Design and experimental assessment of novel 3D-printed catalyst geometries: Pressure drop and heat transfer characterization of baffled logpile structures

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Highlights

- Various design parameters of logpile structures and their effect on performance have been investigated.
- Experimental validation of previous CFD simulations.
- The pressure drop can be decreased with negligible effect on heat transfer.
- This study functions as a proof-of-concept to show the viability of 3D-printed catalyst structures.

1. Introduction

Additive manufacturing, or 3D-printing, of catalyst materials allows structuring of catalytic reactor internals with a degree of design freedom that cannot be achieved through conventional methods of reactor manufacturing. Recent literature has mainly focused on the implementation of so-called "log-pile structures" which consist of stacked cylindrical features. The benefits of this design include, but are not limited to, that it is easier to print with 3D printing methods such as Direct Ink Writing (DIW), and, when alternated by 90° for every layer, can fully support itself without external influence. However, in order to be able to provide a meaningful alternative to conventional reactor types such as packed bed reactors, novel 3D-printed structures need to prove their process intensification viability. One method of doing this is to increase the wall-to-bed heat transfer rate, but this, in general, results in increased pressure drop, which would result in increased operation costs. However, 3D printing allows for careful tuning of all design parameters in order to provide the most flexible window of operating conditions. This work shows our experimental efforts to investigate the effect of relevant design parameters on the performance of such 3D-printed logpile catalyst structures and provide an experimental proof-of-concept for their potential for process intensification.

2. Methods

In order to perform heat transfer and pressure drop measurements, a cylindrical metal reactor was constructed with an internal diameter of 44.2 mm, through which nitrogen was fed from the bottom. The pressure drop over this reactor was monitored with a Keller Series PD-23 differential pressure transmitter. Additionally, the reactor was heated to 70°C with an 80 W heating jacket wrapped around the reactor, with a glass wool layer of 38 mm thickness surrounded by Armaflex tape of 3 mm thickness. A cylindrical 3D-printed logpile reactor module made of PETG was inserted into this reactor vessel and equipped with PTFE sealing tape to maintain a pressure seal. Furthermore, two thermocouples could be inserted into the top of the reactor in order to measure axial temperature profiles in the center and wall of the printed module. This module was designed by selective stacking of cylindrical logs with a diameter of 1.5 mm in order to account for possible industrial DIW applications. A layer of logs consists of identically oriented logs that are aligned side-to-side with a distance between them equal to the log diameter. Each subsequent layer is rotated by 90° around the axial axis in order to support the layers above. Because each logpile is separated from its neighbors, a monolith-like structure is created that allows for flow between the logs due to the alternating orientations of the logs. This can occur both in axial, as well as transverse direction through these channels between logs. In order to improve the transverse movement of gas (i.e. induced cross-flow), baffles were implemented by inserting a log between all but a few logs at the side of a single layer such that gas flow through the baffle layer is restricted to the baffle opening. By alternating the position of the baffle opening, improved heat transfer from the reactor wall to the center could be achieved at the cost of additional pressure drop. All logpile structures were modeled in Blender, sliced in PrusaSlicer, and printed with a Prusa MK3S.

3. Results and discussion

Initial validation of the experimental set-up was performed to increase the reliability and repeatability of the measurements and have a careful assessment of the experimental error. Secondly, the distance between logs in a baffle layer could be adjusted to allow for partial flow between the baffles rather than exclusively through the baffle opening. This creates a gap between the logs, and is therefore called gap spacing. By increasing the gap spacing from 0 μm to 50 μm the pressure drop decreased by 52.3% while the wall-to-bed heat transfer remained more favorable than in a packed bed in the same experimental setup. Further increases in the gap spacing decreased the pressure drop further, but resulted in unfavorable heat transfer. An empirical equation was constructed to predict the pressure drop as a function of the gap spacing. Furthermore, an alternative baffle opening was investigated where the baffle openings alternated between the two sides of the reactor, and in the center. This type of Split-Recombine (SR) opening showed a 50.2% decrease in pressure drop when compared to the standard baffle, and highly comparable heat transfer properties. Furthermore, the number of baffles per reactor length, referred to as baffle frequency, could be fine-tuned by adjusting the number of log layers between the baffled log layers. A 50% reduction in baffle frequency from 208 m^{-1} to 104 m^{-1} was shown to result in a further pressure drop decrease of 60.6% with a negligible decrease in center temperature, seemingly ignoring the traditional heat-transfer – pressure drop trade-off (Figure 1). Finally, a modified version of the SR baffle was constructed. Whereas the baffle openings of previous module designs occurred exclusively on an identical transverse plane, the annular module implemented rotation such that the gas would contact as much of the heated wall surface area as possible. This resulted in highly comparable pressure drop, but increased heat transfer toward the center of the module where the temperature difference between inlet and highest measured position increased by 9%.

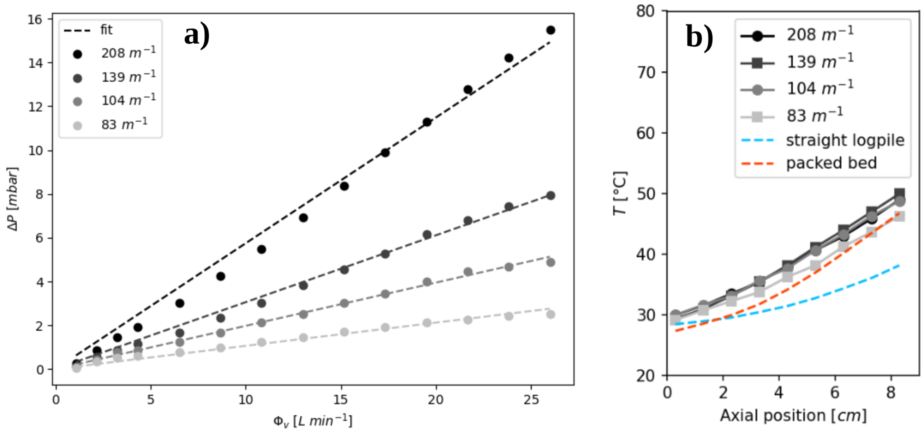

Figure 1. The effect of baffle frequency on (a) the pressure drop at varying flow rates and (b) the axial center temperature profile at 8 L/min

4. Conclusions

This work has shown baffled logpile structures to be a highly flexible catalyst structure that can provide improved bed-to-wall heat transfer at comparable pressure drop or similar bed-to-wall heat transfer at reduced pressure drop. Additionally, the traditional trade-off between pressure drop and heat transfer was seemingly mitigated by the increased customizability of reactor internals, e.g. by a decrease in baffle frequency or rotation in the position of baffle openings between different baffled logpile layers.

References

No references are implemented in this abstract.

Keywords
3D-printing; catalytic reactor; heat transfer; pressure drop