17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0371
FLOW INVESTIGATION IN SINUSOIDAL CHANNEL WITH POROUS LAYER

Leonardo Martins Brondani[1]
Marcelo J.S. de Lemos[2]
Instituto Tecnológico de Aeronáutica, SP, Brasil
[1]*email:* *brondani@ita.br*
[2]*email:delemos@ita.br*

Abstract. *This work investigates the influence in the friction factor of a porous layer adjacent to the walls of a sinusoidal duct. The investigation is done using different properties for the porous layer, in this case the porosity, the permeability and the layer thickness were evaluated. This investigation is done numerically where the transport equations are applied using a control volume method. The mesh grid used is a non-orthogonal grid. For the system of algebraic equations, the SIMPLE algorithm is used to handle the pressure-velocity coupling. These simulations are made in order to obtain the pressure losses inside the duct and consequently the friction coefficient. Analyzing this parameter is important to estimate the influence of the porous layer. This study found that the influence of the permeability and the layer thickness are greater than the influence of the porosity. Also, it was found that turbulent flow regimes have lower friction factors when compared with laminar flow regimes.*

Keywords: *porous media, sinusoidal channel, flow investigation*

1. INTRODUCTION (TIMES NEW ROMAN, BOLD, SIZE 10)

The necessity of evaluating the laminar and the turbulent flow inside a wavy channel with porous surfaces adjacent the walls is given by its industrial applications. A few examples of these applications are found in equipment for chemical compound separation, equipment for drying seeds, equipment used in petrochemical processes and heat exchangers.

Among all the types of corrugated channels, sinusoidal channels have an advantage compared to other corrugated channels due its round corners. Thus, the increase the heat exchange area having 80% less of pressure drop when compared with sharp cornered ducts (Yutaka, 1987).

It is important studying many configurations of sinusoidal channels. For example, changes in the protuberance amplitude have a major influence on the flow structure and in the pressure drop (Hadjadj, 1999).

Also, the friction factor and the turbulence level increase as the corrugation angle increases (S. Ergin, 2001). For low corrugation angles (large amplitude wavelength ratio) the corrugated channel is an effective heat transfer, especially for higher Reynolds numbers (Wang, 2002).

The importance of studying different flow regimes (i.e. laminar and turbulent flows) is due to evaluate the applicability of a sinusoidal channel as a efficient heat transfer enhancer. In corrugated channels, it is observed that an increase in Reynolds number results in increase in Nusselt Number, thus these channels have a high heat transfer applications (Pehlivan, 2013).

2. PROBLEM STATEMENT

Three different lengths based on the diameter were evaluated in this study. The first one has 20 diameters length, the second one has 15 diameters length and the third one has 10 diameters length.

Two flow regimes were studied, one laminar (Reynolds Number = 500) and one turbulent (Reynolds Number = 50000). For the investigations of influence of a porous layer adjacent to the wall, two porosities were considered (=0.6 and =0.8); three permeabilities (K= 10^{-5}, K= 10^{-4} and K= 10^{-3}) and the three thickness of the layer were considered (t = D/8, D/6 and D/4).

3. MATHEMATICAL MODELLING

For a general fluid property, φ, the intrinsic and volumetric averages are related through the porosity ϕ as,

$$\langle \varphi \rangle^{\gamma} = \frac{1}{\Delta V_{\gamma}} \int_{\Delta V_{\gamma}} \varphi \, dV_{\gamma} \tag{1}$$

The porosity is the ratio between the fluid volume and the fluid volume and the ΔV

$$\langle \varphi \rangle^{v} = \frac{1}{\Delta V} \int_{\Delta V} \varphi \, dV \tag{2}$$

The permeability K is usually determined experimentally for each type of porous medium. For a medium formed by an array of circular rods displaced in square arrangements:

$$K = \frac{D^2 \phi^2}{144(1-\phi)^2} \tag{3}$$

The macroscopic form of the mass conservation for an incompressible fluid flow can be written as:

$$\nabla \cdot \bar{\mathbf{u}}_D = 0 \tag{4}$$

where the Darcy velocity is given by:

$$\boldsymbol{u}_D = \langle \mathbf{u} \rangle^{s} = \frac{1}{\Delta V_s} \int_{\Delta V_s} \mathbf{u}_s \, dV_s \tag{5}$$

