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Unsteady Numerical simulation of turbulent forced convection in a rectangular pipe with inclined porous baffles

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Abstract

This study presents an Unsteady Numerical simulation of turbulent forced convection in a rectangular pipe with inclined porous baffles. An Unsteady Numerical simulation was carried out to study the thermal performances of a rectangular pipe with the porous baffles of a different angle. The porous baffles which are arranged on the bottom and top channel wall in a periodically way. This technique is used to increase the heat transfer coefficient the fluid (air). We solved numerically, by the finite volumes method, the equations of conservation, of the mass, the momentums equations, and energy. The Reynolds number the 10000-50000 a k -ε turbulent model was adopted for the taking into account of turbulent. The velocity, pressure, and terms of momentum equations are solved by algorithm SIMPLEC. The parameters studied include the entrance mass flow fluid rate, the unsteady regime of fluid. The influence of mass flow rate of air, the axial velocity and time.The efficiency of rectangular pipe with inclined porous baffles numerically Unsteady. The results show that the flow and heat transfer characteristics are strongly dependent on the mass flow rate of air and the geometry of the porous baffles and the inclined porous baffle. It was observed that increasing the parameters Reynolds number will decrease the Nusselt number, as expected.

Keywords:*Porous media; Horizontal Canal; Thermal transfer and matter; Model Darcy-Brinkman-Forchheimer; Forced convection; Porous baffles.*

Nomenclature

c1, c2	turbulent constant
C	inertia factor
$\mathbf{d_p}$	particle diameter
$\mathbf{D_h}$	hydraulic diameter
f	friction factor
H	heigthtchannel
h	baffle height
I	turbulence intensity
$\mathbf{k_d}$	stagnant conductivity
$\mathbf{k_e}$	effective thermal conductivity of the porous baffle
$\mathbf{k_f}$	thermal conductivity of the fluid
$\mathbf{k_t}$	thermal dispersion conductivity
$\mathbf{K_p}$	permeability
k	turbulent kinetic energy
$\overline{Nu}^{+}_{p,i}$	Averaged Nusselt number for baffled channel flow
$\overline{\mathbf{Nu}}^{+}_{\mathbf{SC}}$	Averaged Nusselt number for the smooth channel
P	Pressure
Re	Reynolds number
S	baffle spacing
$\mathbf{S_\Phi}$	Source term
T	température
$\mathbf{T_{in}}$	température inlet
$\mathbf{U_{in}}$	intel velocity
u	velocity in the x direction
v	velocity in the y direction

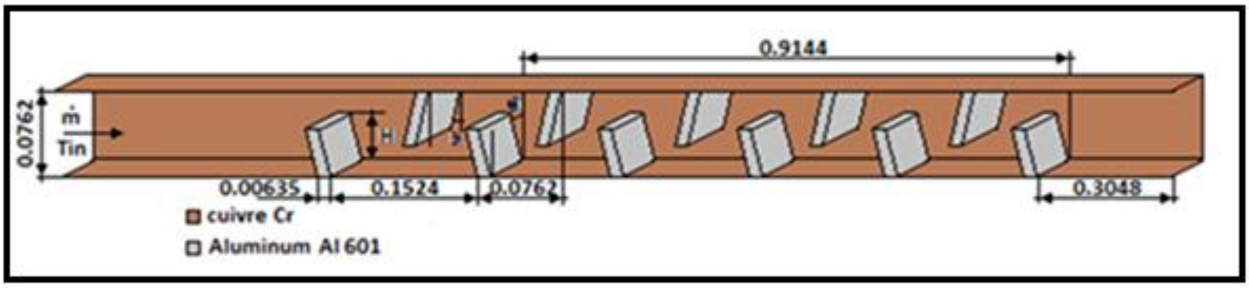


Fig1. The inclined porous baffles porous baffle

The symbols

ø	transported scalar
ρ	density
μ_t,μ_e,μ_l	laminar, turbulent and effective viscosity
σ_k,σ_ε,σ_T	k-ε turbulence model constant of k, ε and T
ε	porosity
α_p	thermal diffusivity of porous media
ε	turbulent energy dissipation rate

The index

f	external flow field
p	porous media

1. Introduction

The Turbulent forced convection in a pipe with different porous baffles geometry was investigated, recently, in a large number experimental and numerical works. This interest is due to the various industrial applications of this type of configuration such as cooling of nuclear power plants and engine... etc.

