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LAYOUT ANALYSIS OF V-GROOVE SOLAR COLLECTOR

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Abstract

This study undertakes the comparative layout study of a V-grooved solar air heater (SAH) with a view to show the optimum design layout for the air heater. Several studies have been conducted on comparing isolated V-groove SAH with other designs of SAH. However, from literature there have not been studies on the comparative layout pattern of V-groove SAHs. It was equally, observed from literature that design layouts of V-groove systems are mainly parallel in nature. Thus, there is a knowledge gap on studies focusing on the layout pattern of V-grooved systems. Thus, the paper seeks to address this with the research question as "What is the optimum layout for a V-groove solar air heater?" In comparison to active mode of solar air heating, the heat energy analysis of passive solar air heaters, has not been widely studied. Hence, the study is limited to natural convection systems. The study focuses on comparative analysis/evaluation of two basic layout of V-grooved solar air heater- parallel and perpendicular air flow design layouts. The outcome of the work has revealed that the systems can easily be adapted to low temperature applications. From the study, it is deduced that even though the Parallel designed layout of V-groove SAH showed a better efficiency when compared to the Perpendicular designed layout of V-groove SAH that both of them are statistically the same at 5% probanility level using the completely randomized design (CRD) statistical method. The layout pattern does not necessarily mean better output in operation. However when compared to similar works done using the same dimensions for flat plate designs that there is an appreciable improvement in the efficiency of operation.

1.0 INTRODUCTION

Energy in various forms has become increasingly essential for global economic progress and industrialization, especially in agricultural processes [1]. However, in many developing countries, epileptic power supply and fluctuations in petroleum products have become issues hard to manage even with so much government policies and non-governmental organization programmes. In agricultural sector of the economy, the impact has resulted to reduced output in addition to the closure of already established industries. Considering the exhaustibility of the limited global energy sources, there is therefore the urgency to delve into alternative sources of energy to satisfy the energy demand in the current global circumstance [2]. Considering all the possible alternatives, the renewable energy options are the most viable option for developing countries of the world especially the sub-Saharan nations. This is because of mainly the poor management of fossil fuel energy systems and comparative ease of accessing

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renwable energy sources in these areas as discussed in [3]. Innovations and technologies based on the renewable energies are usually seen as pristine energy etymology and their efficient application reduces the negative environmental effects leading to reduced secondary wastes [4]. These alternative sources can be sustained bearing in mind the present and future socio-economic demands.

Quantitatively and in comparison to other renewable energy sources, solar energy is the one found in copious supply especially for tropical regions of the world [5]. Chief amongst the main use of solar energy lies in provision of heated air in the processing of agricultural and industrial produce especially the drying operations, and space heating for structures [6-8]. Diverse forms of solar air-heating systems are adopted for various applications; inter alia, flat-plate collectors (FPCs) being widely utilized in mild-temperature applications, due to the fact that they are comparably simple, easy to handle with cheaper capital costs [9]. Other solar air heaters are the parabolic trough collectors, fresnel collectors, evacuated tube solar air heater and solar trombe wall [10, 11]. Even though, the value of thermal transfer coefficient between the absorber plate and air is little leading to lower efficiency in FPCs. To improve on the efficiency, the surfaces are occasionally chapped or longitudinal fins are created in the airflow alley. This increases the surface area exposed to solar radiation without increasing the physical dimensions of the absorber plate thereby improving the efficiency of the FPC.

Assorted forms of SAH have been the essence of most conceptual and experimental studies in order to improve the area of air exposure to the adsorptive surface. A material with roughened surface has been applied to increase the thermal shifting coefficient by introducing turbulence along the flow. In whatever way, it would as well lead to higher frictional losses and thus more power demands for pumping air round the pipe. For the friction losses to be maintained at a low intensity, the turbulence has to be introduced at most in the area extremely near to the pipe surface which is in laminar sub-layer. Thus, V-groove device were established to improve the thermic rate of transfer between air and absorbing-plate via enlarging the exterior region of the thermal energy relay (and yet not increasing the actual physical dimensions) which is necessary in thermal performance improvement of the SAH [12]. The use of V-groove design in SAH has led to an improved thermal efficiency in the reviewed literatures [13-14].

