A comprehensive review on solar cooker tracking techniques for performance enhancement

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Abstract. The paper provides a review on solar tracking system for solar cooker and its potential in increasing its efficiency. This paper mainly discusses the solar trackers for increasing the work output. This technique assists in increasing the amount of radiation falling on solar cookers. The types of solar tracking based on their degree of freedom are single axis solar tracking system and dual axis solar tracking system and its classification are discussed in this paper. The solar tracker types based on the actuating systems are also discussed. The tracking system suitable for the solar cooking applications is mentioned in this paper.

1. Introduction

In the modern world, the energy requirement for cooking is increasing dramatically. Majority of the staple foods need cooking before consumption. According to the Food and Agriculture Organization (FAO) of the United Nations, of all the world’s total energy consumption, the Food sector contributes around 30 %. Cooking using biomass accounts for indoor air pollution resulting due to inefficient cooking practices. According to the World Health Organization (WHO), the impact of human health due to indoor air pollution includes Pneumonia, Stroke, Heart diseases and lung cancer.

Increasing global warming and change in climate has encouraged the use of renewable energy sources. It provides clean energy without harming the environment. Renewable energy has impacted on various fields like transportation, energy generation etc. Of all the renewable energy sources available, solar energy is considered to be the predominant source of all energy resources. According to the Centre of Climate and Energy Solutions, of total renewable energy generation in the United States, Solar energy generation is projected to increase from 11 % in 2017 to 48 % by 2050.

Both light and heat energy of the sun can be extracted to do useful work. For heat energy extraction, numerous devices are available [1] and the efficiency depends on the type of heat collector. Generally, concentrated heat collectors have higher efficiency than non- concentrated heat collectors.
Due to the intermittent nature of the sun, the energy utilization is possible only during the solar hours. To rectify this disadvantage, thermal energy storage systems have been introduced. Different types of thermal energy storage have been proposed.

Concentrated heat collectors should be tracked according to the position of the sun to extract maximum solar radiation. Daily solar hours vary according to the latitude and longitude of the Earth. Types of tracking based on degree of freedom and actuating mechanism is discussed in this paper. Modern research works have been carried out in integrating solar cells on heat collectors. Previous review articles on solar cooker are consolidated in Table 1.

| Author & Year       | Journal Title                                      | Remarks                                                                 |
|---------------------|---------------------------------------------------|-------------------------------------------------------------------------|
| Tian and Zhao 2013  | A review of solar collectors and thermal energy    | This review discusses solar collectors, thermal storage materials and     |
|                     | storage in solar thermal applications              | heat transfer enhancement technologies.                                   |
| Omara et al. 2020   | Improving solar cooker performance using phase     | This review focuses on the different phase change material for         |
|                     | change materials: A comprehensive review           | application of solar cookers.                                           |
| Cuce et al. 2013    | A comprehensive review on solar cookers           | This review discusses the design, thermodynamic analysis and           |
|                     |                                                   | performance enhancement of solar cookers.                               |
| Muthusivagami et al.| Solar cookers with and without thermal storage—     | This review paper discusses types of solar cooker.                      |
| al. 2010 [7]        | a review                                         |                                                                         |
| Nsengiyumva et al.  | Recent advancements and challenges in Solar       | This paper briefly discusses the advancements in tracking systems.     |
| 2018 [11]           | Tracking Systems (STS): A review                  |                                                                         |
| Hafez et al. 2018   | Solar tracking systems: Technologies and trackers  | This review focuses on the tracking system for all PV and thermal      |
|                     | drive types—A review                              | storage systems.                                                       |

The intention of this study is to review the solar tracking methods and to decide the optimum type for the specific application of solar cooking since all types of tracking mechanism cannot be used in solar cooking due to design constraints. Overview of solar cookers has been discussed in section 2. Different types of Solar tracking has been discussed in section 3 and suitable tracking for solar cookers are discussed in section 4. Finally, the conclusion is summarized in section 5.

