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A Literature Survey On Thermodynamic Analysis Of A Flat-Plate Solar Air Heater Having Different Obstacles On Absorber Plate

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ABSTRACT
In this paper, a literature review on flat-plate solar air heater having different obstacles on absorber plates has been highlighted. The thermodynamic analysis of solar air heaters with single pass, double pass, different obstacles on absorber plate and comparisons which was done among them by different researchers is reviewed in this paper. Further, the energy analysis and exergy analysis of solar air heater's have been discussed too.

Keywords:- Solar Air Heater (SAH), Solar energy, Energy analysis, Exergy analysis, Obstacles, Thermal efficiency.

Nomenclature

A_C	surface area of the collector (m^2)	*Subscripts*	
C_P	specific heat of air at constant pressure (kJ/kg K)	a	air
È	energy rate (kW)	ave	average
Èx	energy rate (kW)	C	collector
Ex_D	dimensionless exergy loss (dimensionless)	c	convection
Èx$_{dest}$	rate of irreversibility (kW)	e	environment
h	enthalpy (kJ/kg)	f	fluid
I	solar radiation (W/m^2)	in	inlet
IṔ	rate of improvement potential (kW)	m	mean
ṁ	mass flow rate (kg/s)	out	outlet
M	mass (kg)	gen	generation
P	fluid pressure (Pa)	p	plate
R	universal gas constant (J/kg K)	r	radiation
R	regression coefficients	s	sun
Q_c	useful heat rate (kW)		
Q_s	incident energy in the collector area (kW)		
s	entropy (kJ/kg K)		
Ś	entropy generation rate (kW/kg K)		
t	time (s, min)		
T	temperature (C)		
U	heat loss coefficient (W/m^2 C)		
Ẁ	work rate or power (kW)		
W	uncertainty in the measurement (%)		

INTRODUCTION

The sun is the most powerful heat generator, with which neither of the heat sources created by mankind can compete with. Annually, the solar energy obtained by earth is 15000 times as much as the power industry of the whole world can produce. It means that only a tiny part of solar energy is used for the sake of mankind. Solar Air Heaters (SAHs) are kinds of heat exchangers. Solar air heater is the special type of heat exchanging equipment used to convert the solar thermal energy useful heat for the purpose of agricultural food processing, space heating, ventilation and desalination [1]. The harnessing of solar energy by solar air heaters depends on the conversion efficiency of solar intensity into useful heat output by the absorber plates. The major negative aspect of a solar air heater is its poor heat transfer coefficient between the absorber plate and the moving air, which results in poor energy conversion efficiency. However, the heat transfer coefficients between the absorber plate and the moving air can be improved by heat storage materials [2], by packed bed absorber plates [3], by creating artificial roughness over the absorber plates [4], using extended surface (obstacles) over the absorber plates [5].

The flat plate solar collector shown in figure 1 below is the commonly used component of solar heating systems. Thus, the performance of the flat plate solar collector is an important thing to be considered. The thermodynamic laws were considered to analyze the performance of the system which determines the energy and exergy analysis of the system.

Thermodynamic analysis is an effective means to obtain precise and valuable information about energy efficiency and losses due to irreversibility in a real situation. The first law is widely used in engineering practice and is the basis of the heat balance method of analysis that is commonly used in engineering systems performance analysis. The second law involves the reversibility or irreversibility of processes and is a very important aspect of the exergy method of energy systems analysis [24]. The energy analysis has some deficiencies. Fundamentally, the energy concept is not sensitive to the assumed direction of the process. It also does not distinguish the quality of the energy. Energy analyses on their own incorrectly interpret some processes, e.g., environmental air, when isothermally compressed, maintains its energy (e.g. enthalpy) equal to zero, whereas the exergy of the compressed air is larger than zero. However, exergy data are more practical and realistic in comparison to the respective energy

