Investigation of pressure drop in 3D replicated open-cell foams: coupling CFD with experimental tests

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Highlights

- Systematic investigation of pressure drops in open-cell foams
- 3D printing of virtually generated foam samples
- Cross validation of experimental tests and CFD simulations

1. Introduction

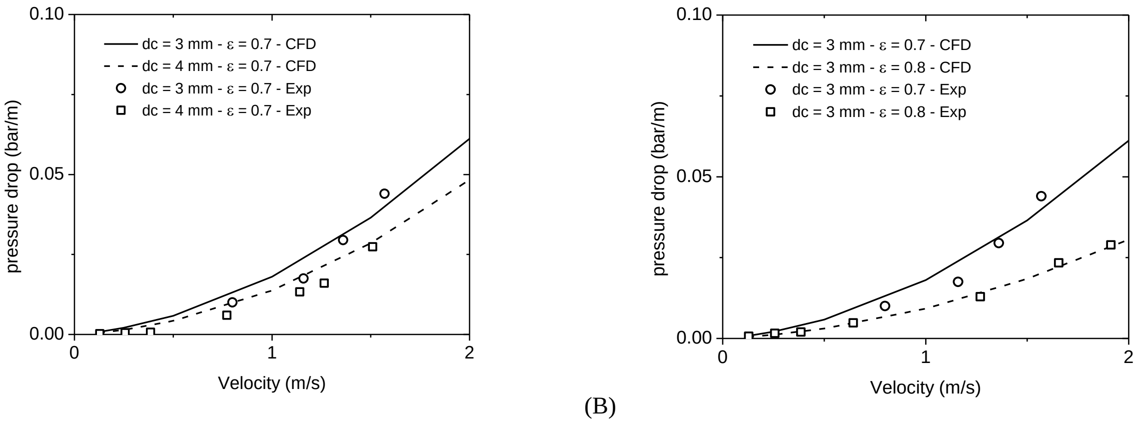
Open-cell foams are well known potential structured catalyst supports which are considered attractive for the intensification of transport processes and for the reduced pressure drops. They are reticulated interconnected solid structures whose repeated open-cells are composed by solid struts and permeable open windows. Many experimental and theoretical works have been presented in the literature for the investigation of pressure drop in open-cell foams. However, severe deviations between engineering correlations and experimental data up to ± 100% are evident, possibly due to the discrepancies between theoretical geometries and real structures [1]. In this contribution, we exploit structures generated according to a virtual reconstruction procedure [2] to exclude the effect of uncertainties in the description of the foam geometry, being the virtual samples totally and accurately defined and characterized. The virtual reconstruction has been proved to show analogous overall geometrical properties, i.e. specific surface area, porosity, and the same flow behavior of the real foam structures [2]. Computational Fluid Dynamics (CFD) and experimental activity over 3D printed samples were exploited to evaluate the pressure drops on the same structural geometry. A very good agreement between CFD simulations and experimental data is found. The effects of porosity, cell sizes and flow regimes have been investigated to derive engineering correlations.

2. Methods

In order to provide a reliable structural model of the open-cell foams for 3D printing and for the CFD simulation, we exploited the methodology reported in [2].The virtual reconstruction procedure is based on the generation of the foam skeleton by means of the Voronoi tessellation, while the effective solid distribution is calculated with a theoretical geometrical model [3] and is used as initial guess for the virtual reconstruction. The reconstructed foams predict with very good agreement the pressure drops measured in real structures [2]. Thus, they are a reliable reproduction of real foams which can be exploited for a comprehensive investigation of the foams. Virtually generated foam samples in the form of cylinders with a length of 20 mm and a diameter of 26.8 mm were 3D printed in Manchester with Stereolitography (SLA) on a FormLab 2.0 printer. In this 3D printing technique an ultraviolet laser beam is focused onto a vat of liquid photopolymer resin that solidifies when irradiated. Despite the bulk material of 3D printed foams does not allow for real catalytic applications due to the low melting point, these foams can be convenient for the 'cold flow' investigation of fluid dynamic properties like pressure drops, gas/liquid interaction or heat transfer. CFD simulations are carried out using OpenFOAM, a numerical framework able to solve Navier-Stokes equations on samples with different porosities and cell diameters and covering flow regimes from fully laminar to post-Forchheimer. The simulation of a single foam cylinder is carried out exploiting periodic boundary conditions on the stream-wise boundaries [2]. Experimental evaluation of pressure drops on 3D printed samples was performed inserting the foams in a tubular reactor, designed to provide a tight fit of the samples and avoid gas bypass. Differential manometers were used to record pressure losses in the range of [5-1000] Pa, while a hot wire anemometer was used for the measurement of the local velocity.

3. Results and discussion

A comparison of the CFD simulated and experimentally measured pressure drops is shown in Figure 1 for three foam samples with different cell diameters and porosities.



(A) (B)

Figure 1. Pressure drops of 3D printed foams: CFD simulations (lines) against Experimental test (empty symbols); effect of cell diameter (Fig 1.A) and effect of the porosity (Fig. 1.B)

This methodology enables the cross validation of the simulated pressure drops with the experimental values, based on the same geometrical models, delivering the intrinsic effects of cell diameter and porosity on the pressure over a wide range of velocities. The complete analysis of foams with different cell properties will enable the development of an accurate yet comprehensive engineering correlation. A central aspect is the evaluation of the pressure drop at low Reynolds numbers. In fact, while the tradeoff between mass transfer and pressure drops in that regime is optimal, the most consistent deviations between literature correlations and the collected data are experienced in this regime.

4. Conclusions

In this contribution, we have performed the analysis of pressure drop in virtually generated samples using both CFD and experimental measurements onto 3D replicated foams. We demonstrate that with this approach rules out all uncertainties on possible deviations between experimental measurements and the geometry assumed for CFD simulations, thus making possible a systematic investigation of momentum transfer in open-cell foams aimed at the derivation of a generalized reliable engineering correlation.

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Keywords
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