CONSTRUCTION AND EVALAUATION OF A PV/T COLLECTOR UNDER LOW CONCENTRATION USING THE BATCH METHOD

Samukonga G.[1*] S. Hatwaambo[1], K. Hansingo[1], M.M. Diale[2]

[1] Department of Physics, University of Zambia, Box 32379, Lusaka.

[2] Department of Physics, University of Pretoria, Private Bag X20, Hatfield, Pretoria.

ABSTRACT

Photovoltaic's are generally made from doped semiconductors whose conductivity decrease with increase in temperature. Suppressing the rise in temperature for cells under concentration by using water could improve the overall efficiency of a Photovoltaic-Thermal hybrid collector (PVT).

In this study a batch method was employed to analyze the performance of a PVT under low concentration. The batch methods employed a system of collecting thermal energy in a predetermined period of time and analyze the consequences on the electrical and thermal efficiencies. The study experimentally revealed that the thermal efficiency reached a maximum of 71.80% while electrical efficiency was increased to a maximum of 23% from a standard reference value of 14% for monocrystaline solar cells. The method produced 2/3 of the tank capacity as hot water per batch with maximum temperatures in the range of 65^0C to 70^0C.We concluded that thermal and electrical efficiency decreased exponentially with increase in outlet temperature beyond 42^oC regardless of any further increase in insolation. Therefore, the stagnant temperature of the system was approximated to be 42^0C. We also observed that the wind profile is important when designing a PVT system because high wind profiles favor electrical efficiency than thermal output due to high thermal losses through convection and radiation at high wind speeds. The batch method provided a large surface area for thermal absorption as a consequence providing better cooling compared to risers as used in many solar heaters and PVT systems. Hence, the batch method has been observed to help optimize the efficiency of a PVT under concentration. The temperature of usable water was attained by losing slightly part of electrical efficiency (temperature beyond 42^0 C) which is almost negligible. The electrical and thermal efficiencies were high at insolation close to one sun (1000 -1340W/m^2 and temperature of 25^0 C).We concluded that PVT overall system efficiency is adversely affected by type of solar cells used than other factors.

---

gilsam2009@gmail.com

1.0 INTRODUCTION

The conversion of energy carried by optical electromagnetic radiation into electrical energy is a physical phenomenon. Photovoltaics are one of the most important types of transducer which carry out such conversions [4]. However, not all radiant energy is transformed by a photovoltaic cell known as the photovoltaic effect [2]. Photovoltaic cells are generally made from doped semiconductors whose conductivity decrease with increase in temperature. For silicon based solar cells, the open circuit voltage drop at 2mV per degree Celsius for any rise in temperature above room temperature [1, 2]. Suppressing the rise in temperature for cells under concentration and using hot water for other purposes, the overall efficiency of the photovoltaic-Thermal hybrid system can improve. Concentrations in photovoltaic/thermal collectors reduce the cost of solar cells by reducing the solar cells collecting area with cheap CPC concentrator materials. The second advantage is that the temperature of the transfer fluid (water) can reach acceptable practical values of 50^{o}c and above [2, 3]. It is for this reason that building PVT systems at an acceptable cost will take care of limited accessible land and costs needed for huge power generation stations. Stand alone PVT systems can become more practical in none and grid zone areas .This would reduce stress on the already over stressed grids especially in developing countries.

1.1: Statement of the problem

The energy conversion efficiency of solar cells depends on the band gap which is affected by the temperature, electron density and type of material. A material with small band gap responds to short wavelength photons, while the other photons of longer wavelengths are wasted as heat. Large band gap responds to long wavelength photons of the solar spectrum which means that no single material can respond to the whole solar spectrum. Therefore, there is always some solar energy wasted from any kind of a solar cell.

1.2: Aim of the study.

The aim of the study was to construct a hybrid solar photovoltaic-thermal system to generate both electricity and hot water in batches by using a low parabolic compound concentrator system in an attempt to increase PVT system efficiency.

1.3: Significance of study.

