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Research Note

Improving Thermal Efficiency of Solar Air Collector by Creating Turbulent Flow Using New Baffles Combinations

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ABSTRACT

The study shows an experimental investigation for a solar air collector with a single pass by adding rectangular baffles for different positions inside the channel. The aim of this study is to improve the thermal efficiency for this collector, and that through testing four cases of baffles positions (mode 1, 2, 3, 4). The study was done under different operating conditions by changing the mass flow rates and positions of baffles. The results show the effectiveness of the baffles in improving the efficiency of the collector, The study also proved that the baffles positions affect thermal efficiency, where the greatest efficiency was recorded in the fourth mode and then in the positioning of obstacles at the middle of the channel for the mode 2 and the mode 4 with a percentage of 76.61▯ and 90.9▯, at mass flow rate m=0.0522 kg/s, while the pressure drop was very high in the mode 4, and after that the mode 2. Through the conditions of the study and taking into account all the results; we can say that the best case was mode 2.

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NOMENCLATURE

Φ	Heat flux (W)	Λ	Pressure drop coefficient
m	Mass flow rate (kg/s)	H	Heat transfer coefficient (W/m^2.K)
Cp	Specific heat (J/kg K)	a	Passage section (m^2)
T_{abs}	The average temperature of the absorber plate (K)	P	Circumference (m)
T_{air}	The average temperature of the air (K)	η	Efficiency (%)
L	Length of the duct (m)	I	solar radiation (W/m^2)
D	Haydraulic diameter (m)	A	Absorber area (m^2)
ΔP	Pressur drop (Pa)		

INTRODUCTION

Solar air collector is one of the most devices made for investigating the biggest benefit from solar energy, and transfer it into thermal energy. In recent years, researchers have focused on the development of these transformers, especially at the level of the transport channel, as many researchers have developed the air transport channel, whether in terms of duct shape, length [1–4], or adding obstacles [5–8]. The study of adding baffles is divided into several sections, some of which focus their studies on the geometrical shape of baffles, some of them focus on the number, and some of them focus on positioning. In this work, we focused on the shape, number, and position of the obstacles inside the channel, in order to observe the effect of these properties on the heat transfer. Among the studies an experimental work was accomplished by Wang et al. [4], where they

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have designed S-shaped baffles at the level of the air transport channel for a solar heat heater, this work gave good results of thermal efficiency by changing the operating conditions compared to the same collector without barriers. Another experimental work was done by Akpinar and Koçyiğit [9] for a solar air collector, where he carried out a series of studies at the duct level by adding various forms of baffles, (collector with triangular baffles, with leaf baffles, with rectangular baffles, and without baffles). This study aims to improve the efficiency of the studied transformer, in operating conditions of mass flow rates changes from m=0.0052 kg/s to m=0.0074 kg/s. It was found that the best model is with leaf baffles, and the lowest value for the return was in the model of without obstacles, through the results of the experimental study, the following has been shown: the efficiency increases with the increasing flow, where it is closely related to the geometrical shape of baffles. In the same context Hu et al. [10] did an experimental and theoretical investigation for the new design of the duct, where this last separated into five-part, this process was done in order to increase the thermal efficiency of this collector. Through the results, it was found that the greatest values of efficiency were more significant than the flat plate collector one at the rate of 16.90%. Aouissi et al. [11, 12] experimentally studied the heat transfer inside a heat exchanger with rectangular baffles; where that was reached that nit just the shape of geometry affects the thermal and hydraulic performance of the collector even the positioning plays a big role in that. Wijeysundera et al. [13] studied a double pass duct solar air collector and its results were compared with other results of a single pass channel collector in different operating conditions. The study showed that a single channel collector has a lower thermal efficiency than a dual-channel. In the same context Chabane and Aouissi [14] conducted experimental work for several cases in order to study their thermal and hydraulic performance, where they found that an increase in obstacles increases the heat transfer and at the same time increases the pressure drop. Ural [15] did an experimental study of a new design solar air collector with textile fabric, and compared with flat plate solar air collector. Hernández et al. [16] comducted theoretical and experimental studie on a double-pass solar air heater with a porous matrix. It was positioned in the second duct to enhance thermal transfer between the air and the absorber plate. The system's energy balance equations were formulated in a separate volume, resulting in a set of time-dependent equations. These equations were solved using the Gauss-Sidel method. Khanoknaiyakarn et al. [8] conducted experimental investigation on a solar air collector featuring v-shaped baffles. The study focused on the thermal properties of the rectangular duct, where the aspect ratio (AR) of width to height was set at 10. The ratio of baffles to the height of the channel was varied at e/H = 0.2, 0.3, and 0.4. The collector was inclined at an angle α of 30° with respect to the direction of airflow. Through the foregoing, in this study we conducted an experimental study if different positions of the baffles inside a channel of a solar air collector, in order to know the extent of the effect of the position of the baffles on the heat transfer from the absorber plate to the passing air.

