Determination of the heat transfer coefficient by convection, according to shape of the baffles (solar air collector)

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ABSTRACT

The aim of this experimental study is to find the thermal transfer coefficient by convection in different modes of transversal baffles to the airflow in the solar air collector. The study enabled us to formulate a mathematical equation for the heat transfer coefficient as a function to pressure drop and the mass flow rate, and this mathematical model gave results that are close to the real results in different position of baffles (45°, 90°, 135°, and mixed between 135°and 45°). Through these results, we find that the perfect heat transfer coefficient by convection was in the mode where β = 90° and the mixed-mode, but we noticed that the pressure drop in the mixed-mode was less, this let us to say that the best mode for the baffles is the mixed one.

Keywords: heat transfer coefficient, convection, baffles, pressure drop, mass flow rate, solar collector.

1. Introduction

Solar energy is free energy, doesn't disappear, and very easy to use, one of the most important ways to benefit from it is to transform it into thermal energy by the solar collectors which are tools that convert solar energy into a thermal and transferred to the fluid which passes from the channel. This energy used in many fields like heating and drying. There are a lot of works that have been investigated in this field to improve the thermal efficiency of these collectors by taking into consideration the pressure drop such as change the shape and length of the channel [1-3] and adding baffles with different geometrical shapes [4-6]. In this context Chabane et al. [4] studied experimentally the thermal performance of solar air heaters with and without fins, the shape of these baffles is semi-cylindrical, for the angle of inclination β= 37 °. The results showed that the thermal efficiency of the solar air collector with semi-cylindrical shaped baffles larger by 19% than the without one. The highest value recorded in the case of the collector with baffles for mass flow rate m=0.02Kg/s which was 75%, also Khanoknaiyakam et al. [7] did an experimental study of solar air collector with v-shaped of baffles, the study was on thermal properties in its rectangular duct, from this work it was concluded that the addition of v-shaped baffles leads to an increase in pressure drop as well as an increase in heat exchange. Hu et al. [8] studied experimentally and theoretically a new model of solar air collector, the channel was divided into five-chamber sections, in order to increase the length of the channel through which the air passes, through the experimental and theoretical results, it was found that the width of the first room has a significant effect on thermal efficiency and a little effect on the pressure drop, for the width of 200mm, the thermal efficiency has the greatest value and it is greater to 16.90% compared with the collector its rooms evenly distributed. In order to improve the heat exchange between the absorber plate and the air passes in the duct, Wang et al. [9] did an experimental study of a solar air heater with s-shapes of baffles, these baffles have an opening to facilitate the passage of air, in this study, the effect of some important factors on thermal efficiency and the difference in temperature between the inlet and outlet were studied, after that these results were compared with solar air collectors with a flat plate, significant increase in thermal efficiency of this solar collector has been recorded compared to the same collector without baffles. An experimental study was performed for multiple obstacles geometrical designs and without baffles of solar air heater by Akpinar et al. [10] this study investigated in order to improve the performance of this collector for three form models of baffles and without baffles (collector with triangular baffles, with leaf baffles, with rectangular baffles and without baffles.), Measurements were made within values for mass flow rate 0.0052 kg/s and 0.0074 kg/s. Through the results of the study, it was found that the best model in terms of efficiency is model II (with leaf baffles)The lowest value was also recorded in the collector without baffles In all of conditions, efficiency has changed the next field from 20% to 82% , the study showed the following : the thermal efficiency of the transformer is closely related to the geometry of the obstacles, as it increases as the mass flow rate increases. A heat transfer model of solar air collector has been developed by Wijeysundera et al. [11] and the results were compared with a single-pass heat collector, the study was in many operating conditions, where the study confirmed that the efficiency of a double-pass solar air collector is better than that of a single-pass duct.

2. Experimental study

This experiment was investigated in the technological lobby of the department of mechanical engineering of the University of Biskra, the experiments in a constant inclination angle $\beta = 38°$. The solar air collector studied consists of a single channel through it; the air passe is well insulated to reduce heat losses.