The study attempts to maximize the overall efficiency of a PVT system and this demand the fabrication of solar cells on substrates as heat sinks for effective cooling of cells and thermal heat transfer.

2.0: METHODOLOGY

A complete assembly of the photovoltaic-thermal collector (PVT) hybrid system is shown in figure 2.1. It consists of a bronze tank retrofitted to a panel of solar cells with diffuse reflectors.

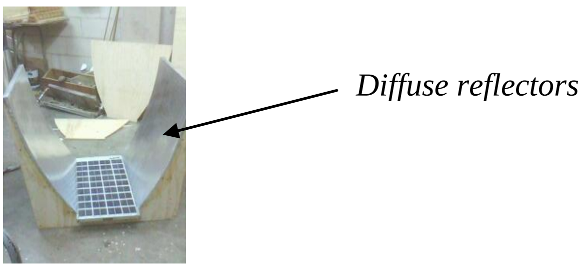

Figure 2.1: The complete PVT system with diffuse booster reflectors.

The PVT was put on a frame tilted at the latitude of Lusaka and facing the North. The system manually trucked the sun on a single axis west- east direction starting at 11hrs.

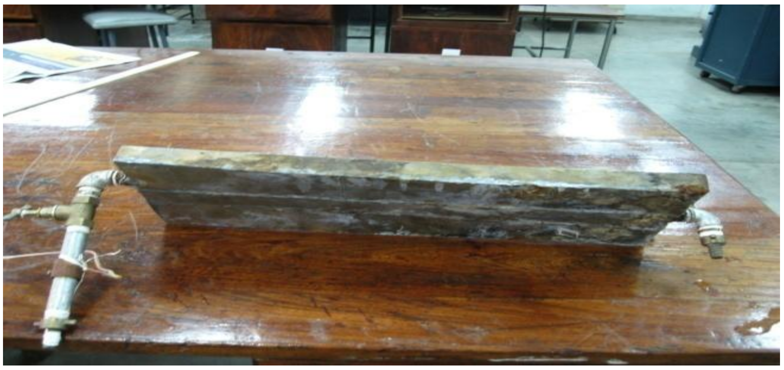

Figure 2.2: The thermal collector tank

A bronze tank 4mm thickness and heat capacity of 360j/kg was constructed as a thermal collector in figure 2.2. The fluid capacity of the tank was approximately 6 litres. The thermal collector was retrofitted to the solar panel (No form of adhesive was used). Glass wool was selected as the insulator. Glass wool has thermal conductivity of 0.044W/m^2 and thickness of 30mm used at the base and sides. Two gate valves were incorporated to assist in controlling the collection of fluids in batches. A simple pressure difference open loop forced circulation per batch was used as a pumping system. A measuring cylinder was used to measure how much hot water was extracted per batch.

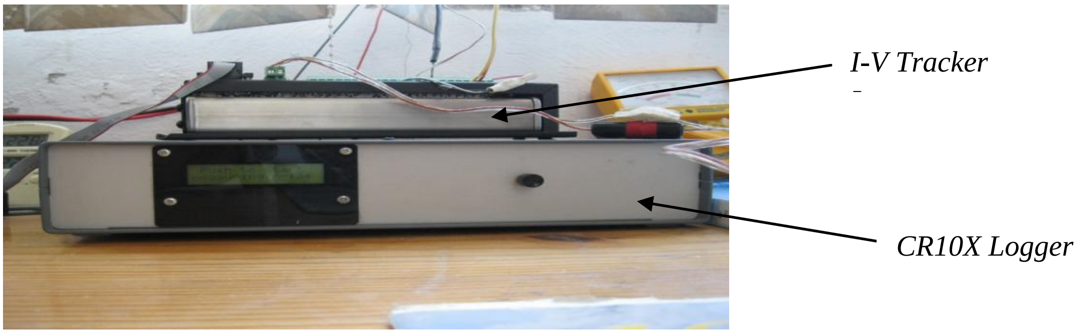

Figure 2.3: The two data loggers and the sensor cables.