EXPERIMENTAL SETUP

This experiment was achieved at the University of Biskra, and specifically in the technological lobby of the department of mechanical engineering, this type of thermal converter is a solar air collector with a single pass channel and baffles [5]. All experiment measurements were in angle of inclination β = 38° (as shown in Figure 1), and different mass flow rates, the considered collector is thermally insulated with good insulation, which reduces heat losses. It was consisted of basic parts as follows: glass plate, absorber plate, bottom plate, and air channel, in addition to the thermal converter, there is an essential element, which is the aspirator where we use to move the air inside the duct. In order to know the average temperature of this transformer, thermal sensors were installed at the level of absorber plate at five different points, and two more were installed, one at the entrance and one at the exit. Through previous work in this field, we found that the addition of baffles increases the heat transfer process [17, 18], and this increases the efficiency of the transformer generally, our work focused on adding rectangular baffles perpendicular to the air duct (as shown in Figure 2), in order to increase the transfer of thermal energy to the air and with taking into account the change in pressure between the inlet and outlet (pressure drop). The experiment was divided into four obstacle modes (as shown in Figure 3); each mode was studied individually under the influence of different mass flow rates. The tests were carried out during the period from February to April 2017.

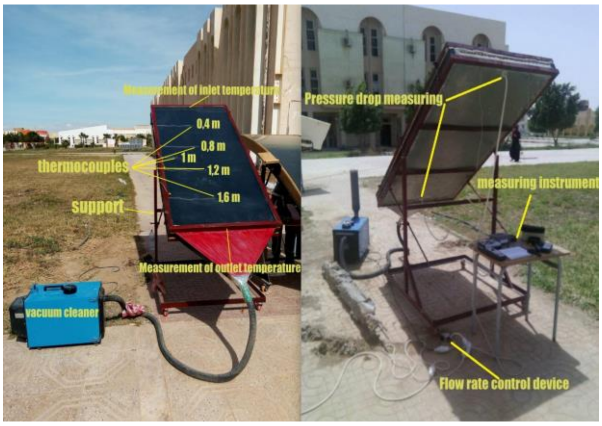

Figure 1. Experimental setup

Figure 2. Shape of baffle

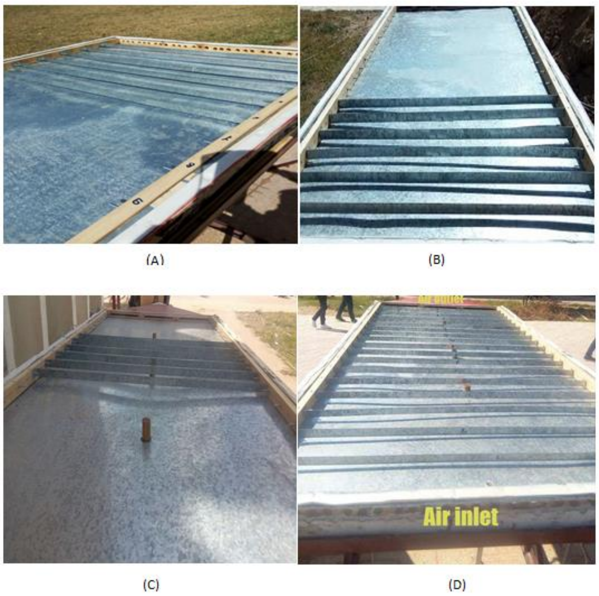

Figure 3. The modes of our study: (A) Mode 1; (B) Mode 3; (C) Mode 2; (D) Mode 4

Detail in modes:
Mode 1: Six baffles in the first third of the channel (as shown in Figure 4).
Mode 2: Six baffles in the middle third of the channel.
Mode 3: Six baffles in the last third of the channel.
Mode 4: Eighteen baffles in the channel.

Measurements were done from 11:00 am to 12:00 am which we took the solar radiation as a constant, every ten minutes we change the mass flow rate.

- **Technical Characteristics**

The main components of the sensor are:
Transparent glasses cover with a thickness of 4 mm.
A thin galvanized steel plate painted with black matte pinned in wood frame.
Two wood sticks are pinned on both sides of the mobile air stream to hold the baffles.
The rear insulation is ensured by a sheet of polystyrene, 40 mm thick.

