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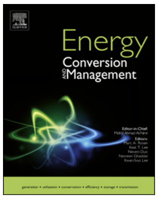

Key factors affecting the water production in a thermoelectric distillation system

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ABSTRACT

A thermoelectric distillation system has recently been demonstrated to have a great potential of improving the efficiency of distillation processes due to the use of waste heat from the hot side of thermoelectric module to assist evaporation while the cold side for condensation. This work investigates the key factors that affect the water production in a thermoelectric distillation system. An experimental investigation was performed to investigate the influence of evaporation temperature, vapour volume, Peltier current and input power on the water production rate. The results of the experiment show that an increase in the sample water temperature from 30 °C to 60 °C led to an increase in total water production by 47%. In addition, an increase in total water production by 58% was obtained by reducing the vapour volume from 600 cm^3 to 400 cm^3 during a 3-h operation. The maximum water production rate is achieved by appropriate selection and control of the Peltier current to the thermoelectric device based on the operating condition of the distillation system.

1. Introduction

Freshwater is an urgent necessity for human life as a person's survival depends on drinking water [1]. A large amount of freshwater resources face the threat of pollution, and people suffer from diseases (such as Cholera) due to drinking polluted freshwater [2]. It is estimated by environmental experts of the United Nations that one-third of the world's population lives in countries with insufficient freshwater to support the population [3]. Distillation is one of the potential technologies for producing freshwater by heating and cooling processes. Numerous experimental and numerical investigations have been conducted on various types of distillation systems to improve the efficiency of the systems through optimisation of the design parameters [4–9]. For example, some key design parameters in a solar still system (such as evaporation area, sample water depth, cover condensing angle, thermal storage materials, additives, solar tracking, reflectors and insulation) have been identified and investigated [10–12]. Phadatare and Verma [13] found that lowering the water depth in the basin led to an increase in productivity during the day but a decrease at night. A number of approaches have been employed to increase the water productivity and enhance the performance of the stills. These include: reducing the sample water mass to increase the evaporation temperature, reducing the pressure inside the still, forcing air convection inside the still, increasing the collecting area, using phase-change materials or nanofluids in the solar distillation systems[14–19].

Many sources of energy can be used for water distillation, such as fossil energy and renewable energy [20]. The use of a thermoelectric cooler to assist seawater distillation is regarded as an attractive technology to improve the condensation and production rates [21–23]. Thermoelectric coolers are solid-state heat pumps based on the Peltier effect which transfers thermal energy from one side of the cooler to the other. They have no moving parts, reliable, noiseless, compact, easy to control, and environmentally friendly products. Because of these advantages, using the thermoelectric coolers for water distillation has received increasing attention [24,25]. Jradi et al. [26] studied an integrated thermoelectric–photovoltaic system for dehumidification and fresh-water production. They found that the air flow rate, air inlet condition and electric current to the thermoelectric modules are the controlling parameters for system optimisation. Yildirim et al. [27] studied experimentally a portable thermoelectric desalination system. They investigated the effect of feed water mass flow rate and air flow velocity on the performance of the system. Rahbar et al. [28] introduced an asymmetrical solar still employing a thermoelectric cooler. They found that the water production can be increased 8 times by using the thermoelectric cooler instead of the usual glass. Aberuee et al. [29] presented a novel solar thermoelectric and desalination system. The system was used to produce electric power, distilled water and hot water, simultaneously. Moh'd and Al-Ammari [30] investigated the

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effects of wind speed, solar intensity, ambient temperature and condenser temperature on the distillation rate and the efficiency of the solar thermoelectric generator system. Recently, a unique high efficiency thermoelectric distillation system was demonstrated [31]. The unique aspect of this system is to use the waste heat from the hot side of thermoelectric module for heating of the feed water, to enhance the evaporation process while using the cold side of the module for cooling the condenser and enhance the condensation process. The theoretical analysis of the thermoelectric distillation system was presented in terms of the evaporation and the condensation processes [19,32]. However, no systematic investigation has been carried out to study the effect of the design parameters on the performance of this new thermoelectric distillation system. The design parameters include sample water temperature, vapour volume, Peltier current and thermoelectric input power. The objective of the present work is to investigate the influence of these parameters in attempts to obtain insights/guidelines for further improve the performance of this system through optimisation of design parameters.