The performance of the solar panel (cells) was monitored by V-I tracker data logger before and after every batch. The CR10X data logger was also programmed to sense inlet, outlet, ambient temperatures and solar insolation every 10 seconds. The computer was interfaced with the data loggers to view and store the data from the sensors.

3.0: DATA COLLECTION, ANALYSIS AND DISCUSSIONS.

The water in the tank was replaced after a predetermined period of time. At the time of introducing cold water in the PVT collector, the instantaneous efficiency was observed to increase to its maximum value, and then decreased as the temperature of the water in the tank increased. The higher the output temperature of hot water, the less the electrical efficiency as shown in figure 3.1 below.

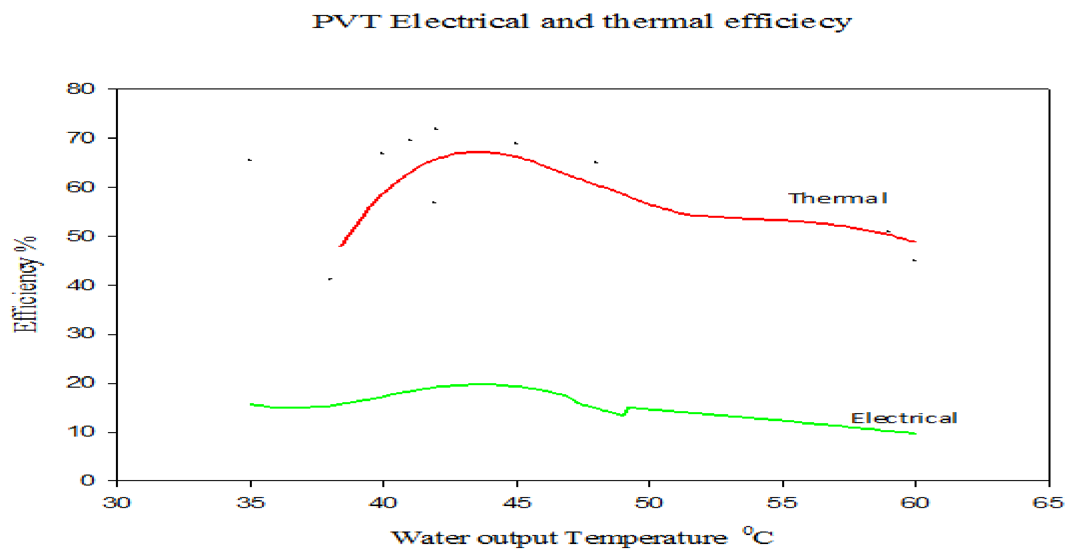

Figure 3.1: The effect of output temperature on the efficiency of a PVT system.

The stagnation temperature of a PVT system is the temperature at which maximum electrical and thermal efficiencies are obtained. Therefore, this should be the operational temperature of a PVT system to enable it effectively yield optimum efficiency. The batch method may be approximated as a load follower in power delivery systems. The efficiency increase exponentially being highest at low water output temperatures but steadily decrease as the output temperatures increase above 42^{0}C(stagnant temperature).This phenomenal can be attributed to increase in shunt resistance with increase in temperature. The shunt resistance losses become a source of power loss after stagnant temperature.