2. Overview of Solar Cooker

A solar cooker uses the energy of direct sunlight to heat or cook the food materials. The principles of solar cooker were proposed by Horace Benedict de Saussure in 1767. The working of solar cooker and solar cooker characteristics are discussed by Löf, G. O. [5]. There are different types of solar cookers available. There are numerous configurations of solar cookers and is constantly enhanced by researchers and scientists [6]. Therefore the solar cookers were broadly classified into solar cookers with storage and storage cookers without storage [7] as mentioned in Figure 1.
2.1 Solar cookers without Storage

This type of cookers does not contain materials to store thermal energy. The solar radiation incident on these cookers got converted into heat energy for use at the instance. These cookers were divided further into direct and indirect solar cookers depending upon the heat transfer mechanism [8].

2.1.1 Direct solar cookers

Direct solar cookers use the solar radiation without the aid of fluids for heat transfer. Solar radiation is directly used to cook food. The commonly used solar cookers of this type are Box type collectors and concentrating collectors. Box type solar cookers are simple in construction and suitable for limited cooking, since they have relatively low heat capacity, while concentrating solar cookers are highly efficient and reach higher temperatures than box type solar cookers.

Meanwhile concentrating solar collectors face a disadvantage of orienting the apparatus to adjust the solar cooker in position of the focus of the concentrators. Therefore tracking mechanism is needed to continuously track the position of the sun and has been discussed in the section 3.
2.1.2 *Indirect Solar cooker*

Indirect solar cookers use thermal fluid which is heated by solar radiation and the heat is transported to the place of cooking [9]. Indirect cooking is explained in Figure 2.

![Indirect Solar cooking](image)

**Figure 2.** Indirect Solar cooking [9]

Indirect cooking can be accomplished using flat plate collectors, evacuated tube collectors or concentrated collectors.

2.2 *Solar cooker with thermal storage*

The main disadvantage of a solar cooker is that it produces effective work output only during the solar hours. The output is minimized after the solar hours or during the cloudy days. Therefore a solar cooker with thermal energy storage was introduced. These materials store the thermal energy during the solar hours and can be utilized after solar hours. The thermal energy storage system for solar cookers can be further classified into sensible heat storage type solar cookers and latent heat storage type solar cookers. Latent heat energy storage system stores more heat compared to the sensible heat energy storage system [10]. Therefore latent heat energy storage systems have a significant effect on heat storage.

3. *Tracking Methods of Solar Cooker*

Generally, a solar tracking system adjusts the face of the radiation falling surfaces to follow the movement of the Sun. This increases the efficiency of solar cookers. Classification of solar tracking systems are shown in Figure 3.
3.1 Solar trackers based on number of axis

Based on the number of axes, solar trackers are classified into Single axis tracking and Dual axis tracking [11]. Single axis trackers have one degree of freedom whereas dual axis trackers have two degrees of freedom.

3.1.1 Single axis tracking solar cooker

When movement of the surface happens by rotation about one axis, it is called single-axis tracking. Further, the single axis tracker is classified into Horizontal Single-Axis Solar Tracker (HSAT), Horizontal Tilted Single-Axis Solar Tracker (HTSAT), Vertical Single-Axis Solar Tracker (VSAT), and Vertical-Tilted Single-Axis Solar Tracker (VTSAT) [11]. Zhao et al. [12] simulated the effects of absorber tube installation errors and reflector tracking errors on a single axis parabolic trough collector using a combined method of coordinate transformation and MCRT method. Results showed that with increase in the incident angle, tracking error has slightly more influence on absorber tube flux distribution. As the Concentration ratio increases, the errors become smaller. Sallaberry et al. [13] analysed the parabolic trough collector and discussed a procedure for the estimation of the optical losses due to the positioning angle error in a single-axis solar tracker.

