
# Additive Manufacturing of Tailor-Made Catalytic Reactors for Single Phase and Multiphase Reaction Systems

Hannsjörg Freund*, Markus Lämmermann, Corinna Busse, Wilhelm Schwieger

*Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Lehrstuhl für Chemische Reaktionstechnik, Egerlandstr. 3, 91058 Erlangen, Germany*

**Corresponding author: hannsjoerg.freund@fau.de*

***Highlights***

- Additive manufacturing of periodic open cellular structures (POCS) as catalyst support
- Characterization of transport processes and reaction in POCS for single- and multiphase applications
- Derivation of new design correlations for POCS
- POCS feature superior heat & mass transport characteristics and outperform conventional packed beds

## 1. Introduction

An intelligent matching of reaction and transport processes is key to the design of optimal catalytic reactors. For the realization of optimal reaction and process conditions, specific requirements regarding heat and mass transport characteristics demand for suitable catalyst support materials and structures. In this regard, open cellular structures have emerged as promising novel catalyst supports due to their remarkable combination of beneficial properties: high specific surface area, low pressure drop and adjustable heat transfer properties [1]. Additive manufacturing (AM) techniques have emerged as enabling technology which unlocks a new degree of freedom in the design. AM allows for the fabrication of open cellular structures of nearly arbitrary geometrical complexity in a well-defined and highly reproducible manner [2-3]. In this contribution, the potential of additively manufactured periodic open cellular structures (POCS) as catalyst support for single phase and multiphase applications is analyzed in detail.

## 2. Materials and Methods

The tailor-made POCS were manufactured via AM, functionalized by catalytic coating, and then applied in two case studies for demonstration. In the first case study, the focus is on the optimization of heat transport in a highly exothermic gas phase reaction for enhancing the selectivity, where the oxidation of methanol to formaldehyde serves as example system. For a systematic investigation the influence of each relevant property of the structure (material, morphology, wall coupling) on the heat transfer was examined in detail by manufacturing a variety of structures. As AM techniques, for the ABS polymer structures fused deposition modeling (FDM) was used, while the metal structures were manufactured via selective laser melting (SLM) and selective electron beam melting (SEBM), respectively.

In the second case study, the phase contacting, i.e. the gas-liquid distribution in a trickle-bed reactor was optimized [4]. As example reaction system, the hydrodesulfurization (HDS) of gas oil was investigated. The POCS for the cold flow gas-liquid distribution experiments were obtained via FDM (ABS) and stereolithography (resin) while the metal structures were produced with SEBM (Ti6Al/4V).

## 3. Results and Discussion

For the single phase system, the heat transfer performance of POCS of different material, morphology and with different coupling to the reactor wall was investigated in a dedicated lab setup. The overall heat transfer was calculated and compared to a conventional randomly packed bed reactor. Especially for materials with high solid conductivity and/or at low to medium flow rates, the POCS clearly outperform conventional packed beds (see Fig. 1, left). These findings and the consequences on the heterogeneously catalyzed oxidation of methanol to formaldehyde (exothermic, wall-cooled reactor) was then explored in another setup. The comparatively flat temperature profile for the POCS (see Fig. 1, right) allows for a significant reduction of undesired carbon monoxide byproduct formation compared to a conventional packed bed system.


