Performance assessment of a sustainable Solar Air Heater (SAH) by using different profiles of absorber plates

Singuru Rajesh¹, Vandrasi Vinay Kumar² and Jana Sai Ram²

¹,² Assistant Professor, Department of Mechanical Engineering, Raghu Engineering College (A), Bhimunipatnam Mandal Visakhapatnam Dist., Andhra Pradesh, Pin-531162, India.

Corresponding Author: rajeshsinguru@gmail.com

Abstract. The main objective of solar air heater (SAH) is to make use of the solar potential for heating air and this is used for drying, crops, fishes, wet grains during post harvesting, space heating and in greenhouses. SAH is a black body which has less emissivity and high heat absorbing capacity. The air enters into the collector gets heated with addition of solar radiation. The collector is placed at an angle due to which the natural draught occurs. The main advantage of this type of air heater is compactness, maintenance, easy to assemble and dissemble. In this work a SAH is examined with the use of different materials, sizes and shapes (like plane, rugged) of absorber plates with optimum tilt angle for better thermal storage performance and greater efficiency.

Key Words: Air heater; collector; solar radiation; draught; absorber plate

1. Introduction

In the present situation, world is concerning on energy shortage and climate changes. Solution for these crises are implementation of clean and green alternating energy for energy production [1]. This results directed to think seriously for new alternate sources for sustainable energy production and products in all the fields. Concept of alternative energy sources relates with renewability, sustainability and low carbon emissions. Challenges such as high energy costs, fuel demand, global warming, unseasonal and acid rains are the targets of these products [2]. Sustainable products are defined as the design and development of products that have a minimal impact on the environment.

Sun is an alternative source of energy which releases abundant and sustainable energy to the environment, termed as solar energy. Various applications are there with this energy mainly used for thermal collection and storage. Solar energy is one of the best option to reach the demand of producing heat for various applications like drying agricultural products, space heating in buildings, textile, marine, dairy farms, desalination and regenerating dehumidification [3] without disturbing the ecosystem and environment. Solar Air Heaters (SAH) an option device in heating application, has been increasing in number day by day because of its simple construction, easy maintenance, feasible operation, made with locally available materials, eco-friendly, no requirement of fuel and cheap in cost [4]. On the other hand thermal efficiency of SAH was poor because of their inherently low
convective heat transfer capability between the air flow and absorber material [8]. The SAH efficiency depends on surface geometry of collector and the solar radiation [5].

2. Literature Review
Karim et.al [6] led performance investigation of finned, v-corrugated and flat absorber collectors and found that air heater with v-corrugated was most efficient. Momin et al. [7] investigated on heat transfer effect of V-shaped ribs and fluid flow characteristics of rectangular duct SAH with V-shaped ribs. Esen [8] conducted a detail study to find the efficiencies of oval flat plate SAH with and without obstacles, found that higher yield efficiency values obtained for the collector with obstacles than without obstacles. Alvarez et al. [9] and Rajesh et al [10] developed an effective solar air collector with recyclable aluminum can absorber plate and compared the thermal efficiency. Koyunchu compared the performance of SAH and concluded that the shape of the absorbing surface effect the performance for crop drying [11].

2.1. Concept Overview
SAH mainly comprises of the following main components i) absorber plate ii) transparent cover, iii) heat transporter medium, iv) insulation, v) frame. The concept working of a SAH is, the ambient air enters into the collector from the bottom end and it gets heated with the addition of solar irradiation, falls over the collector face. This radiation penetrates into the collector through transparent cover and falls over the air heater absorber plate which results in increasing air temp. Because of the natural draught effect the hot air goes up and this will be collected from the outlet. With the understanding of air heater operation in figure 1, a model SAH was developed.