The researchers have sought to resolve the problem of fluid flow and heat transfer in fully developed heat exchangers. Kang-HoonKo et al [1] experimental are done to calculate average heat transfer coefficients and friction factor of the rectangular pipe with porous baffles and the walls are uniformly heated. Heat transfer coefficients and friction factor drop are obtained for completely developed flow regularly and enhancement heat transfer which are obtained porous medium for various porous types and compared with the effect of foam metal baffle. The porous baffles provide heat transfer rate as high compared to heat transfer without baffles in a rectangular channel. Yue-Tzu Yang et al [2] studied numerical simulation to several times know the turbulent heat transfer increase in the conduct of the baffles for which porous media was used for baffles studied. By using the κ-ε turbulent model for analysis, two-dimensional asymmetric simulations were done to study the heat transfer characteristics of a conduct with porous baffle and conduct with solid baffle. HamidouBenzenine and al [3] observed the heat transfer in a complicated component design of nuclear reactor, heat exchangers, cooling industrial machine and electronic components are improved in the turbulent flow. PrashantaDatta and AkramHossain [4] the effect in a rectangular conduct of local heat transfer and friction factor with inclined and perforated baffles is studied. Two baffles are used in this experiment, one is mounted at the top and other one varied to identify the optimum configuration for improving heat transfer. Louhibi et al. [5] studied mainly the influence of baffles inclination and number on heat transfer and fluid flow. The increase in the baffle inclination improves heat transfer and also try to refine more the turbulence model. Srikrishna et al. [6] A numerical study is also performed as part of this investigation primarily for flow visualization and pressure drop prediction model foams with different porosities (0.95, 0.25, 0.75). A non-Darcy formulation is used in the numerical model with a packed bed assumption. The maximum experimental uncertainties associated with the Nusselt number and friction factor are calculated to be ±9.18 % and ±4.79 % respectively

The convection turbulent heat transfer and pressure drop for the rectangular conduct with inclined porous baffles. In this study, the characteristics of a steady-state turbulent flow and heat transfer in a rectangular pipe with inclined porous baffles are investigated numerically using commercial software fluent 6.3.26 under constant wall heat flux boundary condition. Standard k-ε turbulence model is used to simulate flow. The effects of Reynolds number, baffle distance and baffle angle on fluid flow and heat transfer are examined. The results of this investigation are hoped to provide numerical data for turbulent convective heat transfer in complex geometries.

2. Mathematical formulation

The geometry of the problem is presented in Figure. 2-a, and -b. The system consists of air flow moving through a Rectangular channel provided with inclined porous baffles. Two different forms of baffles are analyzed; a first form is plate porous baffle (Figure. 2a) and a second form inclined porous baffle (Figure. 2b). The geometry, coordinate system, computational domain, and characteristics of the rectangular conduct used in the present study are shown in Figure. 2a.

The rectangular channel provided with inclined porous baffles. Two different forms of baffles are analyzed; a first form is plate porous baffle (Figure. 2a) and a second form inclined porous baffle (Figure. 2b). The geometry, coordinate system, computational domain, and characteristics of the rectangular conduct used in the present study are shown in Figure. 2a.

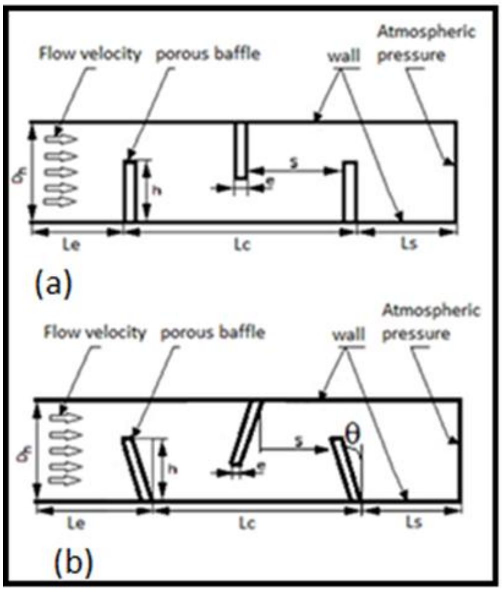


Figure2. A comparison between the inclined porous baffles and the transversal porous baffles

Computational domain consists of three consecutive parts: a 1.2192 m in length entrance section Le, a 1.0668 m in length test section Lc and a 0.3048 m in length exit section Ls and angle of porous baffle the 0°, 15°, 30°, 45°respectively. The principal flow is in the X-direction. In figure. 2-a, s is the baffle distance, Le – the length of the entrance section, Lc – the length of the test section, Ls - the length of the exit section e – the porous baffle thickness, h – the baffle height, and Dh – the diameter of the rectangular pipe. The shaded area consisting of three baffles shown in the figure. 2 (b) is called module.

2.1. Field of study

The general transport equation that describes the principle of conservation of mass and momentum can be written in the following conservative form Patankar [3]. The flow field is compressible, stable, isothermal turbulent flow. In a Cartesian system continuity den formed tensor equation is:

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

with ;

$$G = \mu_t\left\{2\times\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2+\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial z}+\frac{\partial w}{\partial x}\right)^2\right]\right\} \quad (2)$$

$$\mu_e = \mu_l + \mu_t \quad (3)$$

$$K_P = \frac{d_p^2\psi^3}{180(1-\varepsilon)^2}\ ;\ C = \frac{1.75}{\sqrt{150\ \varepsilon^{1.5}}}\ ; \quad (4)$$

$$|U| = \sqrt{u^2+v^2+w^2} \quad (5)$$

3. Numerical approach

Numerical solutions are made using Ansys Fluent 12.3.26, a CFD program based on commercial finished volumes. The unsteady turbulence is modeled by a standard k-ε turbulence model with improved wall treatment, a modeling procedure approaching the wall that combines two different laminar and distended turbulent regions [7]. Numerical simulations were tested by varying the number of calculation elements. The stability and convergence of the model achieved for all networks has been ensured.