The momentum equation for incompressible fluid flow is given by:

$$\rho \left[\nabla \cdot \left(\frac{\bar{\mathbf{u}}_D \bar{\mathbf{u}}_D}{\phi} \right) \right] = -\nabla (\phi \langle \bar{p} \rangle^{i}) + \mu \nabla^2 \bar{\mathbf{u}}_D + \nabla \cdot (-\rho \phi \langle \overline{\mathbf{u}'\mathbf{u}'} \rangle^{i}) - \left[\frac{\mu \phi}{K} \bar{\mathbf{u}}_D + \frac{c_F \phi \rho |\bar{\mathbf{u}}_D| \, \bar{\mathbf{u}}_D}{\sqrt{K}} \right] \tag{6}$$

The Reynolds Number is given by:

$$\mathrm{Re} = \frac{\rho |\bar{\mathbf{u}}_D| H}{\mu} \tag{7}$$

4. RESULTS

In order of evaluating the efficiency of a heat exchanger, the friction coefficient is an important parameter to be studied. The fiction coefficient is related to the pressure losses of the flow inside the duct. It is given by the following equation:

$$f = \frac{\Delta P^{*} D_h{}^{*} 2}{\rho^{*} L^{*} U^2} \tag{8}$$

Where:
$\Delta P = pressure\ losses$
$D_h = hidraulic\ diameter$
$\rho = working\ fluid\ density$
$L = length$
$U = mean\ velocity\ value$

Another important parameter used was the non-dimensional porous layer thickness (D*) which is given by:

$$D^{*} = \frac{Porous\ layer\ thickness\ (m)}{Diameter\ (m)} \tag{9}$$

4.1 Case 1 – Reynolds Number = 500, Length = 20D

The Figure 2 shows that the permeability of the porous layer has a higher influence with the increase of its thickness. Virtually, there is no significant effect of the porosity.

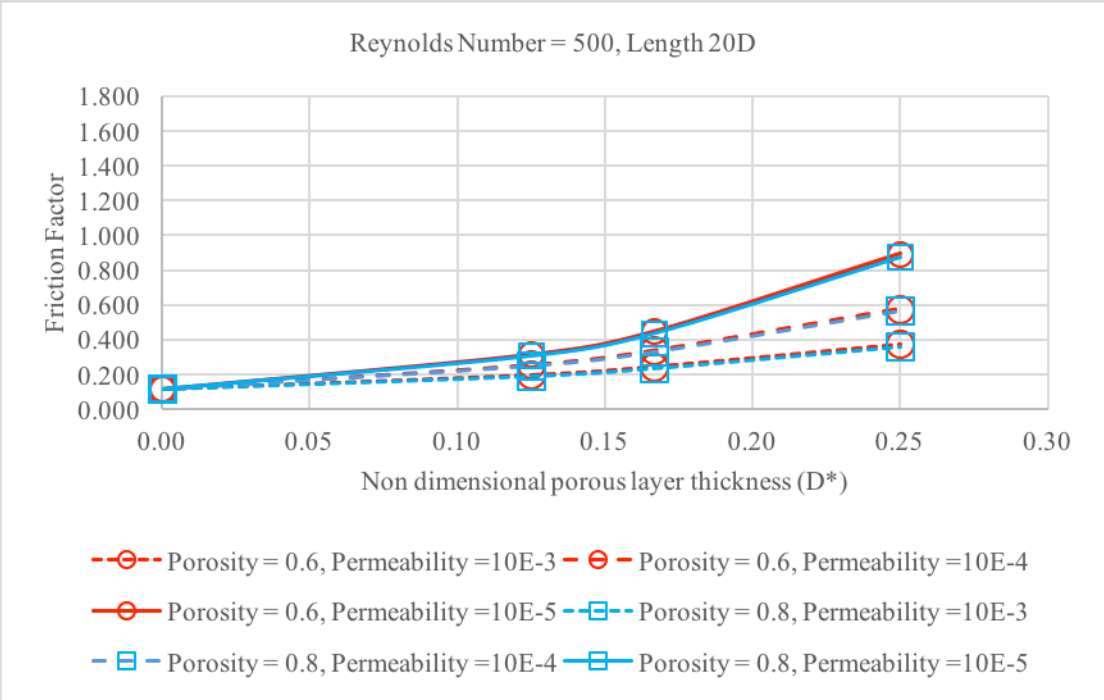

Figure 2. Case 1

4.2 Case 2 – Reynolds Number = 500, Length = 15D

This case, with a channel of 15 diameters length, the behavior of the influence of permeability and porosity was the same as the one observed in the previous case. As it can be seen in Figure 3.