3.1.1.1 Horizontal single axis Solar Tracker

Horizontal single-axis solar tracker rotates on a fixed axis which is parallel to the ground. It tracks the sun throughout the day. This tracker is considered to be the most cost effective method as it requires less material for construction. Wang et al. [14] developed a PLC based automatic Sun tracker for parabolic trough concentrator. The experimental results show that the tracking system has high accuracy and tracking error of the system is less than 0.6°.

3.1.1.2 Horizontal Tilted Single-Axis Solar Tracker

A similar tracker to HSAT but installed at certain tilt. Tilted-axis tracking systems are complex than HSAT, concrete foundation may require. Since mechanical components are not shared between the trackers, cost per panel cannot be reduced in larger arrays [15].
3.1.1.3 Vertical Single-Axis Solar Tracker

VSAT rotates on a fixed axis which is perpendicular to the ground. These trackers maintain a consistent angle of solar incidence when the Sun is lower in the sky because the profile of VSAT is not parallel to the ground. Farooqui [16] developed power free single axis tracking for solar cookers. The setup consists of stretched spring, water container, bearing and intravenous drip set for draining water. Due to pressure difference, the stretching of spring occurs, therefore tracking occurs. Figure 4 shows the mechanism for vertical single axis tracking system.

![Vertical Single axis tracking system](image)

3.1.1.4 Vertical-Tilted Single-Axis Solar Tracker

These types of trackers are similar to horizontal tilted single-axis trackers. The only difference is that the tilt is parallel to the horizontal position and rotates about the vertical axis [17].

3.1.2 Dual axis tracking solar cooker

When movement of the surface happens by rotation about two axis, it is called dual-axis tracking. Dual axis tracker system has primary axis and secondary axis. Dual-axis tracking can accurately orient the solar device towards the sun. They are more expensive than a single Axis tracking system. Generally there are two types of dual Axis tracking system [18]. They are tip-tilt (TTDAT) and azimuth-altitude (AADAT). Abouziyan [19] investigated the paraboloid and box solar cookers with dual axis trackers on both cookers and showed that paraboloid cookers perform better than box type cookers. Attalage and Reddy et al. [20] proposed a correlation of annual collectible energy of two axis tracking flat plate solar collectors for 26 US locations using simulated results based on typical meteorological year data.

3.1.2.1 Tip-tilt dual axis tracking system

TTDAT has horizontal primary axis and the secondary axis normal to the primary axis and parallel to the solar surface. The primary axis can be shared with other arrays hence reducing installation cost.

3.1.2.2 Azimuth-Altitude dual axis tracking system

AADAT has its primary Axis vertical to the ground. Secondary axis is called as elevation axis. It is normal to the primary axis. The advantage of these type of tracking is that the weight is equally distributed around the pole. Gaafar et al. [21] designed and developed dual axis tracking system for parabolic trough collector and tested under two conditions: with and without solar tracker. The average percentage of the thermal gain increase of the Receiver with Two-Axis Tracking is 50.59% during the Flow Test and 54.25% during the No-Flow test. Chong and Wong [22] derived a General formula for on-axis sun-tracking system using coordinate transformation method to improve the tracking accuracy.

3.2 Types of drive in Solar Tracking
There are five classifications based on their tracking technology [18]. They are active tracking, passive tracking, semi-passive tracking, manual tracking, and chronological tracking.

### 3.2.1 Active Tracking

Active trackers use motors and gear to direct the tracker towards the sun by a controller responding to the solar direction. Parthipan et al. [23] designed one axis three position solar tracking system for paraboloidal dish collector. Tracking system with single-axis freedom can increase output by approximately 20%, whereas the tracking system with double axis freedom can increase the output by 40%. The system was designed to lower the cost of tracking. Grass et al. [24] compared the optics of non-tracking and novel types of tracking solar thermal collectors for process heat applications. Salawu et al. [25] proposed the method of microprocessor controlled solar tracking system and eliminated hunting, and usual problem with appropriate motor circuit design as shown in Figure 5.

