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Design and Development of a Solar Thermal Collector with Single Axis Solar Tracking Mechanism

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Abstract. The solar energy is a source of energy that is abundant in Malaysia and can be easily harvested. However, because of the rotation of the Earth about its axis, it is impossible to harvest the solar energy to the maximum capacity if the solar thermal collector is placed fix to a certain angle. In this research, a solar thermal dish with single axis solar tracking mechanism that will rotate the dish according to the position of the sun in the sky is designed and developed, so that more solar rays can be reflected to a focal point and solar thermal energy can be harvested from the focal point. Data were collected for different weather conditions and performance of the solar thermal collector with a solar tracker were studied and compared with stationary solar thermal collector.

1 Introduction

Energy plays an important role in the development every country in the world. Though abundant energy sources are available, renewable energy is believed to be the key source of energy for the future. It is no doubt that renewable energy technologies also contribute to sustainable development.

Malaysia is a country which is located near the equator. This location provided Malaysia high solar energy potential. The daily solar energy potential was recorded to be around 4 kWh/m – 5 kWh/m. With an average sunshine duration of 4-8 h/day, Malaysia has a favorable climatic condition for the further development of solar energy. Solar thermal usage should be encouraged by the public.

Throughout the world, solar thermal collector had already been successfully used for various medium temperature applications. Solar thermal collectors were used to collect solar energy and convert it into another form of energy, namely thermal energy. The majority of these solar thermal collectors was installed fixed at a particular angle directed to the sun. As the sun moves from east to west from sunrise to sunset, and from north to south throughout the course of the year, this resulted in the solar thermal being unable to harvest the solar thermal energy to its maximum capacity. This drawback can be further overcome by applying a solar tracker system to the solar dish. The solar tracker system will change

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the position of the collector dish automatically in accordance with the location of the sun in the sky.

2 Literature Review

Based on the literature review conducted, there are two main factors that affect the efficiency of the solar thermal collector. The first one is usage of solar tracking systems. The second factor would be the reflector used.

In 2012, Liene Kancevica, Henriks Putans, and Imants Ziemelis conducted a simple research and compared the efficiency of the solar collector with and without the presence of solar tracking system. According to their result, a solar collector dish equipped with a solar tracking system is proved to be able to produce 1.4 times more energy compared to the fixed angle solar collector. This experiment was carried out using a 1 m^2 collector dish. Besides, increasing the number of mirrors on the collector could also increase the overall efficiency [1].

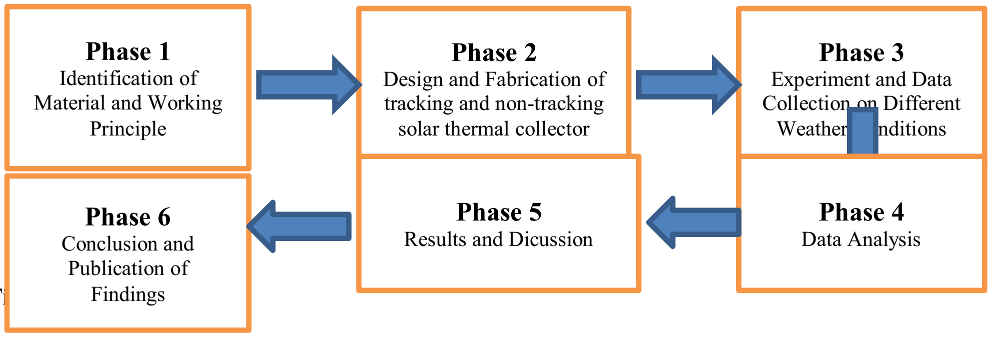
In another research conducted by Fareed M. Mohamed et al, the research, talked about the operating process of solar thermal collector [3]. In this work, the researchers first designed and fabricated a solar dish concentrator according to corresponding theoretical data. The parabolic concentrator that the research team had come up with having high sunlight reflectivity (up to 76%). This high reflectivity potential had increased the outlet water temperature in receiver cavity. Consequently, it managed to increase the system operational efficiency. The researchers claimed that their product had increased the operational efficiency up to 30%.

In 2013, Deepthi et al. [6], presented a research paper that compared the performance of single axis solar tracking system and dual axis solar tracking system with the fixed mount solar system. Based on their research, it is known that the dual axis tracking system performed much better than the single axis tracker system. This better performance even included cloudy weather condition. This proved that the efficiency of dual-axis tracker system is higher. Even though the hardware complexity is higher in the dual axis tracker, it provided a higher efficiency and better performance when compared to a single axis tracker.