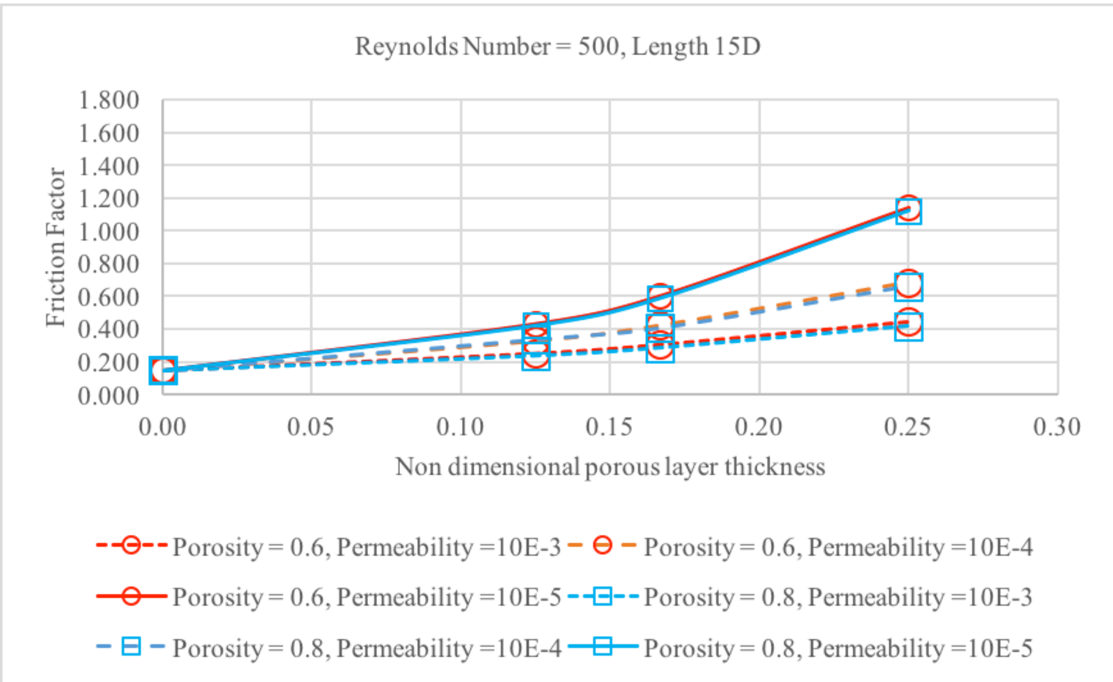

Figure 3. Case 2

4.3 Case 3 – Reynolds Number = 500, Length = 10D

In this case, with a channel of 10 diameters length, the friction factor was higher than the ones previous obtained. Thus, were can conclude that decreasing the L/D there is an increase in the friction factor. As it can be seen in Figure 4.

