Energy Conversion and Management 78 (2014) 493–498

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach

A.E. Kabeel [a,*], Z.M. Omara [b], F.A. Essa [b]

[a] Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt
[b] Mechanical Engineering Department, Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt

ARTICLE INFO

Article history:
Received 27 July 2013
Accepted 5 November 2013
Available online 8 December 2013

Keywords:
Desalination
Basin solar still
Nanofluids
Vacuum
Condenser

ABSTRACT

The distilled water productivity of the single basin solar still is very limited. In this context, the design modification of a single basin solar still has been investigated to improve the solar still performance through increasing the productivity of distilled water. The experimental attempts are made to enhance the solar still productivity by using nanofluids and also by integrating the still basin with external condenser. The used nanofluid is the suspended nanosized solid particles of aluminum-oxide in water. Nanofluids change the transport properties, heat transfer characteristics and evaporative properties of the water. Nanofluids are expected to exhibit superior evaporation rate compared with conventional water. The effect of adding external condenser to the still basin is to decrease the heat loss by convection from water to glass as the condenser acts as an additional and effective heat and mass sink. So, the effect of drawn vapor at different speeds was investigated. The results show that integrating the solar still with external condenser increases the distillate water yield by about 53.2%. And using nanofluids improves the solar still water productivity by about 116%, when the still integrated with the external condenser.

1. Introduction

In the last 40 years, the problem of freshwater shortage has been one of the main challenges in the world. Potable water not only is important for life but also for industrial and agricultural purposes. So, the life without water will be impossible. The origin and continuation of mankind is based on water. Although more than 75% of the earth covered with water, only 0.014% of that can be used directly for the human being and other organisms. On the other hand, sea water constitutes 97.5% of global water, so it can be used for those purposes by converting it to distilled water [1]. There are some techniques for water purification, which among them, solar water distillations is an attractive subject. A single basin solar still is a very simple solar device used for converting available brackish or waste water into potable water. The solar distillation systems are mainly classified into two categories: passive and active solar still. In passive solar stills, solar radiation is the only parameter which affects evaporation, but in active solar stills by using the additional device such as fan [2], pump [3], sun tracking system [4] or solar collectors [5–7], the temperature difference between evaporating and condensing area is increased, and consequently enhancement on productivity is achieved. Active solar stills also can use waste heat of other processes or devices to improve the evaporation rate of water. Productivity of such solar stills is very low. The efficiency of a conventional single-basin solar still is usually about 30–40% [8]. This is because of the loss of the heat of condensation to the environment through the glass cover of the basin and some useful heat carried away by the warm condensate.

Many extensive studies have been carried out to enhance productivity, effectiveness and efficiency of single-basin solar stills. Solar still with sponge cubes in basin is studied by Bassam and Hamzeh [9]. Hiroshi Tanaka [10] constructed a basin type solar still with internal and external reflectors. Tiwari et al. [11] used a multi wick solar still with electrical blower. Jim et al. [12] used a multiple tray tilted still. Velmurugan et al. [13] increased the exposure area of the water surface using sponges and fins in a single basin solar still; the study found that the productivity increases from 1.88 to 2.8 kg/m^2/day. El-Sebaii et al. [14] attempted to improve the daily productivity of the single effect solar stills. a single-slope single-basin solar still integrated with a Shallow Solar Pond (SSP) to perform solar distillation at a relatively high temperature. Jianyin et al. [15] designed a new multi-effect solar still with enhanced condensation surface, which applies the corrugated shape structure. John [16] designed a solar water purifier. Tiris et al. [17] conducted experiments on two flat plate solar collectors integrated with a basin type solar still. Performance study on solar still with enhanced condensation was studied by Vinoth and Kasturibai [18]. Hussaini and Smith [19] studied the effect of applying vacuum inside the

* Corresponding author at: Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt. Tel.: +20 1001543587.
E-mail address: kabeel6@hotmail.com (A.E. Kabeel).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.11.013

solar still. Recently, Gnanadason et al. [20] reported that using nanofluids in a solar still can increase its productivity. They investigated the effects of adding carbon nanotubes (CNTs) to the water inside a single basin solar still. Their results revealed that adding nanofluids increases the efficiency by 50%. Nevertheless, they have not mentioned the amount of nanofluid added to the water inside the solar still. Regarding the addition of nanofluids to the solar still, the economic viability should be considered. Some works reported that adding dyes to solar stills could improve the efficiency. For instance, Nijmeh et al. [21] concluded that adding violet dye to the water inside the solar still increases the efficiency by 29%, which is considerable. On the other hand, it is evident that nanofluids (especially CNTs) compared to dyes are more expensive, hence this may be a challenge on using nanofluids in solar stills, because in this type of use of nanofluids in solar stills the nanofluids have no flow in a closed loop so that they could be recovered.

In this context, the attempts are also made to increase the productivity of water by integrating the still basin with external condenser and using the nanoparticle sized in solar still with conventional water. The fluids with solid-sized nanoparticles suspended in them are called nanofluids. The suspended metallic or nonmetallic nanoparticles change the transport properties, heat transfer characteristics and evaporative rate of the base fluid. These nanofluids are expected to exhibit superior heat transfer properties compared with conventional water in the solar still and hence the increase in the productivity and efficiency of the solar still [22].

