CONSTRUCTION AND THERMAL ANALYSIS OF A PARABOLIC COLLECTOR FOR SMALL SCALE CONCENTRATING THERMAL SYSTEM

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ABSTRACT

Few options are apparent for achieving a benign, sustainable energy future except those relying on the utilization of solar energy in one way or another (Kaneff, 2004). Experience with fossil and nuclear sources has revealed an array of unsolved problems of increasing concern as more evidence and understanding emerges (Quaschning, 2005). Africa has the world's best solar resources. Several countries have exploited solar energy for water heating, crop drying, medical applications, and telecommunications, among other things (Davidson et al., 2007). Solar energy can contribute to supply heat energy in households of Sub-Saharan African countries. A small scale dish concentrating solar energy system is being developed at the Eduardo Mondlane University in Mozambique. The system comprises of the collector, the heat storage and the oven. The main structure of the system has been constructed, consisting of the dish reflector, the sun tracker and the piping mechanism.

An infrared camera was used to scan the temperature of the concentrated heat. The maximum temperature reached so far is 350^{o}C. The experimental focal area was found by mapping the reflections of the whole reflective surface. The shape of the receiver/absorber obtained by the scanning process is semi-spherical. 3D hemispherical absorbers with 110 mm $<$ d $<$ 220 m need to be used and investigated. The collector efficiency is too low.

Key Words: Solar, Thermal, Energy, Concentrating, System.

1. INTRODUCTION

Africa has a landmass of just over 30.3 million km^2 and it housed 885 million people (in 2005) in 53 countries of varied and diverse sizes, socio-cultural entities. Sub-Saharan Africa is a geographical region which lies south of the Sahara. This region has a population of 800 million (in 2007) and is the poorest in the world in contrast of North Africa. Yet, on average, less than 60% of the total adult population in sub-Saharan Africa can read and write - one of the lowest adult literacy rates in the world (Kaneff, 2004).

Sub-Saharan Africa has only 57% of population using improved drinking water sources (in 2002). Access to electricity, a generally accepted indicator for overall socio-economic development of any country or region, is low in sub-Saharan Africa. Only 53% and 8% of urban and rural populations have access to electricity, respectively while in northern Africa 99% and 88% have, respectively, access to electricity. Millions of people die because they don't have access to health care in this region (Quaschning, 2005).

With exception of South Africa, where only 16% of the population depends on traditional biomass energy, almost 80% of the population of sub-Saharan Africa depends on biomass resources for cooking, heating and sometime for lighting. Furthermore, when firewood is burnt indoors, emit health damaging pollutants such as carbon monoxide and many other health damaging substances.

Despite these problems, Africa has a variety of energy resources which include fossil and renewable energy resources. Africa has the world's best solar resources. Several countries in the region have exploited solar energy for water heating, crop drying, medical applications, and telecommunications, among the others (Davidson et al., 2007).

Solar energy can contribute to supply heat energy in households of Sub-Saharan African countries. Having this in mind a small scale dish concentrating solar energy system is being developed at the Eduardo Mondlane University in Mozambique. The system comprises of the collector, the heat storage and the oven.

1.1. SOLAR CONCENTRATING SYSTEMS

Many solar concentrating have been developed around the world. Artur (2009), developed and evaluated a Solar Concentrating System for high temperature heat for solar oven with heat storage unit at the University of KwaZulu-Natal in South Africa. The concentrator is a half satellite communication dish covered with trapezoidal acrylic mirror tiles, and has a total collection area of 2.2 m^2. The receiver/absorber is a spiral coil of blackened stainless steel pipe, and the Calflo HTF was used as heat transfer fluid. The system has high capability to produce high temperatures (around 180^oC at the exit of the storage) for domestic use and yield an overall efficiency of 35%.

Heetkamp (2002), developed a Small Solar concentration system with Heat Storage for Rural Food Preparation at the University of Durban-Westville in South Africa. The system consist of a parabolic concentrator is made of 2.4 metres diameter satellite dish with focal length of 0.915 metres. The reflecting surface consists of 3 millimeters thick acrylic back-silvered mirror material. As in the system developed by Artur (2011), the mirror tiles are trapezoidal. A volumetric receiver of 0.2 metres diameter was used. The system has a geometric concentration ratio of 144, and the atmospheric air is used as heat transfer fluid. Results show that the air is heated at temperatures around 300^oC at the absorber exit and 250^oC is achieved, yielding an overall efficiency of the absorber/receiver between 40 to 80%.

Kaushika and Reddy (2000), worked in design, development and performance characteristics of a low cost solar steam generating system which incorporates recent design and materials innovations of parabolic dish. The concentrator is a deep dish of rather imperfect optics, made of silvered polymer reflectors fitted in the aluminum frame of a satellite communication dish. Semi-cavity and modified receivers were analyzed and thermally optimized. The results indicated a solar to steam conversion efficiency of 70 to 80% at temperature of 450^{o}C.