Kumar [15] experimentally studied an SAH designed using a small damned V-grooved absorption plate with low-cost heat insulation system. The study showed that the system with V-grooved absorber with small damn coupled with ceramic wool insulation recorded higher heat transfer performance. Zulkifle et al. [16] analytically worked on the heat absorbing behaviors of a V-groove developed using cover variations. The study revealed that improved thermal characteristics could be achieved through the use of a small gap betwixt the absorption surface and base plate of the SAH in a miniature sized V-grooved system. In an analytical simulation study, Jin [17] designed a contrived chapped solar air heating system using a multiple V-modeled ribs to analyze the thermal transfer coupled with fluid flow. The work equally examined the effect of the rib design over the Nusselt (Nu) number, friction factor, and flow structure. The study revealed that the multiple V-designed ribs lead to a steam wise spiral eddy flow. This enhanced the blending of the fluid between the glacial upper fluid and the warmer fluid close to the absorption wall which is as a result of the operating secondary eddy structure at the inter-rib area. Abed [18] experimentally and mathematically studied a new grooved and porous solar air heating system in an unsteady state mode. The absorption surface was developed in two different methods: V-porous absorber and U-grooved absorber. The study proved that the system designed using a V-porous absorber has a better performance at mid-day of good sunshine days while the U-grooved absorbing system had better efficiency during sunrise and sunset.

As a follow up to the study, Akhbari et al. [19] worked on a SAH designed using a triangular medium. The study revealed that the triangular medium inside peak angle of 60◦ resulted to a maximum thermo-hydraulic effect of the system. Ruslan et al [20] worked on the V-groove absorbing surface and discovered that increasing the breadth of the absorbing surface improved its thermal energy absorption in addition to enhancing the energy flow from the surface through the fluid channel. Meyer et al. [21] evaluated the convective thermal flow within the one dimensional v-groove SAH. Zhao and li [22] analytically and empirically evaluated the channel developed with v-groove surface and a flat plate under a passive mode. Abuska and Sevik [23] analyzed the impact of environment in addition to thermo-economic effects of v-groove ridge of SAHs systems, developed with copper (*Cu*) and aluminum *(Al*) substance, by carrying out an empirical evaluation. Characteristics of the systems evaluated were: of environment in addition to thermo-economic and exergy patterns. These characteristics were examined with flow rates of air mass respectively at 0.04 with incremental value of 0.02 until 0.1 kg/s.

The results achieved reveals that the mean energy efficiency was 43–60% while the mean exergy efficiency was 6–12% for the solar air heating systems. The copper V-groove system resulted to an optimum performance with maximum thermal energy transfer. The study gives credence to the need for applying V-groove designs into SAHs. These studies show convincingly that V-groove systems in-spite of the relatively greater cost in comparison to other designs, especially flat plate collectors; yield greater thermal energy transfer coefficients. The knowledge gap drawn from literature review is that V-groove design layout has not been considered. However, several works and studies have been done on comparing V-groove SAH with other designs of SAH. There are basically two design layouts to this: parallel and perpendicular air flows to the direction of the groove. The research question then is "What is the optimum layout for a V-groove solar air heater?"

This study goes into comparative studies with the aim of comparing their thermal efficiencies.

2.0 MATERIALS AND METHODS

The systems adopted for this study is as shown in Figure 1 already developed by the Department of Agricultural and Bioresouces Engineering of University of Nigeria. The two systems are identical in every respect except in the layout of their V-groove (Figures 2 and 3) where Perpendicular Layout of V-groove SAH and Parallel Layout of V-groove SAH were represented by systems A and B respectively. The systems were set side by side at the exhibition stand of the University of Nigeria, Nsukka and monitored simultaneously under the same climatic conditions between the months of January and April, 2023. The components of the systems considered were the V-grooved designed solar absorber plate, the glazing and the working fluid (heated air) of the systems. Temperature readings at 30 minutes interval over a four month period between the hours of 8:00am and 6:pm were adopted for comparative analysis of the thermal behavior of the SAHs under evaluation.

