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Numerical study of the effect of focusing the absorber relative to the mirror in a parabolic trough concentrator (PTC) on mixed convection

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Abstract – In the field of solar thermal energy, parabolic trough collectors (PTCs) stand out as a promising technology for renewable energy production. The precise focusing of the absorber located at the center focal of the parabolic mirror, which concentrates solar light, plays a crucial role in maximizing solar energy absorption and enhancing the system's thermal efficiency. This numerical study shows the impact of absorber focusing on mixed convection within a PTC receiver. Through numerical simulations, it aims to investigate how variations in focusing affect heat transfer mechanisms, critical for optimizing energy performance and durability of PTC systems. The study is conducted with a Reynolds number of 2200, a Grashof number ranging from $1x10^6$ to $6x10^6$ and a cylinder inclination angle of $\alpha = 0^\circ$ (horizontal).

Keywords – Parabolic Trough Collectors, Center Focal, Mixed Convection.

1. INTRODUCTION

This For laminar flow in horizontal tubes, natural convection has an important role to consider in flow and heat transfer. Ede [1], Barozzi et al [2] and Mori et al [3] carried out experiments to describe the flow and temperature fields of laminar mixed convection in horizontal tubes and to determine the empirical formula for the Nusselt number in a fully developed region. They found that the Nusselt number increases as the Rayleigh number increases. To avoid circumferential and axial heat conduction in the uniform heat flux (UHF) boundary condition, Bergles et al [4] studied mixed laminar flow convection in circular glass tubes instead of copper tubes.

Mori et al [5] carried out a more detailed theoretical study of mixed convection in a fully developed laminar flow and compared theoretical and experimental results.

Natural convection has a significant influence on turbulent flow and heat transfer in the PTC receiver tube for DSG systems, according to Huang et al [6]. The turbulent mixed convection in the receiver tube under non-uniform heat flow (NUHF) is very different from that under uniform flow (UHF).

In this work, a three-dimensional numerical simulation of mixed convection on the heat exchange between an air flow "Pr=0.72" in laminar regime and the wall of a horizontal cylindrical tube heated on its external surface is presented. The simulation assumptions are designed to approximate the operating conditions of an air/solar heat exchanger heated by a linear concentrated solar flux.

2. GEOMETRY AND PHYSICAL MODEL

The air cavity is heated by a uniform flow of heat. Heat loss due to convection and thermal radiation is not taken into account. The thickness of the absorber tube is also neglected. Air is chosen as the heat transfer fluid Pr=0.72. The air flow inside the tube is laminar.

3. GRID

The receiver tube was modelled and meshed in three dimensions using Gambit modelling and meshing software. The cross-sectional grids are shown in Fig. 1. It can be seen that the mesh near the wall is intense in the radial direction, because the velocity and temperature gradients near the inner wall are greater than in all other regions of the cross-section. The grid system chosen is $200x10^3$ cells.

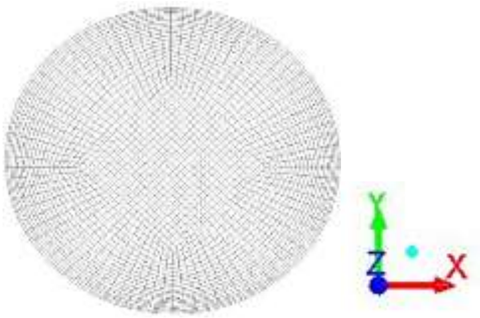


Fig. 1 Grid in cross-section

4. MODEL VALIDATION

The validation of the model is carried out for fully developed mixed convection in a tube under the condition of uniform heat flux limits compared to the experimental results obtained by Mori et al where Re=4250 and τ=dT/dz=11.3 degC/m. As shown in Fig.2. and Fig.3.

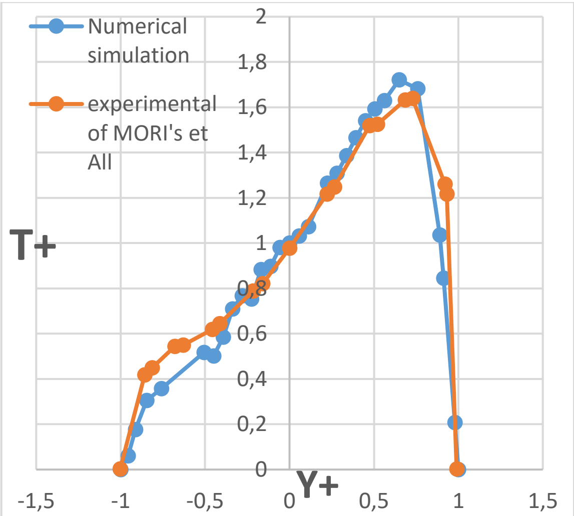


Fig. 2 Comparison between the results of the numerical simulation of T+ and the experimental of MORI's et al

