Dynamic Study of the Flow and Influence of the Artificial Roughness in a Flat Plate Solar Collector

YOUSFI Sidi Mohammed, ALIANE Khaled and SARI HASSOUN Zakaria

Abstract—**In this paper, we introduce a new way to improve the performance of the flat plate solar collector: in addition to the introduction of the baffles was inserted an artificial roughness circular geometry at the insulation. A comparative study between two types of flat plate solar collector (with and without roughness) allows us to drawn some important conclusions on improving the performance of solar air collectors for this type of roughness mentioned above. The governing equations are solved by the finite volume method based on the Fluent code. Turbulence is modeled from the K-ε model. The simulation has shown that in the case of the used circular roughness, the velocity’s are very important compared to the case without roughness especially in the region near the lower wall which greatly favors the exchange of heat and increased performance.**

Keywords— **Flat plate solar collector; circular roughness; k-ε model; finite volume method.**

I. INTRODUCTION

The study of convection in a flat plate air solar collector has an important factor for improving the performance of these. Until now this heat transfer mechanisms in the fluid stream of solar collectors are not yet mastered despite the great progress made by different researchers in this field.

The idea of added obstacles in the fluid stream of the flat plate air solar collector (baffles) is used by various researchers. In the case of obstacles fixed to the insulator, the geometrical forms of barriers used must satisfy certain criteria. Indeed, the shape and arrangement of obstacles affect air flow during its trajectory. Obstacles ensure good irrigation of the absorber, creating turbulence and reduce the inactive zones in the collector, A. Ahmed-Zaid, A. Mulla, MS Hantala and JY Desmons [1] present a comparison between the results obtained in if the flat plate air solar collector with barriers and obstacles without baffles (SC). The different forms studied, both simple and interesting, concern, Delta Longitudinally Curved baffles (DCL), ogivalLongitudinally Curved (OCL) and Longitudinal-Transversal (TL).

In order to minimize thermal losses toward the front of the absorber, Feyza Benyelles and Al [2] have proposed to place an insulating "silica airgel" above the absorber.

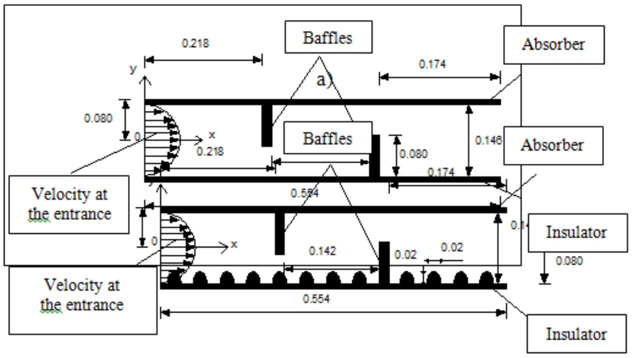
In his work, Mohamad A. A. [3] presented an analysis of this type of flat plate air solar collector by analyzing its performance by comparing it with a conventional solar collector with single and double covers. This analysis indicated that the efficiency of the flat plate air solar collector is high (compared to conventional flat plate air solar collector) and may exceed 75%.

To determine the characteristics of the fluid and heat flow in a solar air that is used for heating (solar heaters) a bed in the form of wire mesh is used as packaging material. Prasad S. B. and al [4] conducted an experimental study which is based on the comparison of the effectiveness of this type of flat plate air solar collector with that of a conventional flat plate air solar collector.

In this work, we compare a solar model with circular roughness and a flat plate air solar collector model with circular roughness. To do this, we conduct a study both qualitative, by means of digital visualization and quantitative studying the streamlines and velocity vectors.

