Research Article

Performance Development and Evaluation of Solar Air Collector with Novel Phase Change Material

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Experiments were carried out on an evacuated tube solar air collector connected to intrinsic thermal power storage to provide warm air unless solar radiation was available. As a phase change material, stearic acid was employed (PCM). Water has been used as a base fluid for converting sunlight into electricity gain to warm air, and the solar collector’s manifold was connected to the intrinsic thermal energy store. The most significant temperature variation between warm air and ecologic air was 38°C and 22°C, respectively, during direct and indirect solar radiation. A circular fin arrangement was used to achieve a flow rate of 0.020 kg s⁻¹. The efficiency of minimum airflow rates (0.020 kg s⁻¹) was 0.08–0.48 times that of maximum airflow rates (0.04 kg s⁻¹). Because of the PCM’s better heat-storing capability, this system has a benefit over sensible storage systems in that it may be used after sunset.

1. Introduction

On the global market, evacuated tube solar collectors (ETCs) are extensively utilized. In 2003, ETC had an 88 percent market share, and in 2009, it had a 95 percent market share. Solar tube collectors (ETCs) convert sunlight into electricity (solar thermal power conversion), making them more suited to operations that require higher temperatures than a none-vacuated system can provide [1]. An evacuated tube solar collector loses minimum heat (UA = 1.2–1.67 W K⁻¹) than a flat base solar collector (UA = 2.3 W K⁻¹). When compared to flat base solar collectors, the coupled influence of specialized plating and pressurized shielding in such photovoltaic collectors delivers enhanced heat processing. As a result, solar thermal applications such as solar air heating are increasingly relying on optical evacuated piping systems...
In China, ETCs with a surface area of about 100 m² have been deployed and are producing hot air.

According to a survey of the literature, much effort has gone into the research and development of ETCs. The efficiency of series combinations declined as the number of collectors increased, while parallel combinations stayed constant as the number of collectors increased [3–5]. When it comes to the thermal characteristics of a solar cooker, an evacuated tube collector outperformed a flat base collector. According to a quantitative analysis of water flow over long tubes, the occurrence of a static zone near the capped side of the tube could impair the collector’s performance [6].

Table 1: Specifications for the evacuated tube solar air collector and thermal power storage system.

| Components                                      | Specifications   |
|------------------------------------------------|------------------|
| The number of collector tubes                   | 36               |
| Tube dimensions                                 | 1.8 m            |
| Outer glass tube diameter                       | 0.05 m           |
| Inner glass tube diameter                       | 0.04 m           |
| Vacuum in between outer glass tube and absorber tube | 0.05            |
| Collector’s inclined angle                      | 20               |
| Rectangular outer box dimension                 | 1.8 × 0.25 × 0.25|
| Rectangular inner box dimension                 | 1.8 × 0.2 × 0.2  |

Figure 1: Layout designs of an evacuated tube solar air collector based on a PCM unit and an air heating system.

Figure 2: Design of an evacuated tube: (a) from the side; (b) from the front.
High thermal performance was achieved in an experimental collector with opposite evacuated tubes by keeping a 0.2 m gap between the tubes and the collecting chamber [7]: a solar cooker with a container made of phase change material (PCM) and a solar collector made of evacuated tubes (ETSC). Sunset cooking expanded faster than noon cooking when PCM was used as a heat chamber [8, 9]. However, lunchtime cooking seemed to have no impact on evening cooking. The rate of movement through the tubes was influenced by the temperature of the tank. Shortening the tube length resulted in high efficiency. The inlet flow rate had no impact on the flow structure in the glass tubes [10]. Over time, there is impact of dust buildup on the solar collector. An energy flow analysis model was used to develop an evacuated tube solar collector with something like a U-tube. They came to the conclusion that when the collector’s heat drop coefficient was high, the impact was clear [13].

