Study of the Flow and Heat Transfer Characteristics

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ABSTRACT
The present work relates to the study of the characteristics of the turbulent and heat transfer flow from the forced convection in a two-dimensional corrugated periodic wall channel, using the Fluent CFD code. The mathematical formulation of the fluid state based on the Navier-Stokes and energy equations. Turbulence is modeled by the standard two-equation model (k-ε). Numerical solutions are obtained using the finite volume method. The obtained results show an increase in the Nusselt number with increasing Reynolds number and corrugation angle and a decrease in friction coefficient with increasing Reynolds number.

Keywords
Corrugation angle, Friction coefficient, Nusselt number

1. INTRODUCTION
Corrugated Periodic walls channels are used in engineering to improve the heat transfer [1]. The frequent use of corrugations in the plate heat exchangers can promote the reduction of the boundary layer and increasing the turbulence in this one. The development of corrugated surfaces has received much attention and motivation by many researchers. For years, various numerical and experimental studies, approaching the characteristics of the fluid flow and heat transfer in corrugated channels were considered. In addition, it was shown experimentally that after 3-5 cycles i.e. after a short distance from the entrance, the fluid flow and heat transfer become periodically developed (Islamoglu et al. [2]). Amano [3] studied numerically the flow in a horizontal corrugated channel for both laminar and turbulent regimes. To predict the heat transfer and friction coefficients, Faghri and Asako [4] used the finite element method for a range of Reynolds number between 100 and 1500. Asako and Nakamura [5] considered a planar bidimensional corrugated channel with rounded corners and conducted a numerical study based on the finite volume method for predicting the fluid flow and heat transfer characteristics for the established laminar regime for a range of Reynolds number varying between 100 and 1000. Xin and Tao [6] simulated a bidimensional sinusoidal channel by assuming the existence of a laminar flow set to values of Reynolds number equal to 1000, using the method of finite differences. Sunder and Trollander [7] have considered bidimensional laminar flow and heat transfer in a corrugated channel considering the finite difference approximations. Wang and Vanka [8] presented the heat transfer characteristics of an unstable flow in periodic wavy passages. Asako et al. [9] considered the laminar flow in a corrugated cross section trapezoidal channel. The effects of parameters related to the corrugated geometry and Reynolds number on the friction coefficients and Nusselt were studied by Wang and Chen [10]. Many experimental studies on the characteristics of mass and heat transfer in corrugated channels have been developed. For example, the study carried by O'Brien and Sparrow [11], where the authors presented for turbulent flow an empirical correlation for the average Nusselt number and they noticed that the coefficient of friction is independent of the Reynolds number. Sparrow and Comb [12] completed the previous observations by analyzing the effect of varying the amplitude and the fluid inlet on the characteristics of flow and heat transfer conditions for a corrugated channel numbers Reynolds from 2000-27000. The effect of two different values of the height (5mm and 10mm) of the channel at an angle $\alpha = 20^c$ on the characteristics of heat transfer and friction of a corrugated channel were examined by Islamoglu and Parmaksimoglu [13]. A numerical study has been developed by the two authors using the finite element method to study and simulate the heat transfer coefficients in a bidimensional periodic corrugated channel. Measurements of heat transfer and pressure drop in a corrugated channel were made by Islamoglu et al. [14] and Islamoglu and Parmaksimoglu [15] with an angle $\alpha = 30^c$ for turbulent flow by considering the air where they presented an empirical correlation for the developed Nusselt number.

2. MATHEMATICAL MODEL
This study concerns the analysis of flow in a corrugated channel. The considered fluid (air) is incompressible, Newtonian and has constant properties. The flow is two-dimensional and permanent. The viscous dissipation is negligible. Turbulence model standard (k-ε) is used to simulate the characteristics of the flow and heat transfer. The governing flow equations are continuity equation; conservation equation of motion; and the turbulent kinetic energy equation.

Boundary Conditions
Experience has shown that the fluid flow is periodically developed after a short distance from the entrance (3-5 corrugations). In the present study, to reduce the mesh size and computation time, the periodicity condition is applied between the input and output channel and a constant heat flux is imposed on the main walls of the channel. To avoid numerical difficulties considering the turbulence model (k-ε), special treatment is applied near the wall. The numerical analysis is considered in order to determine the Nusselt number and the friction coefficient in this corrugated channel.