II. PROBLEMATIC

The geometry of the studied problem is a circular duct fitted with circular baffles through which a stationary turbulent airflow satisfying the following assumptions: (i) Physical properties of the fluid assumed constant, (ii) velocity profiles and uniform temperature, (iii) of constant wall temperature, (vi) turbulence model (k-ε) at low Reynolds number.



a)

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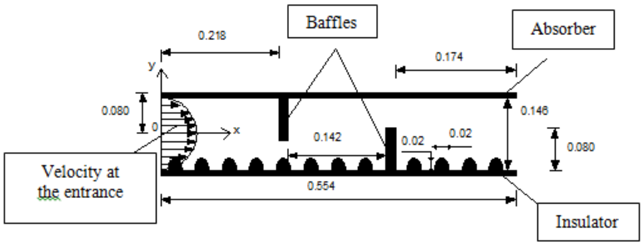

b)

Fig.2The studied geometry:
a) Flat plate air solar collector model without roughness
b) Flat plate air solar collector model with circular roughness

III. EQUATIONS GOVERNING

Under these conditions, the transport equations to consider may be written in the general form:

$$\frac{\partial}{\partial x}(\rho u \emptyset) + \frac{\partial}{\partial y}(\rho v \emptyset) = \frac{\partial}{\partial x}\left[\Gamma_{\emptyset}\frac{\partial \emptyset}{\partial x}\right] + \frac{\partial}{\partial y}\left[\Gamma_{\emptyset}\frac{\partial \emptyset}{\partial y}\right] + S_{\emptyset} \qquad (1)$$

Where $\emptyset$ is a vector composed of the variables $u, v, k,$ et ε. u and v are the local average velocitys in the x and y respectively, k is the turbulent kinetic energy and ε is the turbulent energy dissipation,$\Gamma_{\emptyset}$ et $S_{\emptyset}$are respectively the coefficients of turbulent diffusion and the term source associated with the variable $\emptyset$.

Table 1 summarizes the main region the flow equations by mentioning $\Gamma_{\emptyset}$et $S_{\emptyset}$.

Table1: Summary of equations solved for the flow region

Equation $\emptyset \Gamma_{\emptyset} S_{\emptyset}$

-Continuity 1 **0** **0**

-x momentum

equation$u \mu_e \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left[\mu_e \frac{\partial u}{\partial x}\right] + \frac{\partial}{\partial y}\left[\mu_e \frac{\partial v}{\partial x}\right]$ *(2)*

- y momentum

equation$v \mu_e \frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left[\mu_e \frac{\partial u}{\partial x}\right] + \frac{\partial}{\partial y}\left[\mu_e \frac{\partial v}{\partial x}\right]$ *(3)*

-Turbulent

energy$k \mu_\ell + \frac{\mu_t}{\sigma_k} - \rho_\circ \varepsilon + G$ *(4)*

-Turbulent
dissipation$\varepsilon \mu_\ell + \frac{\mu_t}{\sigma_\varepsilon}(C_1 G - C_2 \rho_\circ \varepsilon)\frac{\varepsilon}{k}$ *(5)*

IV. RESULTS AND DISCUSSION

IV.1 .The stream lines

At the entrance, velocity is uniform is just upstream of the first baffle area "A" for the two models studied (Figure 2). The fluid forms a dead volume (the flow is stagnant in there). The bright upstream stop has a separation point (area "B"), however, that the flow detaches from the wall of the barrier, causing a depression is downstream of that barrier. This is confirmed also by the presence of a very active vortex core "C" area. The existing of the first baffle will direct flow to the lower wall. By cons, the second baffle ("D" area) is the oriented upper wall which allows the fluid captured all heat energy from the absorber. Downstream of the second baffle ("E" field), it appears another dead zone of recirculation.

