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POSTER COMMUNICATION

Effect of POCS geometry on fluid flow and heat transfer

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Abstract
Hydraulic and transport properties of periodic open cellular structures (POCS) based on cubic cells were investigated numerically. Different cell and strut dimensions, as well as strut shapes, were examined. Numerical results of heat transfer and flow resistance, as well as modeled morphological parameters were verified experimentally. The most beneficial properties were obtained for the POCS with convex triangular, circular and hexagonal struts.

Keywords
POCS; heat transfer; flow resistance; CFD

1. INTRODUCTION

The growing interest in the use of 3D-printed cellular structures in catalytic processes results from the ease of their design and the speed of their production. They offer beneficial properties which are desirable in catalytic processes to maximize the efficiency of reactors, e.g. low pressure drop due to high porosity, high specific surface area, and high heat transfer rates due to the high conductivity of the material.

Periodic open cellular structures (POCS) are a good candidate as catalyst support in comparison with honeycomb monolith and random packed bed (Busse et al., 2018; Papetti et al., 2018). Their main benefit is geometrical flexibility which allows to change the shape and size of the unit cell to improve their hydraulic and thermal properties (Iwaniszyn, 2022).

POCS based on cubic, Kelvin, and diamond cells with circular or square struts are the most often described ones. The main conclusions were as follows:

1) the pressure drop is lower for higher cell diameter, while it increases with strut thickening (Bastos Rebelo et al., 2018; Bianchi et al., 2016; Papetti et al., 2018);
2) the cell size and shape, as well as the strut shape, have no significant impact on heat transfer (Bianchi et al., 2016; Bracconi et al., 2020; Kumar and Topin, 2016);
3) heat transfer can be improved by increasing the strut size (Bracconi et al., 2020);
4) the strut shape affects the hydraulic characteristics (Kumar and Topin, 2017).

This paper analyzes the effect of POCS geometry on thermal and hydraulic properties. The cubic cell was chosen because it is the simplest shape that can be modified. Three geometric parameters: strut shape (8 cases), cell dimension, D_c (3 cases), strut thickness, d_s (3 cases), with values different from those in the literature, were considered.

2. METHODS

The "CFD modeling" section contains the description of the solver setting and the geometry modification. Computational domain and morphological parameters of chosen cubic cells are presented as well. The "Experiments" section describes the methods used to create the POCS, characterize it, and evaluate its properties, to validate the computer model.

3. RESULTS

Both numerical and experimental results are presented as charts of heat transfer coefficient and pressure drop versus superficial velocity. As is noticeable in the first six plots in the "CFD modeling" section, the heat transfer coefficient decreases slightly with strut thickening, and with increasing cell size. However, the plot shown below for cubic cells with circular struts ($D_c = 5$ mm, varying d_s) demonstrates that the heat transfer coefficient decreases with strut diameter in the range of $d_s = 0.5{-}1$ mm, while its values are comparable for $d_s = 0.5$ mm, 1.5 mm, and 2 mm. The pressure drop increases with strut thickness but it is lower for higher cell size. Taking into account the strut shapes, the most intense heat transfer and the lowest pressure drop was obtained for POCS with convex triangular struts.

A comparison of experimental and modeled results (porosity, specific surface area, pressure drop, heat transfer coefficient) indicated good agreement. Printed POCS was also compared with monolith, packed bed, and different solid foams, which is presented as charts of Fanning friction factor and Nusselt number versus Reynolds number. The flow resistance of POCS is close to that of solid foams, while its heat transfer is more intense than that of monolith and comparable to that of foams for higher Reynolds numbers.

4. CONCLUSIONS

Intensification of heat transfer and reduction of flow resistance could be obtained by the modification of POCS geometry. The strong impact of geometrical parameters on flow resistance was proven. The slight effect of cell size on heat transfer coefficient, and its dependence on the strut size and shape was confirmed.