In terms of energy and maintenance, compare the behaviour of a flat base solar collector versus an absorber plate evacuated tube collector. The parallel-base collector and thermal pipe evacuated tube collector had yearly collecting accuracy of 46.1 percent and 60.7 percent, respectively, while system efficiencies were 37.9 percent and 50.3 percent [14]. When a mini channel-equipped evacuated tube solar collector was equated to a similar-dimensioned evacuated tube solar collector without mini channels, the mini channel-equipped evacuated tube solar collector outperformed the evacuated tube solar collector without mini channels [15–17]. The two different thermosyphon solar radiation has a better daily and seasonal thermal behaviour than the solitary thermosyphon design. Emphasized monoabsorbers and evacuated tube heat pipes fared better in solar collectors than focused double-sided absorbers and evacuated tube heat pipes. At a reduced rate, a high air temperature variance was obtained in the evacuated tube solar collector. In terms of energy conservation, the evacuated tube collector outperformed the flat base solar collector. The flat base solar collector with PCM obtained the best results at a 10° tilt of inclination, with the effectiveness of 47 percent, 51.1 percent, and 52.0 percent in the instances without PCM, PCM, and Cu-PCM composites, accordingly [18]. Evacuated tube solar air collectors built-in with thermal energy collectors are commonly utilized to achieve high heat fluctuations during sunset hours. Solar energy can be stored using thermal power storage—a form of thermal energy in internal heat storage [19]. PCM-based intrinsic heat storage systems have a higher heat energy capacity for every unit space than conventional storage systems. Because it can store both prudent and intrinsic heat, the PCM is a popular choice in the field of thermal power storage. Because of the solar stove and the PCM storage unit, evening cooking was possible. Over a series of thermal cycles, fatty acids demonstrated proper consistency with fluctuations in melting point and intrinsic heat of reaction [20]. PCMs have many uses, including waste heat recovery, solar energy, building energy-saving, and air conditioning. Because of its excellent energy storage capacity,
PCM has been extensively employed in various latent heat storage devices. The increased interest in utilizing PCM in building applications is primarily due to the constant growth in building energy consumption. However, PCM leakage and poor thermal conductivity have hindered the use of PCM in buildings on a broad scale.

Inorganic PCMs were found to be unsuitable after a specific number of cycles, whereas organic PCMs could withstand up to 1000 heat cycles. Acetanilide was a promising PCM for indoor cooking since it worked well with aluminium as a restricting material [21, 22]. A direct-contact heat exchanger’s heat storage capability was improved using the PCM. Using a PCM storage unit as a cooling system used less electricity than traditional ventilation and air conditioning systems [23, 24]. PCMs were placed near translucent building envelopes because it was desirable to reveal construction methods to direct solar radiation. When a numerous PCM was evaluated as a thermal storage collector, it was revealed that raising the airflow rate during the charging period was more efficient than lowering the incoming air temperature [25]. When stearic acid was employed as the PCM, a quantitative survey of the thermal behaviour of an

**Figure 5:** Schematic representation of (a) the normal collector; (b) the normal copper coil collector; (c) the normal circular fin collector.

**Figure 6:** Changes in temperature and solar intensity evolve over time in the case of stearic material as a phase change material for normal collectors at a flow rate of 0.02 kg s\(^{-1}\).

**Figure 7:** Variation of stearic acid efficiency with time as phase change material at 0.02 kg s\(^{-1}\) in the case of a normal collector.
embedded absorber holding solar heater with a circular reservoir indicated that the behaviour of the intrinsic thermal storage unit was superior to the conventional storage throughout the day. The most extensively utilized technology for energy storage is prudent water heating. Despite its low cost and strong heat transfer properties, water’s low energy storage capacity necessitates a big volume. The vast temperature range across which the stored energy is dispersed is another disadvantage of water storage [26]. Stearic, palmitic, and myristic acids can be used to store energy in solar systems for heating and cooling [27]. Integrating solar collectors into the building envelope is advantageous for aesthetic and economic reasons, but it is essential to observe architectural standards and local construction traditions. Solar collection and heat insulation of the building envelope are provided by a collector device integrally incorporated into the facade. The benefits of facade-integrated collectors include cost savings through the shared use of building components, the replacement of the traditional facade, and collectors suited for both new and existing structures. There has been research on evacuated tube solar air collectors, flat base solar collectors, and piping system evacuated tube collectors, but none on an evacuated tube solar air collector with inbuilt thermal storage [28]. A comprehensive study with incorporated PCM is presented of an evacuated tube solar air collector. The goal of this research is to generate heated air at various flow rates while using direct and indirect solar energy [29]. Because it possesses a significant heating value for every unit of weight, a vast melting temperature range, consistent cycling, is noncorrosive, and chemically inert, stearic acid is used as a PCM [30].

