

A Numerical Simulation of Fluid Flow through a Thin Porous Media Confined within a Narrow Duct

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Introduction

Fluid flow through a mould containing reinforcing porous material, during manufacturing processes, experiences a pressure drop due to the influence of walls and the porous material. The contribution of the confinement and the porous bed, to the pressure drop, depends upon the thickness of the bed and the porosity. A model estimating the pressure losses in porous media for an arbitrary Reynolds number was introduced by Ergun [1], based on Reynolds formula, which represents the instantaneous summation of viscous and kinetic losses [1]. Ergun 1952 considered factors that relate to the fluid and the bed solid material, while the effect from the container is assumed to be negligible owing to high container diameter D to the bed particle diameter D_p in the experiments performed. For thin porous media confined between two impermeable flat walls, where the thickness of the bed h is comparable with D_p , additional viscous losses need to be considered emanating from the flow near the confinement [2, 3, 4]. The effect of these losses will decrease with increasing bed thickness, as compared to the bed losses. The quantitative contribution of viscous forces, from the porous bed and from the confinement, as well as the inertial forces affects the transition from creeping to fully turbulent flow regimes. These forces and its contributions in the total pressure loss is disclosed in this study covering a large span of Reynolds numbers Re_D , calculated based on D_p .

The adopted physical model, chosen to mimic the reinforced composite material, consist of a duct with variable height h embedded with square array of 12×12 porous unit cells, shown in Figure 1. Each cell has a single cylinder of 16 mm in diameter D_p . Two lengths of the cylinders, and equally two duct heights h , were used in order to give D_p/h ratios of 3.2 and ≈ 0 , respectively. The porous unit cell width $W = 40$ mm in both directions. The meshing of the porous domain were done with the aid of ANSYS ICEM 18.0 Hexa. A mesh independency study was performed using Richardson method [5, 6] and the sufficient number of nodes was selected to be 11 & 3.2 million nod for D_p/h ratio of 3.2, ≈ 0 , respectively. The flow field is solved with the commercial software ANSYS CFX 18.0, in order to solve the governing equations and to disclose flow field characteristics. In order to highlight the influence from the top, bottom and right side walls, no-slip boundary condition have been applied to these geometries, see Figure 1. Moreover, no slip boundary condition are also applied on the cylinders surface and a symmetry condition for the left end of the duct was chosen. A uniform flow velocity was set at the inlet, with a turbulence level of 5% for the turbulent cases. A laminar flow setup was used for Reynolds $Re_D=0.01$, and up to $Re_D=2\ 000$, while, a turbulent flow setup is selected for Re_D over 10. Hence there is an overlap between these two set-ups in the transient region. The shear-stress transport, SST, turbulent model is adopted for all the turbulent cases. This model perform well with curved surfaces where adverse pressure gradient and boundary layer separation can occur [5].

