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Experimental Investigation on Flat Plat Solar Thermoelectric Generator

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Abstract

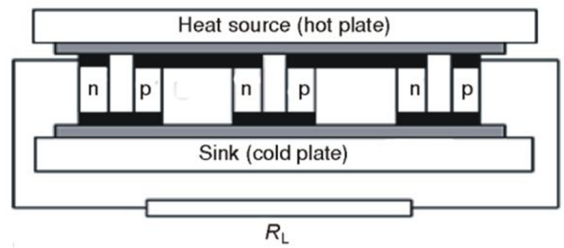
The conversion of solar energy into electricity is dominated by photovoltaic's and solar thermal systems.In this study, an attempt has been made to conduct an experimental investigation on small scale flat plate solar thermoelectric generator.Thermoelectric generator consists of commercial thermoelectric modules embedded between the hot plate and cold plate which is placed in the flat plate collector.The solar radiation and water cooled heat sink is the driving potential to generate electricity,various operating temperature of receiver plate.The design process involved to minimizing heat losses, analyzing heat transfer through the thermoelectric elements, and measuring the electrical power generated by the thermoelectric module connected to varying resistive loads in order to ultimately measure the STEG's efficiency.Inthis study it is identified to use flat plate solar collector and coupled with commercial thermoelectric module is simple fabrication method easy to adopt in the rural techno craft for small scale power generator to meet the isolated energy demands.

1.0 Introduction

The decrease of fossil fuel resources has motivated many research groups to seek technologies for the utilization of alternative energy sources. Because fossil fuels such as coal, oil, and natural gas are the most predominately used energy sources, an intense need exists for an economically and commercially viable renewable energy source [1].Inordertomeettheincreasingelectricaldemandsof society, the many alternative, renewable energy sources have been proposed. One feasible solution is solar energy, with the field dominated by photovoltaics and solar thermal power [2].Solar energy is the radiation resulted by nuclear fusion reactions in the sun. The 30% of the solar power actually reaches the Earth, every 20 minutes the sun produces enough power to supply the earth with its needs for an entire year (3) and the solar systems have a low environmental impact, and one of the most important benefits is that it doesn't have emissions like CO_2 or other toxic gases. The two most commonlystudied technologies are solar photovoltaics and solarthermal power plants. One technology that has special attention is solar thermoelectrics. Thermoelectricsare materials which generate a voltage in the presence of atemperaturegradient(4).When these materials are sandwichedbetween a solar absorber and a heat sink to establish a temperaturedifference and generate power,they are called solarthermoelectric generators (STEGs), thermoelectric generators is solid sate direct energy conversion device, it issimple in construction and easy to fabricate by sintering process. It has many advantages such as highly reliable, having nomoving parts and environmentally friendly, when compared with conventional power generators.In the case of TEG for combination of solar thermal collector for power generation, there have been many conceptual designs of power conversion system which are potentially capable of obtaining application in solar thermoelectric power generation (5).A simple flat plate collector consists of an absorber plate and cold plate in aninsulated box covered with sheets. The mostimportant part of a solar collector is the absorber, which consists of metal plate. And it is made of metallic materials such as copper. The collector housing can be made of metallic sheet, plastic, or wood and the glass front cover must be sealed so that heat does not escape, and the collector itself is protected from dirt, humidity. Solar irradiance passing through the glazing is absorbed directly onto the absorber plate. Surface coatings that have a high absorbtivity value for short-wavelength light are used on the absorber. Paint or plating is used and the resulting black surface will absorb almost over 95% of the incident radiation (6)the developed TEG unit with commercial thermoelectric modules made of bismuth telluride alloys for a maximum power generation of about 130w-150w. In this work an experimental investigation to be made on the flat plate solar thermoelectric generator for small scale power generation and its performancecharacteristic, conversion efficiencyto be validated

2.0 Mathematical modeling

Thermoelectric energy conversion for power generation is based on the "Seebeck effect", where a temperature difference, $T_h–T_C$, across two dissimilar legs of semiconductor material produces a voltage (V_{OC}),This voltage is equal to the Seebeck coefficient of the material, α, times the temperature difference across the device. The dissimilar legs of semiconductor material, one p-type and one n-type, are called a thermoelectric couple. The p- and n-legs are joined by an electrically conducting material at the p-n junction. A thermoelectric module consists of a series of p-n couples, which are connected electrically in series and thermally in parallel. Electrically insulating material separates the electrical connectors from the heat source and sink.



The noload condition ($R_L$loadnotconnected),theopencircuitvoltage asmeasuredbetweenpointsis:

$$V_{oc}= \alpha \, \Delta T$$

where$V_{oc}$is the output voltage from the couple in volts [V], α – the average Seebeck coefficient[V°C–1], and ΔT– the temperature difference across the couple[°C].

$$\Delta T = T_h – T_c$$

WhereT_h[°C]isthehotsideofthe coupleandT_c[°C]– thecold side ofthe couple.

Whenaloadisconnectedtothethermoelectriccoupletheoutputvoltage(V) drops as aresult of internal generator resistance. The current through theloadis:

$$I_{load} = \frac{\Delta T}{R_I R_L}$$

A single thermocouple produces low voltage and in order to obtain high voltage, a number of thermocouples are connected electrically in series and thermally in parallel to form a module.