2. Experimental setup

In this work, two basin stills were designed, fabricated and constructed to compare the performance of the solar desalination system. One of them is a conventional type and the other is the modified basin still as shown in Figs. 1a and 1b. The conventional still has a basin area of 0.5 m^2 (1000 mm × 500 mm). The high-side wall depth is 450 mm and the low-side wall height is 160 mm. The still is made from galvanized iron sheets (1.5 mm thick). The whole basin surfaces are coated with black paint from inside to increase their absorptivity. Also, the still is insulated from the bottom and side walls with wool to reduce the heat loss from the still to ambient. The basin is insulated from the bottom and side walls with low thermal conductivity fiber glass of 5.0 cm thick. The basin is covered with glass sheet of 3 mm thick inclined with nearly 30° on horizontal, which is the latitude of Kafrelsheikh city, Egypt. The gaps between the glass cover and the still box was filled by silicon to prevent any leakage from anywhere inside the basins to outside of them.

The modified basin still has the same dimensions and construction of conventional still. In addition, inside the still, there is a vacuum port to be able to measure the pressure inside the basin still by the pressure measurement instrument. Also, there is a vacuum fan and its output duct to the condenser as shown in Fig. 1a. The condensation unit consists of 3.0 m copper tubes with 3.81 cm diameter encased in polyethylene tank (40 × 40 × 50 cm) filled with cold water. The copper tube is terminated with graded container to collect the condensate water, as shown in Fig. 1a. The used vacuum fan is of the axial-flow type. It has a blade diameter of 8 cm and was attached by a variable speed indicator on a screen to control the fan speed as shown in Fig. 1b. The brushed DC electric motor was used to run the fan. It had a maximum rotational speed of 1440 rpm, power factor of 45°. Also, it consumed 2 A and 12 V. The feed water tank is connected to the main line which is divided into two feed water lines. A flow control valve is integrated at each line inlet in order to regulate the flow rate of water as shown in Fig. 1a.

The experimental setup is suitably instrumented to measure the temperatures at different points of the still (brine, absorber and glass cover temperatures), total solar radiation and the amount of distillate water. The temperatures are measured by K-type thermocouples. The solar radiation intensity is measured instantaneously by a solarimeter. The digital air flow/volume meter is used to measure the wind velocity.

3. Experimental procedure

Experiments are constructed and conducted at Faculty of Engineering Kafrelsheikh University, Egypt. The experiments were carried out at the period from sunrise to sunset, during April 2013 to July 2013. The solar radiation, atmospheric temperature, basin temperature, saline water temperature, glass temperature and

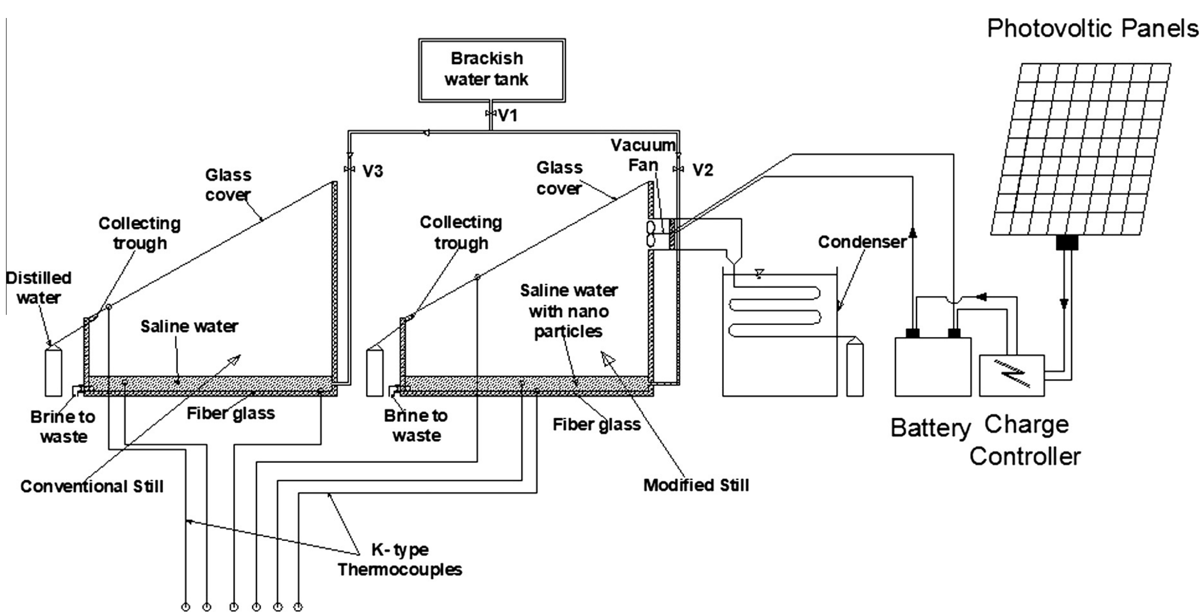

Fig. 1a. Lay-out diagram of the experimental setup.