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Design and Construction of a Simple Thermoelectric Generator Heat Exchanger for Power Generation From Salinity Gradient Solar Pond

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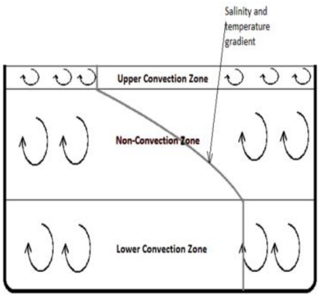
Graphical abstract



Abstract

Solar pond is one source of renewable thermal energy. The solar pond collects and stores thermal energy at the lower zone of the solar pond. The temperature at the lower zone can reach up to 90 °C. The solar pond is capable storing thermal energy for a long period. The stored thermal energy can be converted into electricity by using thermoelectric generators. These thermoelectric generators can be operated using the cold and hot zones from a solar pond. In this paper, the experimental investigation of power generation from the solar pond using thermoelectric generator and simple heat exchanger is discussed. A maximum of 7.02 W of electrical power output was obtained from a simple heat exchanger with 40 thermoelectric modules.

Keywords: Solar pond, thermoelectric generator, renewable energy, power generation

1.0 INTRODUCTION

Air pollution and global warming are two of the greatest threats to living organisms. Most of the energy demand around the world is covered by using of conventional energy sources such as; coal, oil and natural gas. The ongoing use of non-renewable resources will affect the environment and changes the planet's climate, which will harm the coming generations. Power generation is one of the largest air pollution's producers. The power generation could be categorized under non-renewable or renewable energy. In order to reduce the use of non- renewable resources, the use of conventional power generation should be reduced, and the use of the renewable resources should be raised. Furthermore, renewable energy is the energy that comes from natural resources such as sunlight, wind, rain and geothermal heat, which could be good alternatives to conventional energy sources [1]. Renewable energy could be extracted from a wide range of renewable sources such as; hydro power, solar power, wind power and geothermal power. Sustainable energy could be used in everyday life in variant ways such as; electricity generation, water heating, water desalination, industrial heating process and off-grid energy services. Solar power is one of the cleanest energy, which converts sunlight into power. There are many types of solar power generation such as; photovoltaic (PV) panels, solar hot water, solar thermal energy and solar pond. In this paper, the generation of electricity from a solar pond is discussed [2]. Solar pond has many advantages compared to other renewable energy source due to its low cost and simple construction methods.

Solar pond is a pool of saltwater, which acts as a solar thermal collector. It collects solar radiation and stores it as thermal energy for a long period. The heat could be stored up to two days in cloudy weather without dropping the temperature of the heat storage zone. Additionally, solar pond could be used for several applications such as; greenhouse heating, water desalinization, industrial process heating, refrigeration and power generation [3]. A typical solar pond has a density and temperature gradient as shown in Figure 1. It has three different zones, which are Upper Convection Zone (UCZ), Non-Convection Zone (NCZ) and Lower Convection Zone (LCZ). The UCZ is the top most and thinnest layer of the solar pond. It contains almost fresh water. The NCZ has an increase of salt concentration and density with respect to depth of the solar pond. It acts as insulation between the UCZ and LCZ. The LCZ has the highest salt concentration and density of the solar pond.