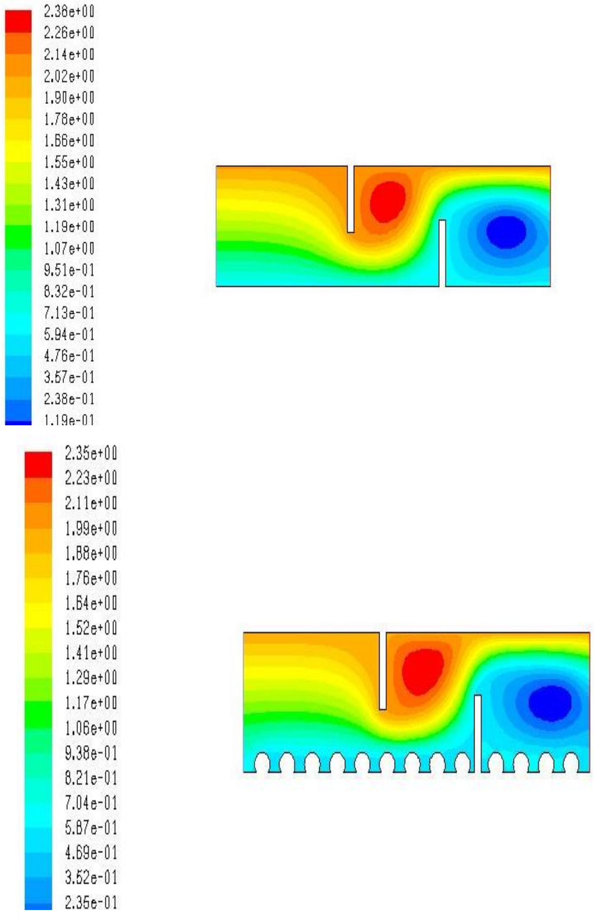

Fig.2 The stream lines for the two models studied

IV.2. The velocity vector V

There are several areas in both models studied, and this according to rate of intensity (Figure 3). Velocity’s are low is just upstream of the first baffle area "A" for both model studied. They are also low on upstream and downstream the second baffle is in its lower part and in the asperities of roughness. Velocity’s are very important below the first baffle and above the second baffle. Thanks to the roughness, velocity is very important in the "D" area compared to the first type without roughness where the velocity is very low view.

In the "E" velocity is important for the circular roughness flat plate air solar collector model (3.65m / s). By cons in the roughness flat plate air solar collector type without the velocity is less important (2.52m / s), see.

In the "C" zone velocity’s become very important. They are between 3.36m / s for the type without roughness see and 4.05 m / s for the circular roughness flat plate air solar collector view. In the "B" zone and "F", it appears a depression caused by the existence of the first baffle(“B" zone) and the second baffle (“F" zone) which reduces the velocity at this point.

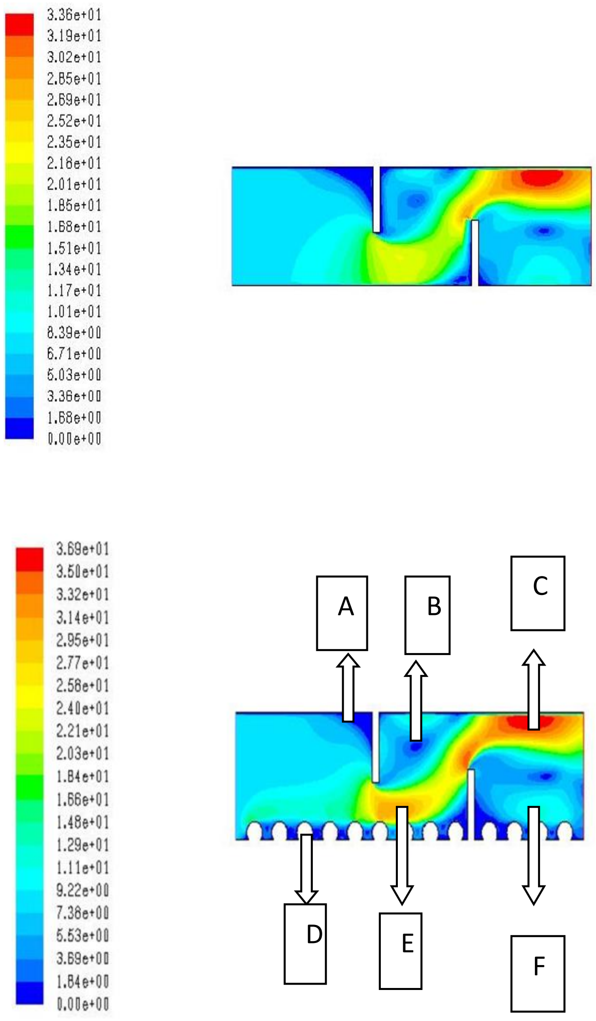

Fig3 *The velocity vector V*

IV.3.Velocity profiles

The velocity profiles enable us to quantify the different emerging areas within the flow. For that these profiles are made in several sections of the fluid stream:

1- Upstream of the first baffle (X = 0.15m).
2- First baffle (X = 0.223m).
3- Between the two baffles (X = 0.299m).
4- Second baffle (X = 0.375m).
5- Downstream from the second baffle (X = 0.467 m).