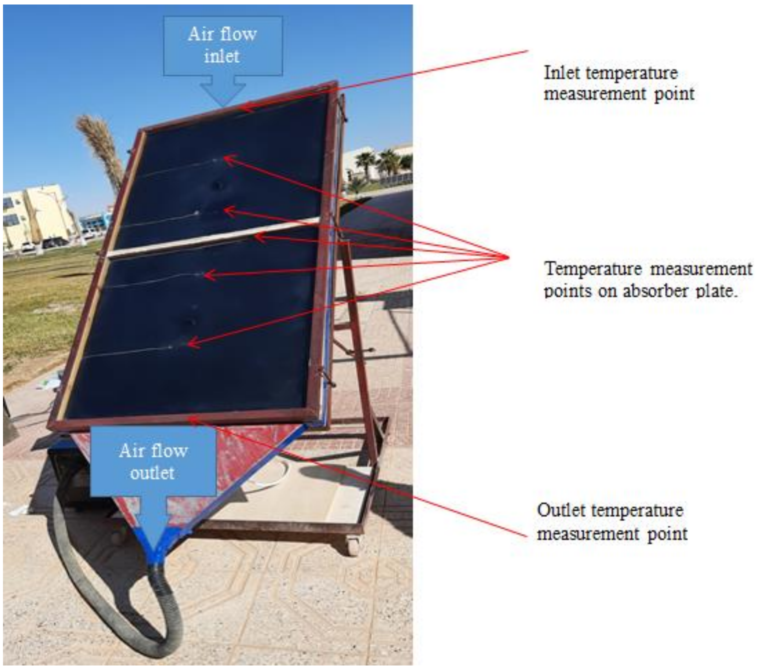


Fig. 1. The experimental setup of a solar collector

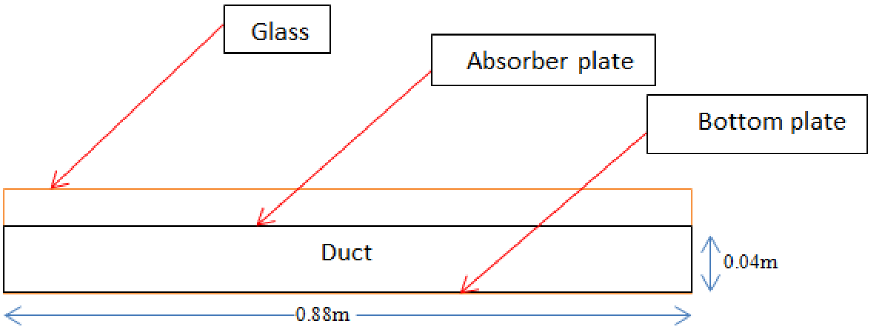
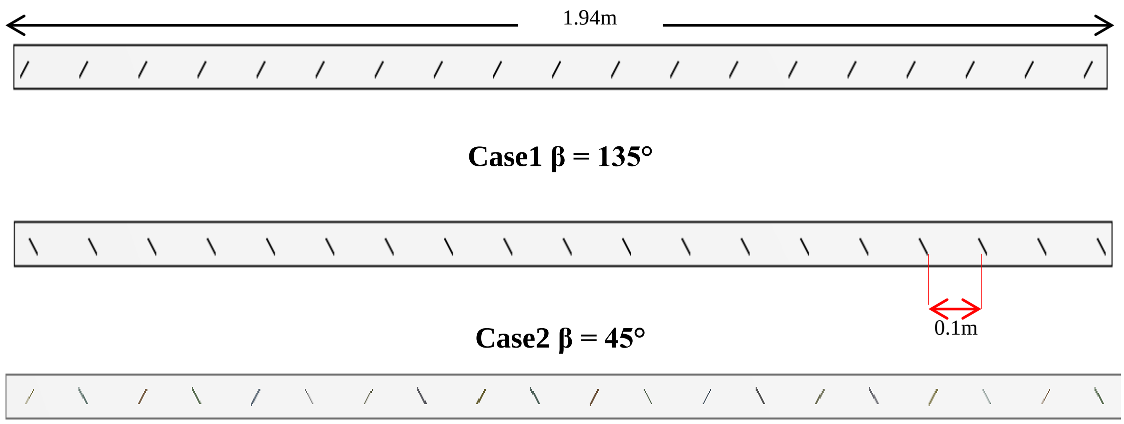


Fig. 2. Cross-section of the solar air collector without baffles

In order to increase the thermal transfer from the absorber to the air passing in the channel and in order to break the dead layers in the areas close to the absorber, rectangular baffles have been added inside the channel perpendicular to the course of the air stream with different inclination angles, and to value this work, it was compared with works of Chabane et al[12, 13]. In this work three different inclination angles for obstacles of the same number and position are studied (18 Baffles), also the case of solar collector without baffles was studied.

