X-ray Tomography Analysis of 3D Structure of Packed Beds of Spheres.

Jennie von Seckendorff[1,2,*], Normen Szesni[3], Richard Fischer[1,2,3], Olaf Hinrichsen[1,2]

1 Technical University of Munich, Department of Chemistry, Lichtenbergstraße 4, 85748 Garching, Germany;
2 Technical University of Munich, Catalysis Research Center, Ernst-Otto-Fischer-Straße 1, 85748 Garching, Germany;
3 Clariant Produkte (Deutschland) GmbH, Waldheimer Str. 15, 83052 Heufeld, Germany

**Corresponding author: jennie.seckendorff@ch.tum.de*

Highlights

- Modern x-ray tomography analysis to gain highly resolved 3D packed bed structure.
- Influence of filling method, material properties and size ratio on packing structure.
- Comparison of real packing structures and those obtained by numerical methods.

1. Introduction

Computational Fluid Dynamics Simulations (CFD) are numerously performed to describe fluid flow, heat and mass transfer in packed bed reactors typically used in chemical industry, in order to quantify problems and improve effectivity. However, before performing the simulations it is essential to validate the packed bed structure used, particularly the porosity distribution along radial and longitudinal tube axes. Only little information about experimentally gained porosity distributions are available [1]. Additionally, these profiles show significant errors due to the imprecise experimental techniques that had been state of the art some time ago. Moreover, it is believed that the porosity distribution follows the trend of its mean value which strongly depends on packing method used as well as the particles material and the tube to particle diameter ratio λ[2]. Most of these influences have not been addressed so far.

Concerning the modeling of packed beds, multiple methods exist, starting with those taking all existing physical laws into account (discrete element method) and a variety of methods using different simplifications in order to increase simulation speed. With a substantial basis of experimental results it is possible to evaluate these methods to give guidance which of these methods should preferably be used in order to gain most realistic packing structures with least computational effort. X-ray tomography was used in some cases to validate single packing arrangements [3]. Both, the packings obtained by x-ray tomography as well as those from packing modeling can be used in CFD simulations in order to investigate fluid dynamics, heat and mass transfer as was done before repeatedly.

All in all, the main aim of our work is to use x-ray tomography (CT) to develop a reliable and adequately substantial data basis that we and others can use to validate their packed bed models for CFD simulation applications, as well as to investigate certain influencing parameters on the porosity profiles to gain more fundamental knowledge about packed bed structures.

2. Methods

Packings of spheres of different material and size were created using different filling methods to gain loose and dense packing arrangements in tubes of 10 cm height and 1.5 to 5.5 cm diameter. This was done according to Pottbäcker and Hinrichsen [2]. X-ray tomography analysis was performed and the obtained images of cross sectional slices processed to gain the center positions of each sphere in the packing. Based on these center positions, the porosity profiles can be calculated on the one hand, and a rearrangement of the spheres into a 3D packing can be performed on the other hand. The results are then compared to simulations obtained using different packing modeling approaches (DigiDEM™ by Structure Vision Limited and BLENDER™) for the packing creation in order to evaluate their significances.

3. Results and discussion

Figure 1 to 3 show exemplarily results of x-ray tomography for our reference packing (λ = 6.4, H/d = 25, smooth plastic spheres, machine filling according to [2]). In Figure 1, the re-assembled 3D structure of the packing is shown, ready to be used in CFD simulations. The porosity profile along the longitudinal axis is shown in figure 2. Herein, the top and bottom section that fall within the scope of the so called end effect is marked. This end effect describes the effect that bottom and top of a cylinder have on the structural order of a packing. In general, the mean porosity is higher when incorporating these regions. In between, the porosity fluctuates along a constant mean value, indicating the bulk of the packing. Figure 3 describes the radial porosity distribution. This distribution is important, as the velocity distribution (obtainable by CFD) will basically follow this trend, indicating unwanted channels of high velocity (were radial porosity is high) and dead zones or zones of low velocity (were radial porosity is low).

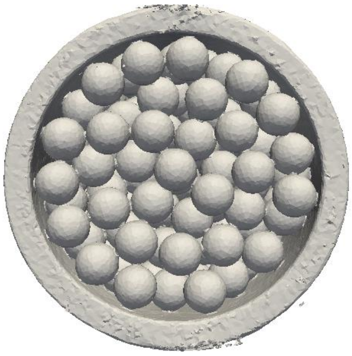

Figure 1. Re-assembled CT images into 3D packed bed structure.

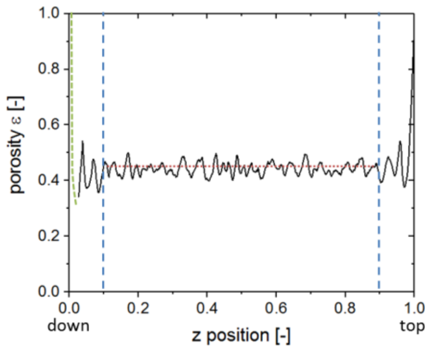

Figure 2. Axial porosity distribution of reference packing.

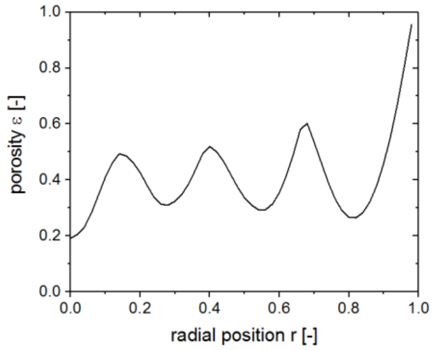

Figure 3. Radial porosity distribution of reference packing.

It is assumed that these porosity profiles, especially the radial distribution will change using different filling methods, material properties and size ratios. This assumption is based on numerical packing generation that was already performed using BLENDER™ and DigiDEM™ and on experimental results concerning the mean porosity that is highly sensitive to all parameters [2]. However, more x-ray tomography runs are planned for the future.

4. Conclusions

The presented work is highly important to validate numerically generated packed beds as there is only little state of the art data available for porosity distributions in packed beds of spheres. In order to fill this gap, modern 3D structure analysis tools (CT) are investigated and first data was obtained. A measurement and analysation procedure was developed and it was found that x-ray tomography measurements can be used to describe packing geometries in a highly accurate way. Furthermore, this technique will be used to gain more fundamental knowledge about packing structures in general and to produce realistic packings that are subsequently incorporated into CFD simulations to increase the significance of the obtained results.

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Keywords
packed bed porosity; x-ray tomography; validation of numerical packing generation; radial porosity distribution.