2.2. Methodology
The objective of this study is to compare four varied types of SAH with the main fabricated model by considering different types of absorber plates such as Type I: SAH without Al sheet, Type II: SAH with Al Sheet, Type III: SAH with black painted flat Al Sheet and Type IV: SAH with black painted rugged Sheet Al Sheet. A model with all the SAH components was developed, to conduct experimentation shown in figure 2 with design considerations and components for fabrication. In this model we are inserting the above types of absorber plates and the values are considered for the performance analysis. Figure 3(a) depicts the cross section of SAH which will be for Type II and III. Figure 3(b) depicts the cross section of Type IV.
3. Experimental Conditions

3.1. Geographical Conditions
For experimenting on a SAH the geographical details and solar radiation data of the testing location are required. The experimentation was conducted in Dakamarri (Latitude of 17.9885°N and Longitude of 83.4010°E), Visakhapatnam, Andhra Pradesh. Satellite image of experimental testing location is shown in the figure 4 and which shows the availability of the location. The experiment was conducted for 4 hr per day. The experimental values were taken at the below Table 1 conditions.
Figure 4. Satellite view of experimental testing location of SAH

Table 1. Geographical details of experimental setup.

| Geography | Details |
|-----------|---------|
| Location  | Raghu Engineering College, Dakamarri, Visakhapatnam, Andhra Pradesh, India |
| Local Time| 10:00 AM to 2:00 PM |
| Date(s)   | 12th - 15th March 2019 |
| Latitude  | 17.9885°N |
| Longitude | 83.4010°E |

3.2. Solar Irradiation
A monthly average radiation data for the experimental location (Dakamarri) are presented in Table 2. The Daily Irradiance of this area as is calculated from the Synergy Environmental Engineers solar irradiance calculator with support of National Renewable Energy Laboratories (NREL), India. Experimental testing are conducted in the month of March, 2019 for 4 days with the different types of air heaters.

Table 2. Daily Irradiance of testing location Dakamarri (Synergy Environmental Engineers) and Annual Average Irradiance is 5.5 kWh/m² per day

| S.No | Month | Irradiance kWh/m² per day |
|------|-------|---------------------------|
| 1.   | January | 5.09                      |
| 2.   | February | 5.84                    |
| 3.   | March  | 6.45                      |
| 4.   | April  | 6.78                      |
| 5.   | May    | 6.50                      |
| 6.   | June   | 5.41                      |
In order to reach the maximum output of SAH, it should be with the optimum tilt. The Figure 5 depicts the optimum tilt of solar collector for every month in the region of Visakhapatnam, Andhra Pradesh. The optimum inclination of present tested SAH in the month of March is 72°. Tilt angle is calculated with the help of Solar Calculator for Collectors optimum inclination.

![Figure 5. Optimum Tilt of Solar Panel for each month in Visakhapatnam, A.P.](http://solarelectricityhandbook.com/solar-angle-calculator.html)

4. Experimental Setup
The experimental setup of SAH mainly comprises of black coated aluminum sheet (absorber plate), tempered glass (transparent cover), ambient air (heat transporter medium), thermo-coal sealing (back insulation), induced fan, wooden frame, solar panel for power supply, thermocouples (temperature measurement) and supporting stand.

The fabrication of SAH is started with the selection of country wood for wooden capsule of 1.2 x 0.6 m² at a low cost. Wood is cut into the dimensions (1.2m x 0.05m) of the outer frame of the collector and the thickness of frame is 5cm. A Plywood Sheet of 6mm is fixed thickness and 0.72m² area at the back of frame. A square hole of 120mm x 120mm of at the top of the collector is made for the exhaust of hot air from collector and a 6mm guide way on the side of the wooden piece is given for inserting glass. Back and Sides of wooden frame is sealed with thermo-coal for thermal insulation. An exhaust fan is fixed on the top of wooden frame to create artificial draught in SAH for the purpose of constant air flow during experiment.
Tempered glass is fixed on the upper part of the wooden frame with the help of Silicon sealant to guide the inlet air from the lower end to the upper end of the air heater and leaves it into the duct provided with the exhaust fan, which was run with the help of solar panel (I=0.028A & V=30V). Measurement of the airflow at outlet and inlet of the collector was measured by Anemometer. T-type thermocouples were installed at outlet and inlet of the air heater to measure temperatures. Temp range of thermocouple is 120-150°C. Insulation is provided to the duct with foam for maintaining constant temperature shown in figure 6. An iron frame is fixed to the back part of the wooden frame for supporting entire setup with a tilt angle so that the sun rays gets incident on the air heater. Optimum Tilt angle of collector is 72° obtained for testing location is from solar-angle-calculator. Table 3 gives the conditions of the considered solar air heater.