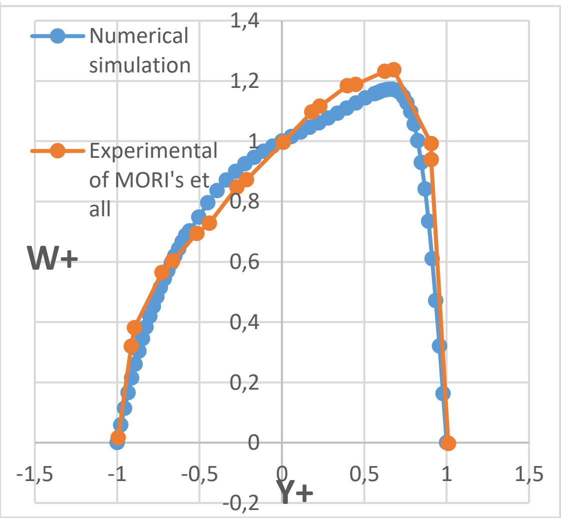


Fig. 3 Comparison between the results of the numerical simulation of W+ and the experimental of MORI's et all

5. CONDITIONS STUDY

Fig. 4 shows two cases of focusing the absorber relative to the mirror in a parabolic trough concentrator (PTC), C=100% and C=50%

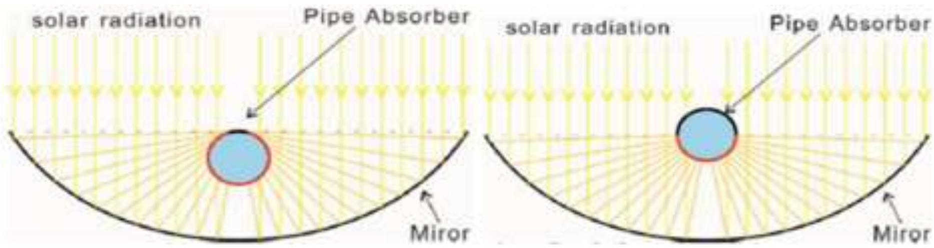


Fig. 4 Representation of two cases of focusing absorber relative to the mirror in PTC
Left: total concentration; Right: half concentration

Fig. 5 schematizes the different cases that we will treat, each case corresponds to a concentration rate applied to the surface of the wall (C=100%; C=75%; C=50% and C =25%). We express C by the expression: $C = \frac{heated\ surface}{total\ surface}$ x100

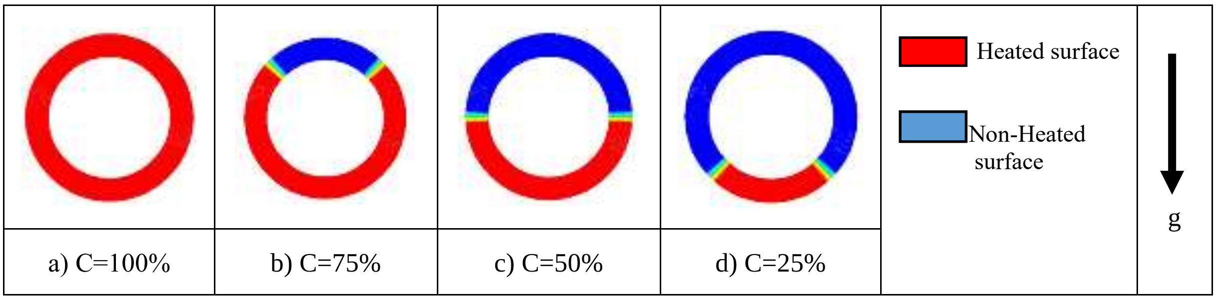


Fig. 5 Representation of the different concentrations on the absorber

6. RESULTS AND DISCUSSIONS

A. The dynamic behavior « Axial velocity »

Figure 6 represents the distribution of the axial velocity in the fully established zone in each simulation case; namely a; b; c and d.