3 Methodology

The following flow chart in Fig. 1 illustrates the different phases in the research project.

The working principle for the solar dish to collect the thermal energy was identified in Phase 1 of the project. Two units of similar solar thermal collector dishes were designed using the parabolic dishes. One is meant for stationary collector, while another one will be equipped with the solar tracking mechanism. The dishes will be used to heat up a container that holds 1L of water at the focal point of the dish. The type of the solar tracker is later identified. Figure 2 illustrates the drawing of the designed solar thermal dish.



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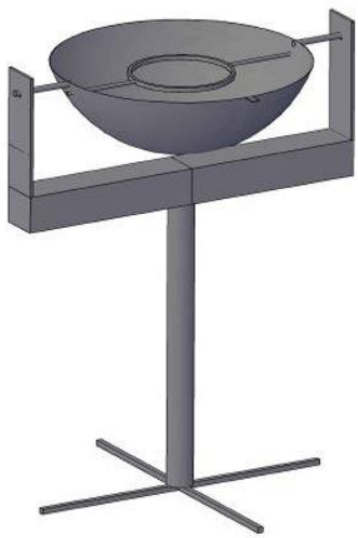

Fig. 2. Design of Solar Thermal Collector

In the second phase, the fabrication of the prototype was carried out. Appropriate solar tracker was acquired and installed in the second unit of the solar thermal dish.

An experiment to obtain the temperature difference between the solar thermal collectors equipped with solar tracker and non-solar tracker was carried out in the third phase. The data collection was carried out for 4 days in UNITEN Golf Range under the sunny conditions and also overcast conditions. The temperature of the water inside the container was measured using a digital thermometer placed in the water container. Reading was obtained with an interval of 60 minutes.

Fig.3. Stationary Solar Thermal Collector and Solar Tracking Solar Thermal Collector Collecting Data

Based on the results obtained from the experiment, the efficiency of solar concentrator is then calculated based on the solar tracking equipped device. First Law of Thermodynamics is used in calculating the efficiency of the overall system.

$$\text{Energy input} = \text{Energy loss} + \text{Energy Output} \tag{1}$$

The energy collected at the solar concentrator can be determined using the following equation:

$$E_t = I_t \times A_{SC} \tag{2}$$

Where:
E_i is the energy input in W
I_t is the total solar energy incident upon the plane of the solar air being heated in W/m^2
A_{sc} is the surface area of the solar cooker

The energy output from the solar concentrator can be found as shown below:

$$E_o = \frac{m_w c_{pw}(T_{wf} - T_{wi})}{t} \tag{3}$$

where:
E_o is the energy output in W
m_w is the mass of water in kg
c_{pw} is the specific heat of water in J/kgK
A_{sc} is the surface area of the solar concentrator in m^2

T_{wi} is the initial temperature of the water in K
T_{wf} is the final temperature of the water in K
t is the time in seconds

The efficiency of the solar concentrator can then be determined using the equation below:

$$\eta = \frac{Energy\ Output}{Energy\ Input} = \frac{E_o}{E_i} = \frac{[m_w C_{pw}(T_{wf} - T_{wi})]/t}{I_t \times A_{SC}} \quad (4)$$

4 Results

Figure 4 till Figure 8 illustrate the data obtained during the 4 days data collection using the solar dishes. The raw data shows that there were 2 days with sunny condition, 1 day with overcast weather condition while another day with sunny and overcast condition.

In the 4 days where data were collected, both tracking and non-tracking solar thermal collector were at work. The temperatures of the water at the focal point were collected, and increment in terms of efficiency is calculated and compared for all 4 days.