Geometrical properties of the various parts of the collector are listed in Table 1.

MODELLING

The phenomena that occur in our system are governed by dimensional or non-dimensional equations. Heat flux is related to mass flow rate, thermal conductivity, inlet, and outlet temperature.

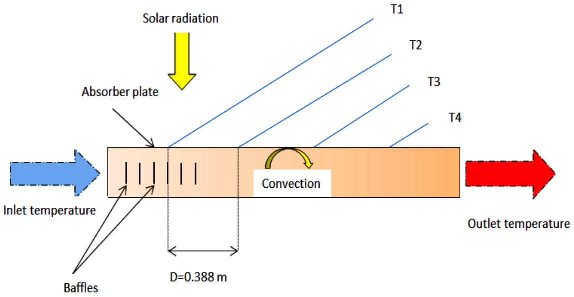

Figure 4. Scheme of the collector channel in mode 1

Table 1. Geometrical properties of the various parts of the collector

Building elements	Length (m)	Width (m)	Thickness (mm)
Transparent cover	1.94	0.94	3
Absorber	1.94	0.94	0.8
Wood frame	2	1	30×30
Wood sticks	1.94	0.03	30
insulating	2	1	40
Case	2	1	80
Baffles	0.88	0.02	0.8

$$d\Phi = m \times C_p \times dT_f \tag{1}$$

Applying it to our system, it becomes as follows:

$$\Phi = m \times C_p \times (T_{out} - T_{in}) \tag{2}$$

In our case, we have a heat transfer by forced convection, one of the most important parameters is the heat transfer coefficient so in this studied system the heat coefficient depends on the heat flux, absorber temperature, and air temperature, its equation as follows:

$$h = \frac{\Phi}{(T_{abs} - T_{air})} \tag{3}$$

The pressure drop was measured in the experiment between the inlet and outlet through the channel, it related to Λ is pressure drop coefficient, D_h is the hydraulic diameter of the air channel, and L channel length. its relationship as follows:

$$\Delta p = \Lambda \frac{L}{D_h} \times \rho \times \frac{V^2}{2} \tag{4}$$

Also, we need another parameter which represents hydraulic diameter it depended on the cross-section and section perimeter

$$D_H = \frac{4 \times a}{P} \tag{5}$$

The efficiency of the collector is calculated by the following equation:

$$\eta = m \times C_p \times \frac{T_{out} - T_{in}}{I \times A} \tag{6}$$

RESULTS AND DISCUSSION

In this section we present the changes of efficiency, and pressure drop as a function of mass flow rate in the field of mass flow rate from m=0 kg/s to m=0.1 kg/s, we also see another thermal characteristic of some parts from the solar air collector, these results, in order to know the pattern of changing these characteristics and improving the efficiency of this collector.

It was noted that the thermal efficiency increases with the increase in mass flow rate; we also found the greatest values for it in mode 4, where the eighteen baffles in the channel as expected. In the other three modes, that was found that the best one is mode 2 where six baffles in the middle third of the channel. The greatest value was in mode 4 at mass flow rate m= 0.052 kg/s where η=90.9% (as shown in Figure 5). As for the three modes, we found that the greatest value η=68.48% at mass flow rate m=0.053 kg/s in mode 2.

We noticed a significant increase in pressure drop in all modes, the lowest pressure drop values were recorded in the two positions mode 1 and 2, where six baffles in the first third of the channel, and six baffles in the middle third of the channel respectively, the highest values were in the situation where eighteen baffles in the channel, this is because the entire number of vertical baffles on the air stream (as shown in Figure 6). We moved on to some thermal properties in some important parts of our studied solar collector, which are the temperature difference, absorber plate temperature, and the heat transfer coefficient inside the channel with forced thermal convection, which would give us an overview of the behaviour of heat transfer inside our solar air collector.

The results obtained represent the changes at temperature difference and heat transfer coefficient as a function of mass flow rate; (as shown in Figures 7 and 8).

