Periodic open cellular structures as catalyst supports: investigation of pressure drop and mass transfer

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Highlights

- Catalytic applications of POCS
- Investigation of mass transfer and pressure drops
- Enhanced catalyst carrier for after-treatment applications

1. Introduction

Structured catalysts are the key for process intensification in many several applications of industrial relevance where the catalytic activity has to be coupled with low pressure drops and enhanced transport properties of the supports. Honeycomb monoliths currently represent the state of the art for exhaust after-treatment applications, whereas random open cell foams are receiving growing interest for non adiabatic and environmental applications. Periodic open cellular structures (POCS) present features common to both these supports, because at the same time they present an ordered geometry – like honeycombs – but allow for radial transport and combine high surface areas to high porosities in analogy with foams. However, at the present time only little information for the estimation of pressure drops are available in the literature [1], while the mass transfer properties of these supports are still largely unknown. In this work, POCS of cylindrical shape were studied for the investigation of pressure drops and gas/solid mass transfer. Finally, a performance comparison of POCS with other supports was performed by means of a merit index, representative of the tradeoff between mass transfer and pressure drops [2].

2. Methods

Periodic open cellular structures were produced with investment casting by Università del Salento as shaped cylinders (9 mm diameter and 20 mm length) with ideal cubic cell geometry [3]; samples with square strut of 0.5 mm, cell sizes equal to 1.5, 1.75 and 2.25 mm and different porosities were tested. Geometrical properties of the supports were derived directly from CAD reconstructions. Experimental activity carried out at the Università del Salento showed that using an external shell bounding the cylindrical cellular structure with thickness greater than 0.5 mm presents the best opportunity for defect reduction in the investment casting process, for any porosity and cell diameter considered [3]. Pressure drops were investigated loading the samples in a tubular reactor to prevent gas bypass; a differential manometer was used to measure the pressure losses at flow velocities of industrial relevance (0.2-7 m/s). CFD simulations were carried out on the same reactor geometry (Figure. 1B). For the investigation of mass transfer, POCS were first activated via spin coating with a Pd/CeO_2 catalyst layer and then CO oxidation runs under external diffusional regime were performed. Reactants and products were measured with a μ-GC while both pressure and temperature of the catalyst were recorded. In order to extend the explored experimental ranges, tests of CO oxidation in excess of both air and helium were performed, corresponding to a 3-70 range of Reynolds numbers.

3. Results and discussion

POCS closely resemble tube banks, accordingly we considered the strut hydraulic diameter as the characteristic length for the evaluation of both mass and momentum transfer. Pressure drops were fitted with an Ergun-type correlation; as shown in Figure. 1A this approach enables to catch the effect of the porosity. Mass transfer coefficients of POCS were derived from CO conversion data assuming an ideal plug flow behavior. Plotting the results in a conventional Sh vs Re diagram, two different contributions are used to correlate the data (Figure. 2A), namely a viscous flow term and a dissipative one which becomes relevant at high Re numbers; an inverse dependency on porosity is also apparent.

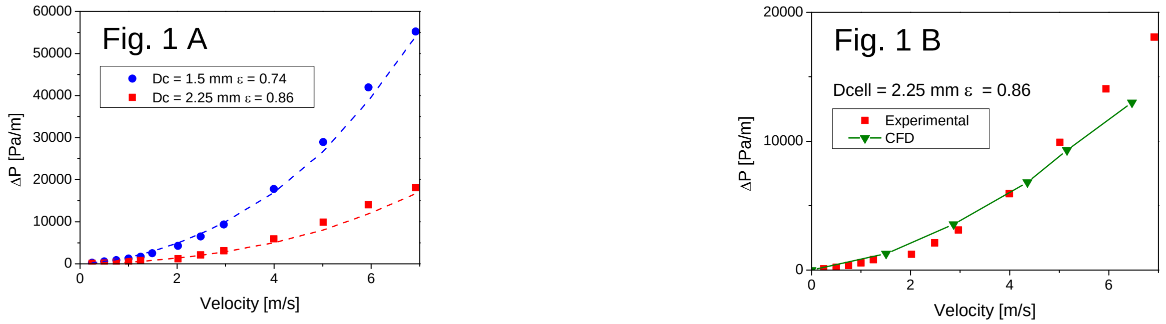

Figure 1. A) Experimental pressure drops of POCS with two different porosities, B) comparison with CFD

Combining the mass transfer and pressure drops correlations it was possible to compute a merit index [2], that represents the tradeoff between mass and momentum transfer. The merit index for honeycombs is a constant value, while for POCS the merit index is a function of the Reynolds number. This analysis shows (Figure. 2B) that POCS with high porosity are able to overcome the state-of-the-art square channeled honeycombs in the low Re range.

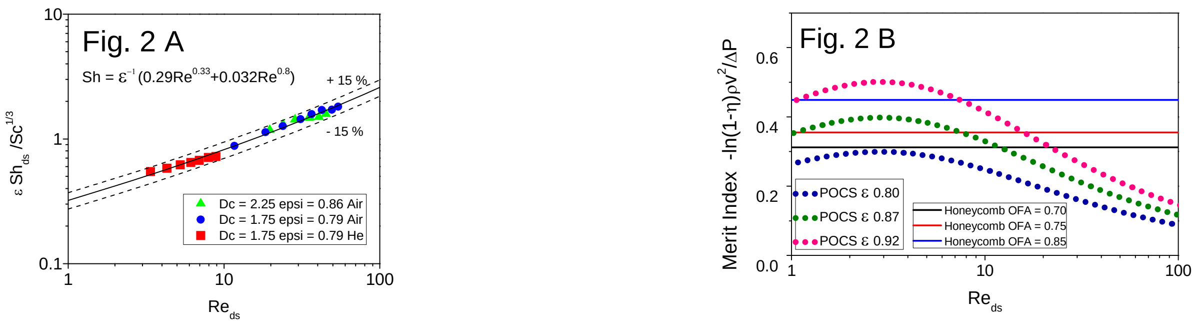

Figure 2. A) Mass transfer correlation for POCS , B) merit index for square channel honeycombs and for POCS

4. Conclusions

In this contribution, we performed a preliminary analysis of pressure drops and mass transfer over periodic open cellular structures with cubic cells and square struts. Engineering correlations able to describe these phenomena were derived from the empirical data showing decent agreement CFD simulations. We also performed a comparison based on an index of performance representing the tradeoff between these two properties. This analysis showed that, in a particular flow regime, POCS performances overcome state-of-the-art honeycombs, hence being a potential enhanced catalyst support for after-treatment applications.

Acknowledgment

This project has received funding from the European Research Council under Grant Agreement no. 694910 (INTENT).

References

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Keywords
POCS; pressure drops, mass transfer