3. MATERIAL AND METHODS

3.1. MATERIAL

The main materials used in the study are:

- Mirror stings
- Laser beam radiation
- Periliometer NIP, 8.49x10^{-6} V/W/m^2
- Fan ASTM A312 1009599, abm papst, RLH108/4200 ag, 230 V, 50 Hz, 55W
- Thermocouples set, T type
- Datalogger, Hi-Speed USB Carrier NI 9162, 16-ch 24-bit thermocouple input, 250 Vrms CAT II, ch-to-Earth Isolation, -40 ^{o}C ≤ Ta ≤ +70 ^{o}C

The reflector consists of six petals, covered with trapezoidal mirror tiles, which together resemble nearly parabolic surface with the parameters shown in table 1:

Table 1: The collector parameters

Name	**Measurement**
Diameter	240 0 mm
Focal lenght	915 mm
F/D ratio	0.315
Half openning angle	66,50º
Half complementary angle	23.49º
Angle of incidence	33.26º

3.2. PROCEDURE

The process of gluing trapezoidal mirrors was done on individual petals using the setup shown in the image. Theoretical focal length was taken as reference to regulate the amount of glue in order to force the reflections to a plan near by the focal plan. An individual petal was covered by 163 mirror tiles. The gluing was preceded by the scanning of each tile. Based on the concept developed by Chikukwa (2008) and the fact that errors cause the spread of the reflected rays, 3-D receiver will be adopted.

The spreadness of the reflections onto the focal plan was determined by scanning the whole reflective surface using a laser beam. Stainless steel fiber was used to build up the absorber and fencing mesh to molde it. Four absorbers were constructed (1 plan with 300 mm diameter and 3 Hemispherical absorbers with 300 mm, 220 and 110 mm diameter).

Figure 1: Reflection scanning process

3.2.1. Testing of the Absorber - Experimental Set Up

Seven thermocouples connected to a data logger coupled with a computer with Lab-View program for logging temperatures were used to measure ambient temperature, outlet temperature of the air (HTF) and the temperature in four different points on the absorber surface.

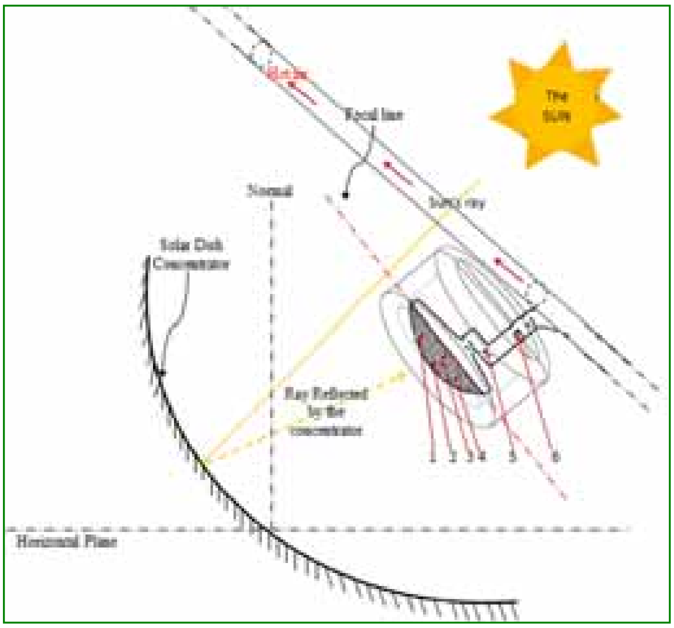

Figure 2: Experiment Set Up

<u>Legend</u>:
1 – T_{c0} is the temperature of the central part of the absorber
2, 3, 4 – T_{c1}, T_{c2}, T_{c3} are the temperatures of the points around the central part of the absorber

5 – T_{c4} is the temperature of the exit air (hot air) in a point immediately after the absorber;

6 – T_{c5} is the temperature of the exit air in a point after **T_{c4}.**

4. RESULTS AND DISCUSSION

4.1. MAPPED REFLECTIONS

Reflected rays intercepted the parabola axis in different points defining a certain region. However, the smallest image was found to be located at height of 920 mm. Thus, this level considered as the location of the experimental focal point.

In order to catch as many reflections as possible while at the same time minimize radiative losses by using the small surface, the hemispherical receiver was adopted. Tests done with solar radiation, revealed how small the spot light was. Therefore it illuminated just a small area of the absorber (with a diameter of 220 mm), but for the small absorber (with a diameter of 110 mm) the entire area was illuminated.