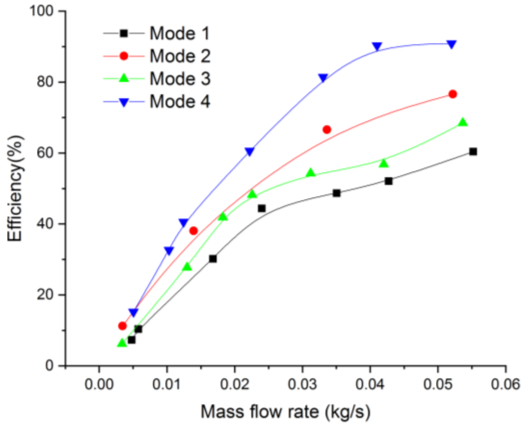

Figure 5. Variation of thermal efficiency as a function of mass flow rate for different modes

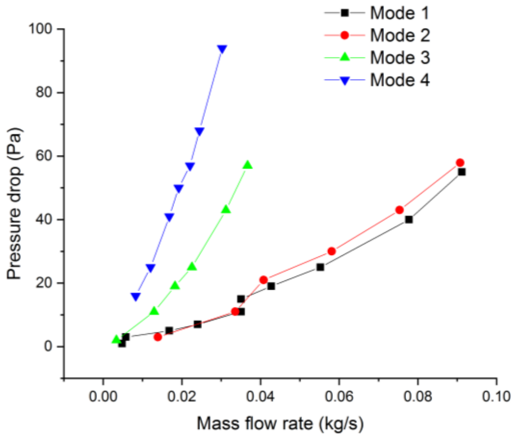

Figure 6. Variation of pressure drop as a function of mass flow rate for different modes

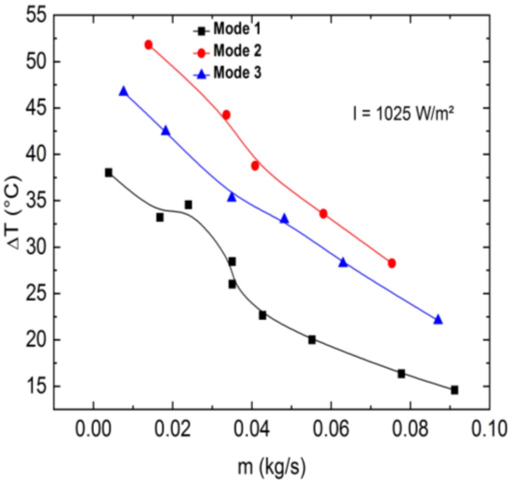

Figure 7. Variation of temperature difference as a function of mass flow rate for different modes

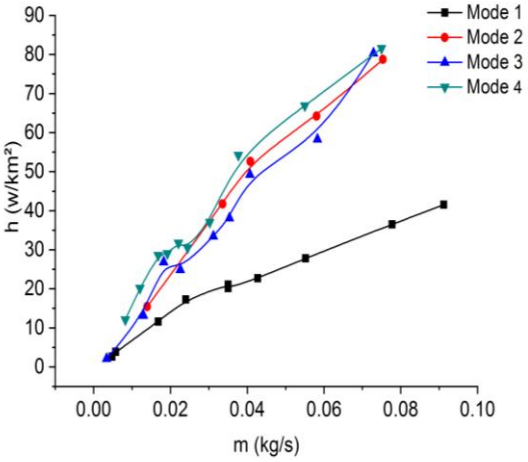

Figure 8. Variation of heat transfer coefficient as a function of mass flow rate for different modes

In this study, we focused on the first three modes 1, 2, and 3 to find out the impact of the positioning of baffles, as for the changes at temperature, the highest values were recorded in mode 2 (Six baffles in the middle third of the channel), where the highest value was at mass flow rate m=0.0139 kg/s, its value ΔT=51.8 °C, as for the changes at the coefficient of heat transfer by forced convection, we found the best values in the same mode, which indicates its efficiency, as the greatest value was recorded at mass flow rate m=0.075 kg/s and its value h= 79 W/m^2k.

We now passed to one of the important measurements, which is to study the temperature changes of the absorber at four points on the same longitudinal level for all modes.

These results give us an explanation of the absorption process (heat transfer from the absorber to air), as well as the impact of the positioning of baffles on this transition, through these results, we note that the baffles have a great role in increasing the process of energy transfer [19], which appears significantly in the third in which the obstacles, so that we notice a decrease in the absorber temperature at it compared to the other two thirds wherein mode 1 when the baffles were in the first third we recorded the lowest temperature values in the first third, and the same thing for the other modes.