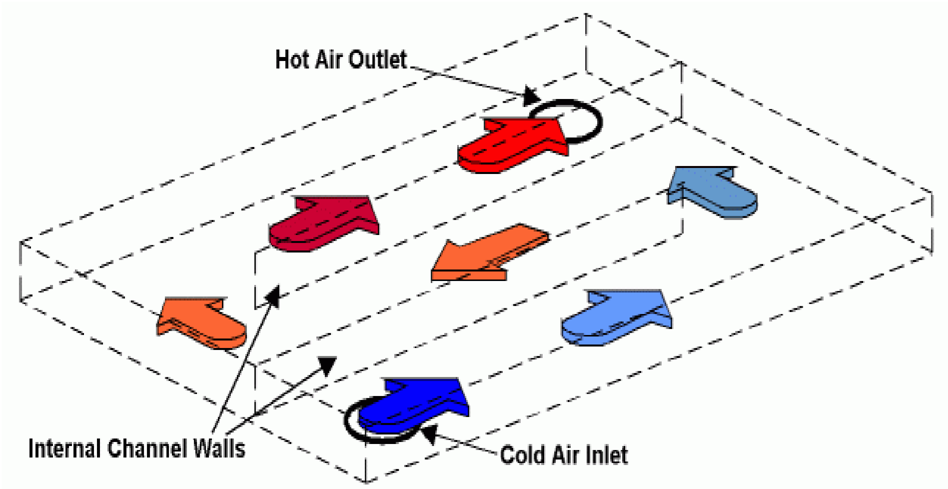

Fig. 1 A typical Solar Air Heater with Flat Plate Collector

values. Thus, the exergy analysis provides a more realistic view of process, sometimes dramatically different in comparison to standard energy analyses [28,29]. Exergy analysis establishes the theoretical limits of ideal operations, very convenient to determine the best collector for a specific application [30].

ENERGY AND EXERGY ANALYSIS

SAHs contain a process where energy intensity is high, in other words where the energy has to be used. This study contains the analysis of the first and second laws of SAH with different absorber surfaces; in other words the exergy and energy analysis.

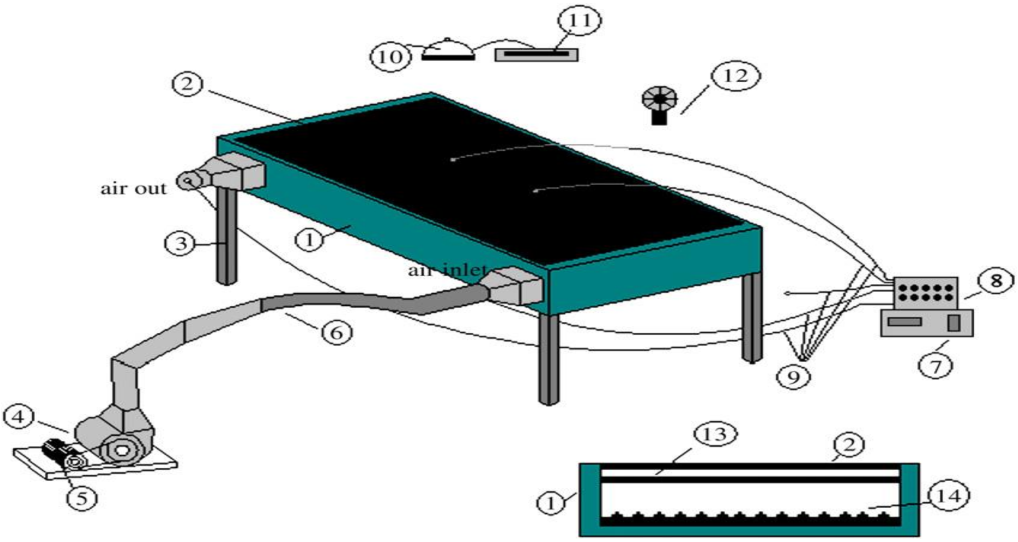

Fig. 2. Schematic view of experimental set-up: 1) Collector Box 2) Glass Cover 3) Foot 4) Fan 5) Fan Engine 6) Connection Pipe 7) Channel Selector 8) Digital Thermometer 9) Thermocouples 10) Pyranometer 11) Pyranometer recorder 12) Anemometer 13) Absorber plate (copper plate that's been painted black) 14) Absorber plate with (Different) obstacles as reported by Ref.[20].

Energy Analysis:

The theoretical model employed for the study of the solar collector that operates in unsteady state is made using a thermal energy balance [6]:

[Accumulated energy] + [Energy gain] = [Absorbed energy] – [Lost energy] (1)

for each term of Eq. (1) the following expressions are formulated:

[Accumulated energy] = $M_pC_p\,(dT_{p,ave}/dt)$ (2)

[Energy gain] = $\dot{m}C_p\,(T_{out} - T_{in})$ (3)

[Absorbed energy] = $\eta_o I A_C$ (4)

[Lost energy] = $U_c\,(T_{p,ave} - T_e)A_C$ (5)