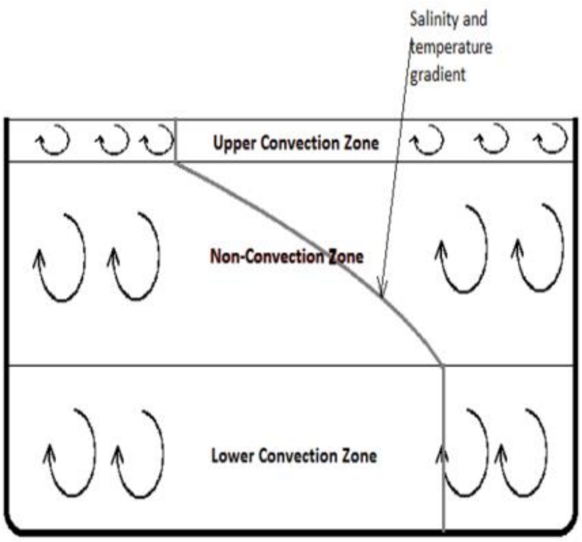


Figure 1 Solar Pond with three different zones

The UCZ absorbs about 45% of the solar radiation, which comes from the sun, while most of the radiation will be lost because of the reflective surface of the water. Some of the heat will be lost in the NCZ due the heat conduction. The LCZ will store up to 25% of the solar radiation as heat. It is important to keep the UCZ and the NCZ clear and transparent to avoid losing solar radiation from the LCZ [4]. Moreover, the three zones of the solar pond vary in temperature. The temperature of the LCZ could reach up to 90°C, while the UCZ temperature is close to the ambient temperature. The heat storage at the LCZ and the temperature difference in the UCZ could be used for various applications such as; electricity generation using thermoelectric generators.

Thermoelectric generator (TEG) uses the temperature difference to generate electricity. TEG are very advantages as they are capable of operating in low-temperature difference with no limitations, also they are noiseless, environment-friendly and almost maintenance free [5, 6]. The UCZ and LCZ of the solar pond are capable of support TEGs. For a single TEG, a cold supply could be extracted from UCZ and hot supply could be extracted from LCZ. Thermoelectric generators could be used where ever heat differences exist. It could be used in variant applications such as; automobiles, industrial waste heat and gas pipelines. TEGs provide a better alternative to power generation from a solar pond when compared to Organic Rankine cycle engine, as it does not require ant threshold in temperature to operate [7].

This paper aims to design and construct a simple TEG heat exchanger. This study is limited to laboratory scale testing of the prototype; it does not include the full-scale prototype tested at the solar pond.

2.0 EXPERIMENTAL

A counter flow heat exchanger was built to supply the maximum heat transfer through TEG. Counter flow heat exchanger is the most efficient, which can transfer the most heat due the fact that the average uniform temperature difference along the length. It contains three main parts, which are the steel square channel, 40 TEGs and Acrylic tube. The steel square channel is 50 mm X 50 mm and 600 mm in length. An inlet and outlet were drilled to allow the hot fluid to pass through. Steel end caps were used to block the square channel. 10 TEG were connected in series and sticked on each side of the square channel by using thermal adhesive glue, which will allow the maximum heat transfer between steel square channel and TEG. A single TEG is 40 mm X 40 mm, arranged in rows of 10 TEGs occupied an area of 40 mm X 400 mm on each side of the square channel. A 90 mm diameter acrylic tube allowed the cold water into the heat exchanger via inlet and outlet on the two ends. The acrylic tube is 500 mm in length. The hot and cold water going through the square channel and the acrylic tube was used to simulate LCZ and UCZ solar pond conditions.

The hot fluid was supplied from an adjustable hot water urn. Water temperature was adjusted from 40 °C up to 90 °C. The water was pumped using a pump to enter the square channel and exits to return to the tank. A flow sensor at the inlet was used to measure the water flow rate. The cold water was supplied by tap water to enter the Acrylic tube and exit to sink. Temperature readings on each inlet and outlet of the heat exchanger were recorded using multi-channel temperature display. The output power was obtained by using an electric load device. Figure 2 shows the laboratory experimental setup for TEG heat exchanger.

