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Experimental study on the sun tracking ability of a spherical solar collector

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Abstract

The present paper describes an experimental investigation on a spherical shape and flat plate absorber exposed to sun without cover. The temperature of both absorbing surface has been measured during the test day, from sunrise to sunset. Temperature distribution has been analyzed using a thermal camera. Experimental results show a good correlation between measured temperatures on the absorbing surfaces and values of the incident solar radiation measured with a fixed and a sun tracking pyranometer. The spherical absorbing surface is behaving like a sun tracking surface, during the day a hemisphere is exposed to sun and the other hemisphere is shaded. The overall daily average temperature on the spherical absorber is smaller than on the flat plate absorber, suggesting that the spherical absorber is not efficient as a solar radiation capturing surface.

Keywords: Solar radiation; solar tracking; spherical absorbing surface; flat plate solar collector.

1. Introduction

Solar-thermal energy conversion is one of the most efficient way of using the sun’s radiation as renewable energy. Increasing the solar thermal conversion efficiency has been the main topic of many research papers. As a result, innovative technical solutions and new materials were adopted in solar thermal industry.

On long term, the economic efficiency of a thermo-solar system depends on its acquisition cost and thermal energy gain, being correlated with solar radiation collected and converted by the solar thermal collector. For

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increased annual thermal energy gain a solar collector must be tilted and oriented at optimum angles, depending on location latitude. As a general rule the tilt angle should be equal with latitude angle [1], for Cluj-Napoca the optimum tilt angle being 45° [2].

Increased solar radiation gain can be realized using sun tracking mechanism [3]. As a result the incident solar radiation on the tracking surface is 1.45 times higher than on a fixed surface [4]. These sun tracking mechanisms are expensive and technologically unfeasible at low temperature, as a result, they are not used in the solar water heating industry. A sun tracking collector with spherical shape was proposed by Samanta and Rajab [5]. They estimated the annual average incident solar radiation on the spherical collector and compared it with a flat plate collector, showing the annual average of the daily incident solar radiation on spherical absorber was about 21% higher than on the flat plate collector.

Similar estimations were made by Gaspar et al. [6] showing a 6% higher annual average incident solar radiation on a spherical collector rather than on a flat plate collector. Pelece et al. estimated the solar energy received by semispherical solar collector showing a 30% higher yield for a semi-spherical surface with the base area of 1 m² over a flat plate collector with the same absorbing surface [7].

Experimental researches were made by Oztekin [8], showing a 79% conversion efficiency for the spherical collector at low outlet temperatures (below 30 °C) and by Pelec [9], showing 1.4 times smaller efficiency for a semispherical solar collector compared with evacuated tube solar collector.

Some spherical and semispherical solar collectors launched on thermo-solar market and various patents [10] also argue the interest for using the spherical shape in solar thermal technology.

The main objective of the present paper is the experimental study on sun tracking ability of spherical absorbing plate compared with a flat plate one correlated with surface temperature distribution analysis.

2. Materials and methods

The experimental setup composed of a flat plate absorber, having 1.75 m² and a spherical absorber with 1.55 m² surface area is shown in Fig 1. Both were coated with Solkote [11] selective paint and exposed to solar radiation from sunrise to sunset without a transparent cover. The flat plate collector was tilted at 45° and South oriented. The incident solar radiation has been measured with a sun tracking and a fixed Davis 6450 pyranometer. ThermoPro TP8S [12] thermal camera has been used for temperature distribution analysis on both surfaces.

The temperature on the absorbing surfaces has also been recorded with DS18B20+ digital temperature sensors. The temperature sensor positions on the absorbing surfaces are shown in Fig 2.
The air temperature and wind speed have also been measured during the test. For data acquisition the Arduino Duemilanove w/Atmega 328 board was used. The experimental test took place in Cluj-Napoca on a sunny day from sunrise to sunset.

3. Results and discussions

The mean hourly incident solar radiation measured with the sun tracking and fixed pyranometer are shown in Fig. 3. Calculating the daily average hourly incident radiation for the test day, the result shows the average hourly incident radiation on a tracking surface is 820 W/m², with about 29% higher than on the fixed flat plate collector with 584 W/m².

The ambient air temperature and wind speed variation during the test day are shown in Fig 4.
Surface temperature variation during the test day registered on the South oriented hemisphere is shown in Fig. 5 and for the North hemisphere in Fig. 6. In both cases the measured temperature is above the ambient air temperature.

Fig. 5. Surface temperature variation measured on the South hemisphere of the spherical solar collector, Ta - ambient temperature.

Correlation between maximum surface temperature and the incident solar radiation on the flat plate absorber is shown in Fig. 7. Correlation between maximum temperature measured on the spherical absorber and the incident solar radiation registered with the tracking pyranometer is shown in Fig. 8. The results show a good correlation between maximum temperatures and the solar radiation variations. The effect of increased wind speed on the surface temperature variation can be observed between 10:00 and 17:00. The correlation between the registered maximum surface temperature on the spherical collector and the measured solar radiation with the solar tracking pyranometer shows, that the spherical absorbing surface behaves like a sun tracking surface.