**Table 3. Specifications of SAH**

| S.No | Description(s)                          | Specification(s)       |
|------|-----------------------------------------|------------------------|
| 1.   | Solar irradiation                       | 1000W/m²               |
| 2.   | Collector area                          | 1.2 x 0.6 m²           |
| 3.   | Absorber plate temperature              | Constant               |
| 4.   | Absorber material                       | Black painted Al       |
| 5.   | Double glazing                          | Applied                |
| 6.   | Wind velocity                           | 1.8 - 2.1 m/s          |
| 7.   | Solar flux over collector face (Iₚ)     | 950 W/m² °C            |
| 8.   | Transmissivity (τα)avg                  | 0.85                   |
| 9.   | Coefficient of top loss (Uₚ)            | 6.2 W/m² °C            |
| 10.  | Coefficient of bottom loss (Uₚ)         | 0.8 W/m² °C            |
| 11.  | Emissivity of top and bottom surfaces (ε) | εₚ = εₚ                   |
| 12.  | Tempered glass emissivity               | 0.95                   |
| 13.  | Tempered glass transmissivity          | 0.88                   |
| 14.  | Tilt angle of collector                 | 72°                    |
SAH thermal efficiency is calculated from the ratio of the total useful specific enthalpy to the solar radiation flux incident on the transparent glass [12].

\[
\eta = \frac{\int_{t_1}^{t_2} \dot{m} c_p (T_o - T_i) \, dt}{\int_{t_1}^{t_2} G \, dt}
\]  

(1)

Aluminum (Al) sheet of 30 gauge as baseplate (absorber plate) to SAH to ensure more heat absorption and reflection. Al Sheet is cut into different sizes for the different types for SAH shown in figure 7. For the Type I the no absorber sheet and the bottom of the frame is coated with black paint. In Type II the absorber plate as Al sheet without black paint of dimensions 1.2 x 0.6m² and a square hole is made at the top is used. In Type III the Al sheet with black paint is used as absorber plate. In Type IV Al sheet with black coated rugged sheet is used as absorber plate. All the above types are inserted into the main wooden frame during testing time. After the completion of main frame SAH fabrication, it is tested in sunny condition by using different profiles of al sheets for the performance assessment.

![Figure 7](image)

Figure 7(a) Type I: SAH with black paint; 7(b) Type II: SAH without black painted Al sheet; 7(c) Type III: SAH with black paint Al sheet; 7(d) Type IV: SAH without black painted rugged sheet

5. Results and Discussions:

The air heater tests were taken on clear sky circumstances. The ambient air entered in the collector was heated through the black painted absorber plate with minimum solar irradiation of 1000W/m² applied. Due to the air flow given by the induced fan, constant mass flow rate results in uniform temp rise, which occurs at inside the SAH of different flat and rugged Al absorber plates. With help of Aluminum (Al) as heat absorber material, noble heat transfer coefficient is obtained, leads to temp increase of absorber plate in SAH. The temperature distributions along the collector at different places were recorded by using T- Type thermocouples shown in figure 8 and relation between Time vs Temperature of collector represented graphically for all the types of SAH in figures 9 and 10 shown below.
Figure 8. Measuring and recording results of air heater

In Figure 9(a) indicates the Type I: SAH without Al sheet the min inlet temp is 33°C and the final out put temperature reaches to max of 45°C. Figure 9(b) shows the Type II: SAH with Al sheet but not black coated, the minimum inlet min temp is 36°C and the final out put temperature reaches to max of 47°C. The Figure 9(c) shows the Type III: SAH with black coated Al sheet, the minimum inlet min temp is 36°C and the final out put temperature reaches to max of 58.7°C. Finally the Figure 9(c) shows the Type IV: SAH with black coated rugged Al sheet, the minimum inlet min temp is 35°C and the final out put temperature reaches to max of 64.3°C.