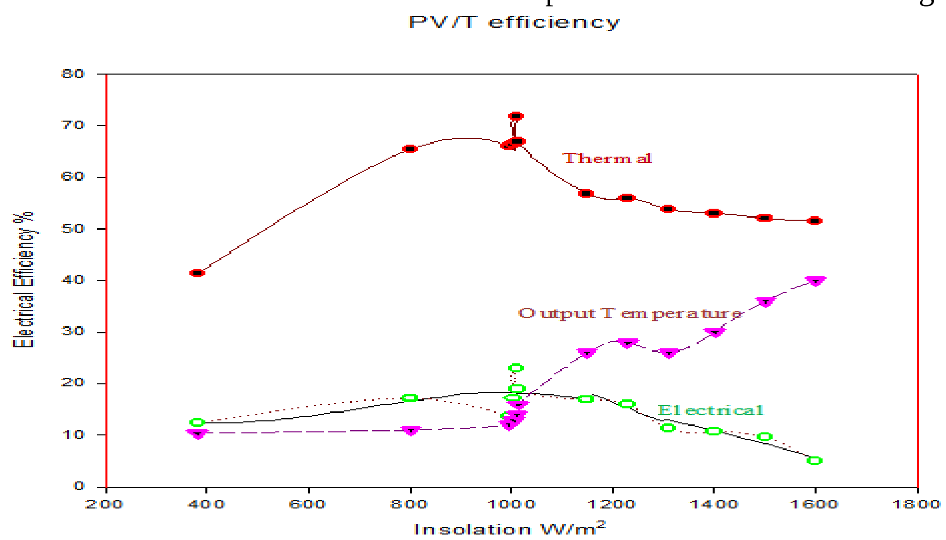

Figure 3.2: The PVT thermal efficiency under Concentration

The electrical and thermal efficiency of a monocrystalline cells in a PVT increased as the insolation was increasing towards 1000 W/m^2 then started to decrease exponentially as the insolation increased as shown in figure 3.2.This is due to the fact that the efficiency of monocrystalline cells respond effectively to insolation close to one sun. Hence, a PVT system will need special cells and substrates to yield high thermal efficiency and good electrical.

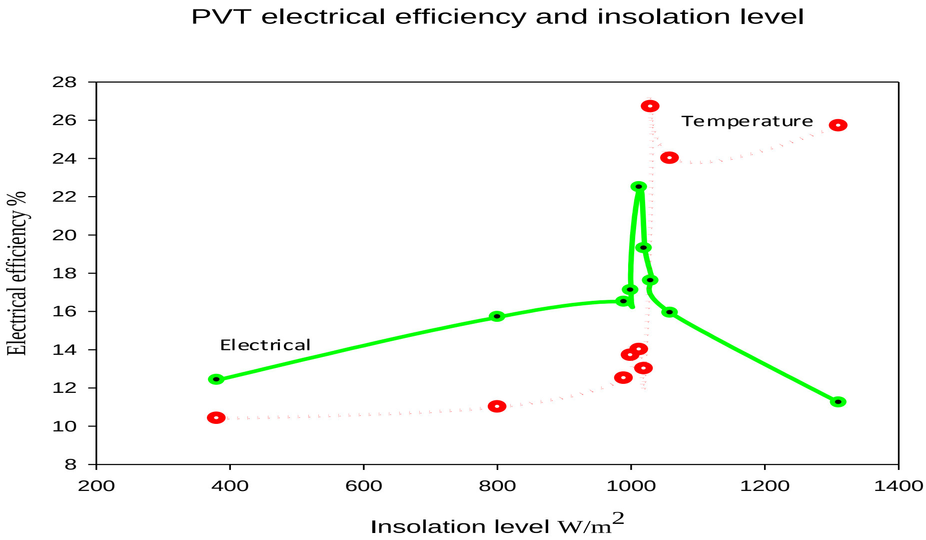

Figure 3.3: The electrical conversion efficiency and the thermal response of a PVT.

For low insolation the thermal output was low and constant. However, the insolation close to 1000W/m both electrical and thermal output went to their maximum. Thereafter, the efficiencies decreased but the cell PVT temperature kept on increasing as shown in figure 3.3.

