Determination and Verification of the Forchheimer Coefficients for Ceramic Foam Filters Using COMSOL CFD Modeling

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Abstract

Experiments have been conducted using water to determine the permeability of 50 mm thick commercially available 30, 40, 50 and 80 Pores Per Inch (PPI) alumina Ceramic Foam Filters (CFF) used for liquid metal filtration. Measurements were made using two different experimental setups: a 49 mm 'straight through' and 101 mm diameter 'expanding flow field' design as shown in Figure 1. Velocities from ~0.015-0.77 m/s have been used to derive both the first order (Darcy) and the second order (Non-Darcy) terms for use with the Forchheimer equation:

ΔP/L = (μ/k1) Vs + (ρ/k2) Vs^2 (1)

where ΔP is the pressure drop [Pa], L the filter thickness [m], Vs the fluid superficial velocity [m/s], μ the fluid dynamic viscosity [Pa•s], ρ the fluid density [kg/m3], and k1 and k2 the empirical constants called the Darcian and non-Darcian permeability coefficients, respectively k2. Equation (1) represents the sum of the viscous (first term) and the kinetic energy losses (second term). In the 101 mm experimental setup the wall effects were virtually eliminated, but no predefined diameter existed to calculate the superficial velocity for use with Equation (1). It was therefore necessary to iteratively solve for the effective flow field diameter using COMSOL 4.2a, adopting the procedure shown in Figure 2, in order to correctly determine the Forchheimer coefficients. The presently obtained results from the two different experimental setups are compared with calculations made using the COMSOL 4.2a 2D axial symmetric Finite Element Method (FEM), as a function of velocity and filter PPI. The model adopts the "Free and Porous Media Flow" interface, with an added second order Forchheimer term, as well as the "Turbulent Flow, k-ε" interface with the low Reynolds number option. Examples of the velocity fields produced by the models are shown in Figure 3. Care was taken to ensure a contiguous velocity field at the interfaces between the fluid and porous media, and careful consideration/experimental verification has been made of the required inlet velocity boundary condition. A high level of agreement was achieved between experimental, analytical and FEM (±0-7% on predicted pressure drop) for both types of experimental setups.

Figures used in the abstract

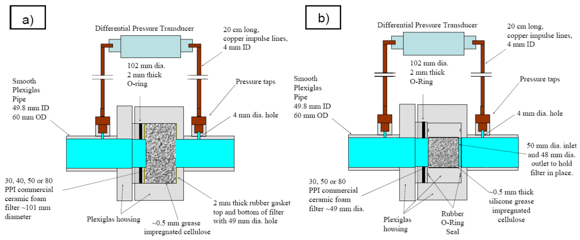

Figure 1: The experimental setup used for the 101 mm (a) and the 49 mm (b) diameter filter experiments (both drawn approximately to scale).

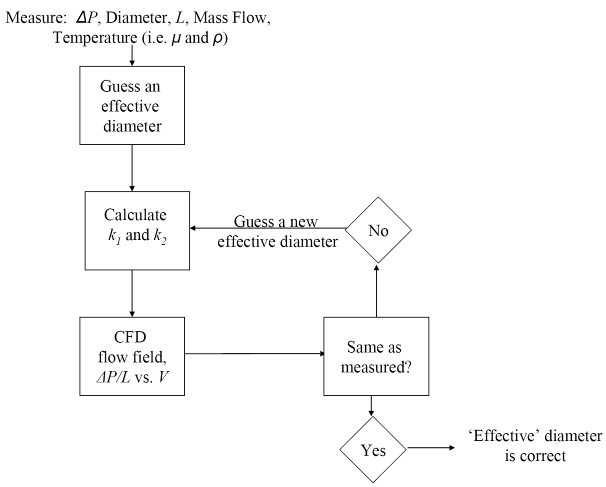

Figure 2: The FEM CFD procedure applied to the 101 mm experimental results to determine the Forchheimer, Eq. [1], parameters k1 and k2.

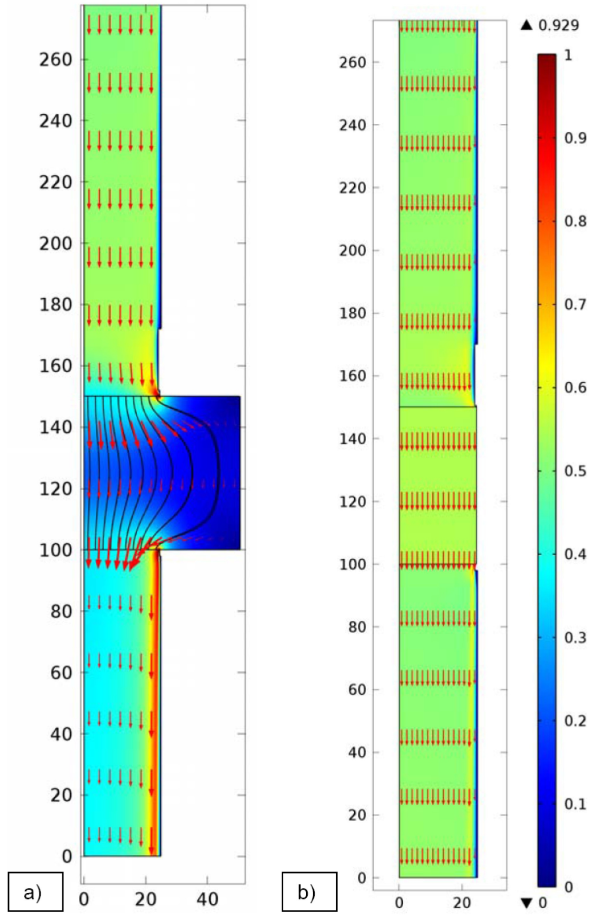

Figure 3: Comparison of calculated flow fields for 50 PPI CFF for the 101 mm ‘expanding flow field’ (a) and the 49 mm ‘straight through’ (b) designs, both for 0.5 m/s uniform inlet velocity and 7oC water temperature, shown with a common 0-1 m/s color scale. Pressure gradients of 501.1 kPa/m and 1612.4 kPa/m were calculated for these two cases.