By combining Eqs. (2) – (5), the thermal energy balance equation necessary to describe the solar collector functioning is obtained:

$$M_pC_p\,(dT_{p,ave}/dt) + \dot{m}C_p\,(T_{out} - T_{in}) = \eta_o I A_C - / U_c\,(T_{p,ave} - T_e)A_C \quad (6)$$

The optical yield (η_o) and the energy lose coefficient (U_C) are the parameters that characterize the behavior of the solar collector. Note that η_o represents the fraction of the solar radiation absorbed by the plate and depends mainly on transmittance of the transparent covers and on the absorbance of the plate [6]. The energy loss coefficient includes the losses by the upper cover, the laterals, and the bottom of the collector. The upper cover losses prevail over the others, depending to a large extent on the temperature and emissivity of the absorbent bed, and besides, on the convective effect of the wind on the upper cover. The thermal efficiency of the solar collectors (η_I) is defined as the ratio between the energy gain and the solar radiation incident on the collector plane [6,7,8]:

$$\eta I = \frac{\dot{m}Cp\,(Tout - Tin)}{IAC} \quad \ldots\ldots\ldots\ldots (7)$$

Exergy analysis:

This article focuses on the combination of the two laws of thermodynamics, which are described in the concept of exergy analysis. The assumptions made in the analysis presented in this study are [6,7,8,9]:

(i) steady state, steady flow operation,

(ii) negligible potential and kinetic energy effects and no chemical or nuclear reactions,

(iii) air is an ideal gas with a constant specific heat, and its humidity content is ignored,

(iv) the directions of heat transfer to the system and work transfer from the system are positive.

The exergy efficiency of a solar collector system can be calculated in terms of the net output exergy of the system or exergy destructions in the system. The exergy efficiency of SAH system has been evaluated in terms of the net output exergy of the system. The second law efficiency is calculated as follows [9]:

$$\eta_{II} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} = \frac{\dot{m}[h_{out} - h_{in} - T_e(s_{out} - s_{in})]}{\left(1 - \frac{T_e}{T_s}\right)\dot{Q}_s} \quad (8)$$

When dealing with the exergy of a process component, the difference between exergy losses and destruction should be noted. Exergy losses consist of exergy flowing to the surroundings, whereas, exergy destruction indicates the loss of exergy within the system boundary due to irreversibility [10].

All physical properties of air were selected according to the following bulk mean temperature:

$$\Delta T_m = (T_{in} - T_{out}) / 2 \quad (9)$$

REVIEW OF DIFFERENT FLAT-PLATE SAHs

In this section a review of thermodynamic analysis of SAHs with and without obstacles on its absorber plate is presented.

A.Ahmed-Zaid, H. Messaoudi, A. Abenne, M. Leray, J. Y. Desmons and B. Abed [11] have extensively studied the thermal performance improvement of a solar air flat plate collector through the use of obstacles and they proceeded to the application of the best two systems waisted ogival lengthways and transverse-longitudinal obstacles for drying an agricultural product like Yellow Onion. By comparing with the collector without obstacles, the thermal transfers and, consequently, the output collector temperature (T_{OC}) and the collector efficiency (η) are clearly improved. And they concluded that the form, orientation, dimensions and disposition of the obstacles considerably influences the collector efficiency.

Enibe [32] designed, fabricated and evaluated a passive solar powered air heating system based on the exergy analysis. The system consisted of a single-glazed flat plate solar collector integrated with a phase change material (PCM) based heat energy storage system. The experiments were carried out under the typical climatic conditions of Nsukka (Nigeria) in the daytime with no-load conditions. In this experimental study, data for different parameters such as ambient temperature and solar radiation were collected and found to be varied in the range of 19–41 ^oC and 4.9–19.9 MJ/m^2 respectively. The peak cumulative useful efficiency was calculated and found to be about 50% while peak temperature rise of the heated air was found to be about 15 ^oC. The system has been found suitable for the use as a solar cabinet crop dryer for plants which do not require direct exposure to the sunlight such as aromatic herbs and medicinal plants.

Kurtbas and Durmus [33] designed a new type of solar air heater and evaluated it using exergetic analysis. They used five solar collectors with dimensions of 0.9 x 0.4 m and were set to four different cases. They found that the efficiency of the collector increases with the increase of mass flow rate which is due to the increased heat transfer to the air flow. They suggested that the collector efficiency, the inlet and outlet temperature difference of the air geometry and pressure loss etc. are some of the more important parameters for evaluating the performance of a solar collector.