Unstructured grid elements used because it felt to be more suited for geometry to study a rectangular pipe with porous baffles. The governing equations of our problem are solved by the finite volume method (FVM), based on the SIMPLEC algorithm (Patankar, 1980) Reynolds averaged Navier-Stokes equations are solved numerically in conjunction with the transport equations for flow turbulent unsteady. Regions close to the wall are fully resolved for y + 14.53 in all calculations. In this study, non-uniform grids are used for all numerical solutions performed. Typical distribution of mesh on x-y-z for various inclined porous baffles.

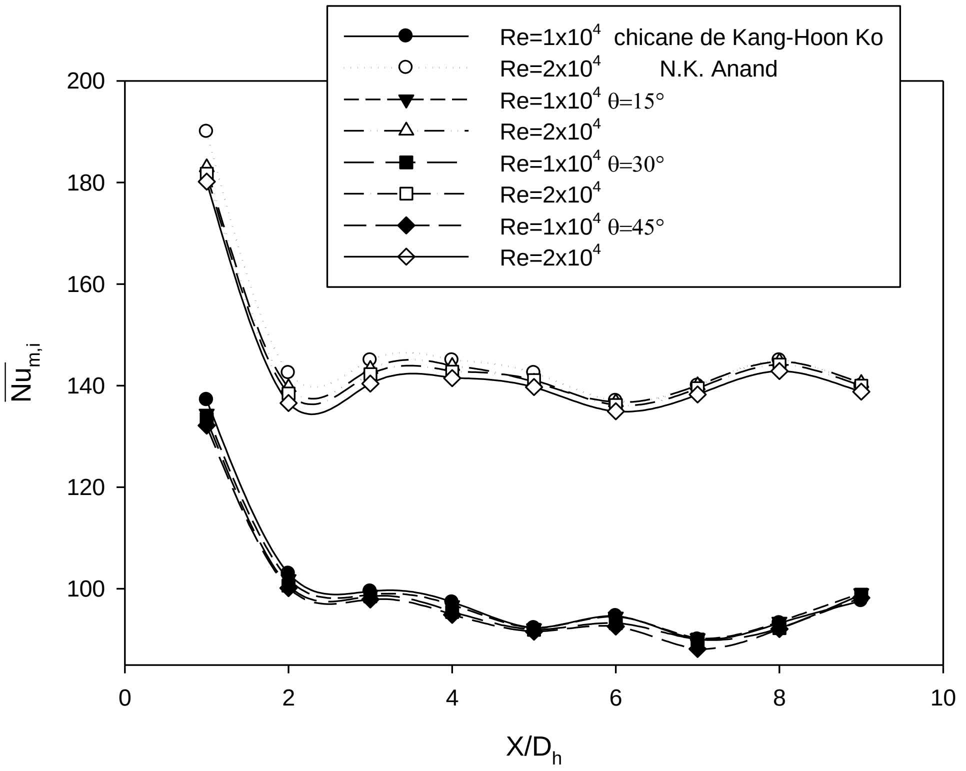


Figure 3. Average module Nusselt number between two forms transversal porous baffle and inclined porous baffle 20PPI, h / Dh = 1/3

The grid independence study is performed by changing the size of the mesh within the computational domain until the variation of the velocity error is less than 0.010% and 0.013%, respectively. The stable segregated solver is used with a second-order wind pattern for convective terms in mass, momentum, energy, and turbulence equations. SIMPLEC-algorithm.in table.1. The choice of this mesh is justified by the difference between the values found is less than 2%.

For the numerical simulations presented in this work, we refer to the numerical and experimental work done by Kang-HoonKo, N.K. Anand [1] who studied the porous baffles with a plane shape. Award porous baffle is considered, and all the modeling conditions are inspired by the numerical study. Sensitivity analysis of the mesh and the numerical model validation is presented in this section.

Table1.Errors of a grid in conduct with inclined porous baffle the Angle θ=0°.

Grid	72×15×15	72×30×30	72×45×45	40×45×45
X(m)	1.67	1.67	1.67	1.67
Y(m)	0.0406	0.0406	0.0406	0.0406
Z(m)	0.038	0.038	0.038	0.038
U_{max}/U_0	1.959	1.985	1.909	2.021
Erreur	0.026	0.023	0.0204	0.028

Table2. The reference velocity for all cases treated.

Baffle Angle	**U_0 [ms^{-1}]**	**U_{max} [ms^{-1}]**	**U/U_0**
θ=0°	5.750923	9.7292	1.6396
θ=15°	5.750923	9.7253	1.6911
θ=30°	5.750923	9.6500	1.6780
θ=45°	5.750923	9.3504	1.6259

5. Resulted and discussion

Dimensionless axial velocity Ux/U0 profiles on the plane, x1, x2, see figure (a), (b).Are plotted in fig. 4 at different locations along rectangular conduct when **Y/Dh** = 1 and θ = 0° for **Re** = 30,000. Axial velocity values are scaled to the inlet velocity. The figure on the left side shows the dimensionless axial velocity profiles along lines of x1, x2, x3, and x4, shown in the figure. 4 at the middle of the baffles, for Re = 30,000 20**PPI** h/Dh=2/3. The figure on the right side indicates the dimensionless axial velocity profiles along lines of x1, x2, x3 and x4 shown in figure 4, at the middle of the baffles in the second half of the modules, for Re = 30,000 **PPI**=20 h/Dh=1/3. As will be seen from figure4, the velocity profiles in third and fourth modules, i. e. along lines of x1 and x2, and x3 and x4 are almost same. In other words, flow approaches periodically fully developed conditions at the third module.

