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# Experimental energy and exergy analysis of a flat plate solar air heater with a new design of integrated sensible heat storage

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ABSTRACT

This paper presents an experimental energy and exergy analysis of a novel flat plate solar air heater (SAH). It has a specially designed absorber plate made up of copper strips (copper tubes with extended copper fins on both sides), welded longitudinal to one another. This structure acts as an integrated absorber-cum-storage unit, where a high quality synthetic oil (Therminol-55) is filled within those copper tubes as a sensible heat storage (SHS) medium. To study the impact of this novel design and the sensible heat storage over the performance of the SAH, the results were compared with the output of a conventional SAH of similar dimensions. For the precise comparison of their performances, the experiments were conducted on both the SAHs at same location, simultaneously. It ensures identical testing conditions such as the amount of solar radiation received and surrounding environment of the experimental setup. Exergy analysis is a powerful thermodynamic tool and it helps in computing the actual output of a system, theoretically. It helps the researchers to optimize the system design to compensate the present and also the future needs. Experiments were conducted for two different mass flow rates (0.018 kg/s, and 0.026 kg/s). The results showed that the maximum energy and exergy efficiency obtained was in the range of 49.4–59.2% and 18.25–37.53% respectively, for the SAH with sensible storage at $\dot{m} = 0.026$ kg/s. Besides, the SAH with sensible heat storage was observed to perform better than the conventional flat plate SAH without storage.



## 1. Introduction

In recent years, India has been making several impressive progress in various fields, such as agriculture, transport, communication and industrial sectors, thereby striding towards an economical self-reliance among other developing nations [1]. The advancement in all these fields has lead to an ever growing demand for energy. To succeed in its planned economic growth, India has to derive adequate energy supply from various sources [1,2]. Though India has a sufficient supply of fossil fuels at present, they are continually being depleted. It will not sustain for a long duration [3,4]. Thus, the need for energy alternatives become inevitable. Various researches are in progress to effectively utilize different renewable energy resources for this purpose. Among them, solar energy is considered as a suitable option because of its value added benefits, such as eco-friendly, economic, easy installation and so on. Though solar energy is available only during day time, it could still be utilized as an effective energy resource, provided with an efficient solar collector design and storage unit [2,5]. The common methods of solar energy harvesting are converting the solar radiation into thermal energy with a help of solar heating system. A typical solar air heating system consists of a collector frame, absorber plate, top glazing, Insulation layer and support structures. Its performance is based on various factors such as collector material, design, surface area, tilt angle, mass flow rate of the heat transfer fluid, environmental conditions and so on [4–6]. Their optimal design is essential to achieve an efficient and economical operation of various applications.

One of the precise methods to evaluate the performance of a solar air collector is by conducting the 1st and 2nd law of thermodynamic analysis, viz. energy and exergy analysis. Both the analyses are valuable tools to study the thermal performance of a system. Energy could be represented as the sum of exergy and anergy, where anergy is the amount of energy spent on the system to obtain the useful exergy. Analyzing a system based on exergy

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## Nomenclature

| | |
|---|---|
| h | enthalpy (kJ $kg^{-1}$) |
| S | entropy (kJ $kg^{-1}$ $K^{-1}$) |
| $\dot{E}x$ | exergy rate (kW) |
| P | fluid pressure (Pa) |
| U | heat loss coefficient (W $m^{-2}$ $C^{-1}$) |
| Q | incident solar energy (kJ) |
| M | mass (kg) |
| $\dot{m}$ | mass flow rate of air (kg $S^{-1}$) |
| $\dot{I}$ | rate of irreversibility (kW) |
| $\dot{Q}_c$ | solar energy absorbed by collector surface (kW) |
| I | solar radiation (W $m^{-2}$) |
| C | specific heat capacity (kJ $kg^{-1}$ $K^{-1}$) |
| $c_p$ | specific heat capacity of air at constant pressure (kJ $kg^{-1}$ $K^{-1}$) |
| A | surface area ($m^2$) |
| T | temperature (K) |
| t1,t2 | time interval |
| W | total uncertainty in the measurements (%) |
| $Z_1$,..,$Z_n$ | uncertainty factors |
| R | universal gas constant (kJ $kg^{-1}$ $K^{-1}$) |

*Abbrevaions*

| | |
|---|---|
| SAH | solar air heater |
| SHS | sensible heat storage |
| IST | Indian standard time |