2. Experimental Procedure

A pictorial representation of an evacuated tube solar air collector with intrinsic thermal power storage is indicated in Figure 1. The heat exchanger is made up of 36 evacuated tubes, a header (heat transfer) with an incorporated PCM storage container, fins, and a reflector, and it is formed of water. Table 1 shows the experimental setup specific requirements.

Figure 2 depicts a hypothetical design for the evacuated tubes utilized in this mechanism. Each evacuated tube is manufactured by fusing the ends of two borosilicate glass or glass tubes. The air is forced out of the gap between the two glass tubes, generating a vacuum that functions as isolation. The clear outer layer tube passes light to travel along with minimal reflection. The outer layer of the inflatable raft is wrapped with an aluminium nitride (Al-N/Al) coating material that soaks up and gets converted solar radiation to thermal energy. The selective absorption coating has a low emissivity and a high absorptivity.

A header with two squares intra and inter is employed in this arrangement, as indicated in Figure 3. It is made of two rectangular boxes of mild steel. There are 36 holes outside, 18 on each side of the rectangular box. The exposed ends of the evacuated pipes are placed in these pipes, while the frame supports the sealed ends of the pipes. A 0.075 m diameter mild hollow steel tube is in the centre of the inner rectangular box. 50 kg of commercialized stearic acid is put into the internal rectangular box (PCM). Polyurethane isolation is utilized to ensure that temperature distribution from the header to the environment is avoided on the outside of the rectangular box.

At a 20° angle on the horizontal south side, the collector is inclined. To optimize the thermal behaviour of the evacuated tube solar air collector, a variety of designs and reflectors are used. A reflector composed of an aluminium sheet with an 85 percent reflectivity sits beneath the evacuated tubes. The purpose of the arrangements is to enhance the heat of the air by placing the output air concentrically into the circular pipe. As a result, the airflow slows and the air’s residence time within the pipe increases, elevating the heat of the outflow air. In the experimental arrangement, two various types of fins are used:

(i) Circular fin
(ii) Copper coil

![Figure 8: Temperature variation and solar intensity with a flow of 0.04 kg s⁻¹ for a normal collector in the case of stearic acid as phase change material.](image-url)
The copper coil used is 1.8 meters long and 0.1 meters in diameter. The copper wire is 0.007 m in diameter. The other fin is 1.5 meters long and has a diameter of 0.085 meters. Mild steel is used for the circular fins. Figures 4(a) and 4(b) show a schematic of a copper coil and a circular fin in a circular header pipe. Reflectors can improve the effectiveness of an evacuated tube solar air collector by minimizing the amount of solar radiation wasted as it goes through the tubes. The liquid within the pipes is heated by sunlight which then passes finally into the air into the thermal storage unit. An extractor blows the solar air collection with a rating of 0.350 KW. A controller regulates the airflow, and an AC provides a power supply for the blower. Two reflectors, one side of the header to emit light on the evacuated pipes, are put beneath evacuated pipes. Each mirror measures 1.56 meters in length and 1.18 meters in width. It is a galvanized mild steel sheet with an aluminium coating for excellent reflectivity. A header with 100 liters of water and evacuated tubes that operate as a convective heat transfer medium is part of the experimental setup. The water present in the tubes is heated by solar radiation and then moved to the thermal storage container and eventually to the air. A capacity with 0.350 KW power blows the air in the solar air collection. The airflow rate is regulated by a regulator, and an AC main supply powers the blower.

Thermal degradation, latent heat of fusion, toxicology, and other properties are used to select phase transition materials. Commercially available stearic acid was utilized in this experiment, and it has the thermophysical parameters listed.
Table 2. 50 kg of stearic acid is added to the rectangular header as a thermal storage component (heat exchanger). It survives as a means of heat transfer and heats up the liquid over the day and releases it into the atmosphere at night.