3. NUMERICAL PROCEDURE
The used numerical method to solve the conservation equations of our system is based on the finite volume method (Patankar [16]). The TDMA (Tri-Diagonal Matrix Algorithm) algorithm is used for solving the

equation system. Convergence is reached when the maximum of the standardized residues (absolute values) for each φ variable, relative to a reference value in all control volumes is less than ε. To obtain satisfactory solutions, different meshes were considered for the two and three-dimensional flow. The independence mesh test showed that for two-dimensional and three-dimensional flow, 99270 and 227392 respectively meshes give satisfactory numerical solutions.

4. RESULT AND DISCUSSIONS

The numerical results of the Nusselt number as a function of Reynolds number for a corrugated channel are shown in Figure 1. We see that the Nusselt number is influenced by the Reynolds. We also find that the more Reynolds increases and the more Nusselt increases and the Nusselt numbers are higher than that of the smooth channel. Note that our numerical results are in good agreement with the experiment (Islamoglu et al.)[2]

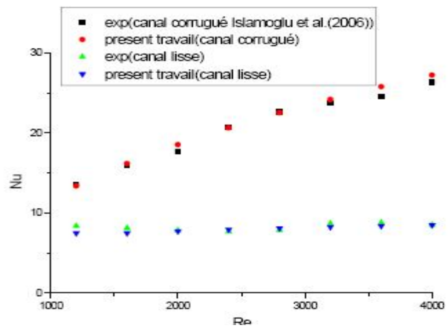

Figure1: Variation of Nusselt number as a function of Reynolds number

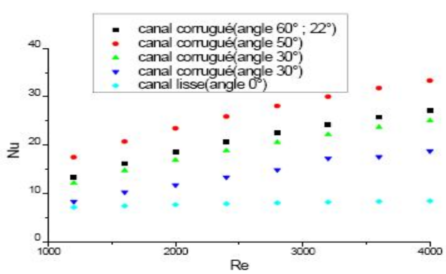

Figure2: Effect of corrugation angle on the Nusselt

Figure 2 shows the influence of corrugation angle on the Nusselt number. It increases with increasing angle. The numerical results for the coefficients of heat transfer as a function of Reynolds number for different corrugation angles are presented in Figure 3. The heat transfer coefficient increase with increasing angle of corrugation and especially for large Reynolds numbers. These results are in good agreement with the experimental Islamoglu et al.[2].

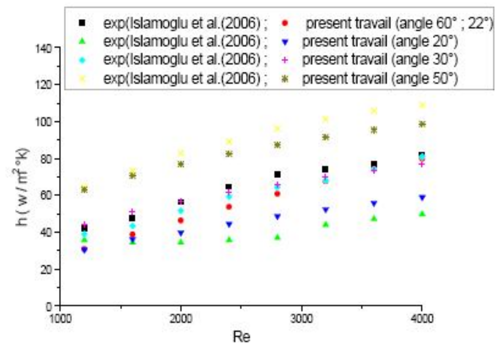

Figure 3. Effect of corrugation angle on heat Transfer coefficient

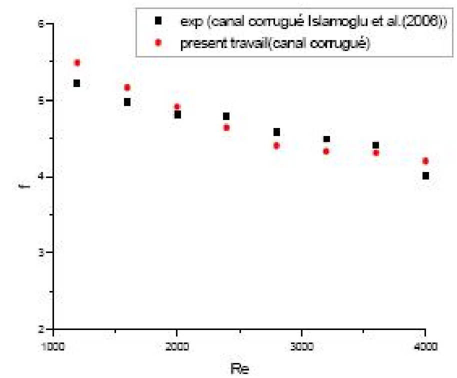

Figure 4. Friction factor as a function of Reynolds

The representation of the friction coefficient as a function of Reynolds number is given by figure 4. It is seen that the friction coefficient decreases with increasing Reynolds number. It also noted that there is good agreement between these results and those of Islamoglu et al. [2].

Figure 5 shows a central flow with large velocity and particularly where the section is reduced and decrease to zero near solid walls of corrugated channel.

Figure 6 shows that the imposed periodicity condition is satisfied, the flow is the same in the channel.