Fig. 3. The rectangular shape of the baffles

The baffles with different angles that have been studied in order to get the best position that gives the highest value of the heat exchange coefficient with taking into consideration the pressure drop, were as follows: $\beta = 90°$[12, 13], $\beta = 45°$, $\beta = 135°$ and $\beta = 135°-45°$



Case3 mixed between β =135°, and β =45°

Fig. 4. The different angles of baffles.

3. Modelling

By experiment, the temperature of the air in the inlet and outlet is measured at the same time; we measure the temperature at five points on the absorber plate, and that for calculating the heat flux of the solar air collector which is given by the following mathematical relation:
Heat flux in the general condition:

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

Heat flux in our case:

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

Through this relation, the heat transfer coefficient can be calculated by the average temperature of the absorber plate and the average temperature of the air passing through the duct which is given by the following relation:

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

Also during the experiment, the air pressure difference between the inlet and the outlet was measured, which is given by the following relation:

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

Where Λ is pressure drop coefficient, D_h is the hydraulic diameter of the air channel, and L channel length. Also the phenomenon is controlled by dimensionless properties Reynolds number represents the relationship between inertial forces and viscous forces and characterizes nature of the flow regime:

$$\mathrm{Re} = \frac{\rho \times V \times D_h}{\mu} \tag{5}$$

4. Theorical study

After the experiment study, we can observe that the heat exchange coefficient affected by two terms the first one is mass flow rate, and the second estimate the form of the baffle into the stream channel then we tried to create a new mathematical model for a product the coefficient of heat exchange by convection as a function of the mass flow rate and the pressure drop which was as follows:

$$h = a \times \left(m^b \times \Delta p^c\right)$$

Where the constants a, b, and c relate to the angle of the obstacle, which has been organized in the following table:

Table 1 Change of coefficients as a function of the positions of baffles.

	°45	°135	°90	°45-°135
a	24.41	20.7	20.5	13.85
b	0.2	0.21	-0.045	0.07
c	0.423	0.46	0.58	0.46
R^2	0.9818	0.998	0.98	0.9665

5. Results and discussion

In this part of the study, we present the heat exchange coefficient and pressure drop in the field of Reynolds (Re) from 624 to 2834 for smooth plate and different cases of the position of baffles, the reference for which the comparison was made is Chabane [12, 13], whose results show the change pressure drop and heat transfer coefficient as well.

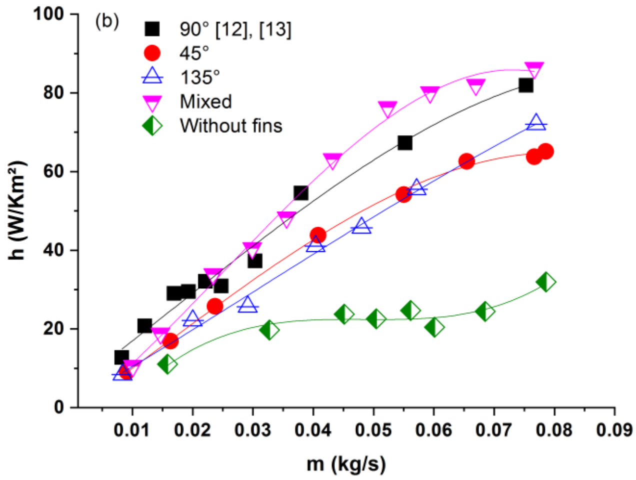


Fig. 5. Variation of heat exchange coefficient as a function of mass flow rate for different modes.

Figure 5 shows the variation of the heat transfer coefficient as a function of the mass flow rate. The first thing that can be noticed is the big difference between the results of the solar collector without obstacles and the solar collector with obstacles, as there was a significant difference in the heat thermal coefficient, where the maximum difference was recorded at the mass flow rate m = 0.06 Kg/s between the mixed-mode (135°and 45°), and the collector without baffles and its value was 62 W/k.m^2 evaluated. We can note also that the heat transfer coefficient gives perfect values corresponding in two configurations with baffles β = 90° and the mixed where was its value h = 85 W/k.m^2 in mass flow rate m = 0.08 Kg/s, and we noticed that the lowest values were at the lowest mass flow.