The SAHs cumulative efficiencies (η_{cu}) were calculated by using Equation 1, where Q_u is the cumulative heat gain over a given time (t), A_c is the absorber plate area (A_c for both systems are the same) and I_T is the total radiation for the period.

$$\eta_{cu} = \frac{Q_u}{A_c I_T} \quad (1)$$

Figure 1A: Experimental layout of the Two V-groove SAHs

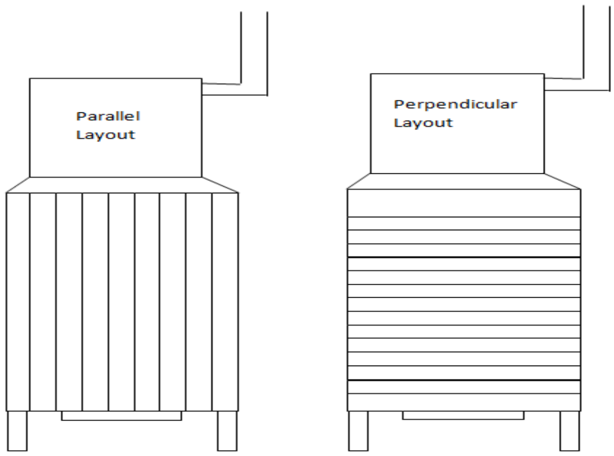

Figure 1B: Front view of the Two V-groove SAHs

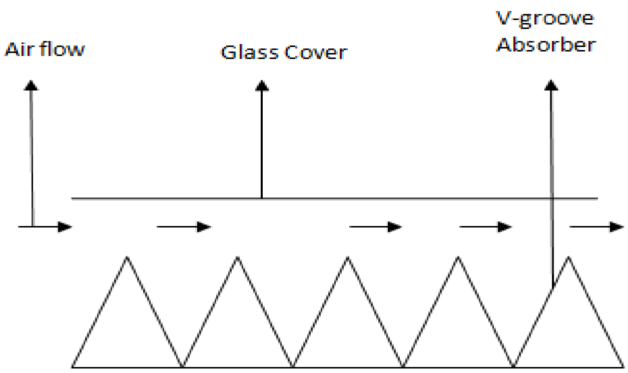

Figure 2: Perpendicular Layout of V-groove SAH

The solar radiation data was collected from the weather station of National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka (latitude-6.86ºN, 7.39ºE) which is equally where the air heaters were set up. The ambient and solar collector temperatures were monitored with k-type thermocouples positioned at various points of the SAHs used.

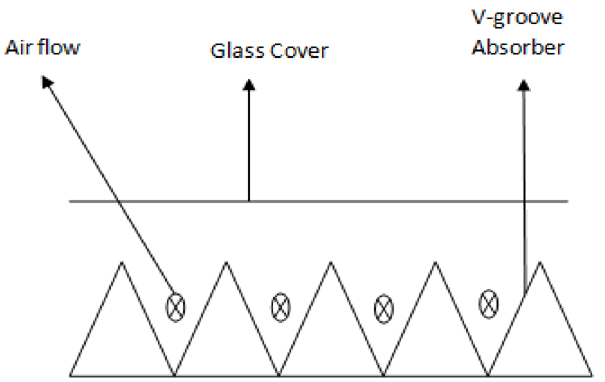

Figure 3: Parallel Layout of V-groove SAH

The statistical evaluation of the impact of the layout pattern on the thermal behaviour of the systems was done using the completely randomized design (CRD) statistical method [24]. The whole process was executed using GenStat Discovery Edition software. The observed data for the two systems and the ambient conditions were used as the treatments. If there was a significant difference, Least Significant Difference (LSD) was conducted to detect the difference between the means [24].

3.0 RESULTS AND DISCUSSIONS

Table 1 showed a four-day recorded data of the overall solar radiation and ambient temperature in respect of the two systems in which 16th March recorded the highest solar radiation while the 15th April recorded the highest and average ambient temperature. The four days were carefully selected for the discussion of the study as they reflect the mean day solar characteristic for the months in which they appear [25]. This helped to simplify the discussion. Equally, the harmattan season was covered by the month of January; the peak dry season was covered by the month of February and March while April reflected the setting in of rainy season as reflected by the National Basic Space Research Centre, Nsukka.