2. Experimental investigations

The performance of a distillation system is affected by many factors including water, vapour and condenser temperatures, dew point, water volume (or water depth at a constant water-vapour surface area), vapour volume (or volume occupied by the vapour), geometry of the enclosure and pressure. In a thermoelectric distillation system, these factors can be controlled by the input power to the thermoelectric module. The evaporation process requires heating, while the condensation process requires cooling. The higher the temperature of the water, the higher the rate of evaporation and the lower the temperature of the cooling surfaces, the higher the rate of condensation. In a recent thermoelectric distillation system reported in [31],both the heating and cooling are provided by a single thermoelectric module in a closed-loop system, resulting in a significant improvement in the efficiency due to the waste heat from the hot side of the thermoelectric module being circulated back to the evaporation chamber to increase the temperature of the sample water. However, in order to investigate and observe the influence of these parameters on the performance of such system, an open-loop system is needed. Fig. 1 shows a schematic diagram of the thermoelectric distillation system employed for this investigation. An aluminium heat sink with fins (condenser) is attached to the cold side of the thermoelectric module, which is employed to condense the vapour particles.

A copper heat exchanger is employed to dissipate the heat from the hot side of thermoelectric module into cold water. The hot water circulation loop, connecting between a hot water bath and the sample water basin, controls the evaporation temperature of the sample water. The cooling water loop, connecting the heat exchanger at the hot side of the thermoelectric module to the mains water supply, controls the condenser temperature. The system uses two power supplies – one for powering the thermoelectric module and the other for the water pump, which is used to return the sample water from the basin to the water bath and to keep the sample water in the basin at a particular level. A data logger and a laptop were used to monitor and record the temperatures of the system components.

The actual experimental setup is displayed in Fig. 2, showing a hot water bath, power supplies, a digital scale and a digital flow meter with one-way valve connected to the heating water. A single thermoelectric module (GM250-49-45-30; European Thermodynamics; 6.2 cm × 6.2 cm × 0.58 cm) is sandwiched between two heat exchangers. The top water heat exchanger (black) was mounted on the hot side of the thermoelectric module. The bottom condenser (fins) was attached to the cold side of the module as shown in Fig. 3. The volumes of the chamber and the fins are 850 cm^3 and 150 cm^3 respectively. The water-vapour surface area is 100 cm^2 and the total surface area of the condenser fins is 410 cm^2. A small ruler (3 cm) was fixed on the corner walls of the chamber to monitor the water level. The experiments were conducted in a lab environment for a period of 180 min with the chamber filled with tap water. During the experiments, temperatures of ambient, water, vapour, condenser surface and hot/cold sides of the thermoelectric module were measured and recorded using a laptop, RS232 cable and a data logger (Pico Technology: TC-08). The water produced at the outlet during the condensation process was measured using a weight scale, and the total power consumed by the system was determined from voltage and current to the system.

In order to ensure the reliability and accuracy of the experiments, the following measurement procedures were employed.

1. All the experiments were repeated three times and the data were presented using the average value of the three experiments with the errors represented by the standard deviation.
2. The water inside the hot water bath was heated to a set temperature before pumping to the thermoelectric distillation system. This was to ensure that the sample water in the evaporation chamber could reach the set temperature quickly.
3. Hot sample water was supplied and regulated by the hot water bath using a one-way valve and a digital flow meter (range: 0.05–1 L/min) to keep the sample water at a desirable level.
4. The electric current to the thermoelectric module (referred to as the Peltier current in this paper) was provided by a high precision constant current power source and was set to a desired value between 5 A and 10 A. The operating range of the applied electric current was selected based on the thermoelectric module data sheet. In this range, the thermoelectric module operates close to its optimal current for maximum cooling.
5. The cooling water was connected to the mains water supply directly. The temperature of the cooling water is 12 °C during the experiments. In addition to the components and instruments used in [31], specifications of the additional components used in the experiments are given in Table 1. Accuracies, ranges and standard uncertainty of the additional instruments are listed in Table 2.
6. Laboratory door and windows were closed to ensure minimum air movement inside the lab during the experiments. The ambient temperature of the Laboratory is approximately 24 °C, and the humidity is around 28%.
7. The temperature difference between the hot and the cold side, vapour temperature and humidity in the chamber (presented in Tables 3–5) were measured every 10 min and given as the average values over the duration of the experiments. The average value was calculated by dividing the sum of the values by the number of the values.

3. Results and discussions

The water production was measured every 10 min and the effect of the key factors on the water production rate can be summarised as follows:

3.1. Effect of sample water temperature

The experiments were performed at a constant Peltier current of 7 A and sample water level of 30 mm. Table 3 shows the average temperature differences between the hot and cold sides of the thermoelectric module for the sample water temperature at 30 °C, 40 °C, 50 °C and 60 °C, respectively. Fig. 4 shows the water production rate at the different sample water temperatures. It can be seen that the water production increased with increasing the sample water temperature. The effect of sample water temperature on the water production rate is significant. The total water production increased from 49.3 mL to 72.4 mL as the temperature of the sample water increased from 30 °C to 60 °C. This represents a 47% increase in the total water production after 3 h of operation. The increase can be attributed to an increase in water

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