, this energy has been used for decades. Photovoltaic cells fill up buildings, streets, and square around the world and take a significant part of the energy production of many countries. The use of solar energy in water distillation is not a new idea and began in Chile in the 19th century. Since that day studies have been continuing to obtain high-capacity solar distillates to eliminate the burning of fossil fuels in distillations, which takes a large part of the resources of some countries (Dehghan et al., 2015; Ibrahim and Dincer, 2015).

Single slope solar distiller is the simplest type of solar distillers and the least productive compared to other types of solar distillers (Khalifa and Hamood, 2009). This type has been selected in the current study because any increase in its productivity means a doubling of other distillation systems. Several studies focused on increasing the productivity of solar distillates to make them commercial systems. Table 1 shows some of these studies.

In Table 1, the researchers investigated and studied variables within the distillers, trying to develop their productivity across them. While other researchers have worked to increase distilled productivity

* Corresponding author.
E-mail address: 20185@uotechnology.edu.iq (M.T. Chaichan).

https://doi.org/10.1016/j.solener.2018.02.049
Received 9 September 2017; Received in revised form 29 January 2018; Accepted 19 February 2018
0038-092X/

Nomenclature

A	basin base area (m^2)
Al_2O_3	alumina (or aluminum oxide)
h_{ca}	coefficient of convection heat transfer (kJ/kg)
h_{fs}	the latent heat of the distiller water (kJ/kg)
I	the hourly solar radiation intensity (W/m^2)
q_{ca}	energy lost from transparent glass to ambient air due to convection and radiation
q_c	transferred thermal energy by convection between solar still basin and glass cover
q_r	transferred thermal energy by radiation between solar still basin and glass cover
q_e	transferred evaporating energy between solar still basin and glass cover
m_{PCM}	mass of the PCM used
$m_{n-Al_2O_3}$	mass of the added nano-Al_2O_3
P	productivity (l/m^2)
P_B	partial pressure at basin water temperature (Pa)
PCM	phase change material
P_{Cm}	partial pressure at average transparency cover temperature Pa.
SEM	the scanning electron microscopy
T_a	ambient temperature
T_B	basin water temperature (K)
T_{Cm}	average transparency cover temperature (K)
T_g	glass temperature
Ø%	mass fraction
ε_w	emissivity coefficient
σ	Stefan-Boltzmann constant = (5.667×10^{-8}) ($W/m^2 K^4$)
η_h	the hourly efficiency

through linking the distiller with a heating system that increases the inlet temperature of the entered water, so as to increase evaporation and thus improve productivity. Table 2 shows part of these studies.

The use of large systems to heat the water entering a distiller is not economically feasible if it is not available naturally. For example, the establishment of a solar salt pond has high costs compared to the limited increase in the productivity of distilled water. So, many researchers have turned to using the latent heat thermal storage instead of using auxiliary systems. Phase change materials have been a major objective of modern studies because they have high thermal storage properties in addition to their toxicity and ease of circulation. Table 3 represents some of the latest studies.

The negative property that limited the use of PCM in distillation systems production is the low thermal conductivity of these materials. Because of this characteristic, there is always a delay in the acquisition of heat and storing it. The development of the science of nanomaterials, their industries, and their uses, especially to enhance the thermal conductivity of some substances, was directed towards adding these materials to the phase change materials in thermal storage applications. Table 4 lists some of the latest studies in this field.

This study conducted to evaluate the improvements in the productivity of a simple solar distiller contains nanoparticles- PCM in its structure. The aims of the study seek to find an efficient, inexpensive and locally available solar filtration system. The addition of nanoparticles to paraffin wax in the simple solar distillate was not previously examined, according to the researchers' knowledge, and after conducting extensive survey of most research in this field.

2. Experimental setup

Three simple single slope solar distillers were made. The solar basins are made of plates (galvanized steel), with a width of 1 m, depth of 0.4 m, and a height of 36 cm on the back side. The lower front edges are 11 cm high; the still upper surface tilts angle was 30° from the horizontal. The condensate water on the transparent lid flows through a small channel that was welded and extends along the distilled sides with a 5-degree from distiller sides. The distilled water from the transparency lid is collected from the inclined collection channels. Distilled water comes out using a polyethylene tube of 1.27 cm diameter connected to a fixed slot on one side of the distilled. This tube has been extended into the assembly channel to ensure that the vapor stays inside and does not leak out using the distilled water outlet.

The upper edges were horizontally obliterated by 1 cm at the edge, to secure the transparent glass cover. Plastic filler with 1 cm width and thickness of 0.3 cm was used to ensure the full containment of the steam inside the internal distillation area and prevent its leakage. This material was fixed using silicone material to make sure that the plastic has fully adhered to the top edge. The glass cover was also affixed employing fillers. The inner surface of the still colored in a black color (non-shiny) to increase absorption of solar radiance. Three of the four distillers' walls were made as described above with one exception. The three inner sides of the still were isolated using the same material of the basin body (galvanized steel). The isolated parts (from the left, right, and back sides) were 1 cm thick. The spaces made, here between these new partitions and the distiller wall, were loaded by the wax. These sections were also covered and welded, so paraffin wax was completely covered and prevented from contact with water. A thickness of 1 cm of the same wax was also allocated in the bottom of the distillery and was covered by a plate of galvanized steel and soldered. One of these distillers is filled with paraffin wax and nanoparticles Al_2O_3. Table 5 lists some of the used Iraqi paraffin wax properties.

The temperature measurements conducted by employing many thermocouples type K distributed in variable distiller parts. At the stills sides, three thermocouples were immersed in the middle of the wax, one at the each side. In the wax in the basin, three thermocouples were distributed in three variable locations. A thermocouple fixed on the glass cover face while another one on its back. Three thermocouples set on the basin plate. Two thermocouples were suspended in the space between the glass cover and the basin's water. These thermocouples were drawn out of the basin and connected to a selector switch. Fig. 1 represents a diagram of the distillation system used. All used thermocouples were calibrated in the lab by comparing their measured values with the readings of a calibrated mercury thermometer. Water temperatures were measured in the tank and pump using mercury thermometers placed in the connected pipes. The air temperature measured employing a thermometer located in shadow.

A wooden box used to contain the metal basin; this box was built for this purpose. The wooden box was made of 2 cm thickness wood planks and the use of thermal insulation (glass wool) to isolate the basin. A fiber cover was used after sunset to cover the glass surface to eliminate the heat losses to the environment and to preserve the collected energy.

The three distillers were connected to a brackish water tank. Distillers were routed to the south to get the greatest amount of solar radiation throughout the day. A float was used to control the distiller water height level at 1 cm and to maintain a continuous water flow. The brackish water streamed to the basin employing polyethylene pipes attached to the water treasurer.

All temperature readings were measured and recorded at intervals of one hour each. The gathered and measured distilled water quantities employing a cylindrical vessel with a capacity of ten liters. The distillation process started from the first beginning of a new day. The charging and discharging periods are important in determining the heat transferred from and to the PCM, which determines the system performance. For the purpose of studying these two periods, the PCM