

Two-Phase Flow inside the Rotating Packed Bed

Resolving the Two-Phase Flow inside the Rotating Packed Bed with Open-Cell Foams

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In Short

- Goal: fundamental understanding of the flow morphologies in Rotating Packed Bed with metal foam packing.
- Resolution of the open-cell foam to enable first-principle modeling.
- Interface-capturing simulation method to calculate the phase distribution.
- Understanding the influence of rotational speed and flow rate on the flow.

The Rotating Packed Bed (RPB) is a device that exploits high-gravity fields to intensify gas-liquid heat and mass transfer and has its use cases in fluid separation processes especially in distillation and absorption as well as reaction engineering [1]. In essence, the RPB consists of a rotating annular rigid bed which produces a high centrifugal field. This centrifugal force is the driving force for the liquid flow, where liquid is distributed onto the bed at its hollow center and flows outwards due to the rotation. The gas phase with lower density flows from the casing of the RPB radially inwards through the packing in a counter-current manner driven by pressure difference.

The promise of intensified transfer in RPBs motivates further research of the device. Experimentally, characteristics for mass transfer such as the specific mass transfer coefficient have been determined integrally [2, 3]. A further approach through local temperature measurements inside the rigid bed has also been conducted [4, 5]. Based on these experiments, mass transfer correlations were developed for the RPB. However, the accuracy of these correlations is limited without the knowledge of the phase distribution of the gas-liquid flow. Many of mass transfer investigations rely on the assumptions of extreme conditions, either that the liquid covers the surface of the packing completely or that the liquid flows in form of droplets between the pores of the packing. Available experimental methods currently cannot determine the form of the liquid flow yet, not to mention quantitative data such as the specific surface area.

Considering the necessity of the phase distribution of the gas-liquid flow for further development in

RPB and current CFD investigations on the topic, we believe that further CFD investigation for the three-dimensional metal foam packing will be essential for the understanding of mass transfer in RPBs.

To resolve the geometry of the metal foam, we implemented a foam reconstruction workflow presented in [6] in an in-house software written in C++. The software produces the topology of a metal foam in form of a triangulated surface geometries in the STL format, which can subsequently be applied in the mesh generation process for the CFD computation. An example of the reconstructed metal foam as well as the resulting CFD mesh is shown in Figure 1.

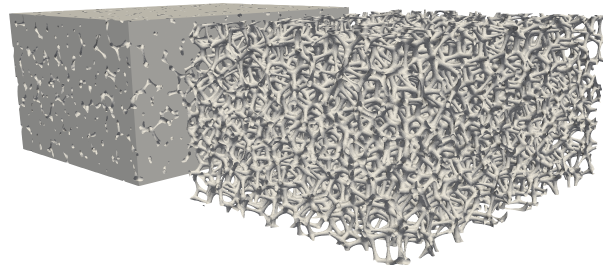


Figure 1: Example mesh for CFD simulations (left) generated from the open-cell foam produced by the reconstruction workflow (right).

In our preliminary study, the metal foam is extended to an inner radius of $r_i = 73$ mm and an outer radius of $r_o = 100$ mm, which corresponds to one segment of the metal foam packing in the RPB plant from [7]. A snapshot of this study is shown in Figure 2. Qualitatively, we observe various morphologies of the liquid such as rivulets and droplets inside the pores of the metal foam. At low rotational speed, the liquid tends to fill the void in the metal foam and flows as rivulets. By contrast, the liquid becomes more dispersed as the rotational speed increases. In these preliminary simulations, the liquid flow rate amounts to $\dot{V}_L = 0.378 \text{ m}^3 \text{ h}^{-1}$ and the gas flow is not yet enforced ($\dot{V}_G = 0 \text{ m}^3 \text{ h}^{-1}$).

For this compute project, we have extended the simulation domain to allow for counter-current flow of the gas phase. In this setup, the liquid inlet velocity is set whereas the gas flow is pressure driven and set through pressure differences between the inlet and outlet patches. The simulation setup is also designed to resemble the RPB's actual geometry as close as possible. The rotation in the domain is realized with the Multiple Reference Frame approach. No turbulence model is applied since preliminary single-phase simulations suggest laminar flow in the metal foam packing.

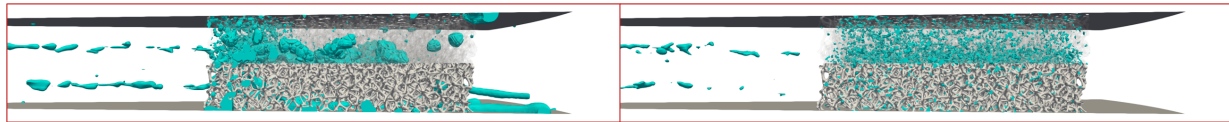


Figure 2: Gas/liquid flow interface in the metal foam for rotational speeds 300 RPM (left) and 1200 RPM (right).

The outcome of the simulations should cover all of the followings:

- Qualitative form of the gas-liquid flow;
- Time-averaged radial profiles of the specific holdup $\varepsilon = V_{\text{liquid}} / (V_{\text{liquid}} + V_{\text{gas}})$ of the liquid and the specific interfacial area $a = A_{\text{interface}} / (V_{\text{liquid}} + V_{\text{gas}})$ between the two phases;
- Comparison of the time-averaged radial profile of specific holdup ε with experimental data.

The last objective aims to increase confidence in the simulation results. The first two aspects would provide significant insights in further analysis of mass transfer experiments in RPBs and further development of process models of the device, which would eventually increase the likelihood of RPB applications in industrial context and in turn help reduce the carbon footprint of thermal separation in chemical industry. Until now, insights for these quantities are still missing due to the lack of suitable measurement methods for the RPB.

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More Information

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DFG Subject Area

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