Experimental Validation of a New Model for the Pressure Drop in Dual Cell Density Monoliths

Consuelo Reinao[1], Pablo Diaz[1], Gonzalo Nuñez[1], Iván Cornejo[1]*

[1]*Universidad Técnica Federico Santa María. Vicuña Mackenna 3939, Santiago, Chile.*

**Corresponding author: ivan.cornejo@usm.cl*

Highlights

- The validated model precisely predicts pressure drop in dual cell density monoliths.
- Experiments confirm pressure equilibrium in core and ring regions of the substrate.
- The proposed model paves way for designing monoliths with optimized flow control.

1. Introduction

Chemical reactors design has seen significant integration of structured substrates, notably honeycomb monoliths, known for their high contact area and good flow distribution. Monoliths are suitable for process intensification, especially in reactions where the temperature control is critical, such as in the conversion of green hydrogen into methanol [1]. Recent developments have introduced dual cell density monoliths, offering a novel approach to manipulate flow distribution within these reactors [2, 3]. However, while theoretical and computational models have provided an interesting insight into the flow dynamics and pressure drop in such structures, there remains a gap in empirical validation. This study addresses this gap by experimentally validating a new model for predicting pressure drop in dual cell density monoliths, offering further opportunities for reactors design optimization in industrial processes.

2. Methods

In general terms, this research involved designing, 3D printing, and testing dual cell density monoliths to measure pressure drop at various flowrates using an experimental rig. The observed pressure drop, in a cold flow condition, was compared with the predictions of the proposed model.
Digital models of cylindric dual cell density monoliths were prepared in Autodesk Inventor v2021. Each model comprised two concentric regions: a core with one cell density and a surrounding ring with a different one, as shown in Figure 1. The monoliths considered square channels, 150 mm long and had 70 mm in diameter. The core region had 3 mm as channel size and 0.9 mm as wall thickness. The ring has 2.5 mm in channel size and 0.45 mm as wall thickness. Those features gave a ratio of ring over core apparent permeability (α_r/α_c) close to 1.36. The core sizes (λ_c) tested, fraction of the cross-section area given to the core, were 0.25 and 0.50. The models were 3D printed in resin in a Creality Halot Sky.

(a) (b)

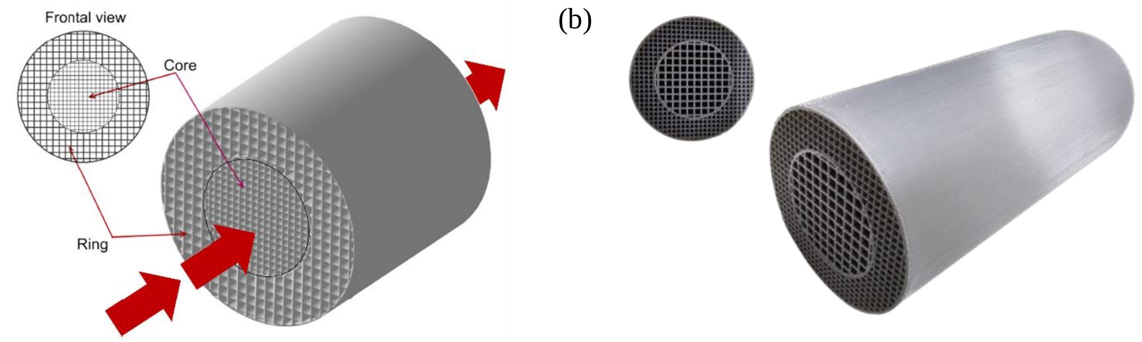

Figure 1: Example of a dual cell density monolith (a) schematic [2], and (b) 3D printed physical monolith.

The experimental rig is shown in Figure 2. Atmospheric air was fed into the system. A manual valve (v-1) allowed us manipulating the flowrate, which was measured with two mass flow controllers model Aalborg GFC37 (FT-1) put in parallel. The monoliths were placed at the end of the tube of the rig, so, the system discharges to the room. Backpressure through the substrate was measured by using a differential pressure transmitter model Ashcroft GL42 (PT-1).

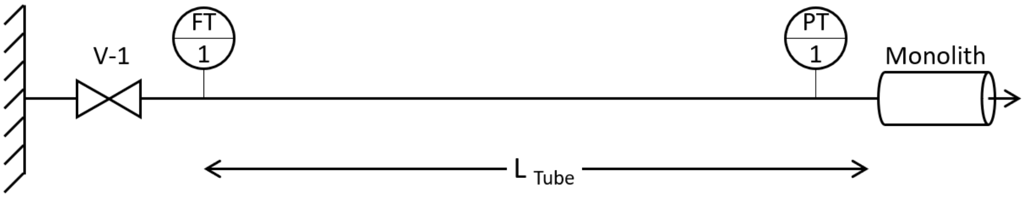

Figure 2: Experimental rig

The experiments were compared with the values predicted from using theoretical model proposed by Reinao & Cornejo [2]. The model assumes back pressure equilibrium between the core and ring regions of the substrate to compute the core velocity inside the monolith; hence, Darcy's law can be used to compute pressure drop. The core velocity (u_c) can be computed from the inlet one (u_{in}) as follows:

$$u_c = \frac{u_{in}}{\lambda_c + (\alpha_r/\alpha_c)(1-\lambda_c)} \tag{1}$$

and the pressure drop was computed as:

$$\Delta p = \frac{\mu}{\alpha_c} u_c \tag{2}$$

3. Results and discussion

Tube Reynolds numbers ranging from 60 to 1300 were tested in two dual cell density monoliths. Both had the same relative permeability but differed in core size. The two core sizes tested were 0.25 and 0.50. Figure 2 shows the results for the 0.5 core size monolith together with the model prediction.

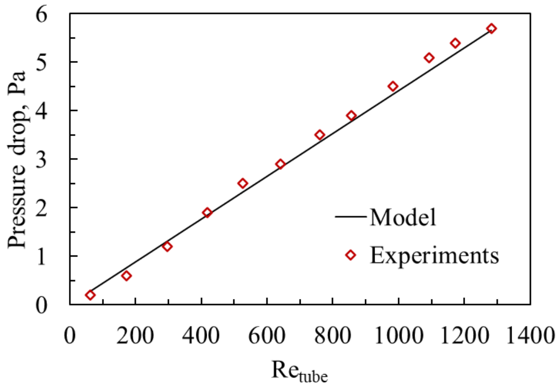

Figure 2. Comparison of the experiments and model prediction from Eq. (1) and (2). $\lambda_c = 0.50$, α_r/α_c=1.36.

According to the figure, the experimental results validated the model in the analyzed conditions. The measured pressure drops closely matched the model's predictions across the tested range of flowrates. A linear relationship between pressure drop and tube Reynolds number is observed. As expected from both Darcy's law and the flow distribution model for dual cell density monoliths in Eq. (1), corroborating the backpressure equilibrium that supports the flow distribution model.

4. Conclusions

This study successfully validates a new model for predicting pressure drop in dual cell density monoliths, showing its agreement against experimental data. The findings enhance the understanding of flow distribution and pressure drop in monolith substrates for further design optimization.

It is recommended to test the validity of the model in a reacting flow condition with future experiments.

References

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Keywords

Dual Cell Density Monoliths; Pressure Drop; Flow Distribution; Experimental Validation.