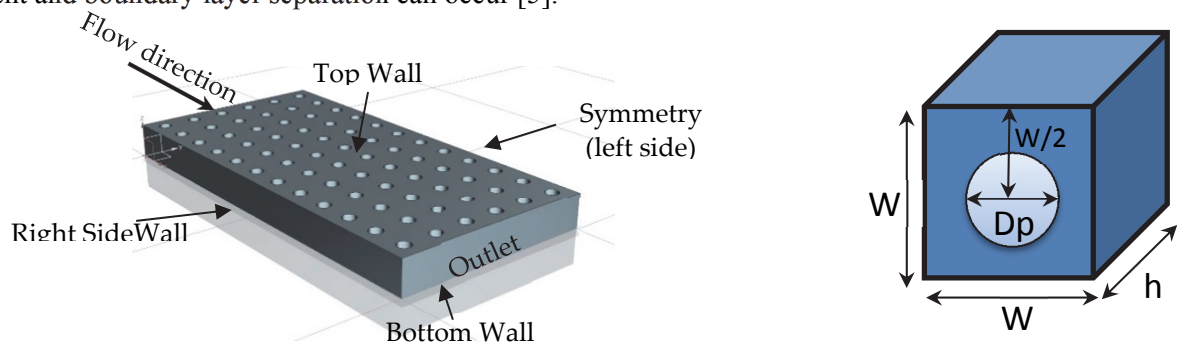
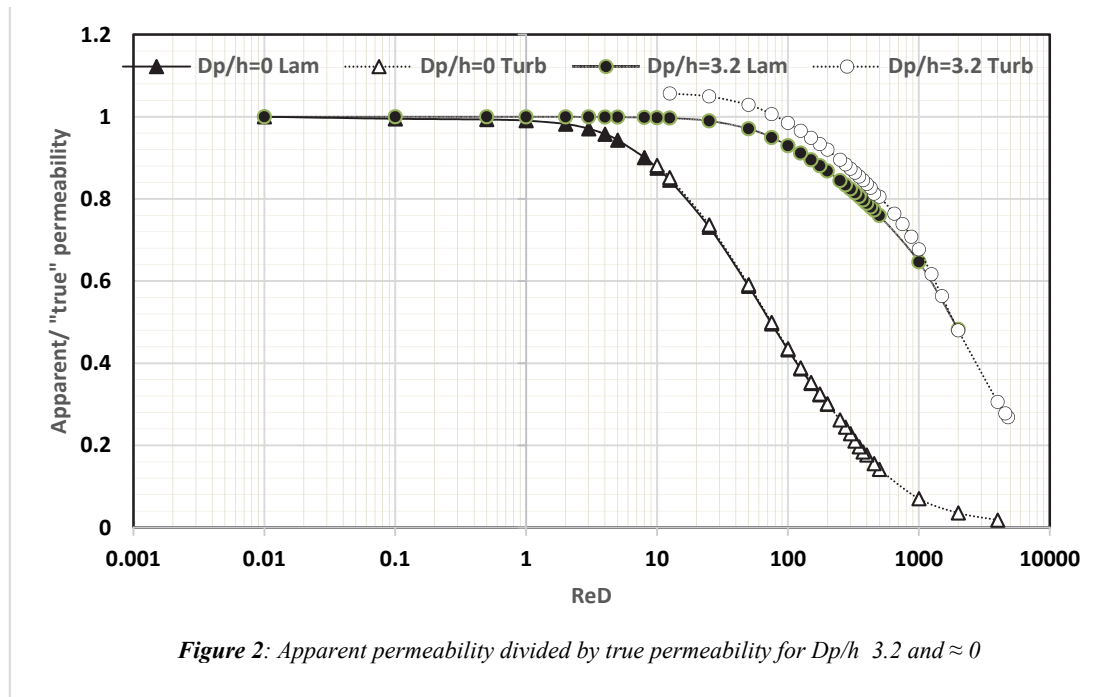


Figure 1: a) unit cell b) computational domain.

Result and discussion

The flow field characteristics shows that the flow becomes fully developed after the fifth column from the entrance, while, the influence from the right side wall vanishes after the first row, for the worst cases. Hence, the evaluations were made between the sixth column and the eleventh column, in order to prevent any influence from the developing section and channel outlet. The apparent calculated permeability values were normalized with the permeability value for creeping flow condition, at $Re_D=0.01$, and depicted in figure 2. For laminar cases, where the full Navier-Stokes equation is solved, values are relatively horizontal with increasing Re before $Re_D=1$ for $Dp/h \approx 0$ while it continue with the same level up till $Re_D \approx 25$, for $Dp/h=3.2$. Then, the permeability decreases with increasing Re_D and follow a smooth curvature path for both cases. Inertia effects and turbulence starts to influence the overall flow field. The current behaviour, for the different thickness, is a result of the addition of walls which add viscous forces and attenuate inertial forces effect. Streamlines change were recognized with increasing Re_D , while back flow start for Re_D around 5 and 100 for $Dp/h=3.2$ and ≈ 0 , respectively. Circulation and back flow volume increase with increasing Re_D and then it decreases again even with increasing Re_D which can explain the levelling out of the permeability curves. In general, viscous forces influence attenuate and inertia effect dominants with increasing Re_D for both bed thicknesses. The inertial to the viscous forces ratio increases more for the thick bed than for the thin bed with increasing Re_D . Another results for the thin bed is that a couple of swirls, in the axis of flow, start to develop near the wall-cylinders contact region with increasing Re_D . These swirls can mix the flow momentum in this region and showing higher velocity than velocity near the surface of cylinders, at the same section.



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