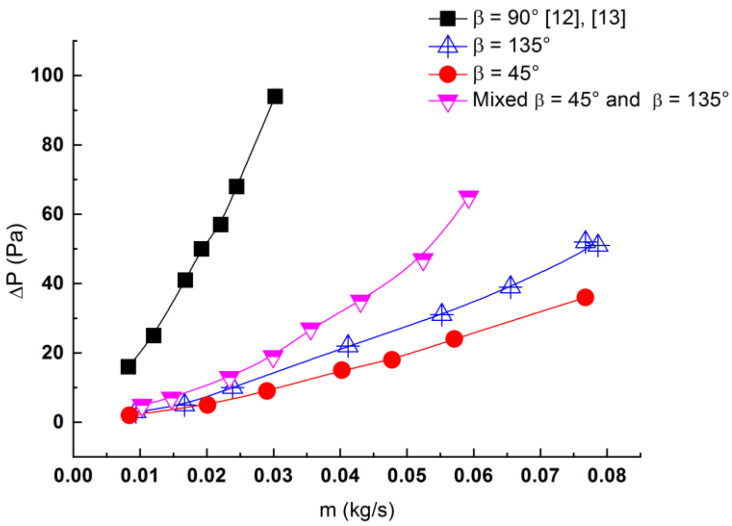


Fig. 6. Variation of pressure drop coefficient as a function of mass flow rate for the different inclination of the baffles.

Figure 6 shows the variation of the pressure drop as a function of the mass flow rate, we notice that the pressure drop increases with the increase in the mass flow rate. The lowest values were recorded in the position of baffles β = 45° then β = 135°, and the highest value of the pressure drop was also recorded in the reference case where the obstacles β = 90°.

To determine the best position of the baffles, the best values of the thermal coefficient must be determined in the studied cases, and the pressure drop must also be taken into account, so when we see the evolution of pressure drop between the configurations with baffles β = 90° and the mixed (135°and 45°) let us choose the best heat transfer coefficient by convection corresponding to configuration with mixed baffles because it has a minimum pressure drop from the other configuration with baffles β = 90°.

The pressure drop coefficient is a parameter related to the hydraulic diameter of the duct and the density of the air passing through, in addition to the air velocity and the length of the channel, there are two types of this parameter: the partial coefficient and the global one, the first is in terms of the length of the channel, and the second is in relation to one meter.

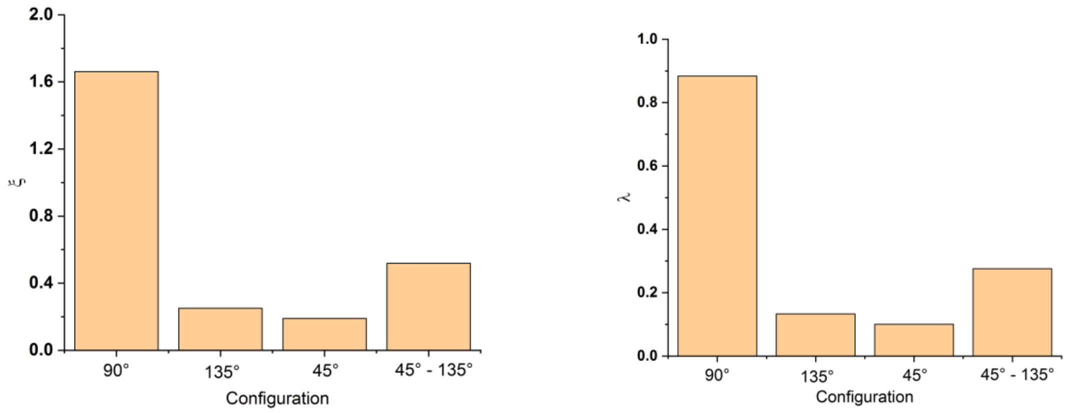


Fig. 7. Global and partial pressure drop coefficient respectively.