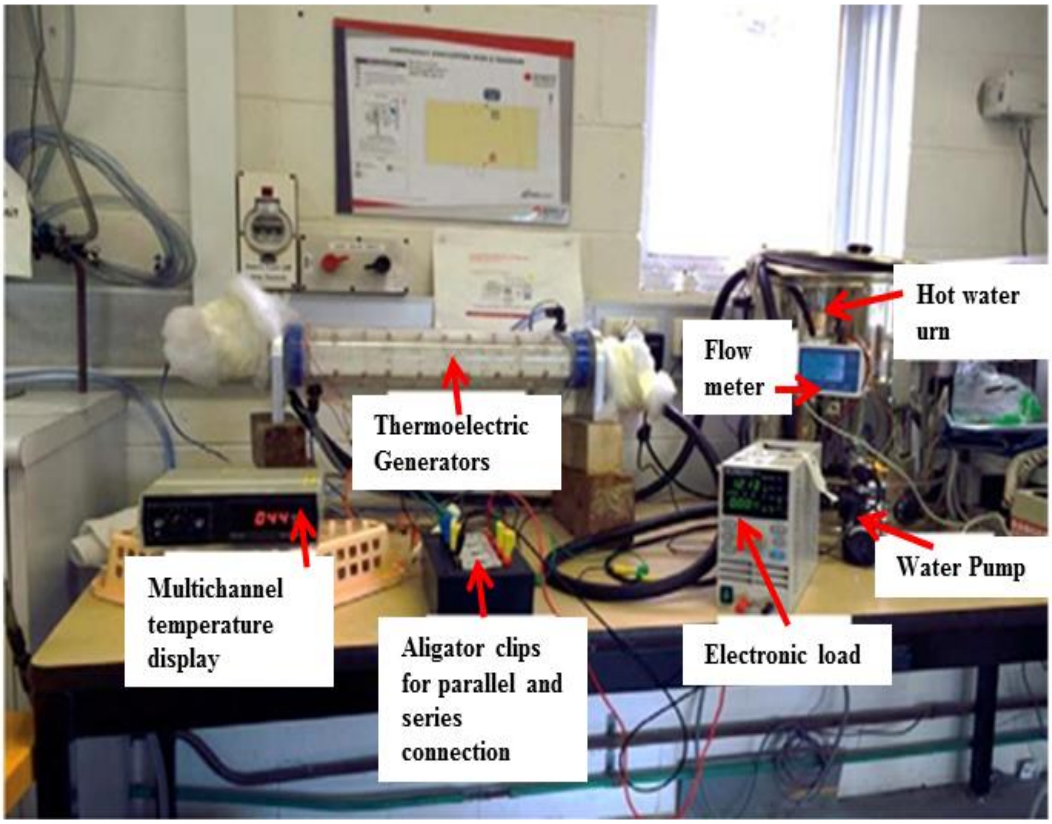


Figure 2 Laboratory experimental setup for TEG heat exchanger

3.0 RESULTS AND DISCUSSION

Figure 3 below shows open circuit voltage versus hot water temperature. It is clearly shown that, as the temperature of the water increases, the open circuit voltage of the system increases linearly. Thermoelectric generator modules on all four rows were connected in series individually. These four rows on the heat exchanger were then tested with all rows connected in series, all rows connected in parallel and two rows connected in series and parallel with other two rows. This is because the various connections allow for the thermoelectric generator system to produce the voltage and current needed for the required output. From the experiment, the highest reading for the open circuit voltage was obtained for series connection as shown in Figure 3. This was followed by the series-parallel combination connection. The lowest output was obtained by the parallel connections of the rows. This is because the parallel connection results in higher current output that results in higher Joule heating losses through the connection system as well as the resistance network. A balance between the parallel and series network must be obtained to suit the end requirement needs. For a number of thermoelectric modules, a series connection will cease to produce power if a module fails due to unwanted reasons. Therefore, a combination of series and parallel connections will result in good reliable long term operation of the thermoelectric modules.