### 3. Instrumentation

In these experiments, the following are different parameters:

(i) Fluid temperature, air outlet temperature, and material temperature for thermal storage

(ii) Temperature atmosphere

(iii) The intensity of solar radiation

(iv) Rate of airflow

The following devices measure these parameters.

Temperatures of the working liquid, air ventilation, and thermal storing material are measured using RTD PT100 thermocouples. The temperature indicator is displayed with ±0.3°C exactness and an adjustment of 0.1°C on the digital heat indicator. The dry environmental air temperature with an exactness of ±0.5 percent and an adjustment of 0.5°C is measured by a sling psychrometer. In order to monitor the sun intensity at the test site with an exactness of 2W/m² and an amendment of 1W/m², a pyranometer CM11 in Kipp and Zonen in Holland is used over the day.

At the beginning of the experiment, an anemometer is being used to estimate airflow. An AM-4208 separate sensor

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**Figure 11:** Efficient change in the flow rate 0.02 kg s⁻¹ for a normal copper coil collector when stearic acid is the phase change material.

**Figure 12:** Temperature variation and intensity of time in stearic acid as phase change material at the flow rate of 0.04 kg/s⁻¹ for a normal copper coil collector.
with a 0.1 m/s resolution and a (±2% ±dp) accuracy is used for monitoring of airspeed. Thanks to digital understandability and the comfort of a remote sensor, it provides fast and precise readings. The roller bearing, minimal friction ensures unrestricted fan motion and thus accuracy at all speeds.

4. Analysis of Experimental Data

All 36 evacuated tubes and the header are full of water at 28°C during the experimental setup. The solar collector is exposed to air every day at 06:30 h to gain solar radiation, and readings are obtained every one hour beginning at 09:30 h. When solar radiation strikes evacuated tubes, the heat is soaked up and converts to water. Now that the water has been heated, the thermosyphon effect, when hot water is raised, but instead cold water comes into evacuated tubes. These evacuated tubes deliver hot water to the outside rectangular box. The thermal power storage container is kept inside the outer rectangular box’s internal rectangular box. The thermal power storage device in the interior rectangular box heats up as a result of the heat absorbed from the water. In the interior inside the rectangular box, air flows through a circular pipe. The circular pipe is heated by absorbing heat from the thermal power storage device. The hot working liquid is at the maximum head, and the cold working liquid is at the minimum head in the header (heat transfer), resulting in the same thermosyphon effect.

Three scenarios are examined.

The heat absorbing from the water is responsible for the combined heat and power utilization in the inner rectangular box. The air passes through a circular pipe inside the rectangular box. The circular tube is heated from combined heat and power material by absorbing heat. The high-temperature working liquid is on the upper head, the heat exchanger is on the lower head, and the cold working liquid has the same thermosyphon effect.

(i) Normal collector
(ii) Normal copper-coil collector
(iii) Normal circular fin collector

As illustrated in the schematic picture in Figure 5, a normal collector comprises a collector with reflections (a). Reflectors are utilized beneath the evacuated tubes to reflect solar energy onto the evacuated tubes’ bottom surface. A typical collector, as indicated in Figure 5, comprises a copper coil and a collector with reflectors (b). A copper coil absorbs the heat from the PCM inside the circular pipe and transfers it to passing air. The coil is 1.8 meters long and 0.1 meters in diameter. The copper coil diameter is 0.007 m. This type of collector has a reflector and circular fin, as shown in Figure 5(c). The circular fin is used in this arrangement to collect temperature from the PCM and distribute it through the tubing into the air instead of the copper coil inside the circular tube. The circular fin is made from mild steel and has a length of 1.8 meters and a diameter of 0.085 meters.

5. Results

This study will evaluate the efficiency of an evacuated solar air heater tube and examine the air outflow temperature of the evacuated solar air tube with inbuilt PCM during daylight and off daylight hours at various airflow rates. During the months of April and May 2020, the experimental analyses will be carried out. The ambient temperature ranges between 31°C and 41°C for most of the days. The tests were carried out on days when the sky was clear. The measurements were made between the hours of 08:00 and 24:00. The evacuated tube collector was oriented northward.