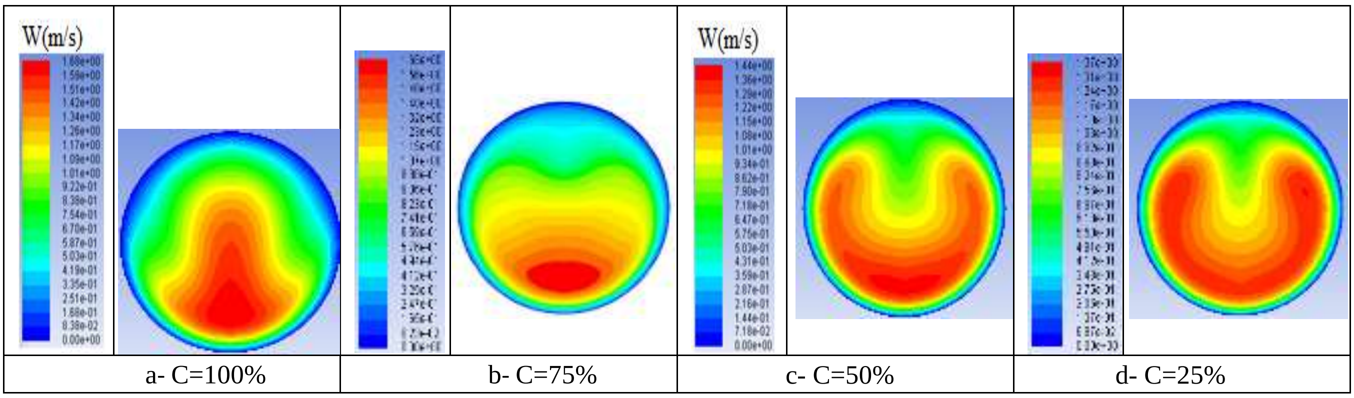


Fig. 6 Axial velocity distribution at Re=2200 and Gr=3x10^{6} for different concentrations.

For case a) (C=100%), the axial flow lengthens and shifts towards the bottom of the pipe. For case b) (C=75%), the high speed region descends completely towards the lower half-section of the tube.

Under the effect of the buoyancy force, the axial velocity appears in a bilateral concave form for cases c) (50%) and d) (25%). The latter appears in a more closed form.

B. Secondary flow

Fig.7. represents the secondary flow velocity field “Vs” for the four cases.