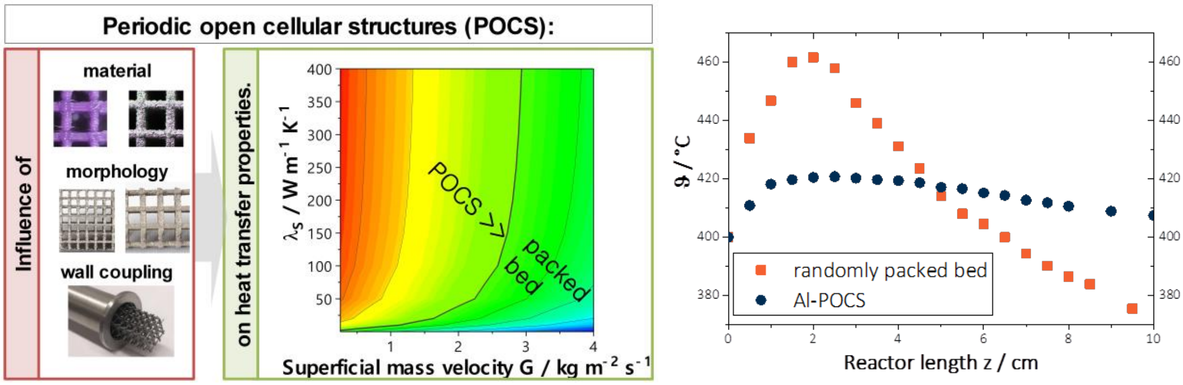


**Figure 1:** Left: POCS of different material, morphology and wall coupling and diagram depicting the overall heat transfer performance. Right: Resulting temperature profiles in the reactor for POCS vs. conventional randomly packed bed.

The gas-liquid distribution performance of POCS in trickle-bed applications was investigated in a cold flow setup [4]. With a newly designed unit cell type (see Fig. 2, left) a uniform liquid distribution along the reactor bed height and a significant reduction of the liquid maldistribution factor compared to a conventional packed bed could be achieved (see Fig. 2, middle left). Besides, static and dynamic liquid holdup as well as single- and two-phase pressure drop was measured in the different POCS, and suitable correlations were derived. POCS were then manufactured by SEBM and catalytically functionalized in a sequence of coating and impregnation steps (see Fig. 2, middle right). Finally, the improved performance of the POCS could be demonstrated in reactive HDS experiments in a miniplant setup (see Fig. 2, right).

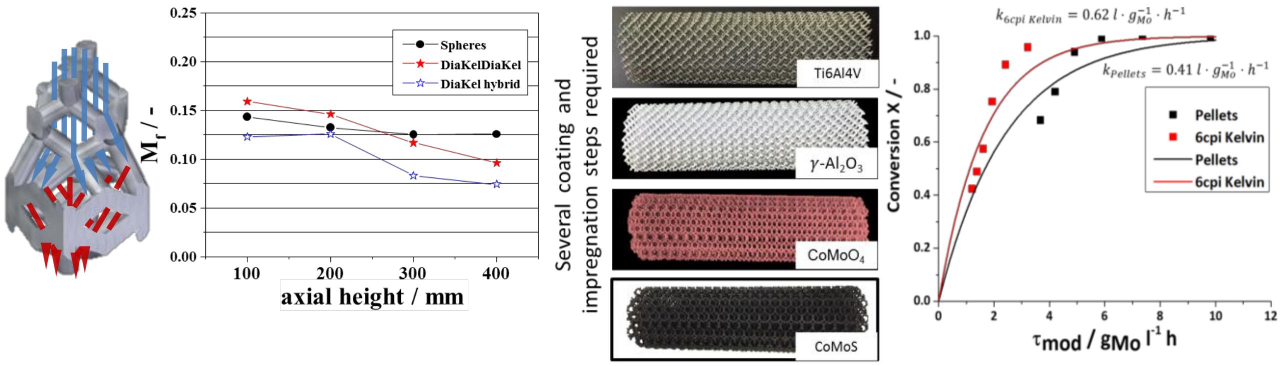


**Figure 2:** Left: Newly designed DiaKel unit cell; middle left: liquid maldistribution factor over reactor length; middle right: catalytic functionalization of the POCS; right: conversion plot for POCS vs. conventional randomly packed trickle bed reactor.

## 4. Conclusions

We have extensively investigated POCS regarding their performance as catalyst support. First, the POCS were characterized with respect to their morphological/geometrical properties, fluid dynamic behavior and mass and heat transport properties [1-4]. Models for the estimation of properties important for reactor design such as specific surface area, pressure drop and heat transport were developed and validated by experiments. The established models allow for the design and optimization of POCS that are tailor-made according to the needs of the reaction system, representing a new class of superior catalyst supports. For both reaction systems in this study, the tailor-made POCS were benchmarked against a traditional randomly packed bed reactor, and clearly a great potential for process intensification could be demonstrated.

## References

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***Keywords***
Additive Manufacturing, Catalytic Reactors, Structured Catalysts, Process Intensification