Figure 6 shows fluctuated air temperatures at inputs and outputs, as well as changes in temperatures at a minimum and maximum head of water and PCMs and sun intensity over time in the evacuated tube collector. At midday, 845 W/m² was the highest intensity, while the temperature in the environment was between 30°C and 41.5°C. A maximum difference in airflow temperature of 21.8°C, with air outlets reaching 62.5°C, was achieved. Maximum-head and minimum-head water temperatures of 98.7°C and 94.3°C, respectively, while maximum-head and minimum-head temperatures of PCMs were at 90.4°C and high and lower head temperatures of 64.5°C. A temperature variation of 9.4°C in the air was reached due to a large amount of heat stored by the PCM. Sensitive as well as latent heat can be stored in it.

Figure 7 shows the efficiency of the solar air collector tube, both daytime and nighttime, over time. The maximum efficiency of a conventional collector at a minimal flow rate of 0.02 kg/s was 18%. During off-sunshine hours, a temperature variation between output air and ecologic air is achieved because of the use of PCM, and effectiveness drops swiftly at first and then gradually with a low beat rate.

Figure 8 demonstrates that at a higher flow rate of 0.04 kg/s, the maximum intensity was 844 W/m² throughout the day, with ambient temperatures varying from 33°C to 42°C. The largest temperature difference measured at 18.2°C, with a higher exit air temperature of 60°C. The maximum water temperatures
were 98.4°C and 96.5°C at high and low head, respectively, whereas PCM attained maximum temperatures of 94.3°C and 63.5°C at maximum and minimum head, respectively. The air temperature differential was 8.4°C at 24:00 h, which was slightly less than the usual collector at a low flow rate.

The change ineffectiveness in the evacuated tube solar air collector over time, both day and at night, is depicted in Figure 9. At a high airflow rate of 0.04 kg s⁻¹, the highest efficiency in a traditional collector was 35%. The research shows that at a higher flow rate, maximum efficiency is 2.05 times the maximum at a low flow rate. This is due to the high inflow rate that roughly doubled the low airflow rate, while the temperature variation between the environmental and outlet air remained practically constant. Due to rising air resolution time at a low flow rate, the output air temperature progressively increased with a copper coil at a low airflow rate. As for layout in Figure 10, the high intensity over the day was 750 W/m², and the environmental temperature ranged from 30°C to 40°C. The highest heat variation between the entrance and outflow air was 25°C, with the outflow air reaching a maximum temperature of 61.5°C. The maximum water temperatures were 105.5°C and 92.4°C at high and low head, respectively, whereas PCM attained the highest temperatures of 99.6°C and 59.5°C at high and low head, respectively. A temperature variation of 12.4°C could be achieved in the air. According to the statistics, the use of copper coils resulted in a higher temperature increase than the previous example. The rate of heat transmission from the surface to the air was boosted with copper coils. Figure 11 shows the evacuated tube solar air collector’s efficiency and sun intensity with time, both over daytime and at nighttime. At a modest airflow rate of 0.02 kg s⁻¹, the highest efficiency in a standard collector with the copper coil was 38 percent. The efficiency of a low airflow rate collector was discovered to be 2.25 times that of a high airflow rate collector.

The air output temperature with the copper coil decreased slightly due to a major drop in the resolution time of the air at high rates. Figure 12 indicates that the maximum intensity over the day was 840 W/m², with ambient temperatures varying from 32°C to 39°C. The largest temperature variation among the entrance and output air was 24.5°C, with the outlet air reaching the highest temperature of 63.1°C. The maximum water temperatures were 108.5°C and 98.2°C at high and low head, respectively, whereas PCM achieved maximum temperatures of 103.2°C and 65.4°C at high and low head, respectively. A temperature difference of 12.6°C could be achieved in the air.