Power generated between the two terminals is given by:

$$P=V^2/R_L$$

The energy balance across the absorber can be expressed in terms of the solar radiation incident on the top of the absorber, the heat leaving the bottom of the absorber to the thermoelectric module, the heat losses due to radiation from the top and bottom of the absorber, and the heat losses due to convection [2]:

$$Q_{abs} = Q_{TE} + Q_{rad,bottom} + Q_{rad,top} + Q_{conv}$$

Because this STEG is designed for an evacuated environment, the convective heat losses are zero (although the system was later determined to not be able to hold a vacuum, as described further in this paper). An illustration of the absorber's energy balance can be seen in Fig 1.

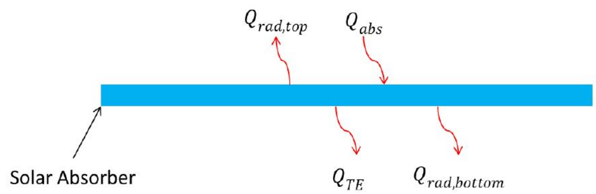


Figure - 1

The heat losses from the bottom and top of the absorber due to radiation are expressed as

$$Q_{rad,\ bottom} = A_{abs}\varepsilon(T_h^4 - T_c^4)$$

$$Q_{rad,\ top} = A_{abs}\varepsilon(T_h^4 - T_{amb}^4)$$

The combined emittance of the top surface of the absorber and the bottom of the absorber is equal to the sum of the individual emittances. Assuming $T_c = T_{amb}$, the sum of the heat losses due to radiation is represented by

$$Q_{rad,\ bottom} + Q_{rad,p} = A_{abs}\varepsilon\sigma(T_h^4 - T_c^4)$$

The radiation incident on the top of the absorber is expressed as the product of the transmittance of the glass covering, the solar absorptance of the absorber, the optical concentration ratio of the system, the heat flux from the sun incident on the system, and the absorber area [2]:

$$Q_{abs} = \tau\alpha C_{opt} q_i A_{abs}$$

With no optical concentration, C_{opt}=1; τ and αcan also be assumed to be 1.

3.0 Experimental setup

The system consists of the thermoelectric modules, the heat sink device, the receiver plate, and manual trackingarrangement for the solar flat plate collector. The GI sheet box acts as heat sink and theirflat surface having its surface area of 0.075m^{2}and sheet thickness of 10mmwhich is opposite to the lid which is attached to cold side of thermoelectric modules. The cold water is circulated to the internally fined heat sink to maintain the cold side temperature at minimum.Thecold water is drawn from the over head tank. The flow rate of cold water is adjusted manually by the valve arrangement in order to maintain the constant outlet temperature of the water. So, we can maintain the mean temperature of water is considered as the heat sink temperature.

The hot plate is made aluminum sheet have 10 mm thickness, its surface area of 0.075m^{2}and the bottom of the plate was sanded to smooth the surface in order to obtain a high thermal conductivity.A National Pipe Thread tapered hole is tapped into the heat sink for the hose fitting to connect the system to a vacuum pump. The outside edges of the heat sink were originally lined with rubber to avoid glass-to-metal contact under a vacuum since the system's covering is made of glass. The STEG's covering is comprised of low-emissivity window glass, which allows light to enter the glass but keeps the heat in the system. The sealant used to hold the covering together is a heat resistant RTV silicon sealant. The glass covering can be seen in Fig 2.The receiver plate as heat sources is attached to the hot side of thermoelectric modules.

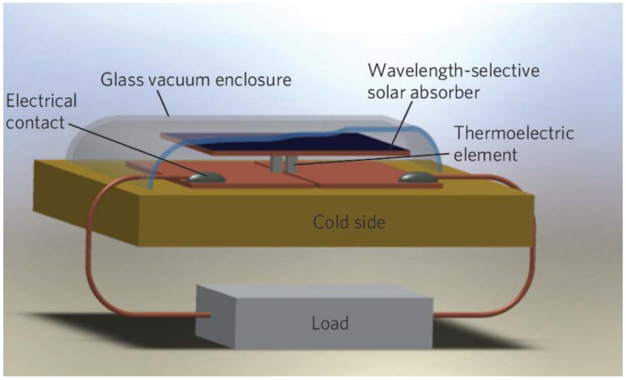


Fig – 2 glass covering model

The flat receiver plate made of aluminum sheet with 360mmx210mm in size with thickness of 10mm to absorb the solar radiation from the sun. The absorbed heat energy in the receiver plate is transmitted to the hot side of thermoelectric modules after the convection, radiation, and conduction losses. The receiver assembly, which comprises heat sources, thermoelectric modules and heat sink is attached tothe cross base of two mild steel plates.

The TEG unit consists of the receiver plate made of aluminum sheet; thermoelectric modules are made of bismuth telluride and the heat sink made of aluminum materials as shown in the Fig 3.