It is found for the case X = 0.15m (Figure 4) (upstream of the first baffle), the dynamic behavior of the case of circular roughness is greater than the case without roughness.

Figure 5 shows the velocity profiles in the first baffle (X = 0.223). We see that the velocity profiles for the type with roughness are very important in the position (-0.01 to 0.05)

To the position X = 0.299m (between the baffles) (6) we see that the profiles of almost similar rates for both cases except that there is an increase in velocity for the case with roughness at (-0.05 to 0.01).At X = 0.375 m (second baffle) (Figure 7), the velocity profiles are similar for both cases. Velocities are very important for the case with roughness at (0.015 to 0.06). To the position X = 0.467m (downstream of the second baffle) (Figure 8) we see that the velocity profiles have the same size, except that the shape of the velocity profile is different.

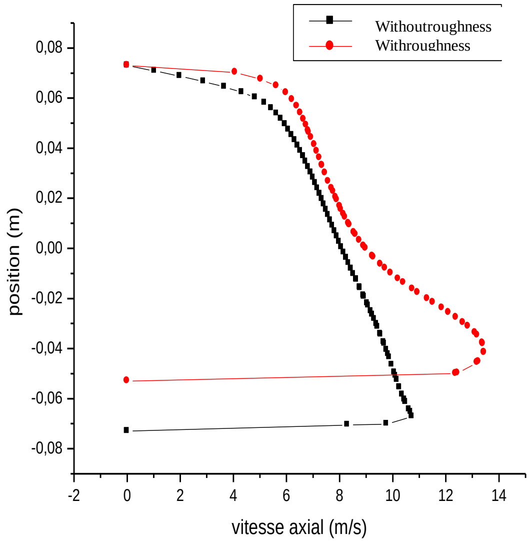

Fig.4 *Velocity profile at x=0.15m*

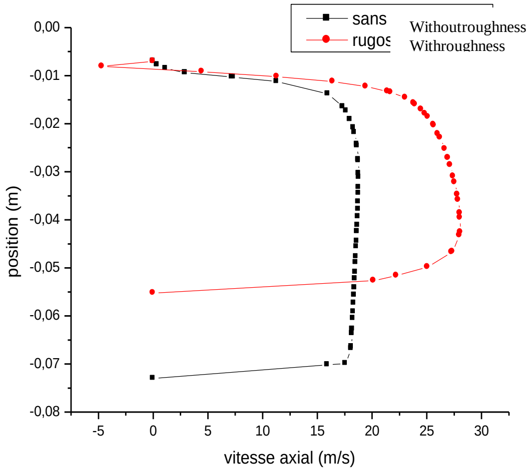

Fig.5*Velocity profile at x=0.223m*

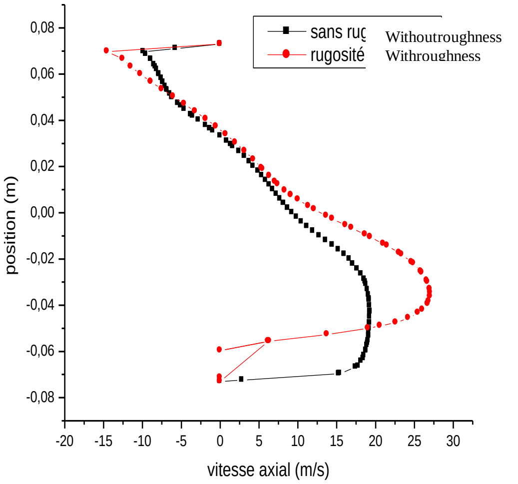

Fig.6 *Velocity profile at x=0.299m*

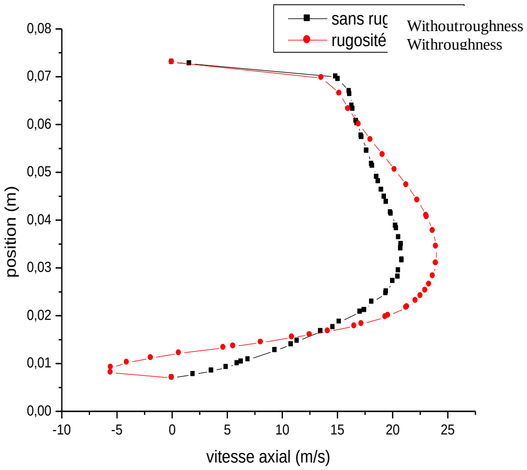

Fig.7 *Velocity profile at x=0.375m*

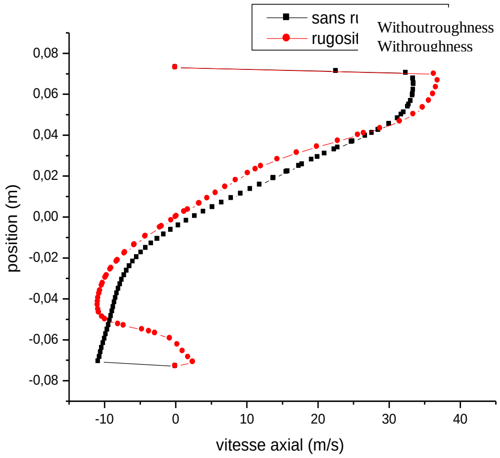

Fig.8 *Velocity profile at x=0.467m*

V. CONCLUSION

This work presents an effective contribution to improving the performance of a solar air plan.

Due to insufficient heat exchange performed in the solar collector air plane between the fluid and the absorber it is interesting to make improvements to ensure better thermal efficiency.

The improved performance of the solar collectors was to limit heat loss between the absorber and the ambience with a judicious choice of flat plate air solar collector components. It's late; performance optimization focuses more on the circulation of coolant.

These parts of simulation show us that upstream portion of the first baffle (zone «A» velocities is low for both types of flat plate air solar collector studied. Is more, the level of roughness (for the case of flat plate air solar collector with roughness) that velocity is near zero. This is equivalent to forming a thin layer of fluid trapped in these asperities.

