Dual axis solar tracking system for a parabolic dish CPU water heater

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Abstract. The solar parabolic dish water heater is highly efficient but has limited hours of work only when sunlight is perpendicular to its surface. Therefore, this work aims to continue the work of the solar parabolic dish in the daytime using a dual tracking system, depending on the geographic location of the system (longitude and latitude angles) and using the C # programming language. To verify the effect of the dual-axis solar tracking system, the current study considered two types of solar parabolic dishes, the first was fixed, and the second was a rotating dish (by the dual tracking system). It was observed that the water temperature at the outlet of the tracking type solar water heater is 22% higher than that for the fixed dish type; this means that the proposed system has improved the temperature of water in the heat exchanger. Therefore, the highest water temperature value of about 51.4°C was at the outlet of the heat exchanger for the tracking type at 1:00 pm, while the temperature recorded for the fixed type was about 46.1°C. The highest energy gained from the solar heating system was at 1:00 pm for both types, which was about 76.9 W from the tracking type and 54.7 W from the fixed type. It was also observed that in the fixed dish type, most energy losses occurred during the daytime, while for the tracer of the dish type, useful energy was gained during most of the sunny working hours depending on the solar radiation intensity.

1. Introduction

The theoretical potential of solar energy reaching the Earth during the year, according to various experts, exceeds all recoverable reserves of fossil fuels by 10 - 20 times [1]. Solar water heating is one of the most important applications of solar energy. This technology depends on the use of flat collectors to heat water directly or the use of evacuated tubes and other technologies for solar water heating [3]– [6]. In industrial and domestic applications, a flat plate solar water heater or evacuated-tube solar water collector are usually used to produce hot water for direct use, or it is integrated with another system such as a solar distillation system to supply it with hot water [6–8]. The traditional solar water collector is composed of an absorbent plate of galvanized steel to absorb heat energy from the solar radiation, a water pipe made of stainless steel with high thermal conductivity, and a transparent cover [9–11]. Usually, the solar water heaters are classified into two types: the flat plate type (non-concentrating) and the focusing type (concentrating). Flat plate solar water collectors are usually used in applications...
requiring temperatures below 100°C. The non-concentrating heaters are classified into two types: flat plate and evacuated tube. In various climates, flat plate solar water collectors are more economical than evacuated tubes. However, the evacuated water tube collectors are suitable for relatively low ambient air temperatures and can work in low solar radiation conditions [12]. The main types of focus collectors include parabolic water trough, the parabolic solar dish, and others. The parabolic dish is designed to heat water by solar rays for domestic application. The data showed that the proposed solar water heater could operate at 110°C and a pressure of 2 bar. A new design of a solar water heater was proposed for domestic and cooking applications with an area of 16 m² [13]. It is evident from the above that the parabolic solar tracking system is characterized by high efficiency and low cost. Therefore, the current study proposes a small solar water heater (CPU heat exchanger) integrated with the parabolic dish and equipped with a two-axis tracking system depending on the geographical location (angle of longitude and latitude) of the device under study using the C# programming language, thus verifying the effect of the tracking technology on the performance of the water heater. So, this paves the way for future use of the proposed design in rural and remote applications.

2. The principle of improvement
Specific system was used to ensure that the water is heated throughout the daytime and according to the intensity of solar radiation. The dual-axis (X and Y) solar tracking system modified in C# has been programmed according to the geographical location of the solar heating device (latitude and longitude angles). Solar radiation that reaches the parabolic dish surface is reflected and collected at the center of the dish as a radiation beam (in the center where the CPU heat exchanger is installed). This radiation is absorbed by water inside the heat exchanger CPU, which is then fed to the water tank by a micro water pump, to be recycled back to the heat exchanger with a low flow rate of about 66 ml/min.