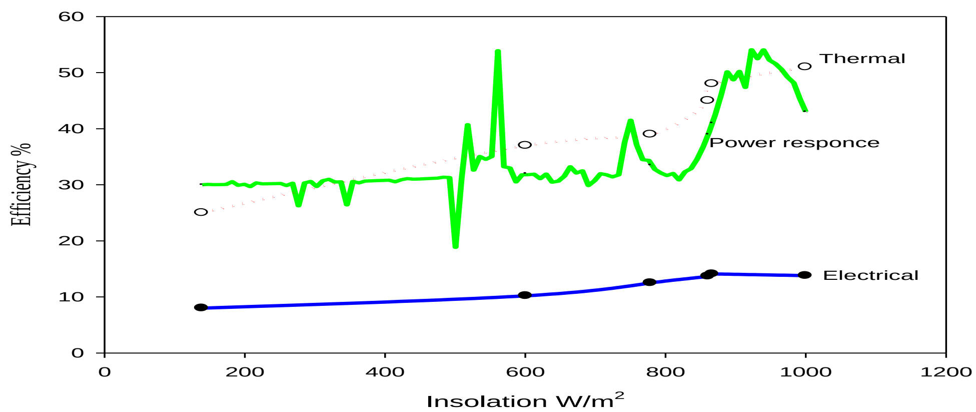

Figure3.4: The efficiency of Unconcentrated PV/T with respect to insolation.

It is clear from literature that the amount of power generated by a solar cell increase with increase in insolation. However, there is a limit to which this power can be increased. The experimental results show that electrical output adversely affect the thermal output of a PVT system even though other factors such as the optical (reflector ,concentrator) and thermal transfer characteristics of the materials can limit the PVT system efficiency . In PVT systems the thermal efficiency does not linearly increase as the concentration increases due to thermal losses. These losses are mainly due to radiation and convection. The radiant losses increase as a power of four in accordance to Stefan law. Moreover, the conductivity of air and the insulator increases with temperature rise which make the thermal efficiency to decrease due to such added sources of energy losses.

4.0: CONCLUSIONS

In this research a batch method of collecting heated water and its effect on the power output of a solar panel has been investigated. It has been experimentally observed that the thermal efficiency reached a maximum of 71.80% while electrical efficiency was increased by a maximum of 23% from a standard reference value of 14% for monocrystaline solar cells. We concluded that thermal and electrical efficiency decreased exponentially with increase in outlet temperature beyond 42^{o}C regardless of any further increase in insolation. Therefore, the overall efficiency of the PVT increases logarithmically with increase in insolation until stagnant temperature of the system is reached. We also observed that the wind profile is important when designing a PVT system because high wind profiles favor electrical efficiency than thermal output. High wind velocities help the PVT systems lose a lot of thermal energy which keep the cells at low operating temperatures. The batch method provided a large surface area for thermal absorption as a consequence, the cells operated at a lower temperature delivering more power because it makes the minority carriers lifetime to increase by effectively cooling both the substrate and solar cells. The electrical and thermal efficiencies were high to insolation close to one sun (1000-1342 W/m^2) and ambient temperatures close to 25^{o}C.

ACKNOWLEGMENTS

I would like to give my gratitude to the international programme in physical sciences of Uppsala University in Sweden for financial support .I'm also indebted to Professor P. Kaloyeru, Dr. H. Mweene and Dr. Chinyama for their academic assistance. Dr. Chuba, the assistant dean for postgraduate is acknowledged for his valuable advice. Not the least but also the technical staff at the department of physics for their tireless assistance.

REFERENCES

[1] Yiannis Tripanagnostopoulos, (1st July-10th July 2004, Patra),"*low concentration hybrid photovoltaic/thermal solar energy systems", PV systems Teaching and Learning.*

[2] Brogren M. P. Nostell , and B. Karlsson .2000, "*optical efficiency of a PV-thermal hybrid CPC module for high latitudes" solar energy*, Vol ,p 173-183.

[3] Ommen R, S. Jayaraman. 2001. "*Development and performance analysis of compound parabolic solar concentrators with reduced gap loses-oversized reflector*", energy conversion and management **42**,p1379-1399. India.

[4] Goetz M, P. Torres, P. Pernet, J.Meier, D. Fischer, H. Keppner, A.Shah. 2000, " *N-I-P michromorph solar cells on aluminium substrates*", Institut de Microtechnique (IMT) de l'Université de Neuchâtel, Rue Breguet 2, CH-2000, Neuchâtel, Switzerland.