Solar Distillation Thermoelectric Power Generation

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Abstract. In this paper, a phase change material (PCM) heat storage and thermoelectric cells were integrated into a solar still. This project aim is to store the available solar heat using the PCM for generating power and increasing freshwater production. An experimental test rig of the solar still was designed, built and tested. The solar still consists of a single slope basin container with a PCM storage located at the bottom. The thermoelectric cells were installed beneath the PCM storage. The natural convection cooling method was used to cool the thermoelectric cells. The study showed that the solar still thermoelectric power generation (SSTEG) was able to produce 9.6 ml/m² of fresh water and at the same time generated peak open circuit voltage of 44mV. The study is hopefully could provide a simple and cheap solar still system that can solve the water and electricity problem in rural areas.

1. Introduction
The contaminated drinking water becomes a major health hazard in countryside areas. Women and children are the particularly affected victims due to their vulnerability to the water-borne diseases [1]. Approximately 5 million children dead per year were recorded by the UNICEF in 1995 due to this polluted water [2]. The growth of human population, industrial and agricultural activities caused an increase demands of the freshwater resources. The water distillation is one of the feasible solutions to overcome the freshwater crisis. The abundant source of solar energy could provide the thermal power for the distillation process. Solar power is a source that can be renewed, clean and will not run out [3]. It is caused by electromagnetic radiation from thermonuclear actions by the sun's core [4]. The power emitted by the sun is 1.8 X 1011 MW which is many times greater than the current rate of energy harnessed. The heat harvested from the solar thermal system can distillate the contaminated water to clean water. Whereas excess heat from the sun can be stored in phase change materials (PCMs). Energy stored by PCM later will be used when sunset. PCM is a substance that is utilized for efficient waste heat conservation [5]. PCM has the benefits of a high heat storage capacity because of the latent heat of the fusion and almost isothermal solid-liquid phase change. The benefits of using organic PCM are because they are usually readily available, chemically stable, do not react with other substances, and have a high thermal melting point. Its weakness is flammability and low thermal conductivity. In this project, paraffin wax is selected as PCM, which fills the storage tank outside the contaminated water tank. Paraffin is usually relatively cheap. It has an excellent latent heat of fusion for a desired operating temperature range. The electricity can be generated by the thermoelectric (TEC) cells using the heat stored in the PCM for small-scale power generation. Thermoelectric generators (TECs) are a device that produces electrical energy converted from thermal energy [6]. TEC does not have a moving part, thereby making its operation quiet, compact, highly reliable, requiring very low maintenance and environmentally friendly. TEC is located between the source of heat and the heat sink to generate electrical power. The temperature gradient created becomes the driving force for heat.
to conduct across the module and dissipates to the environment through heat sinks. The electricity will generate continuously as long as the temperature difference constantly exists. The TEC attracts a lot of researchers' attention because of its ability to convert heat into electricity as a solid state device. A TEC converts heat into electricity using heat exchanger from many heat sources such as factories, vehicles exhaust and electronic devices [7 - 13]. The earliest use of thermoelectric effects is in metal thermocouples for measuring temperature and radiant energy [14]. However, despite numerous studies on power generation using TEC, there were no similar studies found abroad or in Malaysia, where the investigation was set up on a tank of PCM in a solar still system. On the other hand, high rainfall in Malaysia must be taken into account to investigate TEG's performance and behaviour. The effects of weather conditions on air velocity and humidity are not considered in this study.

2. Concept of the solar still thermoelectric generator (SSTEG)
In this work, an experiment was conducted using the solar still thermoelectric generator (SSTEG). The SSTEG consists of two tanks: water tank (inner tank) and PCM tank (outer tank) as shown in figure 1. The TEG was positioned at the centre bottom of the outermost tank which was the PCM tank so that the excess heat absorbed by the solar still can be used to generate a voltage. The thermoelectric cell (TEC) used has 40mm (length) x 40mm (width) x 4mm (thickness) size. The basin plate was insulated with fibreglass at both of the wall sides to minimise the heat energy loss to the ambient. The glass cover was placed on top of the basin plate with an inclination of 10° to the horizontal. The distillate water which was condensed at the glass surface was fed through the distillate channel and collected in a container. The saline water was placed in the basin still made from aluminium sheet. The design was simplified and modified for the installation for both of the PCM and the thermoelectric generator.