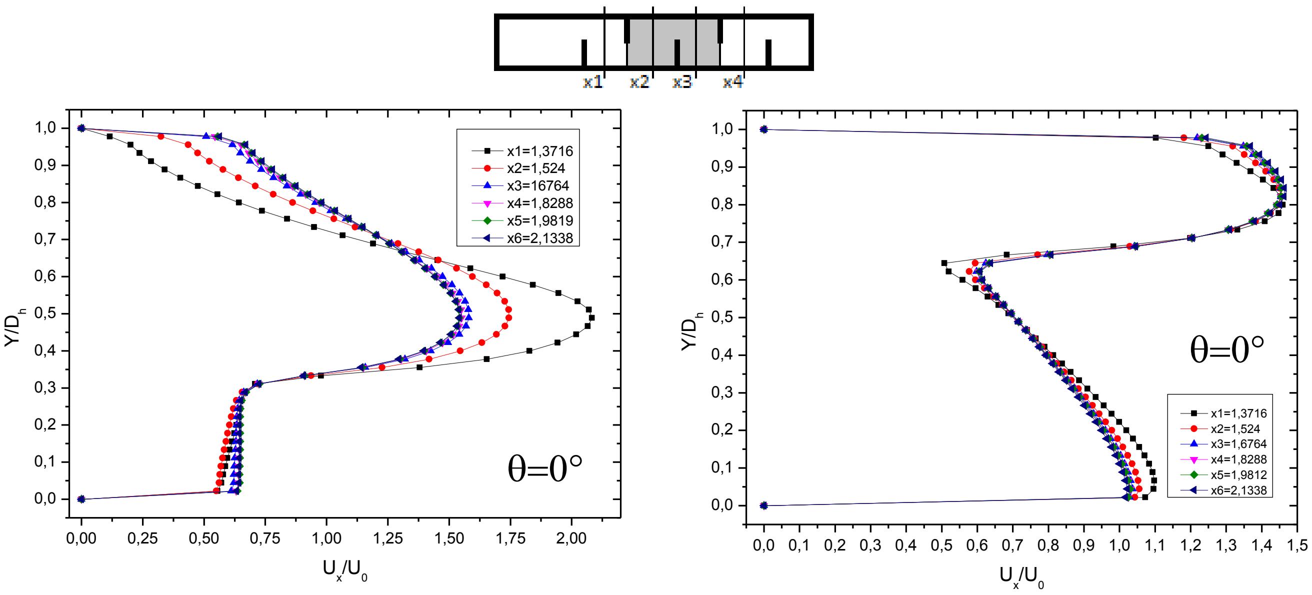


Figure 4. Axial velocity profiles on the conduct with porous baffle for θ =0°, Re = 30,000 and 20PPI

The negative velocities point out the presence of recirculation behind the porous baffles. It can be seen in fig. 8a that velocity increases in the lower half of the pipe due to baffle placed in the higher part of the duct, and reverse flow occurs in the higher part of the conduct. Regarding figure.4 (b), velocity increases in the higher part of the rectangular section pipe due to increasing the height of the porous baffle placed in the lower part of the rectangular conduct, and reverse flow happens in the lower part of the pipe. As can be seen in figure 2, the velocity at the wall is zero due to no-slip boundary conditions which are used in this study.

In figure5, dimensionless axial velocity profiles Ux/U0 on the plane, see figure5 (a), (b), are plotted along line x1 shown in figure, at the middle of the two inclined porous baffles in the first half of the fourth module (last module), at four different porous angle baffle when θ = 0°, 15°, 30°, 45°and Re = 2×104 and 40 PPI. It is seen that the magnitude of dimensionless axial velocity increases with decreasing porous baffle angle.

It is also seen that the intensity of reverse flow increases with decreasing porous baffle angle, so reverse flow with high-intensity results in high-pressure loss and high friction factor flow in the higher half of the pipe. As can be seen in the figure. 5, recirculation occurs after porous baffles.Typical streamline contours are given in figure6 for four different porous baffle angles at h/Dh =1/3 and Re = 20,000 and 20 PPI

It is seen that the presence of the baffles which are placed in the lower half of the pipe cause a reduction of velocity in this region while they cause an increase in the flow in the higher half of the pipe. As can be seen in figure 6, re-circulation occurs after porous baffles

Maximum velocity is obtained for θ = 0° due to decreasing flow passage area. Typical streamline contours are given in figure 6 for four different baffle angle (θ = 0°, 15, 30° and 45°) at h/Dh = 1/3 and Re = 20,000. It is seen that reverse flow occurs after the baffles; negative values on the scale indicate the reverse flow. It is also seen that velocity increases due to angle porous baffles decreases. These results clearly show the importance of the presence of porous baffle (acting as a cooling fin). Since the recirculation zone, downstream of the porous baffle, depend on the inclination angle so this last effect isotherms and streamlined structures and effect, consequently, the heat transfer through the channel.

Indeed, the porous baffle increases heat transfer between the wall and the fluid. So, this increase depends on porous baffle position and angle inclination. Concerning temperature distribution one distingue two different zones:in the top region, fluid temperature is higher in the case of vertical porous baffles θ = 0°.