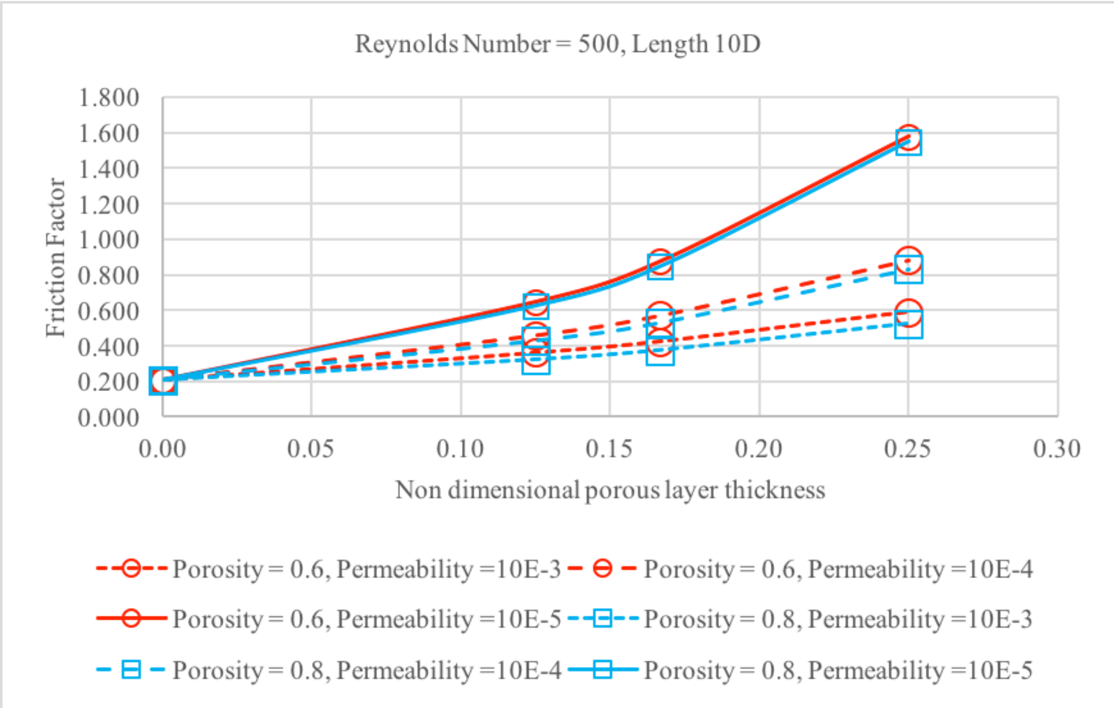

Figure 4. Case 3

4.4 Case 4 – Reynolds Number = 50000, Length = 20D

This case shows a similar behavior of the laminar flow. The porous layer thickness and permeability have a larger influence in the friction factor when the porosity has virtually no effects. As it can be seen in Figure 5. Another thing that can be observed is that the friction factor values were lower when compared with the laminar case.

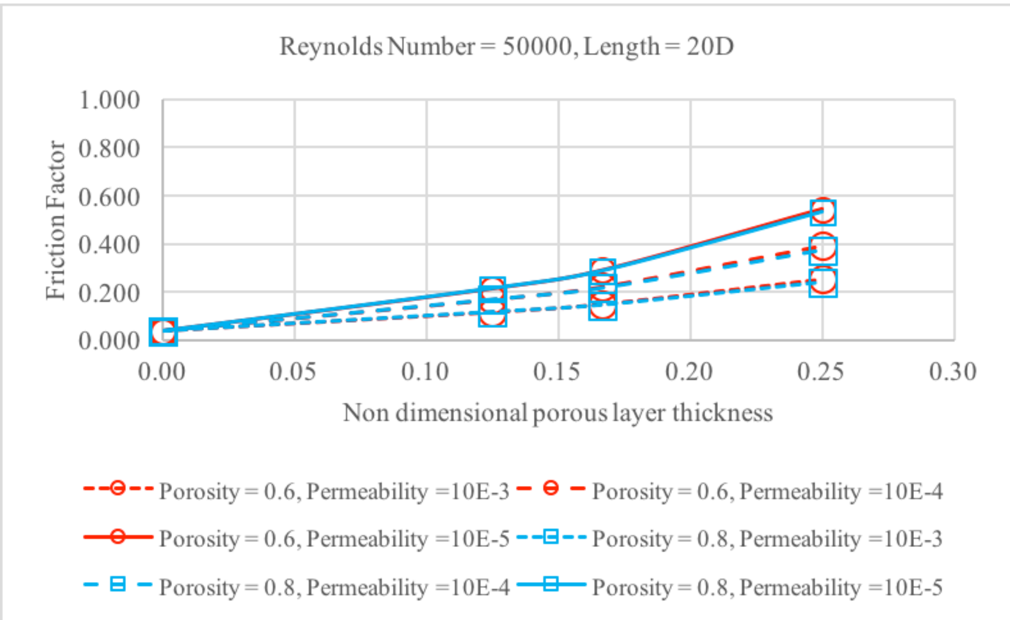

Figure 5. Case 4

4.5 Case 5 – Reynolds Number = 50000, Length = 15D

This case shows a similar behavior when compared with the laminar regime. However, the friction factors are lower. As it can be seen in Figure 6.