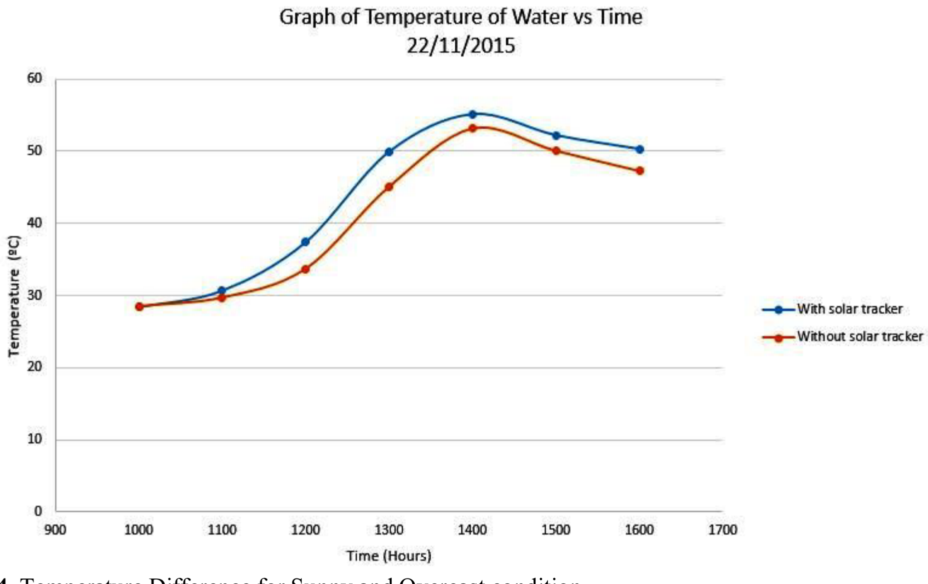

Fig. 4. Temperature Difference for Sunny and Overcast condition

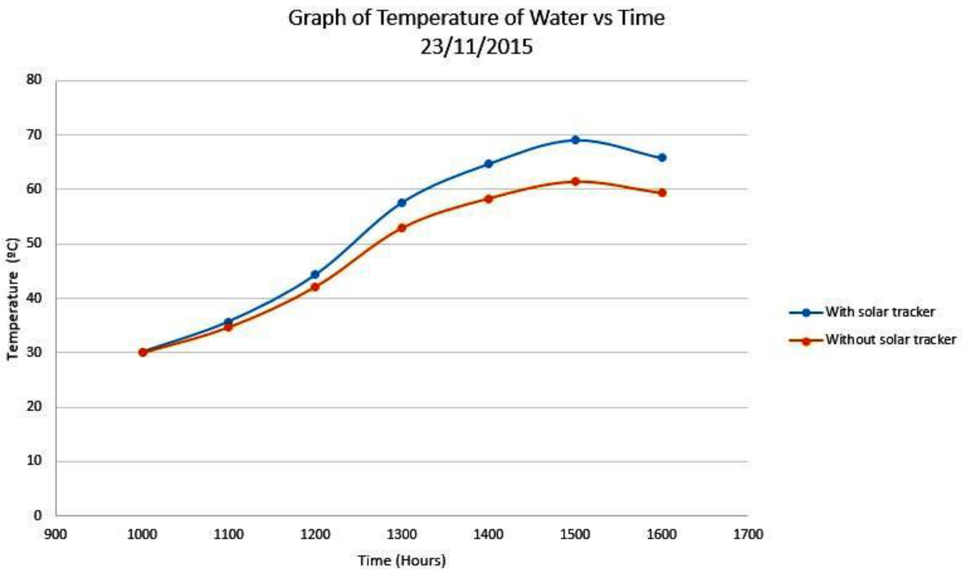

Fig. 5. Temperature Difference for Sunny Day Condition (Day 1)