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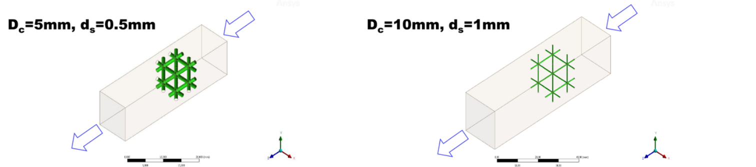
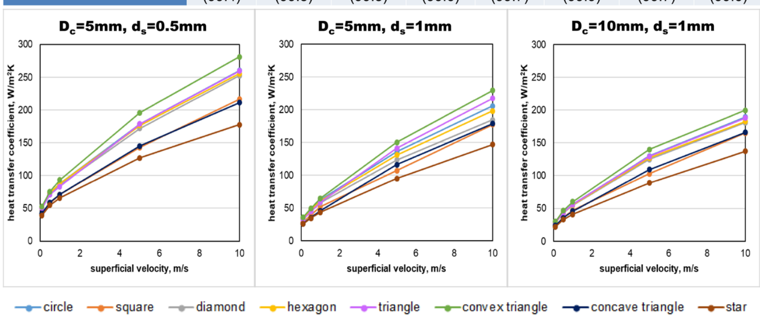
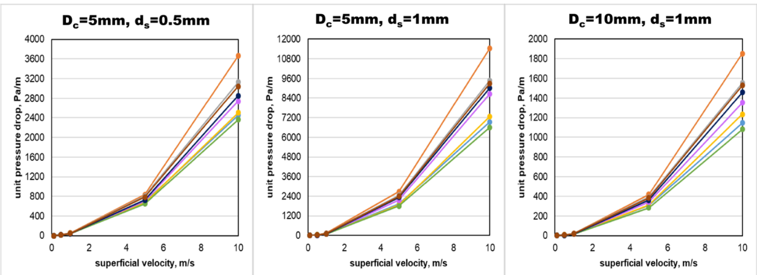
CFD modeling

Periodic open cellular structures based on cubic cell were studied numerically in the field of heat transfer and flow friction coefficients. ANSYS Fluent code was employed as a CFD tool. Computational domain was performed for single cubic cell with constant heat flux boundary condition (1000W/m^2) on struts wall, initial flow velocity (0.1-10m/s) and temperature (300K) on inlet and atmospheric pressure on outlet. Steady-state, laminar and incompressible flow condition was assumed.
Circle, square, diamond, hexagon, triangle, convex triangle, concave triangle and star were considered as cross-sectional struts shapes. Preliminary studies were carried out for strut thickness (d_s) and cell size (D_c) in the range of 0.5-1mm and 5-10mm, respectively, to select the most efficient strut shapes. Additionally, computational simulations have been extended for structures with circular struts for D_c=5mm and d_s=1.5mm, D_c=5mm and d_s=2mm, D_c=2.5mm and d_s=0.5mm.