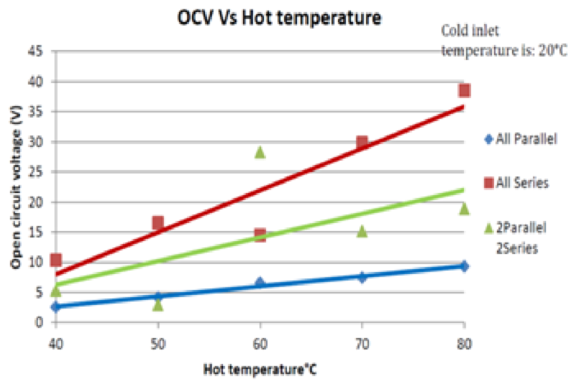


Figure 3 Open circuit voltage output versus hot water temperature

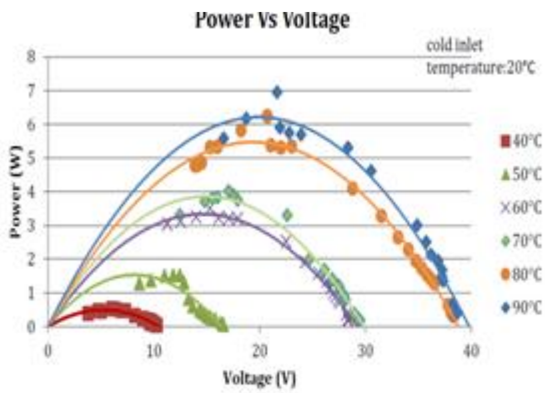


Figure 4 Output power versus output voltage

Using the electric load device, the current and voltage was found by applying variable resistance to the TEG circuit. All TEGs were connected in series connection, including rows to obtain maximum power output from the system. Figure 4 above shows power output versus voltage output for different hot water temperatures. By multiplying output voltage and output current obtained from data acquisition system, the power was calculated. The highest power obtained was recorded at 7.02 W for 90°C hot water temperature. The maximum power of each hot water temperature testing was obtained when the internal resistance of the TEG modules matched the resistance of the electronic load. From Figure 4, it is evident that the maximum power output increases hot water temperature. Even at low-temperature conditions, the TEGs were able to produce electrical power. Based on these results, low-grade heat from a solar pond can be converted into electricity using TEGs.

4.0 CONCLUSION

The study shows that the thermoelectric generator and a heat exchanger prototype can produce electrical power. The construction of the thermoelectric generator is simple to manufacture and low in cost. The maximum power of 7.02 W was obtained from 40 TEG modules. The result obtained shows that there is a good prospect in power generation from a solar pond using TEGs. For higher power output requirements, the TEGs could be scaled and sized depending on application specifications. The proposed system will be most suitable for small-scale applications of solar ponds for power generation.

References

[1] Jacobson, M. Z. 2009. Review of Solutions to Global Warming, Air Pollution, and Energy Security. *Energy & Environmental Science*. 2(2):148-173.

[2] Lovegrove, K. And Dennis, M. 2006. Solar Thermal Energy Systems In Australia. *International Journal of Environmental Studies.* 63(6): 791-802.

[3] Randeep Singh, Sura Tundeeb , Aliakbar Akbarzadeh. 2011. Electric Power Generation From Solar Pond Using Combined Thermosyphon and Thermoelectric Modules. *Solar Energy*. 85(2): 371-378.

[4] Velmurugan, V. and Srithar, K. 2008. Prospects and Scopes Of Solar Pond: A Detailed Review. *Renewable and Sustainable Energy Review*. 12: 2253-2263.

[5] Xiaolong Gou, Heng Xiao, Suwen Yang. 2010. Modelling, Experimental Study and Optimization On Low- Temperature Waste Heat Thermoelectric Generator System. *Applied Energy*. 87(10): 3131-3136.

[6] Xing Niu, Jianlin Yu, Shuzhong Wang. 2009. Experimental Study on Low-temperature Waste Heat Thermoelectric Generator. *Journal of Power Sources.* 188(2): 621-626.

[7] Bertrand F. Tchanche , Lambrinos, Gr. Frangoudakis, A. Papadakis., G. 2011. Low-Grade Heat Conversion Into Power Using Organic Rankine Cycles–A Review of Various Applications. *Renewable and Sustainable Energy Reviews.* 15: 3963-3979.