Whereas it's lower in the bottom region. This can be explained by the fact that the fluid passing the region between the first porous baffle and the channel top wall is heated more and more when the inclination angle, θ, creases.

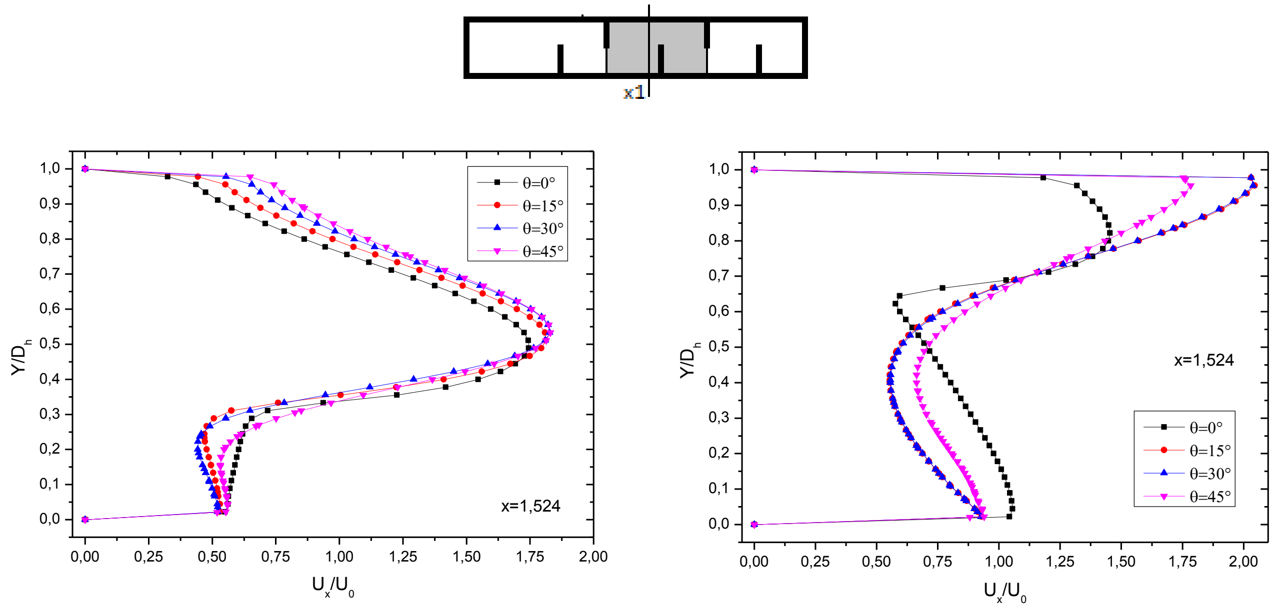


Figure 5. Axial velocity profiles on the conduct with porous baffle for x1 =1.9812, Re = 20,000 and 40PPI

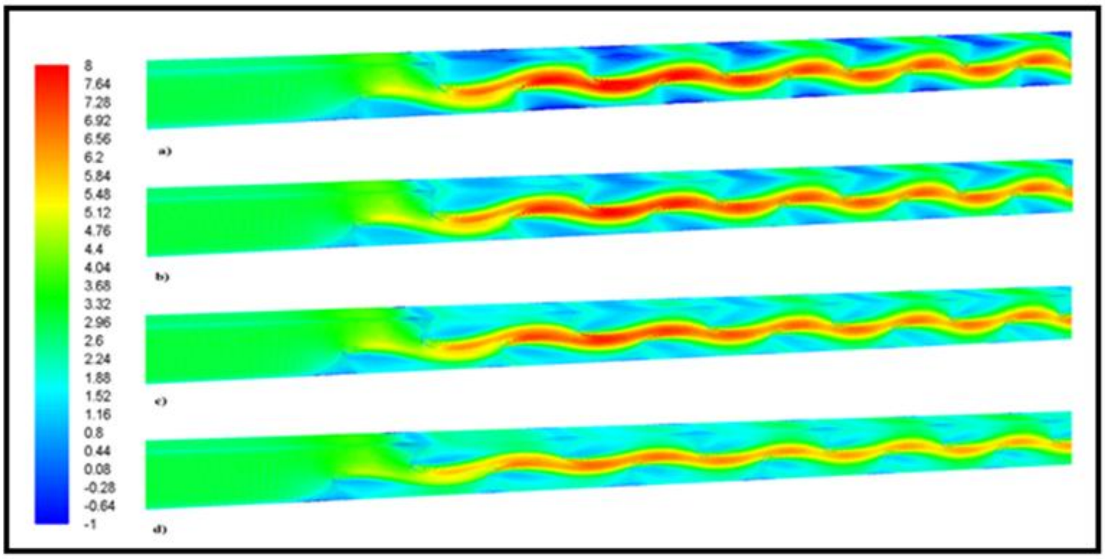


Figure 6. Axial velocity field in a rectangular pipe with inclined porous baffle a) θ=0°9

This is because this region becomes small as the inclination angle θ increases. Thereby the fluid reaches the second porous baffle with a higher temperature and velocity. Indeed, the higher velocity allows the fluid to keep its temperature, due to the exchange with the lower cold region minimal. Consequently, the fluid in the lower region has a minimum temperature. As will be seen from fig. 7.