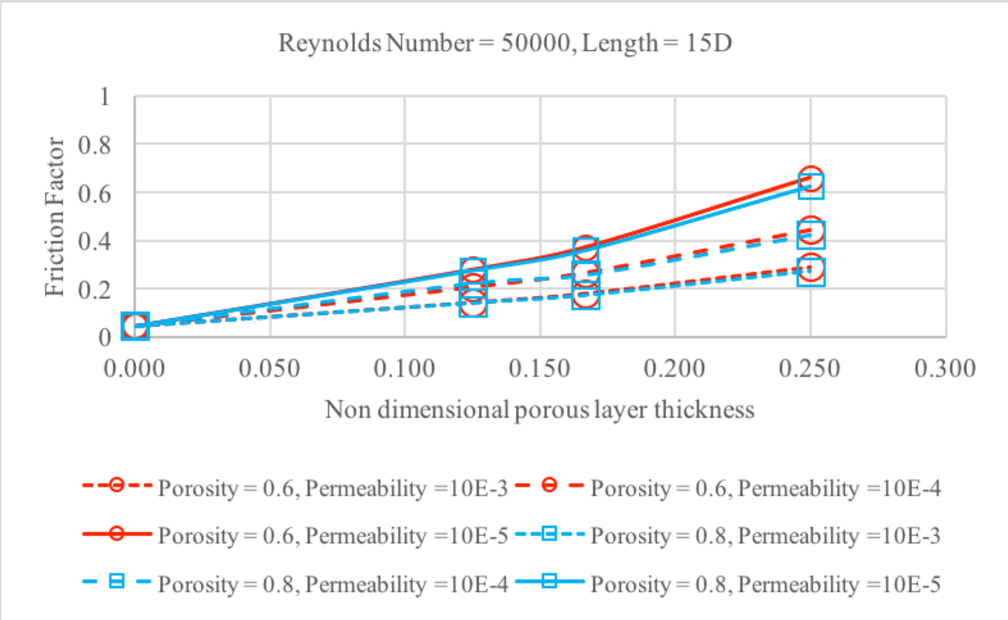

Figure 6. Case 5

4.6 Case 6 – Reynolds Number = 50000, Length = 10D

This case shows a channel with a small length. In this case the influence of porosity was greater than in the previous cases. However, its influence still low when compared with others properties. As it can be seen in Figure 7.

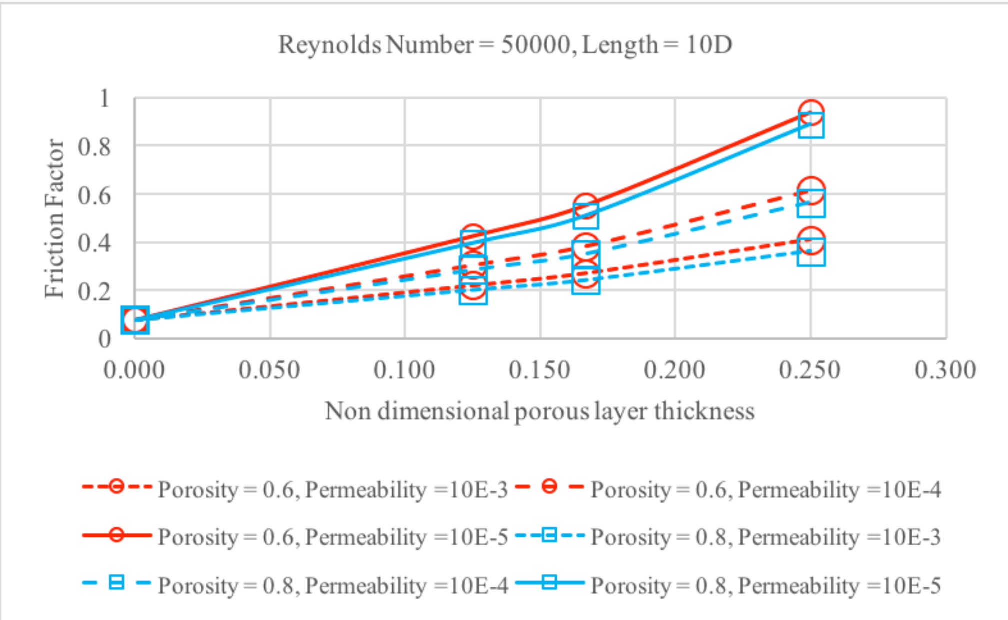

Figure 7. Case 6

5. CONCLUSION

This work investigated the effects of the porous layer into the friction coefficient of sinusoidal with different length, porosities, permeabilities and porous layer thickness. The main conclusions from this work are:

a) The permeability has a major effect in the friction factor when compared with the porosity

b) Turbulent flow regime has lower friction factors when compared with the laminar regime

c) For cases with long channel length, variations in the porosity have no significant influence in the friction factor. However, as the wavy channel length decrease, the effect of porosity starts to become significant.

6. ACKNOWLEDGEMENTS

The authors are thankful to CNPQ and CAPES for their financial support during the course of this research.

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