Ajam et al. [34] worked on the optimization of the solar air heater based on the exergetic analysis. For this purpose, an integrated mathematical model of thermal and optical performance of the solar heater has been derived. The overall thermal loss coefficient and other heat transfer coefficients of the heater were assumed to be variable. Using MATLAB toolbox the exergy efficiency equation has been optimized and compared with the thermal efficiency of the heater, which ultimately resulted in the increase of exergy efficiency. They concluded that the exergy analysis is a better method for design, development and optimization of solar air heaters. This was shown due to the fact that exergy efficiency is a proportion to common quantities in solar engineering such as, thermal efficiency, temperature, pressure drop, mass flow rate of fluid etc. and other important parameters.

Kurtbas and Turgut [35] investigated the solar air heater with free and fixed fins using exergy analysis. In this study each of the fins with rectangular shape was having two different surface areas and located on the absorber surface in free and fixed manners. In the free fins type model, the fins were located on the absorber surface in a way that they are able to move freely, while in the fixed fins type model fins were fixed to the absorber surface. They revealed that the fins located in flow area enhance the heat transfer coefficient and outlet temperature of the air due to which the collector efficiency enhanced. They also found that, both the heat transfer and exergy loss enhanced due to increase in pressure drop and also the loss ratio affected slightly with the pressure drop inside the air heater.

The solar air collectors with the passive augmentation techniques using exergetic analysis were studied by Ucar and Inallı [36]. In order to provide a better heat transfer surface suitable for the passive heat transfer augmentation techniques, different shape and arrangement of the absorber surfaces in the collectors were reorganized. The performance of such solar collectors with staggered absorber sheets and attached fins on the absorber surface were analyzed and tested experimentally. It was found that the efficiency of solar collector has increased approximately by 10–30% using the passive techniques as compared to the conventional solar collector.

Koca et al. [37] investigated the flat-plate solar collector with phase change material (PCM) using energy and exergy analyses. They used calcium chloride hexahydrate ($CaCl_2.6H_2O$) as the PCM in the thermal energy storage (TES) system while the solar energy collection and storage units were combined into a single unit. The experiments were carried out for 3 different days in the month of October at a typical location. From the measured data experimental it was found that the stored and instantaneous solar radiation exhibits a bell-shaped variation during all experimental days. The exergy efficiencies of latent heat storage systems were found very low which was due to the fact that the temperatures of the storage material and ambient were close to each other.

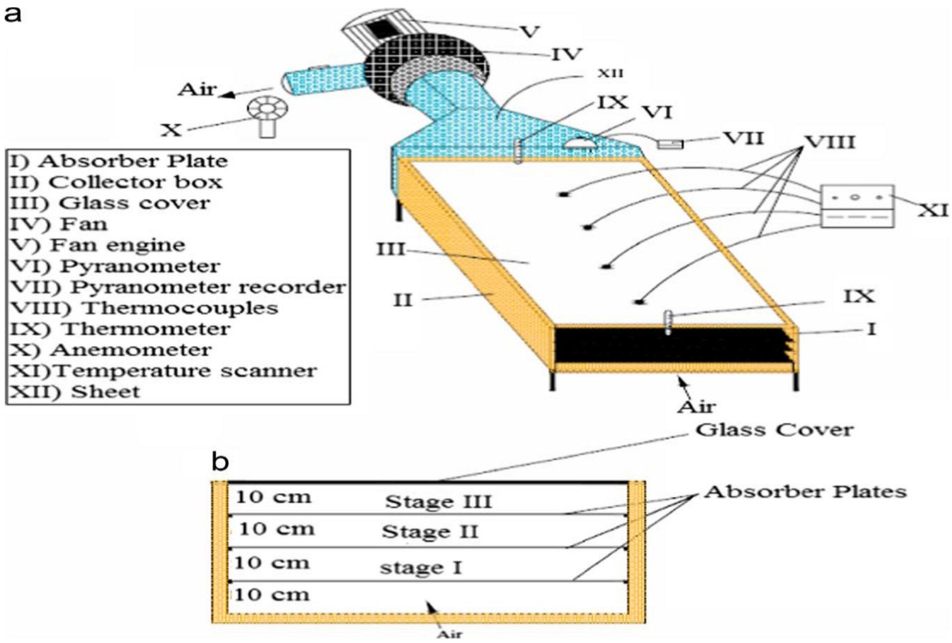

Fig. 3. Schematic assembly of the (a) SAH system and (b) front view of the collector