3. The methodology and experimental setup
All experiments were conducted according to the climatic conditions of Yekaterinburg, Russia, during August of 2020; and 06 July of 2020 was chosen as the typical day. Figure 1 shows the experimental setup in a photograph and a schematic view of a parabolic dish type solar water heater, the first on a fixed dish (FD), the second on a rotating dish (RD) which is equipped with a dual-axis solar tracker system [14]. The experimental plant consisted of a water heating system, a biaxial tracking system, and a measuring and control system. The dimensions of the parabolic dish are 56 cm in diameter and 0.055 cm thick. It is made of galvanized steel and its inner surface is covered with a heat-resistant reflective aluminum foil. A small heat exchanger (Heatsink-CPU) is installed in the focus of the dish, CPU is made of pure copper and contains internal water channels, a thermally insulated water tank (reservoir) with a diameter of 40 cm and a height of 80 cm, a flow meter and a small water pump to circulate water between the solar water heating system and reservoir.
3.1 Tracking system method
The two-axis solar tracker system (dual-axis), as illustrated in Figure 2, consists of two parts: software and mechanical. The software part is implemented using the Solar Orientation package, developed by a group of researchers from the Renewable Energy and Nuclear Power Department at the Ural Federal University. Solar Orientation consists of two programs: SO Automatic and SO Manual. SO Manual is designed to provide manual control of the tracking system using textual commands. SO Automatic is designed to provide automatic control of the tracking system of the parabolic dish with the sun rays (in a direction perpendicular to the direction of the sun rays). For an automatic sun tracking system, SO Automatic uses numerical algorithms by C# to determine the current solar position by terrain coordinates (latitude and longitude), time of day, date, and time setting (time intervals between turns). The dual-axis solar tracker has a directive accuracy of ~ (0.1°) and algorithm accuracy of ~ (0.05°). Therefore, two pieces of equipment have been used to track the sun rays by the water heater unit: the first one is the rotator azimuth-elevation (Radant AZ1000V) for satellite and parabolic antennas and the second one is the antenna rotator controller AZV. The controller AZV is connected to a PC. The mechanical part (Radant AZ1000V) consists of 12 V DC 63-Watts motor gearboxes and installs 12 V-DC motor gearboxes for azimuth angle.

3.2 SO Automatic development process
SO Automatic is developed to provide automatic control of the sun orientation system. For this, an algorithm for numerical simulation of the sun position in the sky is used. The program allows sun orientation based on various input data: latitude and longitude of the installation location, time zone of installation location, time setting (time intervals between turns). The rotation is made only if the sun has not set yet, i.e. if the elevation value is greater than zero.
Figure 3 shows the photographic view of the main window of the program and the console window. The top menu contains the Start/Stop, Settings, and Console control buttons. These buttons activate/stop the program, show the settings window and the console window, respectively. In the middle of the window, there are the components of the graphical display of the current position of the sun in the sky. On the azimuth component, an angle of 0° indicates north, angle of 90° indicates west, angle of 180° indicates south, and angle of 270° indicates east. On the elevation component, the direction to the horizon is taken as 0°, and the direction to the zenith is taken as 90°. The algorithmic data fields display the numerical value of the angles of the sun position in the sky. The “until next turn” field displays the interval at which the next turn will be made. The current data fields display the current time and date, as well as the azimuth and elevation values directly on the installation. In the console window, which is shown in Figure 5, all data about the program operation are displayed: start/stop commands, rotations made, data received from the installation, errors that occurred during the program operation. It can be noted from Figure 4 that the settings window allows entering the latitude and longitude of the area, time zone, time setting (in milliseconds), and selection of the serial port to which the unit is connected. While the program is running, the settings can be changed by first stopping of the program. SO Automatic system requirements: Windows 7 and later versions, Internet service, RAM 10 MB, and 10 MB of free hard disk space.

3.3 The test method and uncertainty analysis
To give authenticity and credibility to the results of the experimental study from each measuring device, the uncertainty must be calculated for each measuring device by determining the values of accuracy and error ratio, shown in Table 1, and analyzing the uncertainty by the following equations [2].

\[ S = \left( \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \right)^{1/2} \]  

(1)
Where \( S \) is the standard deviation, \( X_i \) the value of the measurement, \( \bar{X} \) is the average value measurement, and \( n \) the number of measurements taken. The standard error (S.E) and error ratio (E\%) have been calculated as follows:

\[
S.E = \frac{S}{\sqrt{n}} \tag{2}
\]

\[
X' = \frac{\sum_{i=1}^{n} X_i}{n} \tag{3}
\]

\[
E\% = \frac{S.E}{X'} \times 100 \tag{4}
\]

| Device                | The accuracy | The range   | Accuracy |
|-----------------------|--------------|-------------|----------|
| The solar power meter | ± 1 W/m2    | 0-2000      | 1.5      |
| Data logger           | ± 1 °C      | -200-1370   | 1        |
| Thermocouple          | ± 1 °C      | 0-100       | 1.3      |
| Anemometer            | 0.05 m/s    | 0-30        | 2.5      |