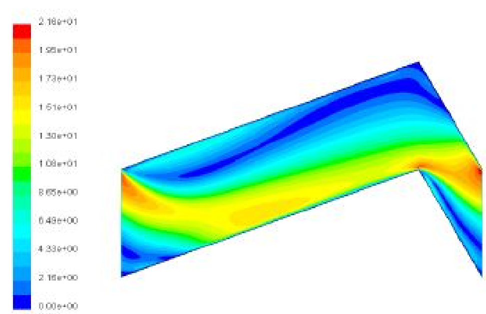

Figure 5. Contours of the average velocity S/e=3, H/S=0.33, and Re=4000

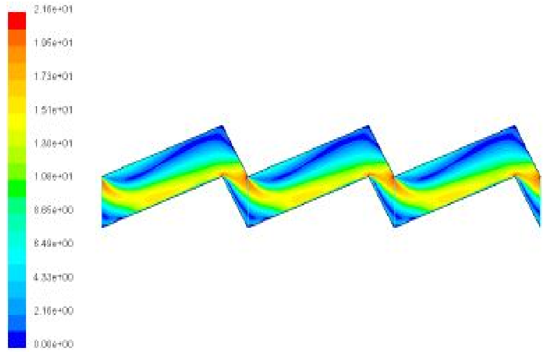

Figure.6 Contours of velocity with S / e =3 H/S=0.33

Figure 7 shows the contours of pressure. Pressures are the highest at the impact of the fluid. On the end facing of the flow the kinetic energy is transformed into pressure energy.
Figure 8 shows that the imposed periodicity condition is satisfied

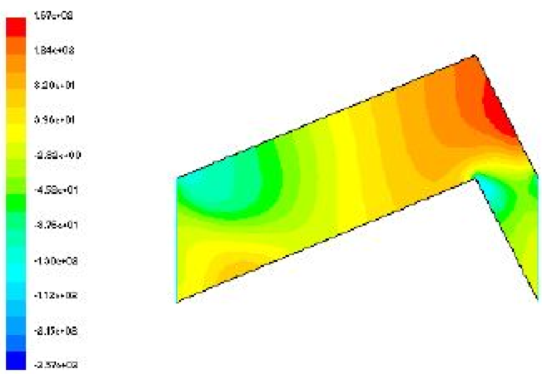

Figure 7. Contours of pressure S/e = 3, H / S = 0.33and Re = 4000

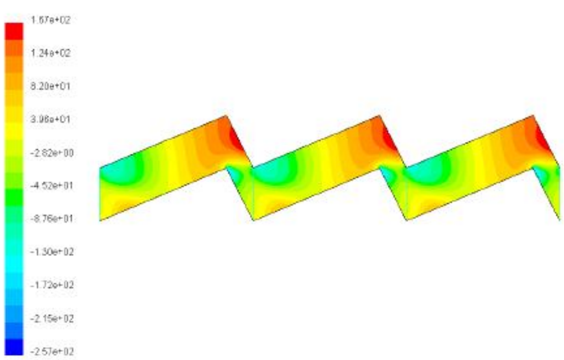

Figure 8. Contours of pressure with S/e = 3, H / S = 0.33

The velocity contours for different aspect ratios are shown in figure 9(a, b, c) for a Reynolds number Re = 4000. A decrease in H / S that is to say the height causes an increase in velocity.