Hikmet Esen [6] presented a detailed experimental energy and exergy analysis for a novel flat plate solar air heater (SAH) with several obstacles and without obstacles on absorber plate. The schematic view of the double flow SAH system and front view of the collector are shown in Fig. 3 (a) and (b) respectively. For increasing the available heat-transfer area can be achieved if air is flowing simultaneously and separately over and under the different obstacle absorbing plates, instead of only flowing either over or under the different obstacle absorbing plates, leading to improved collector efficiency. The measured parameters were the solar radiation, the absorbing plate temperatures, the inlet and outlet temperatures and the ambient temperature. The measurements were performed at different values of air mass flow rate (i.e., between 0.015 and 0.025 kg/s) and different types of absorbing plates (Type I, Type II, Type III and Type IV) in flow channel duct on days with clear sky conditions at Elazig location. The experimentation was done for a period of one month from 01.07.2005 to 31.07.2005. Test results yielded higher efficiency values for Type III (great turbulence) than for Type I (no turbulence, without obstacles) flat plate collector. The obstacles ensures i) a good air flow over and under the absorber plates ii) creates the turbulence and iii) reduces the dead zones in the collector. The largest irreversibility occurs at the Type I flat plate SAH, since, in flat plate collector (Type I) only a little part of solar energy absorbed by the collector can be used in the exergy analysis.

Ozgen et al. [38] studied on a flat-plate solar air heater with an absorbing plate made of aluminium cans into the double-pass channel using three different absorber plates. In Type I, cans were arranged in zigzag manner on the absorber plate while in Type II they were arranged in order. On the other hand, the plate was kept without cans for type III model. The experiments were performed for two different air mass flow rates of 0.03 kg/s and 0.05 kg/s, respectively. The double-flow type of the solar air heater with aluminium cans, having more heat-transfer area achieved higher thermal efficiency.

Ebru Kavak Akpinar, Fatih Koçyig˘it [20] analyzed about Energy and exergy of a new flat-plate solar air heater having different obstacles on absorber plates. They experimentally investigated the performance analysis of a new flat-plate solar air heater (SAH) with several obstacles (Type I, Type II, and Type III) and without obstacles (Type IV). Where the Type I, Type II, Type III are triangular, leaf and rectangular type obstacles. Experiments were performed for two different air mass flow rates of 0.0074 and 0.0052 kg/s. The comparisons were made among the different SAHs by determining the first and second laws of efficiencies. The values of first law efficiency varied between 20% and 82%. The values of second law efficiency changed from 8.32% to 44.00%. The highest efficiency were determined for the SAH with Type II (leaf type obstacle on absorbent plate) absorbent plate in flow channel duct for all operating conditions, whereas the lowest values were found for SAH with Type IV absorbent plate (without obstacles). The results depicted that the efficiency of the solar air collectors significantly depends on the surface geometry of the collectors, extension of the air flow line and solar radiation. The largest irreversibility occurred for the SAH with Type IV absorbent plate (without obstacles) in which collector efficiency is smallest. At the end of the study, the energy and exergy relationships were delivered for different SAHs.

The efficiency of the collector improved with increasing mass flow rates due to an enhanced heat transfer to the air flow. The efficiency decreased as the temperature parameter increase, meaning, at higher temperature parameter, the overall loss was lower. The exergy loss of the system decreased depending on the increase of the collector efficiency. There was a reverse relationship between dimensionless exergy loss and heat transfer. The more important parameters in order to decrease the exergy loss were the collector efficiency, temperature difference of the air.

Gupta and Kaushik [31] established the optimal performance parameters for the maximum exergy delivery during the collection of solar energy in a flat-plate SAH. They stated that based on the output energy evaluation, the SAH should have high aspect ratio, low duct depth, and low inlet temperature of air. They have observed and proved that if the inlet temperature of air is low, then maximum exergy output is achieved at low value of mass flow rate.

CONCLUSIONS

The thermodynamic analysis of SAHs with different obstacles on its absorber plate was discussed. An effort has been made to present critical and comprehensive review in this subject. It has been observed in this literature survey that most of the researchers have done work on solar air heaters and with different obstacles on its absorber plate such as triangular, leaf and rectangular type obstacles. Further, it can be said that there exists a lot of research opportunities in SAHs on issues related to obstacles. This survey paper will serve as a valuable reference for researchers to work on energy and exergy analysis of solar air heaters with different obstacles on its absorber plate.

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