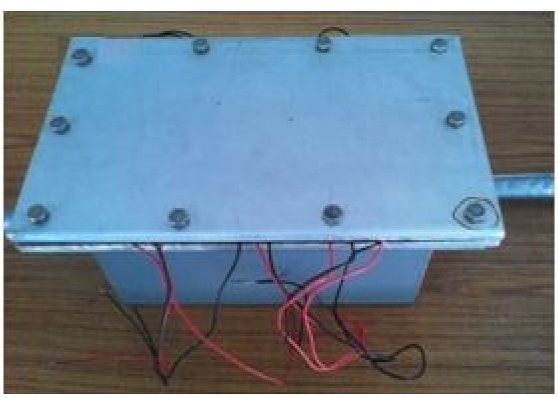


Fig – 3 pictorial view

Ten thermoelectric modules with total rated power generation of 147W are embedded between the receiver plate and the heat sink. Commercial thermoelectric modules having the dimension of 56 mm x 56 mm, a matrix ofthermoelectric couples (p-type and n-type), generate electric power of 14.7 Wwhen the temperature of 235°C and 30°C and heat supplied is 350 w. Thermal grease is placed between all of the thermoelectric modules /receiver plate and heat sink interfaces in order to minimize the thermal contact resistance.The receiver unit has size of 360x210mmand thickness of 100 mm.

4.0 Result and discussion

The performance evaluation of the TEG system is carried out on the basis of data derived from tests.The actual mathematical modeling is done and the instantaneous efficiency is found to be almost same as that of the steady state value. The experiments are conducted for a range of operating conditions as follows; the receiver plate temperature is varying between 325 K and 455 K and the mean temperature of heat sink 300 K to 320 K. the test has been conducted two different times on both the collectors and the average values have been taken into account for the following calculations.

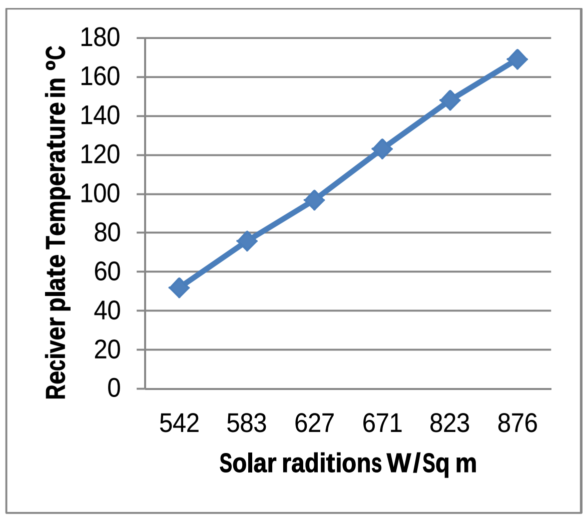


Fig – 4 receiver plate temperature Vs solar beam radiation

Figure 4 shows the variation of receiver plate temperature over the measured solar beam radiation. The receiver plate temperature obtained was maximum 169 ºCat the solar beam radiation of 876 W/m2. The minimum temperature of the receiver plate obtained was 52 ºC at solar beam radiation value of 542 W/m2. The average Solar radiation received by earth in terms of energy R = 722 W/m2/Hr.

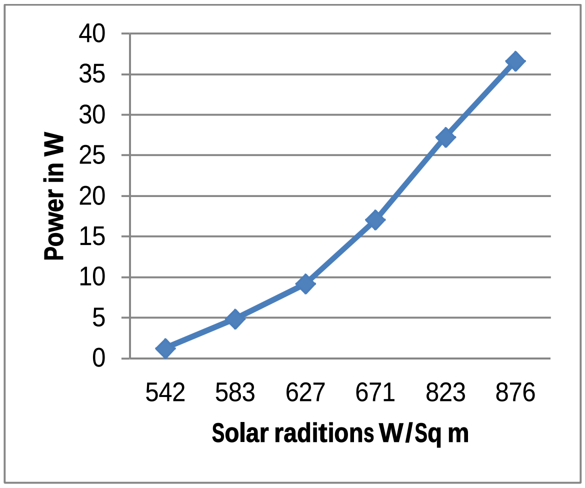


Fig – 5 Power output Vs solar beam radiation

The electrical power output from the flat plate solar thermoelectric power generator over the beam radiation is illustrated in Figure 5. The measured current and voltage for constant resistance of 4.4 Ω in terms of electrical power generation. The maximum power output of 36 W obtained when the solar beam radiation the maximum value at 876 W/m2 with the receiver plate temperature of 169 ºC. The minimum power output of 1.3 W was obtained when the solar beam radiation value at reaches 542W/m2 with the receiver plate temperature of 52 ºC.

5.0 Conclusion

The power generation from the flat plate solar thermoelectric moduleswas developed. The results of absorber plate temperature, power output are derived from theexperimental investigation are reported for the different solar beam radiations. The performances of the systems are greatlyaffected by the heat sink temperature. Correlations for determining the plate temperature, electrical power output have been developed in terms of solar beam radiation. This research proposes to design, build, and test a small-scale flat plate solar thermoelectric generator (STEG) to contribute to the further development of STEGs as a reasonable solar thermal energy source in a consumer market.

6.0 References

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