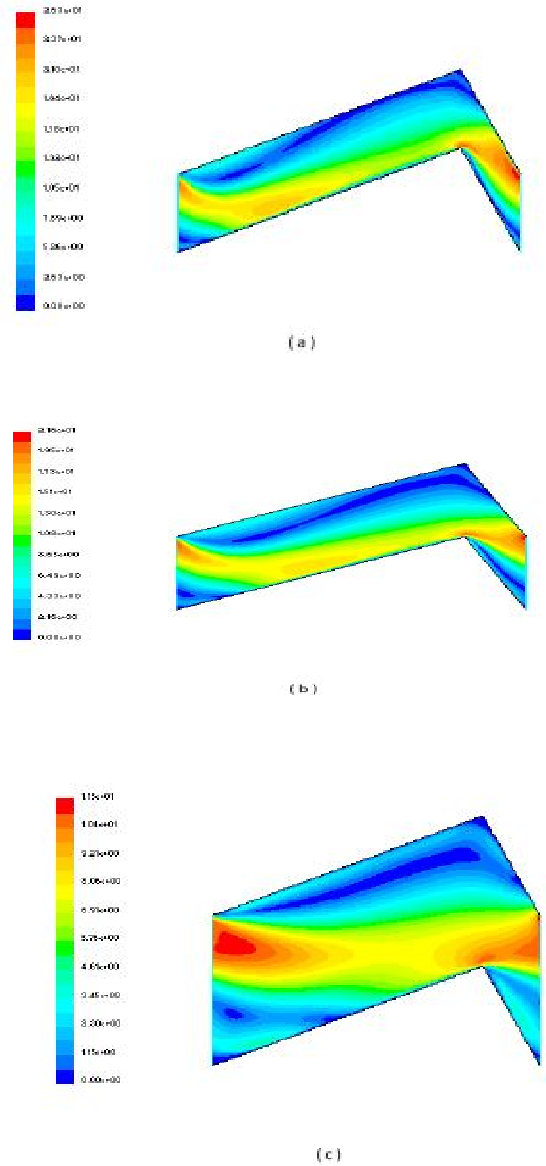

Figure 9. Velocity contours for different ratios S / e = 3 and Re = 4000 (a) H / S = 0.25, (b) H / S = 0.33, and (c) H / S = 0.5

The velocity contours in different planes x = const and z = const are shown in Figures 10 and 11 On entering the maximum velocity value is located in the top wall, the same phenomenon is observed at the output (periodicity conditions satisfied) and is offset towards the bottom walls in the other planes.

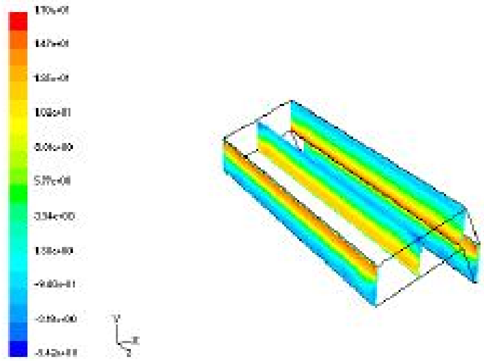

Figure 10. Velocity Contours in different plane x = constant with Re = 4000

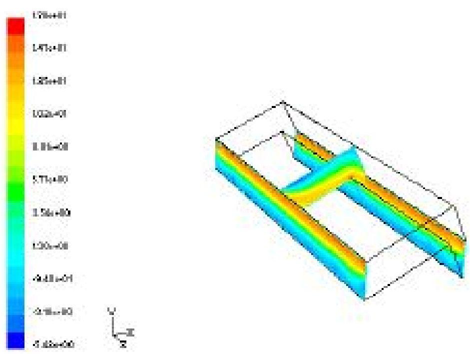

Figure 11. Velocity contours in planes z = constant and x = constant, Re = 4000

The contours of pressure in different planes x = const and z = const are shown in figures 12 and 13. At the entrance, the pressure is relatively low along the upper wall and high along the lower wall, this result is consistent with the velocity field, the same phenomenon is observed at the output.

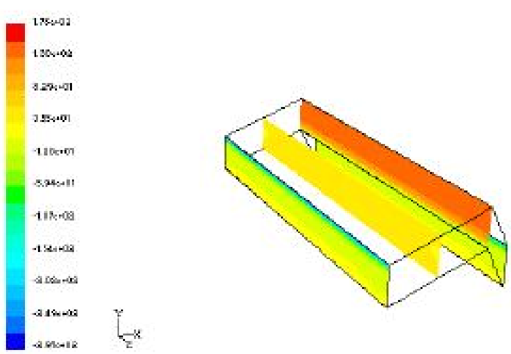

Figure12. Contours of pressure in different plane x = constant, Re=4000

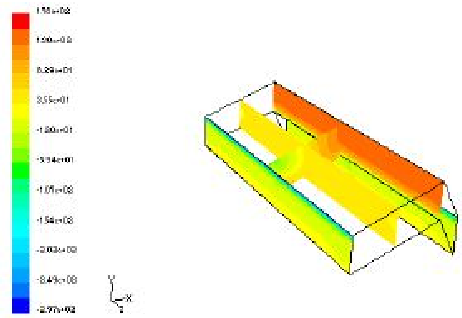

Figure13. Contours of pressure in planes z = constant and x = constant, Re = 4000

5. CONCLUSIONS

The effect of Reynolds number and geometric parameters, that is to say, corrugation angle and aspect ratio on the friction coefficient and the Nusselt number were studied.

1- The results show that the Nusselt numbers are very high as compared to those of the smooth channel.

2- They also show that increasing the Reynolds number leads to a decrease in the coefficient of friction.

3- These results were compared with those of experience and a good agreement was noticed.

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