Thanks to the roughness incorporated in the flat plate air solar collector, the velocity is very important in the "D" "E" "C" compared to the case without roughness flat plate air solar collector where the velocity is very low view.

REFERENCES

[1] A. Ahmed-Zaïd, A. Moulla, M. S. Hantala et J.Y. Desmons « Amélioration des Performances des Capteurs Solaires Plans à Air:Application au Séchage de l'Oignon Jaune et du Hareng » Rev. Energ. Ren. Vol.4 (2001) 69-78.

[2] F. Benyelles, B. Benabadjia, B. Benyoucef, Z.Ziani, « Comparaison entre un capteur à aérogel de silice et d'autres capteurs plans », 13emes Journées Internationales de Thermique (2007).

[3] A. A. Mohamed« High efficiency solar air heater» Solar Energy, 60 (1997), pp. 71-76.
https://doi.org/10.1016/S0038-092X(96)00163-6

[4] Prasad, S.B. et al. « Investigation of heat transfer and friction characteristics of packed bed solar air heater using wire mesh as packing material» Sol. Energy, (2009), doi:10.1016/j.solener.2008.11.011

[5] K.Aliane, O.Sebbane, A. Hadjoui, A.Azzi, R.Saim, “Contribution à l'étude de l'influence de la distance inter-obstacle sur la génération des zones tourbillonnaires au sein d'un écoulement”, Proceedings du 1erCongrès International deMécanique, Constantine, Algérie, 14-16 Décembre 2002, (2002),500-507.

[6] C. Dipankar, M. Bittagopal, Control of flow separation around bluff obstacles by superimposed thermal buoyancy. International Journal of Heat and Mass Transfer, Vol. 72, May 2014, pp 128-138, 2014.
https://doi.org/10.1016/j.ijheatmasstransfer.2014.01.013

[7] F. W. Roos J.TKegelman, Control of coherent structures in reattaching

[8] M. Kiya., M. Shimizu, O. Mochizuki., Y. Ido, H. Tezuka, Active forcing of an axisymmetric leading-edge turbulent separation bubble. AIAA, pp. 32-45. vol. 93 1993.
https://doi.org/10.1108/eb059389

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