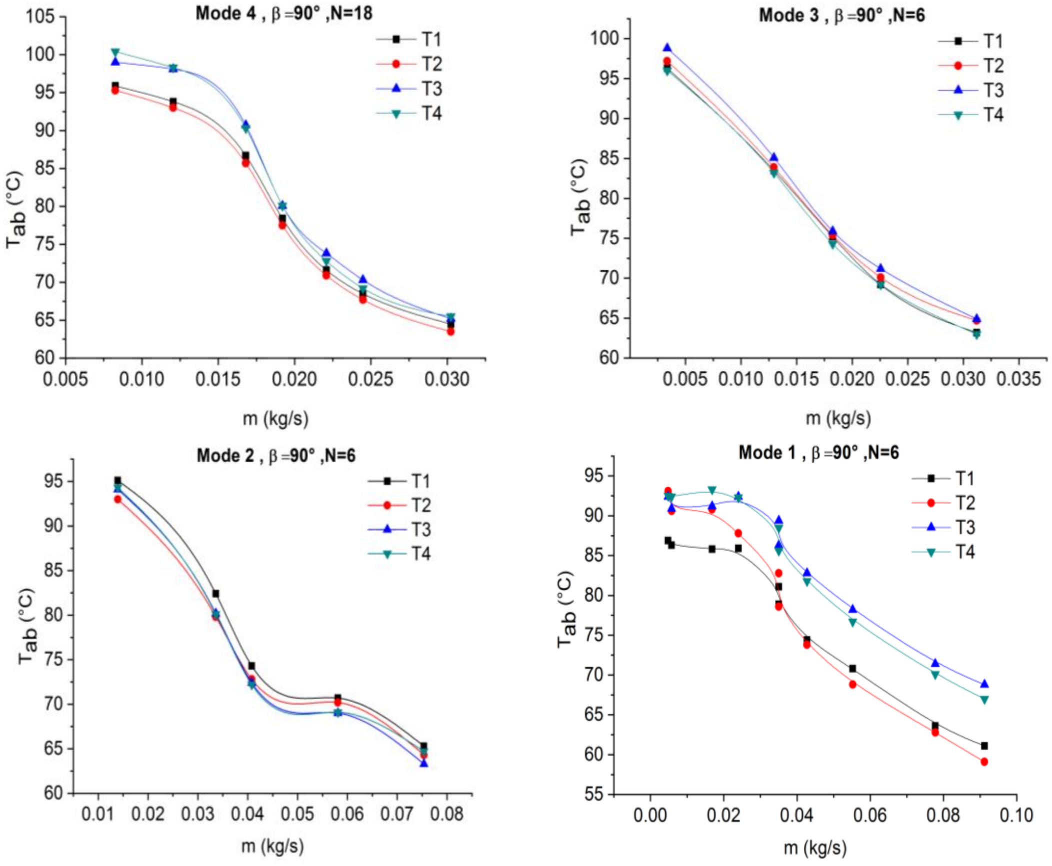

Figure 9. Variation of absorber temperature as a function of mass flow rate for different modes

CONCLUSION

The aim of this experimental study is to test the effect of adding rectangular baffles with an angle of inclination β=90° perpendicular to the airway. Through the results obtained from this work, the mechanism of the impact of baffles on the heat transfer process and its positions was understood, as the following was concluded:

-The addition of obstacles increases heat transfer and improves the efficiency of the collector.

-Not only the addition of baffles affects the thermal properties, but their positions also play a major role in the heat transfer.

-The best position of the studied positions based on efficiency and taking into account the pressure drop is mode 2, where the highest efficiency was recorded when mass flow rate m= 0.0522 kg/s, it was η=76.61%, with a small pressure drop compared to the rest of the positions.

-When the flow increases, the heat transfer increases, and the pressure drop increases in all positions.

-The heat of the absorber is very much related to the positioning of the baffles.

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Persian Abstract

چکیده

این مطالعه یک بررسی تجربی را برای یک کلکتور هوای خورشیدی single pass با افزودن بافل‌های مستطیلی برای موقعیت‌های مختلف داخل کانال نشان می‌دهد. هدف از این مطالعه بهبود راندمان حرارتی برای این کلکتور و از طریق آزمایش چهار مورد موقعیت بافل (حالت ۱، ۲، ۳، ۴) است. این مطالعه در شرایط عملیاتی مختلف با تغییر نرخ جریان جرمی و موقعیت بافل‌ها انجام شد. نتایج نشان‌دهنده اثربخشی بافل‌ها در بهبود راندمان کلکتور است، همچنین این مطالعه ثابت کرد که موقعیت بافل‌ها بر راندمان حرارتی تأثیر می‌گذارند، جایی که بیشترین بازده در حالت چهارم و سپس در موقعیت قرارگیری موانع در وسط کلکتور برای حالت ۲ و حالت ۴ با درصد ۷۶/۶۱ و ۹۰/۹، در دبی جرمی ۰/۰۵۲۲کیلوگرم بر ثانیه ثبت شد. در حالی که افت فشار در حالت ۴ و پس از آن حالت ۲ بسیار زیاد بود. شرایط مطالعه و با در نظر گرفتن تمام نتایج می‌توان گفت بهترین حالت، حالت ۲ بود.