Figure 13 shows the evacuated tube solar air collector’s efficiency with time, over the day and at night. At a high airflow rate of 0.04 kg s⁻¹, the highest efficiency in a normal collector with a copper coil was 40%. The highest accuracy at a high rate of airflow was discovered to be 1.25 times that of a standard copper coil collector at a high rate of airflow. The highest accuracy, in this case, is 1.14 times that of a normal collector at a high rate of airflow.

At low flow rates, the air residence period in the conventional collector with a circular fin was longer than the usual collector with projector headlights and a copper coil. The highest heat variance of exhaust air was obtained in this circumstance.

The highest intensity over the day was 800 W/m², and the environment temperature ranged from 31.5°C to 38.5°C. The highest heat variation between the entrance and output air was 38°C, with the outlet air reaching a maximum temperature of 75.5°C. The highest water heats were 107.5°C and 103.2°C at high and low head, respectively, whereas PCM attained maximum temperatures of 104.5°C and 67.5°C at high and low head, respectively. A heat variation of 22°C might be achieved in the air. Figure 14 shows the evacuated tube solar air collector’s efficiency and sun intensity with time, both over daytime and at nighttime. At a higher flow rate of air 0.02 kg s⁻¹, the greatest efficiency was 43 percent in a standard circular fin collector. In this illustration, the overall efficiency is 2.6 times that of an airflow normal copper coil collector and 1.25 times that of a low airflow normal copper coil collector.
The intensity over the day was 835 W/m² with environmental temperatures between 30°C and 38°C. With outlet air reaching a maximum temperature of 72.2°C, the biggest temperature differentiation between inputs and outputs was 30.5°C. The maximum water temperatures were 108.4°C and 101.4°C at high and low head, respectively, whereas PCM attained maximum temperatures of 103.5°C and 64.5°C at high and low head, respectively. It was possible to achieve a 13.5°C change in air temperature (Table 3). Figure 15 shows the evacuated tube solar air collector’s efficiency with time, over the day and at night. In a normal circular end collector at a maximum rate of airflow of 0.04 kg s⁻¹, the highest efficiency was 59%. At a high airflow rate, the highest efficiency is 1.5 times the rate of a normal collector over a circulatory fin at a high airflow rate. In this term, the maximum effectiveness is 1.75 times the effectiveness of a copper-coiled collector with high airflow and 1.5 times the effectiveness of a regular coil-coated collector at an airflow rate. According to the experimental results, the average air temperature difference is 1.5 times higher than the median copper sprocket collector and two times higher than the median copper sprocket collector during incident solar radiation. Furthermore, in a common collector with a circular fin, the mean air temperature difference is 1.5 times that of the normal copper coil collector and 2.25 times the conventional nonsunny time collector method. As a result, the behaviour of the evacuated solar tube collector was raised using a circular fin configuration.

6. Conclusion

This research explored the thermal behaviour of an evacuated tube solar air collector with thermal energy. They built a header with a PCM storage device to store solar energy during solar radiation incidents and generate warm air without solar radiation. It can derive the following conclusions from the findings of the experiment.

The experimental arrangement can generate warm air during nonincident solar radiation. When PCM is employed in a system, it has been discovered that it functions well during the off-sunshine hours. According to the findings, a solar air collector with an evacuated tube and a latent thermal energy store might store enough heat to deliver hot air for up to 24 hours.

Using a circular fin and copper coil inside an evacuated tube, the solar air collector, as such designs, allows a faster heat transmission rate inside the concentrated circular pipe which can significantly increase the air supply. In the case of incident and nonincident solar radiation, the most significant
temperature difference observed between heated air and environmental air was 38°C and 22°C, with a circular fin design and a flow rate of 0.02 kg s⁻¹.

If a low airflow rate is used, then when a high flow rate is used, the maximum efficiency of the solar air collector is lower. As the working time of the experimental setting extends, the effectiveness of the use of circular fin and copper coils can significantly be increased. The efficiency was 0.035–0.45 times lower in low (0.02 kg s⁻¹) and high (0.04 kg s⁻¹).

**Data Availability**

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

**Conflicts of Interest**

The authors declare that there is no conflict of interest regarding the publication of this article.

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