Figure 9(a) Temp vs Time SAH without Al sheet
Figure 9(b) Temp vs Time SAH with Al sheet (no black coat)

Figure 9(c) Temp vs Time SAH with black painted Al sheet
Graphical data illustrates, when time changes, collector temperature increased in between 10:00 AM to 2 PM. Thermal efficiency also plays vital role in performance of SAH. Hence, depending on solar radiation with AM to PM, the thermal efficiency increasing gradually. Figure 10 is the comparison graph of all the 4 types of solar air heaters, in which Type IV is having the higher in efficiency by obtaining outlet temp because of the double pass of air.

Figure 10. Temp vs Time graph in comparison of 4 types
Table 4. Comparison of all types SAH

| S.No | Date     | Type of SAH | SAH min inlet Temp (°C) | SAH max outlet Temp (°C) | Air flow Avg (m/s) |
|------|----------|-------------|-------------------------|-------------------------|-------------------|
| 1    | 12/3/19  | I           | 33.0                    | 56.9                    | 1.8               |
| 2    | 12/3/19  | II          | 38.0                    | 58.1                    | 1.7               |
| 3    | 12/3/19  | III         | 36.0                    | 60.2                    | 1.7               |
| 4    | 12/3/19  | IV          | 35.0                    | 63.4                    | 1.8               |

6. Conclusion:
This paper deliver the performance analysis of varied types (four) of SAH by changing different absorber plates. According to the results of the experiments, the SAH with black coated Al rugged absorber plate (Type IV) is having the higher efficiency values of outlet temperatures, when compared with the other types. The effectiveness order of these SAH types are as Type IV, III, II and I in a descending manner. Since v-shaped rugged absorber plate air heater showed better values, this type was considered for heating application.

References
[1] Sreekumar A Development of solar air heaters & thermal energy storage system for drying application in food processing 2007 Thesis on Doctor of Philosophy, Department of Physics Cochin University of Science and Technology Kochi - 22 India
[2] Franco A, Shake M, Kalubi D and Hostettler S A Review of Sustainable Energy Access and Health care facilities 2017 J. Sustainable Energy Technologies and Assessment 22 92-105
[3] Rajesh S and Choudary RB A cost effective desalination plant using a solar chimney with recycled aluminum can collector 2016 J. Solar Energy 2016 1-10
[4] Abene A, Dubois V, Le Ray M and Ouagued A Study of a solar air flat plate collector use of obstacles and application for the drying of grape 2004 J. Food Eng 65 15-22
[5] Karsli S Performance analysis of new-design solar air collector for drying applications 2007 Renewable Energy 32 1645-60
[6] Karim Md A and Hawaldar MNA Performance investigation of flat plate, v-corrugated and finned air collectors 2006 Energy 31 450-70
[7] Momin M E, Saini J S and Solanki S C Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate 2002 Int. J. Heat and Mass Transfer 45 3383-96.
[8] Esen H Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates 2008 Build Environ 43 1046–54
[9] Alvarez G, Arce J, Lira L and Heras MR Thermal performance of an air solar collector with an absorber plate made of recyclable aluminum cans 2004 Solar Energy 77 107-13
[10] Rajesh S and Choudary RB A cost effective solar air heater with recycled al can (RAC) collector 2017 J. Mat Sci and Mechanical Enng 4 45-50
[11] Koyunchu T Performance of various design of solar air heaters for crop drying applications 2006 Renewable Energy 31 1073-88
[12] Sukhatme SP and Nayak JK 2008 Solar Energy- principles of thermal collection and storage (New Delhi: McGraw Hill Education) chapter 4 pp 173-199

Acknowledgements
Authors wishing to acknowledge assistance and cooperation from Project Associates Mr.R.Haibabu, Mr.Y.Muralikrishna, Mr.P.V.S.Venugadav Reddy and Mr.Sk.Jilani from Department of Mechanical Engineering in Raghu Engineering College, Visakhapatnam, Andhra Pradesh, India.