![Figure 5. Block diagram of solar tracker [25]](image)

### 3.2.2 Passive Tracking

A passive solar tracker follows the principles of thermal expansion and uses a compressed gas fluid with low boiling point that rotates to the other side to make the tracker move in response to an imbalance in pressure. Farooqui [26] designed a mechanism for one-dimensional tracking along the azimuth of box type solar cookers to eliminate the need of usual manual solar tracking using gravitational potential energy stored in springs.

### 3.3.3 Semi Passive Tracking

Semi passive tracking system uses a micro heliostat array, fresnel lens and receiver to track the position of the sun with minimal movement and mechanical efforts. Noel et al. [27] discussed the design process of a semi-passive tracking system. Tracking is performed by the rotating prisms arrays, which are lightweight individual prisms instead of big heliostat.

### 3.3.4 Manual Tracking

Manual solar tracker is a method where the tilt angle is adjusted manually. This method is a cost effective method and simple in construction. One of the significant applications is that the manual tracking is applied to the secondary axis of a tracker which requires seasonal tilting compared to the primary axis which requires daily tilting. Mwithiga et al. [28] designed a solar dryer and manually adjusted the angle according to the position of the sun. Results showed that Drying of parchment coffee could be reduced to 2–3 days as compared to sun drying which takes 5–7 days.

### 4. Tracking Techniques of Solar Cooker

#### 4.1 Tracking method used for solar cooker based on axis

Since various tracking methods are available, horizontal single Axis tracking is widely used in single axis solar cookers, azimuth altitude trackers are used in dual axis solar cookers. Akayleh et al. [17] fabricated a parabolic trough collector working on a clockwork mechanism consisting of a gearbox and control unit. Results showed that the ability of the tracking system to produce bread is 3-5 times higher than the fixed system. Further, the proposed system costs 970 Euros while without tracking costs 380 Euros. Theban et al. [15] compared non-tracking and HSAT parabolic solar cooker...
and achieved operational efficiency of 31% with tracking mechanism involved. Figure 6 shows the solar cooking dish with and without tracking system

![Figure 6. Non-tracking (left) and HSAT (right) [15]](image)

Wang et al. [14] used PLC based Automatic Sun tracker for parabolic trough collector and achieved tracking error less than 0.6° This system is reliable and does not depend on weather during operation. The overview structure of PLC is shown in Figure 7.

![Figure 7. Overall Structure of PLC [14]](image)

Bhave et al. [29] developed a solar cooker with thermal energy storage system using salt hydrate. The system consists of dual axis azimuth altitude trackers with manual control. Nuwayhid et al. [38] fabricated a simple dual axis azimuth altitude tracking system parabolic solar cooker for educational purpose.

Agarwal [30] designed and fabricated azimuth altitude dual axis solar tracker using four bar mechanism. The tracker consists of motor and worm gear drives for actuation. Figure 8 shows the tracking mechanism with four bar linkage.

![Figure 8. Tracking mechanism consisting of four bar linkage [30]](image)

### 4.2 Tracking mechanism based on actuating mechanism for solar cookers.

Since all the discussed mechanism can be applicable for solar cookers, most experiments were carried out using active trackers. Skouri et al. [31] used LDR sensors, PIC microcontroller and
motors to orient the parabolic solar cooker towards the sun. Figure 9 shows the parabolic solar dish with tracking system.

![Parabolic Solar Dish with Tracking System](image)

**Figure 9.** Parabolic tracking [31]

Li et al. [34] developed a semi passive type solar cooker, which uses a lens to concentrate the sunlight to the cooking surface. The system possesses two motors one for controlling the lens position and other for controlling the azimuth. The experimental set up of solar cooker is shown in Figure 10.