The variations of the heat transfer enhancement ratio $(\overline{Nu^{+}})$ and friction factor f with the Reynolds the number of various cases is shown in Fig.8. Respectively for a fixed value of $h / D_h = 1/3$.

The friction coefficient decreases slightly with increasing Reynolds $h / D_h = 1/3$, $h / Dh = 2/3$ Fig 8. and9. As expected porous baffles $h / D_h = 1/3$ is the highest contribution by the inclined porous baffles $h/D_h = 2/3$. In general, the coefficient of friction increases with an increase in porous density PPI for a fixed Reynolds number decreases with the angle θ increase. This behavior is attributed to the surface of contact between the fluid and the solid. Increasing the density of the pores, there by increasing the amount of hydraulic resistance.

The influence of the friction coefficient depends on the speed, the density of pores and inclined baffles. With the angle θ increases. This behavior is attributed to the surface

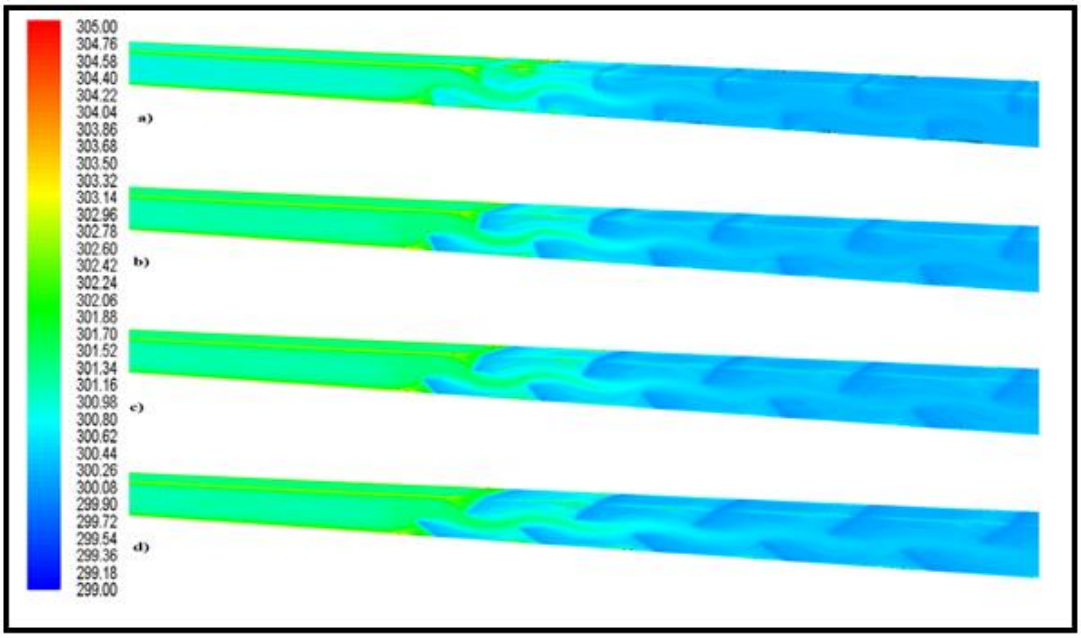
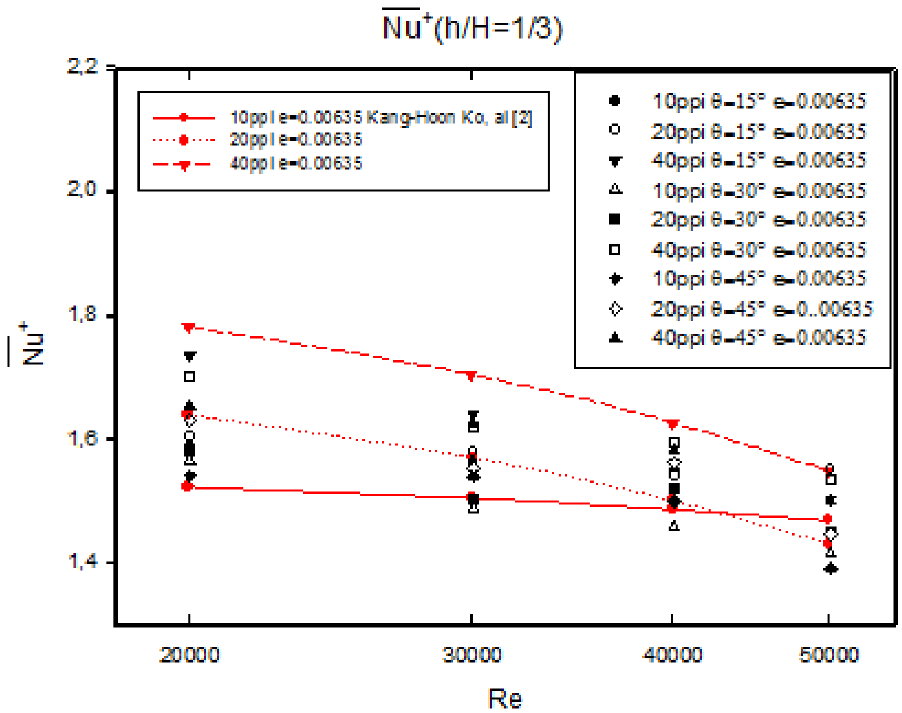


Figure 7. The distribution of the total temperature in a rectangular pipe for four cases studied θ = 0 °, 15 °, 30 °, 45 ° for PPI20 inclined porous baffles, h / D_h = 1/3 Re = 2 × 10^4

of contact between the fluid and the solid. Increasing the density of the pores, there by increasing the amount of hydraulic resistance. The influence of the friction coefficient depends on the speed, the density of pores and inclined baffles.