### 4. Trends and results

One of the most important weather factors affecting the performance of a parabolic dish is the intensity of solar radiation, the solar rays should be perpendicular to the surface of the dish so that are reflected and concentrated at their focus. In the current work the solar radiation values were verified on three different surfaces: on the horizontal surface, fixed dish surface (FD), and the moving or rotating dish surface (RD). Figure 5 (A) shows the hourly solar radiation intensity recorded for these three surfaces. The rotating dish integrated with the dual-axis solar tracking technology has taken the sun as a reference for its movement and rotation instead of the earth. From this figure, it was observed that the solar radiation intensity demonstrates its highest values with the moving dish, due to the continuous orthogonality between the sun rays and the dish during the sunrise hours. It was noticed from Figure 5 (A) that the solar radiation intensity received by the fixed dish was the lowest due to the non-perpendicularity of the solar rays with its surface in most of the testing times; this surface received only diffused and reflected radiation from neighboring surfaces. Around 11:00 am, the solar radiation began to be perpendicular to the surface of the dish, and at 1:00 pm, the values of radiation received from the fixed surface were equal to the recorded value of the moving dish of about 999 W/m\(^2\). After that, the sun's rays began to deviate from the perpendicular path. To investigate the impact of the proposed tracking system on the water heating system (CPU heat exchanger), the temperature of water at the inlet and outlet of the heat exchanger, wind velocity, and ambient air temperature were measured for both FD and RD models. In this work, the water temperature at the inlet of the heat exchanger was considered the same for both models. Figure 5(B) shows the water temperature per hour at the inlet of the heat exchanger, the wind velocity, and the ambient air temperature. From this figure, it was noticed that the inlet water temperature was directly affected by the climatic conditions. The water temperature at the inlet was about 28°C when the ambient air temperature was 24.3°C, the solar radiation intensity was 416 W/m\(^2\), and the wind velocity was 0.9 m/s, while at midday of around 1:00 - 2:00 pm the highest value of inlet water of about 32-33°C was reached, the ambient air temperature was 29.8-31.1°C, the solar radiation intensity was 870-888 W/m\(^2\), and the wind velocity was 1.6-1.7 m/s. The lowest value of inlet water temperature of about 28°C was recorded at 8:00 pm (end of the day), and the ambient air temperature was 27 °C, the solar radiation intensity was 25 W/m\(^2\), and the wind velocity was 0.4 m/s.

Figure 6 (A) shows the hourly water temperature at the heat exchanger outlet according to the temperature at its inlet for both FD and RD types. It was observed from this figure that the outlet water
temperature of RD type was 22% higher than that of FD type, because of the dual tracking technology of the RD type, which enhanced the water temperature depending on the intensity of the solar radiation received. Therefore, the highest values of outlet water temperatures were recorded for both types at 1:00 pm, up to 51.4°C from the RD and 46.1°C from the FD, when two types (FD and RD) received high solar radiation intensity of 1000 W/m². Figure 6 (B) shows the amount of energy gained by water per hour of both types of solar water heaters, FD and RD. From this figure, it is found in the FD type that the energy of about 54.75 W and 46.81 W gained from water was limited only to a few hours only at midday between 1:00- 2:00 pm when the solar rays were perpendicular to the dish surface. While the tracking heat exchanger technology (RD type) was effective in most working hours (8:00 am — 7:00 pm), as water continued to gain thermal energy (useful energy) from sunlight, due to the influence of the solar tracking system, and this raised the water temperature. The highest value of energy gained from the water was recorded at midday (1:00 pm), but after 7:00 pm, the solar radiation decreased, so the circulating water did not gain the energy.

5. Conclusion
In this work, the effect of a solar tracking system on the thermal performance of a solar water heater with a dual-axis tracking system was studied, according to climatic conditions, the following was concluded:
1. In the RD type, the water temperature at the outlet of the heat exchanger increased by 22% as compared to the FD type.
2. In the FD type, the highest useful energy of about 54.7 W was produced only at 1:00 pm (the solar radiation was perpendicular to the dish surface). In the RD type with the effect of solar tracking
technology, useful energy was produced throughout the day, and the highest value of about 76.9 W was at 1:00 pm at the highest solar radiation intensity received from the rotating dish.

3. The azimuth and elevation angles have a direct effect on the heat exchanger performance equipped with the solar tracking technology, and the highest power gained was 76.9 W at the highest elevation angle of 49.9° and the azimuth of 181.9° at midday 1:00.

4. The most important obstacle to application of the suggested tracking system proposed in the current study in the rural and remote region is the need for internet service to determine the geographical location, longitude, and latitude of the place of study, so it is proposed to design a new tracking system working without internet such as Arduino, which is depended on the LDR sensors to track the sun rays.

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