Fig. 6. Surface temperature variation measured on the North hemisphere of the spherical solar collector, Ta - ambient temperature.

Fig. 7. Variation of the maximum surface temperature (tpmax) and incident solar radiation (Gp) on the flat plate collector.
Fig. 8. Maximum surface temperature variation on the spherical collector (t_{\text{sm}}) correlated with solar radiation measured with the Sun tracking pyranometer (G_{\text{s}}).

07:49 am; 420 W/m².
08:49 am; 676 W/m².
09:49 am; 825 W/m².
10:50 am; 848 W/m².
12:01; 875 W/m².
13:07; 908 W/m².
14:02; 503 W/m².
14:49; 870 W/m².
16:16; 760 W/m².
At this hour, due to surrounding buildings the spherical collector was shaded.

Comparison of maximum daily average surface temperature of flat plate absorber (51°C) with spherical absorbers (61.2 °C) shows the advantage of sun tracking ability of the spherical surface. However this is not a realistic comparison, as temperature distribution analysis shows the maximum temperature characterizes only a small area of the spherical surface (theoretically only one point) (Fig. 9). A difference of 30°C can be observed between the maximum and minimum temperature on the spherical surface, while in the case of the flat plate absorber (Fig. 10) the difference is in the range of 3-6 °C.

Regarding the uneven temperature distribution on the spherical surface the hourly average temperature has been calculated for a realistic comparison with the flat plate absorber.

The variation of hourly average temperature of the spherical surface correlated with the flat plate absorber’s average temperature is shown in Fig 11.
The daily variation of the hourly average surface temperature shows, that the flat plate absorber is better than the spherical absorber between 9:00 and 18:00, while the spherical absorber’s slim advantage can be observed at sunrise and sunset hours.

The daily average surface temperature of the flat plate absorber (48.8 °C) is 1.34 times higher than the daily average surface temperature of the spherical absorber (36.5 °C).

Analyzing the thermal photo captures taken during the test day (Fig 9) reveals the effect of solar radiation as a thermal “finger print” of the sun on the spherical absorber. At any time of the day a hemisphere is radiated by the sun and the other hemisphere is shaded. The sun oriented hemisphere is behaving like a self tracking solar collector. Temperature distribution analysis on the spherical absorbing surface is shown in Fig 12.

![Temperature distribution over the marked lines direction](image1)

South view; 13:01; 895 W/m²; 0.53 m/s; 29 °C.

![Temperature - surface area correlation](image2)

Histogram - C1

50.8°C - 60.0°C; 8.1%

71.6°C

East and West view are symmetrical

![Histogram - C1](image3)

[50.3°C - 56.7°C]; 3.7%

72.3°C

North view

![Histogram - C1](image4)

[46.7°C - 55.2°C]; 1.5%

52.2°C

Fig. 10. Analysis of the temperature distribution on the spherical collector from four different points of view.

The analysis made on spherical surface from four different points of view shows an uneven temperature distribution. Only a small area of the total surface is characterized by high temperatures (50 - 70 °C), this being correlated with the different incident angles of each point on the spherical surface.

For each point of view a histogram has been plotted to show the temperature values correlated with surface area percentage of the exposed surface. The plotted histogram for the South view shows that only 15 - 20% of the exposed hemisphere is characterized by the maximum temperature (68 - 69 °C), while half of the exposed surface has a temperature bellow 55 °C. Temperature distribution on West and East view is symmetrical, more than 70% of the surface has temperature bellow 55 °C. The North view shows that the back hemisphere is shaded above 95%.
The inside surface of the spherical collector has been isolated with 0.05 m mineral wool to eliminate the heat transfer by convection. The hemispheres had also been separated physically to eliminate conductive heat transfer from the South hemisphere to North hemisphere. Knowing that the minimum temperature on the North hemisphere was above the ambient temperature, it can be concluded that the shaded hemisphere is collecting diffuse radiation.

4. Conclusions

The absorbing surface of a flat plate and spherical solar collector has been exposed to sun during a day, without transparent cover. Temperatures on both absorbing surfaces has been measured in different points, photos were taken with thermal camera.

The experimental results show a good correlation between measured maximum temperatures and registered incident solar radiation with a sun tracking pyranometer. Temperature distribution analysis (with the thermal camera) shows the sun thermal “finger print” on the spherical surface. It has been observed that a hemisphere is always radiated proving that the spherical surface behaves like a sun-tracking surface, while the other hemisphere is shaded.

Temperature distribution analysis on the spherical absorber shows an uneven distribution (as expected), due to incident angle variation for each point on the spherical surface. A 30°C difference has been observed between maximum and minimum temperatures of the spherical absorber surface.

The daily average surface temperature of the flat plate absorber is 1.34 times higher than the spherical one. A small advantage of the spherical absorber has been observed at sunrise and sunset hours.

As a general conclusion, a spherical shape absorber surface behaves like a sun tracking mechanism, but is not efficient compared with a flat plate collector due to lower average surface temperature. To establish the conversion efficiency and real performance of these spherical collectors further experimental researches should be made.

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