The heat transfer enhancement ratio decreases with increasing Reynolds number. This is attributed to the turbulence effect plays a much more important role than the effects of porosity. For a density of well-defined pores, the ratio of the height h / D_h = 2/3 improve the heat transfer increases with the porous density PPI 10 20 40 PPI inclined shape. It is obvious that the ratio $\left(\overline{Nu^+}\right) = \left(\overline{Nu^+_{P,i}}\right)/\left(\overline{Nu^+_{SC}}\right)$ for a porous baffle, always transverse upper baffle inclined porous. This behavior is expected that the porous rectangular baffle provides a large heat transfer by convection and by diffusion of heat. But from Fig 8. it is clear that to greater heights h /Dh = 2/3, the flow increases proportionally to the density of the porous effect. Reynolds increases inversely with the heat transfer rate $\left(\overline{Nu^+}\right) = \left(\overline{Nu^+_{P,i}}\right)/\left(\overline{Nu^+_{SC}}\right)$slightly by intake Kang baffles - Hoon NK. [1].



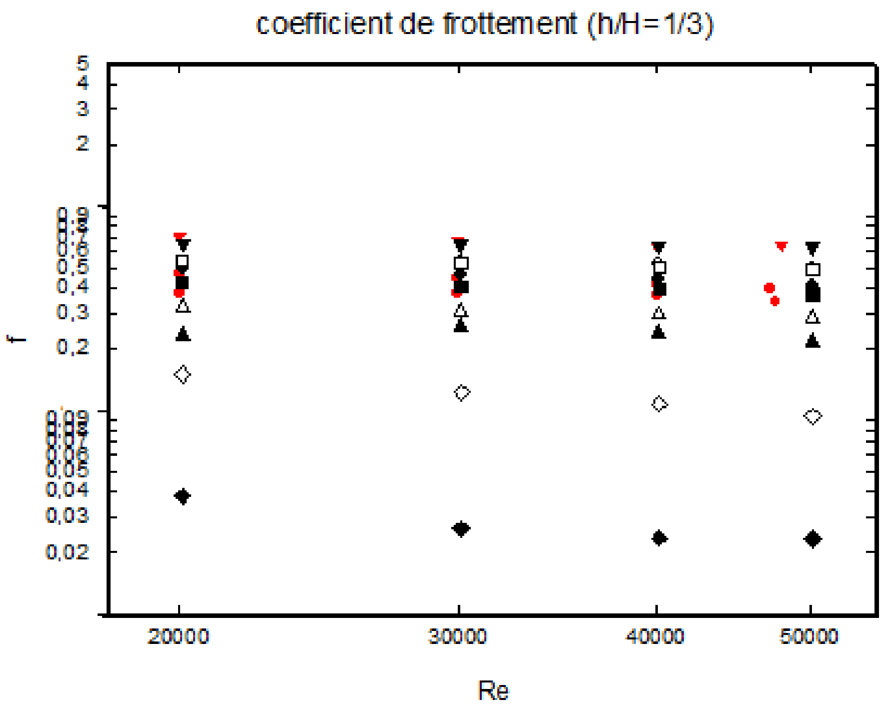
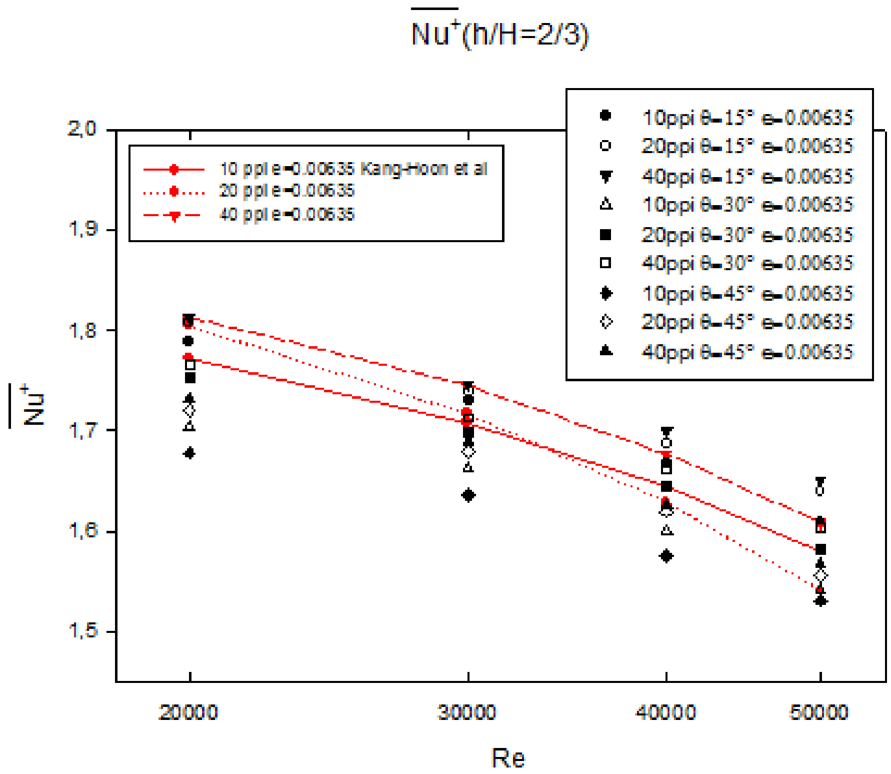