*Greek Symbols*

| | |
|---|---|
| α | absorptance of absorber plate |
| τ | transmittance of glass cover |
| θ | inclination angle of solar collector (degree) |
| η | first law/Energy efficiency |
| Ψ | second law/Exergy efficiency |

*Subscripts*

| | |
|---|---|
| c | collector |
| pl | absorber plate |
| avg | average |
| con | convection |
| e | environment |
| out | output |
| in | input |
| s | surface |

accounts for the irreversibility in a system during the energy conversion process [7,8]. It is a tool for assessing the efficient usage of solar energy, which gives the maximum power that can be extracted from a system [9]. Besides, it helps in quantifying the collection of solar energy and the amount of energy exchanged to the heat transfer fluid [5]. Both energy and exergy efficiencies could be improved by changing the design and operation of SAH, such as the collector surface area, mass flow rate and so on [6,7]. For example, the higher collector surface area could lead to increased exergy efficiency, but it will also increase the capital cost of the solar air heater. Thus, an optimal collector area should be chosen. Similarly, the higher mass flow rate not only improves the exergy efficiency, but it also decreases the outlet temperature. Besides, higher blower power input is needed for higher mass flow rate. So, an optimal mass flow rate should also be chosen for economic and efficient operation [10–15].

Saidur et al. [10] reviewed the energy and exergy analysis of various solar applications and conveyed that the 1st law efficiency is alone not sufficient to select a desired system, but the exergy (2nd law) efficiency is also important. Exergy analysis determines the source and magnitude of irreversibility in detail and plays a vital role in understanding the system performance. The study shows exergy destruction is higher in solar heating and air conditioning systems among various solar applications. Akpinar et al. [11] experimentally investigated the energy and exergy performance of a SAH with and without different types of obstacles (type-I to IV). The study showed that the 1st law efficiency varied between 20% and 82%, whereas, the 2nd law efficiency varied from 8.32% to 44%. Among the case studies, the SAH with leaf shaped obstacles yielded the maximum output compared to the SAH without any obstacle. Besides, the results showed that the thermal efficiency is significantly dependent on solar irradiation, surface geometry, area of the air channel and air mass flow rate. Torres-Reyes et al. [12,13] presented a paper on optimizing the performance of a flat-plate solar air heater by minimizing the entropy generation. A preliminary design of an efficient solar air heater was made based on the entropy generation number, mass flow number and stagnate air temperature, which are subjected to a thermodynamic optimization procedure. Öztürk et al. [14] conducted an experimental investigation of the thermal performance of a SAH with packed bed Raschig rings. From the results, the net energy efficiency ranges from 2.05 to 33.78% whereas, the net exergy efficiency ranges from 0.01 to 2.16%. Moreover, Öztürk et al. [15] experimentally analyzed the energy and exergy efficiencies of SAH with paraffin wax as storage for greenhouse heating. The mean daily rate of thermal exergy transferred and stored in latent heat storage was found to be 111.2 W and 79.9 W, respectively. The average net energy and exergy efficiency were computed as 40.4% and 4.2% respectively.

Esen et al. [16] conducted an experimental investigation on the energy and exergy efficiencies of double-flow SAHs with several obstacles and without obstacle. It was observed that obstacles in the air duct of the double-flow collector is an efficient method of adapting air exchange according to the user demands. Alta et al. [17] analyzed the energy and exergy performance of SAHs with and without fins. Among them, the double glass finned type heater found to be operating with higher exergy efficiency compared to other types. Sami et al. [18] presented the microscopic exergy and energy analysis on the dynamic mathematic model of an indirect cabinet solar dryer. The analysis reveals that the indirect solar cabinet has a relatively lower exergy efficiency compared to energy efficiency and it was also found that the exergy losses were maximum during the mid-day. Impacts of various factors like collector surface, its length and mass flow rate over the exergy destruction and efficiency were investigated. Tyagi et al. [19] reviewed the solar heating system with and without thermal storage. To overcome the limitations of solar energy such as its time dependent and intermittent nature, this paper focused on phase changed material (PCM) based thermal energy storage to improve the performance. It was found that the latent heat storage is more efficient compared to the sensible heat storage.

Saxena et al. [20] reviewed the various ways to improve the thermal performance of SAHs such as dimensions of the air heater components, different types of obstacles, usage of latent and sensible heat storage material, usage of concentrators to multiply the available insolation and so on. Bahrehmand et al. [21] performed