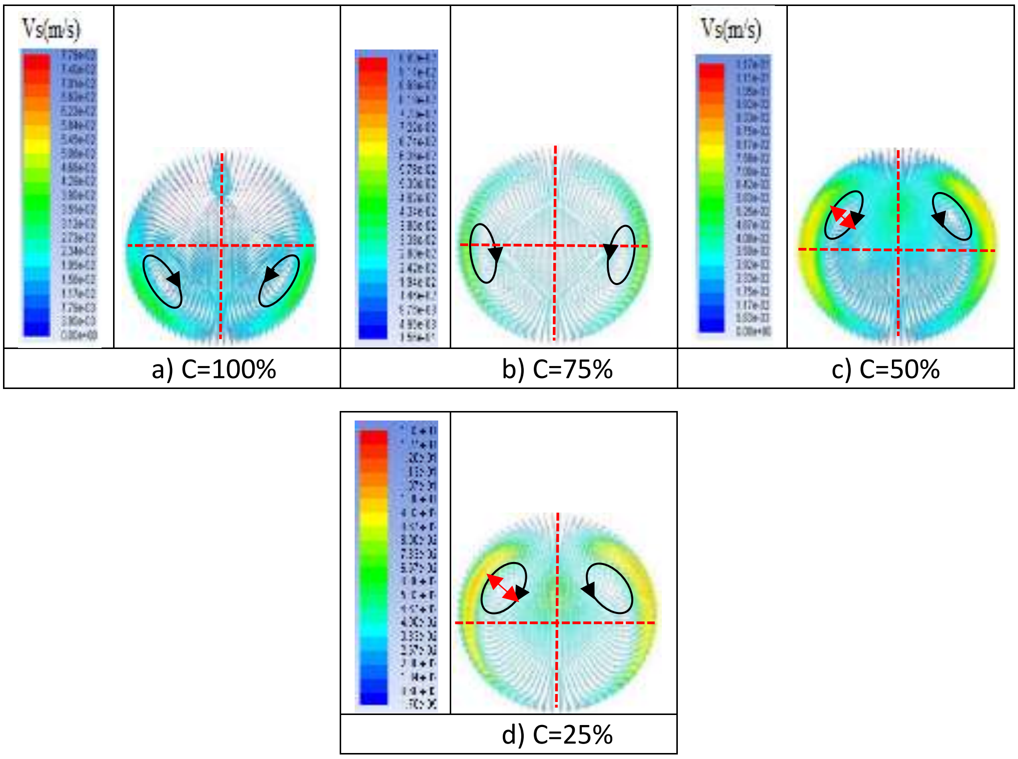
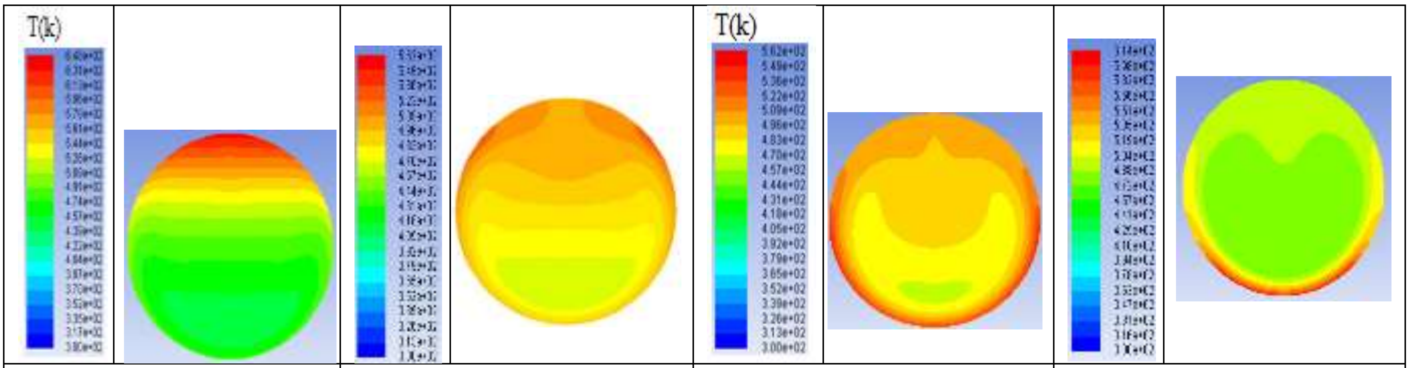


Fig. 7. Secondary flow velocity distribution at Re=2200 and Gr=3x10^6 for different heat flux concentrations.

Under the condition of Boussinesq; we noted the presence of two counter-rotating transverse rollers of a secondary hydrodynamic flow. For case a) (C=100%), the fluid at a higher temperature flows symmetrically along the wall of the tube, from bottom to top, conversely the fluid becoming colder flows towards the down ; This scenario generates a pair of symmetrical vortices or cells emerging in the lower half-section. In case b) (C=75%), the two vortices progress slightly upwards and are located on the horizontal diameter. The latter two are positioned in the upper right half-section for both cases c) and d). In the latter case they appear in a well-established form.

C. Thermal behavior « température »

Fig. 8 represents the evolution of the temperature in the fully established zone of each simulation case. For case a) (C=100%), we observe a temperature stratification throughout the right section. Here the heat transfer is quasi-conductive from top to bottom. In cases b) and c), the temperature contours stretch on both lateral sides to result in a bilateral symmetric concavity, where case c) (C=50%) is well established. As for the last case d) (C=25%), it is the opposite of case a) mentioned above, the high temperatures are concentrated in the lower circumference of the tube (the zone of concentration of the heat flow).



a- C=100%	b- C=75%	c- C=50%	d- C=25%

Fig. 8 The temperature distribution at Re=2200 and Gr=3x10^6 for different heat flux concentration

D. Development of Nusselt number Nu and Friction factor f for different cases of heat flux concentration

Fig. 9 schematizes the evolution of the ratio of Nu in mixed convection compared to that of purely forced convection Nu_0, as a function of Gr at different concentrations.

The Nu number for the case of concentration C=75% is the most affected by natural convection, reaching more than three times its value in forced convection for high Gr numbers.

Fig. 10 illustrates the evolution of the ratio of friction in mixed convection f compared to that of purely forced convection f_0.

The friction factor f is inversely proportional to the concentration rate.

The friction factor for the two cases C=25% and C=50% are very close and are the highest, reaching values more than twice its value in forced convection.