![Tracker Using Concentrating Lens](image)

**Figure 10.** Tracker using concentrating lens [34]

Misra and Aseri [35] new approach for thermal performance improvement of solar cookers. He compared the natural and forced heat transfer to the utensil. In his experiment a box type cooker with manual tracking is used which is depicted in Figure 11.
Different tracking systems and the type of solar cooker used by researchers are consolidated in Table 2.

**Table 2. Types of tracking systems Opted for Solar Cookers**

| Authors                        | Year | Country & Location | Solar tracking method | Solar tracking mode | Solar tracking type | Solar Cooker Type               |
|--------------------------------|------|--------------------|-----------------------|--------------------|---------------------|---------------------------------|
| Bhave et al. [29]              | 2018 | India              | Dual                  | Manual             | Azimuth altitude    | Parabolic solar cooker          |
| Ali S. Akayleh [17]            | 2018 | Tafila, Jordan     | Single                | Active             | Clockwork mechanism | Parabolic trough                 |
| Mbodji and Hajji [36]          | 2016 | Morocco            | Dual                  | Active             | Azimuth altitude    | Parabolic solar cooker          |
| Parthipan et al. [23]          | 2016 | India              | Single, Dual          | Active             |                     | Paraboloidal dish                |
| Theebhan et al. [15]           | 2016 | Malaysia           | Single                | Active             | Horizontal          | Parabolic dish                  |
| Wang et al. [14]               | 2016 | China              | Single                | Active             | Horizontal          | Parabolic trough collector      |
| Skouri et al. [31]             | 2016 | Tunisia            | Dual                  | Active             | Azimuth altitude    | Parabolic solar concentrator    |
| Gaafar and Zobaa [21]          | 2016 | UK                 | Dual                  | Active             | Azimuth and altitude| Parabolic trough collector      |
| Farooqui [16]                  | 2015 | Pakistan           | Single                | Passive            | Vertical            | Box type solar cooker           |

**Figure 11.** Box type solar cooker with manual tracking [35]
| Authors               | Year | Location | Actuation | Mechanism                  | Collector Type                  |
|----------------------|------|----------|-----------|----------------------------|---------------------------------|
| Sallaberry et al.    | 2015 | Spain    | Single    | Active Horizontal          | Parabolic trough collector      |
| Lwin and Win         | 2014 | Myanmar  | Dual      | Active Azimuth-tilt        | Parabolic dish                  |
| Okafor [38]          | 2013 | Nigeria  | Dual      | Manual Azimuth altitude    | Parabolic solar cooker          |
| Li et al. [34]       | 2013 | USA      | Dual      | Semi passive Azimuth altitude | Box type                       |
| Farooqui [26]        | 2013 | Pakistan | Single    | Passive Novel one dimensional | Box type solar cooker           |
| Misra and Aseri [35] | 2012 | India    | Single    | Manual Vertical            | Box type solar cooker           |
| Abu-Malouh et al.    | 2011 | Jordan   | Dual      | Active Two axis tracking   | A parabolic solar cooker        |
| Nuwayhid et al. [37] | 2001 | Lebanon  | Dual      | Active Azimuth altitude tracking | Parabolic solar cooker          |
| Abou-Ziyan [19]      | 1998 | Egypt    | Single, Dual | Active Azimuth elevation tracking | Parabolic dish solar cooker     |
| Agarwal [30]         | 1992 | India    | Dual      | Active Altitude Azimuth    | Parabolic solar cooker          |

5. Conclusion

The current review article consolidates the research work carried out to improve the performance of solar cookers by tracking technology. Among the tracking technologies, based on axis, dual axis tracking provides better efficiency. For cost is concerned, single axis Tracking proves to be effective. Based on actuating mechanism, active trackers for primary axis and manual trackers for secondary axis is the efficient way. Though numerous works have been carried out, the effect of wind in performance of tracking based solar cookers are yet to be explored. Performance improvement of solar cooker would tend to replace the existing conventional method of cooking, thereby would reduce the emission of polluting gas.
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