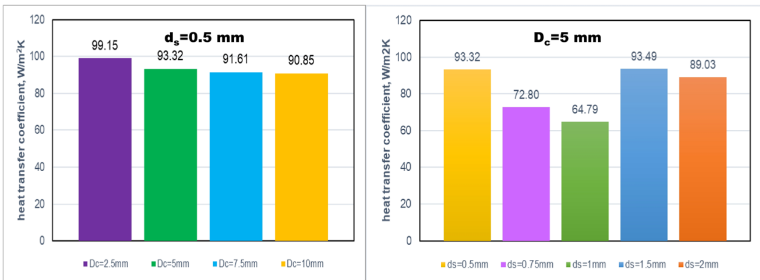


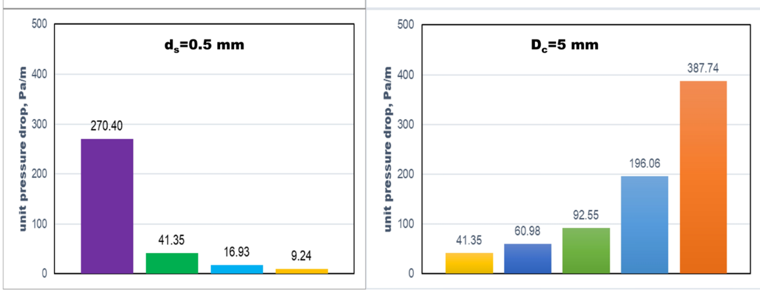
Strut shape D_c=5 (10) mm, d_s=1 (0.5) mm	circle	hexagon	square	diamond	star	concave triangle	triangle	convex triangle
Specific surface area S_v m^2/m^3	328 (46)	317 (47)	408 (58)	301 (41)	370 (51)	310 (40)	284 (38)	291 (40)
Porosity ε, %	91.7 (99.4)	93.1 (99.5)	89.6 (99.3)	94.6 (99.6)	95.3 (99.7)	98.6 (99.9)	96.4 (99.7)	94.3 (99.6)





Circular strut, u=1m/s

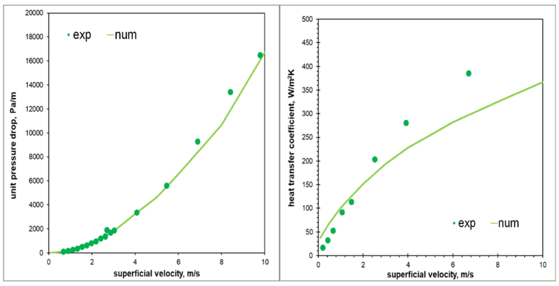


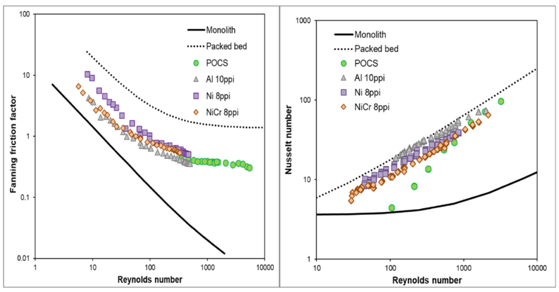


Experiments

The computational model was validated based on the experimental data. POCS with circular struts of D_c=5mm and d_s=1.5mm was manufactured using the selective laser melting (SLM) method (Renishaw, AM125) from M789 steel (Bohler Edelstahl). The computed tomography technique was applied to evaluate the porosity and specific surface area of 3D printed structure. The flow resistance and heat transfer experiments were carried out in a rectangular reactor (30 x 45 mm) filled with the POCS sample. The Recknagel manometer was used for pressure differences measurement, while K-type thermocouples measured the temperature of POCS surface and flowing air. The superficial air velocity was changed from 0.2 to 12 m/s.

Sample	ε_{CAD} [%]	ε_{cT} [%]	ey [%]	$S_{v,CAD}$ [m2/m3]	$S_{v,cT}$ [m2/m3]	ey [%]
D_c=5mm d_s= 1.5mm	81.1	80.2	1	469	488	4





Support	POCS D_c=5mm d_s=1.5mm	Monolith 25CPSI	Packed bed D_p=3mm	Al foam 10PPI	Ni foam 8PPI	NiCr foam 8PPI
Specific surface area S_v m^2/m^3	488	651	1220	866	1537	1675
Porosity ε, %	80.2	68	39	90	92	92

Conclusions

- The geometry of cellular structures can be freely modified in order to intensify heat transport and reduce flow resistance.
- Structures with convex triangular, circular and hexagonal struts turned out to be the most effective among the studied shapes.
- The larger the cell diameters and the smaller the struts diameters, the more favorable the ratio of heat transfer to friction coefficient.
- Cell structures with different structures and controlled morphological and geometric parameters can be produced by 3D printing.

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