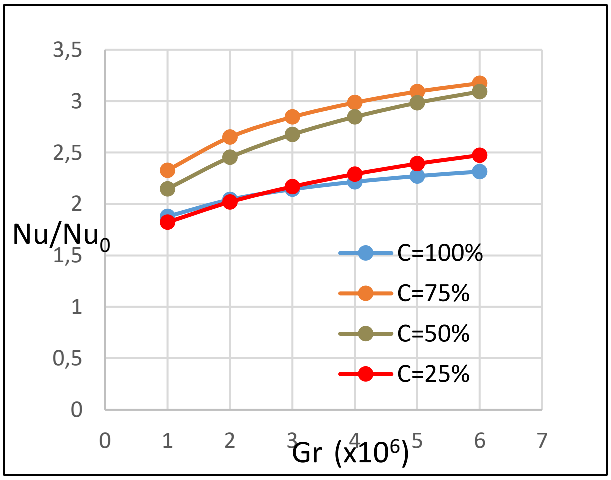


Fig. 9 Nu/Nu_0 vs Gr pour différentes concentrations à Re=2200.

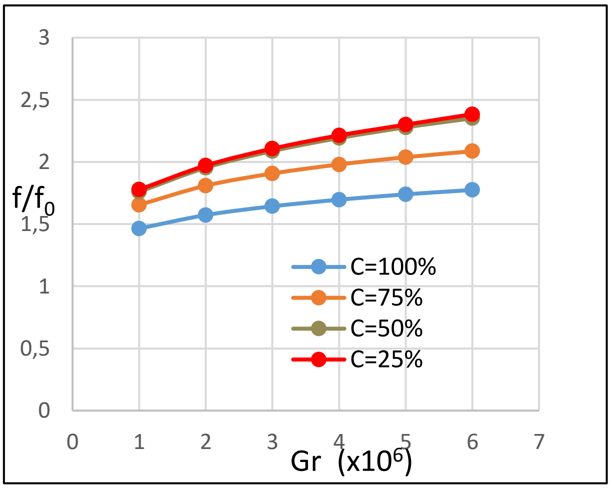


Fig. 10 f/f_0 vs Gr pour différentes concentrations à Re=2200.

E. Performance of naturel convection (Nu/Nu0)/(f/f0) for different heat flux concentrations

We can see in fig .11 that natural convection makes a positive contribution in terms of energy input by improving the performance of the PTC absorber.

In terms of energy, the concentration C=75% is the most favorable because of the Archimedes thrust.

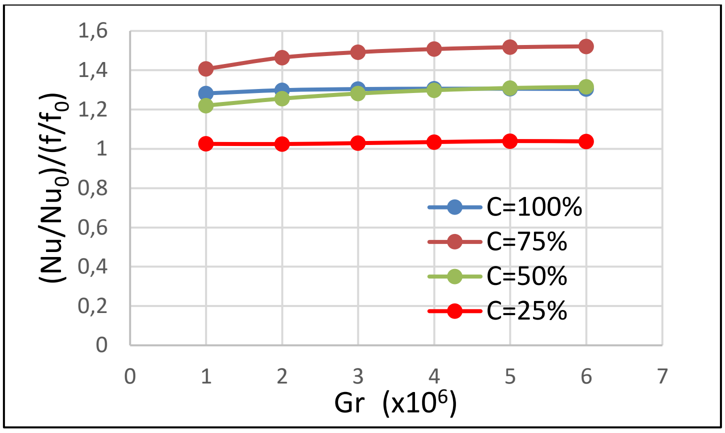


Fig. 11. (Nu/Nu0)/(f/f0) vs Gr for different heat flux concentrations at Re=2200

7. CONCLUSION

The aim of this work is to describe the thermal and dynamic behavior of the absorber of a parabolic cylindrical collector for different heat flux concentrations. Concerning the numerical study, the absorber is horizontal, the heat flow is uniform with a flow in laminar regime. We take into consideration the "Boussinesque approximation" to realize the principle of mixed convection. We conclude that:

- We noted the presence of two counter-rotating transverse rollers of a secondary hydrodynamic flow.

- The heat flux concentration strongly influences the velocity and temperature profile in laminar mixed convection.

- The performance factor of natural convection reaches its maximum value (Nu/Nu0)/(f/f0)=1.52 for the case of C=75% and Gr=6x106.

- The calculation of Nusselt Nu and the friction factor F shows that the concentration C=75% is the most favorable for convective exchange.

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