Table 1: Daily Solar Radiation and Temperature Patterns

Date	Total Solar (+0.8)	Ambient Temperature (^{0}C) (+0.5)		
Av. Day of the month	Radiation (MJ m^{-2})	Min.	Mean	Max.
17 January	22.4	19.5	24.3	29
16 February	25.9	22	26.7	31.4
16 March	26.6	24	28	32
15 April	26.5	24.4	28.5	32.5

The temperature pattern for the ambient, absorber plates and outlet air of SAHs being evaluated during the evaluation duration is as given in Figure 4 in which *Tamb*, *Topl* and *Tapl* are respectively the temperature readings for ambient, air outlet and absorber plate temperatures in Parallel designed layout of V-groove SAH where *Tapp* and *Topp* on the other hand represent respectively the temperatures of the absorber plate and air outlet in the Perpendicular designed layout of V-groove SAH.

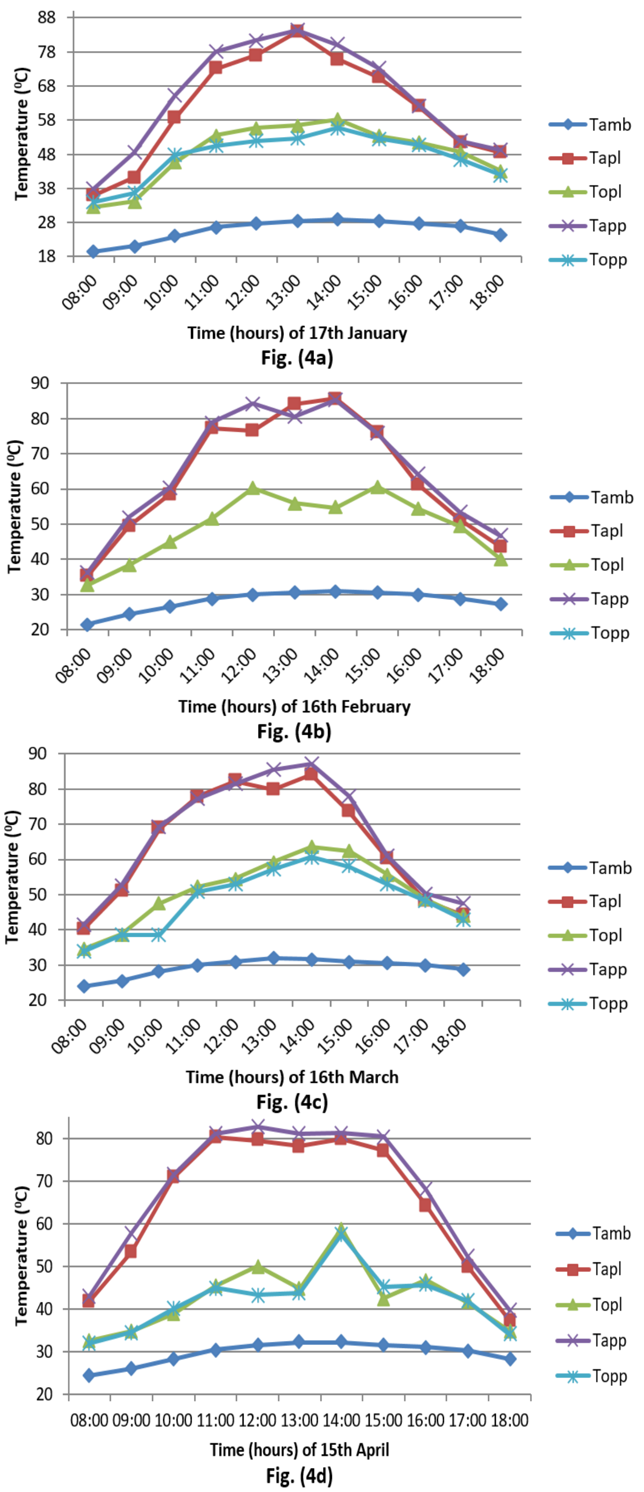

Figure 4: Temperature structures of absorber plate, ambient and air outlet

The Figures show that the ambient temperatures were generally low in the morning hours. This is easily understandable due to the fact that the sun is just