Figure 8. A comparison between the baffles of Kang-HoonKo, Anand, N.K, the inclined baffles porous and the heat transfer ratio and the friction factor h / D_h = 1/3



5. Conclusion

A numerical study has been carried out of the transfer of heat by forced convection turbulent is available in a rectangular tube equipped with porous inclined baffles to improve the phenomenon of the transfer of heat at the exit of the pipe. The effects of the geometry and density of the pore pulses on the dynamic behavior of heat and flow were examined for the two cases, Hoon Kang baffles, NK and the porous inclined type.

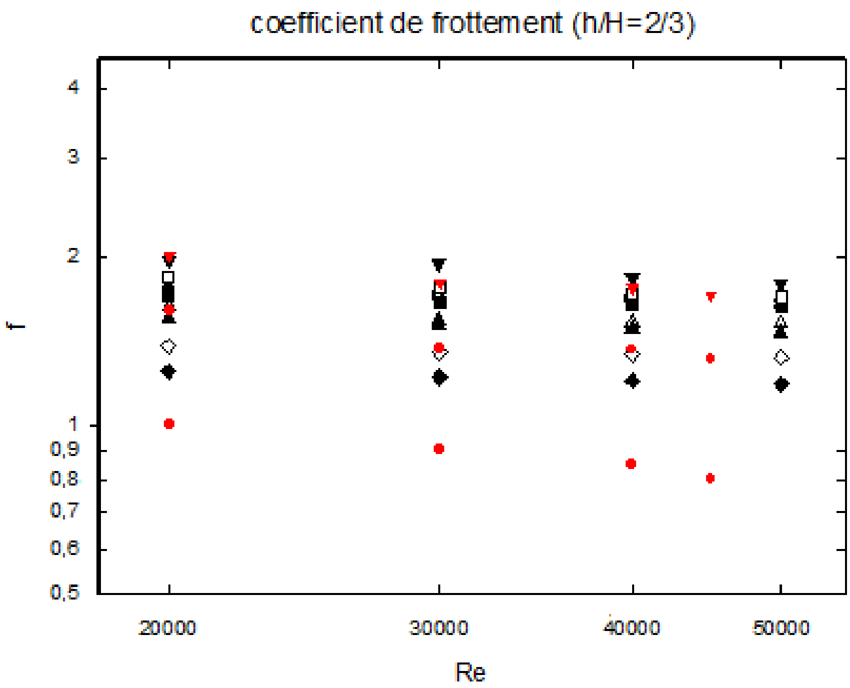


Figure 9. A comparison between the baffles of Kang-HoonKo, Anand, N.K, the inclined baffles and the heat transfer ratio and the friction factor h / D_h = 2/3

The coefficient of friction and heat transfer decreased slightly with an increase in Reynolds number and pore density

Based on data from Kang-Hoon K, N.K. The geometry influences the heat transfer parameters at the outlet. The ratio of heat transfer improvement $(\overline{Nu^{+}})$was developed in terms of Reynolds number.

The results show that the density of the decrease results in a substantial decrease in the number of Nusselt and the loss of pressure.

The use of inclined baffles in heat exchangers is effective in cold climate systems, which could lead to a reduction in energy consumption, which benefits both the economic and environmental aspects.

We studied mainly the influence of porous baffles inclination and number on heat transfer and fluid flow. One can conclude that the increase in the porous baffle inclination improves heat transfer between channel walls and fluid passing through it, and that heat transfer becomes decreasingly important with a decrease in height of the inclined porous baffles. In perspective, we intend to deepen and clarify our results. Indeed, we will adapt our code to others geometric cases thick porous baffles. Finally, we will also try to refine more the turbulence model.

References

[1] Kang HoonKo. Anand, N.K. Journal of Heat and Mass Transfer 46:4191(2003) 4199.

[2] Yue Tzu Yang, Chih Zong Hwang., International Journal of Heat and Mass Transfer, Department of Mechanical Engineering, National Cheng Kung University, Tainan 701, Taiwan, ROC 771(2003)780.

[3] H. Benzenine et al, Department of Mechanical Engineering, Faculty of Mechanical Engineering, University of Science and Technology (USTO), 19(2): 150 (2013)158.

[4] Prashanta Dutta and Akram Hossain, International Journal of Heat and Fluid Flow, 26: 223(2005)232.

[5] M.A. Louhibi1, N. Salhi, H. Bouali, K. Amghar, Research Inventory, International Journal of Engineering and Science, PP 12-23 2319(2014)6483.

[6] Srikrishna Mahadevan, Mark Ricklick, J.S. Kapat, Research Laboratory for Turbine Aerodynamics, Heat Transfer, and Durability University of Central Florida, Orlando, FL, 32816, USA. 47th Joint Propulsion Conference (2011).

[7] Ansys Inc. Fluent 12.0 User's Guide, Lebanon, USA, (2008).