3. Result and Discussion
The SSTEG were tested under real ambient as shown in Figure 2. Test 1 was conducted without filling any paraffin wax (PCM) into the PCM storage tank. Test 2 was done with approximately 2 kg of paraffin wax. Both tests were conducted at different days due to a long time required for data measurement. Figure 3 shows the solar radiation data (W/m²) for Test 1 (without PCM) and Test 2 (with 2 kg of PCM). The solar radiation for Test 1 was slightly better than Test 2. The Test 1’s solar radiation reached at a peak with 935W/m² at 13:00 h, however, for Test 2 on day 2, the solar radiation reached a maximum value quite late at 16:00 h with 748W/ m². The variation of the solar radiation was due to the cloudy weather. Figure 4 depicts the water basin temperature and water production for both tests. The hourly freshwater productivity increased in the morning until noon but decreased gradually in the evening. Although the peak solar radiation for day 1 was higher than day 2 by 25%, the basin water temperature for Test 2 reached a peak temperature at 56°C, which 5°C higher than solar still without paraffin wax (Test 1). More fresh water produced by the SSTEG in Test 1 with a total of 9.6 ml/m² compared to 5.8 ml/m² in the SSTEG without PCM. Between 18:00 to 20:00 h, the solar radiation for Test 2 (SSTEG with 2 kg PCM) had shown almost no reading, however, the solar still had continuously produced fresh water up to 19:00 h. On the other hand, the solar still without PCM...
stopped producing fresh water earlier at 18:00 h even though the solar radiation still exists with significant amount until 19:00 h. The water evaporation rate and condensation rate are the factors that give rise in the hourly condensate output in which the rate of condensation is due to the difference of the basin water temperature and the outer cover glass temperature. As the consequence, the higher basin water temperature contributes to a higher the hourly productivity of the solar still with PCM. These results proved that the SSTEG with PCM is capable to store more heat compared to the common solar still.

Figure 3. Solar radiation versus time

Figure 4. Variation of the Basin water temperature and freshwater production.

Figure 5 demonstrates the potential of the voltage generated by the thermoelectric cell (TEC) that been installed under the heat storage tank. The voltage had been measured between 11:00 to 14:00 h on 30 May 2018 within 20 minutes interval. Two cells were used in this test and were connected in series. The cold side of the TEC was attached with pin fins to create a cooling effect. It had been observed that the maximum temperature gradient (across the cell) could be achieved during the testing period was approximately 2.1°C. This maximum temperature gradient was capable to generate approximately 44 mV open circuit voltage (OCV). Overall, during the testing, the OCV showed a variation between 10 to 44 mV depending on the temperature gradient created. Both voltage and temperature gradient readings had not been consistently increasing due to weather factor as the experiment was not set up in a controlled environment. For the system to be applied in the real applications, the current system has to be modified as follows:

I. To use more the PCM for increasing heat storage capacity,
II. To increase the volume of basin water for the distillation process,
III. To set the glass cover with an optimum inclination of 30° to the horizontal,
IV. To introduce an effective cooling for the TEC such as using active liquid cooling.
4. Conclusion and Recommendations

The study has been carried out successfully to meet the objectives of this project, that was to design, fabricate and test the combined solar still with heat storage using PCM and thermoelectric power system. The testing results showed that by adding paraffin wax, the basin temperature had increased to 56°C which 5°C higher than the solar still without PCM. This basin temperature is sufficient enough to melt the paraffin wax into liquid for heat storage. The solar still with PCM had proven its ability to store more heat by extending the fresh water production time to 1 hour longer and produced a total of 9.6 ml/m², that 3.8 ml/m² more than the conventional solar still. In addition, the system also produced a peak 44mV open circuit voltage using the installed TEC cells. Although the result demonstrated that only a small amount of water and power were produced due to the lacking several factors such as weather conditions, non-optimise design and also the volume of PCM. A few optimization study could be conducted to get better yields for the future study such as to use better TEC cooling system including using forced cooling water or heat pipe, to increase the volume of the solar stills, to increase the amount of PCM, or to use a controlled space that the heat absorbed by the solar still or PCM is steady and possible for generating more electricity.

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