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rising, hence low solar radiation to heat up the environment [7, 25]. With time the ambient temperatures increased steadily till they reached their peak when the sun is vertically overhead. After the peak period, the ambient temperature steadily declines in values due to the setting of the sun till the end of the day. The irregular fluctuations in the ambient temperatures were due to various effects like inconsistent cloud cover, constantly varying ambient humidity and other atmospheric characteristics [26]. All the other temperatures in the figures were proportionally related to the ambient. Altogether, the absorber plate recorded the maximum temperature whereas the lowest values were noticed in the ambient temperatures all through the period. The outlet air temperatures of the Parallel designed layout of V-groove SAH were higher than that of Perpendicular designed layout of V-groove SAH. For all through the experimental study, the hot air produced from the systems (the observed system outlet air temperatures) was higher when compared to the ambient temperatures. The higher temperatures of the systems against the ambient is as a result of the effect of the absorber plate converting the solar radiations to heat and then the collector glazing minimizing the loss of the heat from the surface of the absorber plate. This has been well discussed in [26].

Table 2 showed the average air temperature of the study systems where the superscripts represent the level of significance at 5% levels of probability level. The same letter means the difference in means are not significant. As observed the temperature values had varying values for different days of the systems assessment. A careful look at the table reveals that there is no observed significant difference between the two SAHs except with the ambient temperature for days evaluated. Throughout the entire evaluation period, the produced average air temperatures were above the average ambient temperatures with at least 20°C except on April that the difference was about 15°C. The lower temperature difference in April was as a result cloudy weather as the rainy seasons have actually set in.

Table 2: Daily Average Hot Air Temperature Patterns

Date	Ambient (°C) ($\pm$0.5)	Parallel designed layout of V-groove SAH ($\pm$0.5)	Perpendicular designed layout of V-groove SAH ($\pm$0.5)
17 January	24.3^a	50.4^b	47.9^b
16 February	26.7^c	53.4^d	51.4^d
16 March	28^c	53.1^d	49.5^d
15 April	28.5^c	43.0^e	43.0^e

Table 3 showed the cumulative efficiencies of the solar air heaters under study. Parallel designed layout of V-groove SAH showed higher mean efficiency than Perpendicular designed layout of V-groove SAH. The periods that have poor solar radiation recorded greater efficiencies and improved cumulative efficiency for the two SAHs. According to Pottler et al [27], the minimal daily efficiencies were partly as a result of the relatively reduced volumetric thermal capacity in addition to the minimal level of air conductivity. These efficiencies are perceived as an improvement over other designs of flat plate solar thermal collectors especially the single cover flat plates SAHs with efficiency of 17 – 22% as seen in the in the literature [26]. This has given confidence in the adoption of V-groove design in the development solar air heater as applied in this present work; equally proposed by [25] for enhanced efficiencies. The observed efficiencies are in line with the works of Abuska and Sevik [20] who recorded 43–60% efficiencies in the studies of the impact of environment in addition to thermo-economic effects of V-groove ridge of solar air heating systems, developed with *Cu* and *Al* substance, by carrying out an empirical studies modeled using the flow rate of air mass as 0.04, 0.06, 0.08 and 0.1 kg/s.

Table 3: Cumulative efficiency of the SAHs

Date	Parallel designed layout of V-groove SAH (%)	Perpendicular designed layout of V-groove SAH (%)
17 January	56.1	54.3
16 February	51.8	50.5
16 March	49.6	47.8
15 April	48.4	48.1
Mean Efficiency	51.5	50.2

4.0 CONCLUSION

The study has revealed that for low temperature purposes the SAHs evaluated can auspiciously be applied. From the study, it can be concluded that even though the Parallel designed layout of V-groove SAH showed a better efficiency when compared to the Perpendicular designed layout of V-groove SAH that both of them are statistically the same. The layout pattern does not necessarily mean better output in operation. However when compared to similar works done using the same dimensions for flat plate designs that there is an appreciable improvement in the efficiency of operation especially in drying processes. Hence, development of solar air heaters with V-groove designs will immensely benefit poor rural dwellers of the developing nations since they cannot afford the comparatively higher cost of active systems and equally meet the global goal of sustainable development.

5.0 CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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