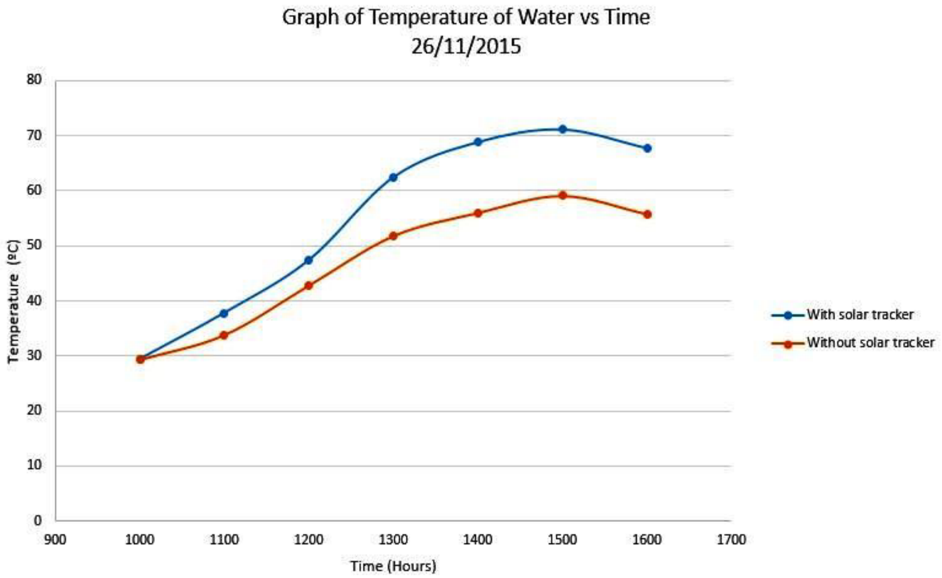

Fig. 6. Temperature Difference for Sunny Day Condition (Day 2)

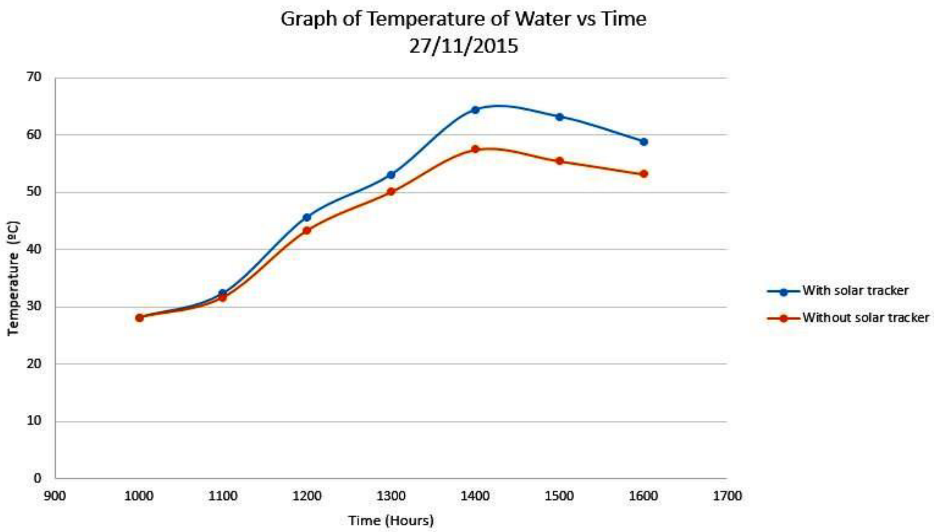

Fig. 7. Temperature Difference for Overcast Condition

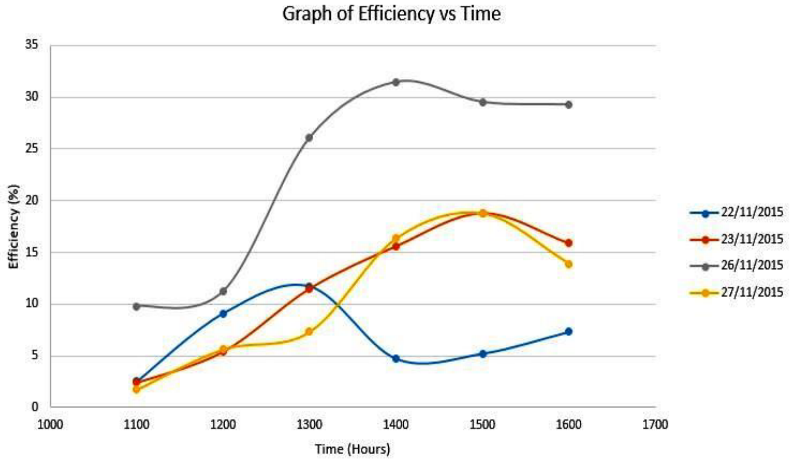

Fig. 8. Efficiency Increment

5 Discussion

From the results obtained, it is clear that the temperature of the water in the container is much higher for the solar thermal collector with tracking mechanism. Thus, the increment in efficiency is higher during sunny day's weather conditions where up to 31 % increment in efficiency.

The efficiency increment in both sunny and overcast, as well as overcast weather condition are lower compared to the sunny day condition. However the increment in efficiency can go up from 1.7 % to 18.76 %.

6 Conclusion

In this research project, a stationary solar dish concentrator as well as other solar dish concentrator equipped with had been designed and fabricated. The parabolic concentrator reflected the solar radiation at the focal point and increased water temperature in the container, and consequently arising system operational efficiency. Solar thermal collector, equipped with tracking system increased the operational efficiency to 31 %.

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