We notice that the change in this parameter is directly related to the pressure drop, as we notice that the lowest value was in the case β = 45° in the global coefficient and the partial one, where was its value 0.2 and 0.1 respectively, and the greatest value was in the case of β = 90° in both types where the value in the global coefficient was 1.65 and in the partial coefficient was 0.88.

6. Conclusion:

The results obtained during the experiments show the effect of adding baffles on the heat exchange between the absorber plate and the air, and its effect on pressure drop, three cases was studied in addition to the reference case and the case of without baffles, through the experimental results, it was found that the addition of baffles increases the heat transfer between the air and the absorber plate, as the addition of the baffles creates a disturbance that causes of cracking the dead layers near the absorber plate, and that causes an improvement in the heat exchange because the dead layers decrease the thermal transfer through it. The best value of the heat transfer coefficient was recorded in the case of position mixed (135°and 45°) then the case of β = 90°, the results showed that the lowest pressure drop was in the case of β = 45° and the same for pressure drop coefficient. Through the results of the thermal transfer coefficient and taking into account the change in pressure drop we can say that the best model is the mixed model.

Nomenclature

Φ :	Heat flux	(W)
$\dot{m}$:	Mass flow rate	(Kg/s)
Cp:	Specific heat	(J/Kg K)
Tabs:	The average temperature of the absorber plate	(K)
T_{air}:	The average temperature of the air	(K)
L:	length of the duct	(m)
D:	haydraulic diameter	(m)
ΔP:	pressur drop	(Pa)
Re:	reynolds number	
Λ	pressure drop coefficient	
ρ	Fluid density	(Kg/m^3)
V	Velocity	(m/s)
μ	kinematic viscosity	(m^2/s)
h	heat transfer coefficient	($W/m^2.k$)

References :

1. Yeh, H.-M. and C.-D. Ho, *Collector Efficiency in Downward-Type Internal-Recycle Solar Air Heaters with Attached Fins.* Energies, 2013. **6**(10): p. 5130-5144.
2. Naphon, P. and B. Kongtragool, *Theoretical study on heat transfer characteristics and performance of the flat-plate solar air heaters.* International Communications in Heat and Mass Transfer, 2003. **30**(8): p. 1125-1136.
3. Sopian, K., et al., *Thermal performance of the double-pass solar collector with and without porous media.* 1999. **18**(4): p. 557-564.
4. Chabane, F., N. Moummi, and A. Brima, *Experimental study of thermal efficiency of a solar air heater with an irregularity element on absorber plate.* International Journal of Heat and Technology, 2018. **36**(3): p. 855-860.
5. Karim, M.A. and M.N.A. Hawlader, *Development of solar air collectors for drying applications.* Energy Conversion and Management, 2004. **45**(3): p. 329-344.
6. Ozgen, F., M. Esen, and H. Esen, *Experimental investigation of thermal performance of a double-flow solar air heater having aluminium cans.* Renewable Energy, 2009. **34**(11): p. 2391-2398.
7. Khanoknaiyakarn, C., S. Kwankaomeng, and P. Promvonge. *Thermal performance enhancement in solar air heater channel with periodically V-shaped baffles*. in *2011 International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (ICUE)*. 2011. IEEE.
8. Hu, J., et al., *Performance improvement of baffle-type solar air collector based on first chamber narrowing.* Renewable Energy, 2019. **135**: p. 701-710.
9. Wang, D., et al., *Evaluation of the performance of an improved solar air heater with "S" shaped ribs with gap.* Solar Energy, 2020. **195**: p. 89-101.

10. Akpinar, E.K. and F. Koçyiğit, *Energy and exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates.* Applied Energy, 2010. **87**(11): p. 3438-3450.
11. Wijeysundera, N., L.L. Ah, and L.E.J.S.E. Tjioe, *Thermal performance study of two-pass solar air heaters.* 1982. **28**(5): p. 363-370.
12. Chabane, F., et al., *Experimental study of a solar air heater by adding an arrangement of transverse rectangular baffles perpendicular to the air stream.* International Journal of Green Energy, 2019. **16**(14): p. 1264-1277.
13. Chabane, F., et al., *Influence of the rectangular baffle on heat transfer and pressure drop in the solar collector.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020: p. 1-17.