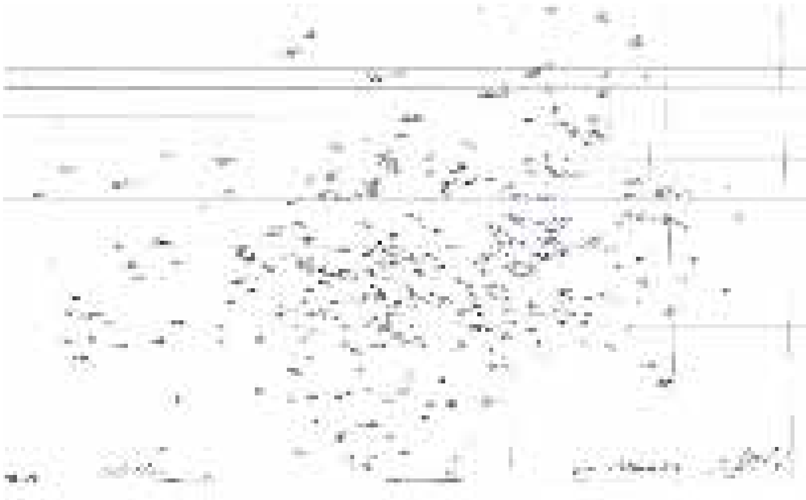

Figure 3: The image defined by reflections

4.2. TEMPERATURE PROFILE:

As can be seen from this graph, although solar beam radiation remained fairly high and fairly high temperatures were achieved at the absorber, the collection efficiency still very low. Moreover, manual tracking was also a problem, resulting in displacement of the spot light from the centre.

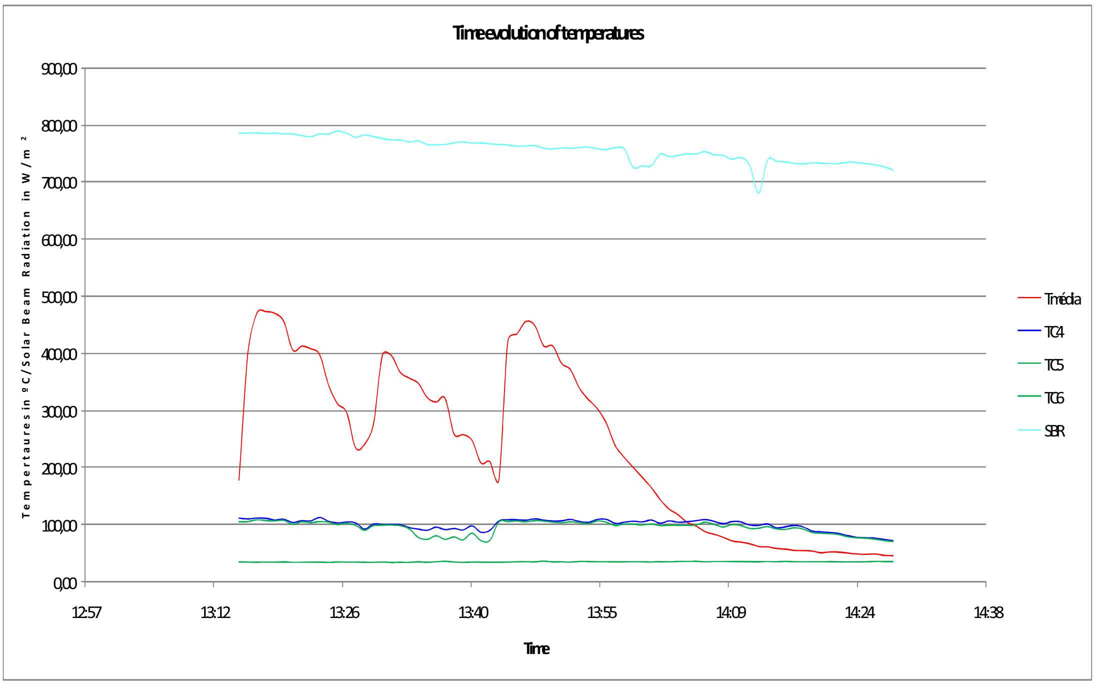

Figure 4: Temperature Profile

4.3. ***DISCUSSION***

Several factors could influence the poor thermal performance of the collector among others are the following:

The thickness of the absorber and density of the fibers delay the air flow through it. Thus, increasing the convective heat loss.

The shape of the absorber support may favour turbulence set up .

Manual tracking makes difficult to keep the spot light at the centre of the absorber.

5. CONCLUSIONS

3D hemispherical absorbers with 110 mm < d < 220 m need to be used and investigated. The collector efficiency is too low.

6. RECOMMENDATION

Test with an absorber of 150 mm; Decrease the density of the fibers; Decrease the thickness of the absorber; Test with absorber support with another shape; Test using insulating material; Consider to use a glass cover for the absorber?!

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