Pore network modelling and tomographic visualization of particle packing drying

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Introduction. A detailed understanding of evaporative drying of porous materials is an important research topic that has led to the development and adaptation of various numerical and experimental techniques. At the pore scale, discrete pore network model has been developed and drying experiments with packings of glass beads have been carried out by high resolution X-ray microtomography. The discrepancy of simulation and experimental results may be explained by films of liquid rings which are neglected in the previous pore network drying model. Such liquid films have been incorporated into 3D regular pore network drying model and simulation results are compared with X-ray drying experiments.

Problem Definition

The pore network model is a suitable tool to examine the pore-scale behavior of porous media. However, some physical effects are still absent in the recent pore network model. Results from pore network simulations also need to be validated by pore-scale drying experiments.

Objectives

Use X-ray microtomography to validate the pore network drying model by drying experiments with particle aggregates initially saturated with liquid. Develop and implement the liquid film effect in the three dimensional irregular pore network drying model.

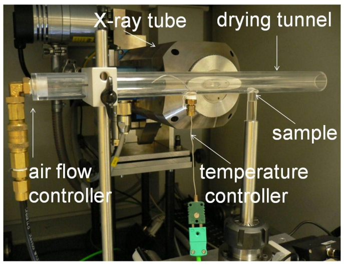
Cooperation

- M.Sc. Zinaida Kutelova (GKmm): Surface coating of glass beads, contact angle measurement
- M. Sc. Maryam Sada Dadkhah (GKmm): Image processing
- M.Sc. Oleksandr Prygorniev (GKmm): Voronoi tessellation

Materials and Experimental Setup

- Cylindrical PMMA container with diameter 8 mm and height 8 mm
- Mean diameter of 0.7 mm hydrophilic glass beads / hydrophobic coated glass beads
- Liquid solution: water with salt tracer
- Equal amount of liquid for each sample
- Drying time between each scan: 30 minutes
- Number of projections: 400
- Exposure time: 1000 µs
- Voxel size: $16 \times 16 \times 16$ µm^3
- Scanning time: 30 minutes

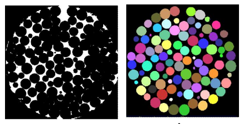
CT-ALPHA-160
ProCon X-Ray GmbH



Dryer setup inside X-ray tomography device for convective drying

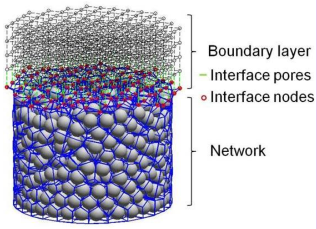
Image Processing

- Crop original image to suitable size
- Apply median filter for reducing noise
- Binarization (Fig. a represents liquid phase)
- Segmentation of solid phase based on pre-flood watershed algorithm to obtain center coordinates and radii of particles (Fig. b)



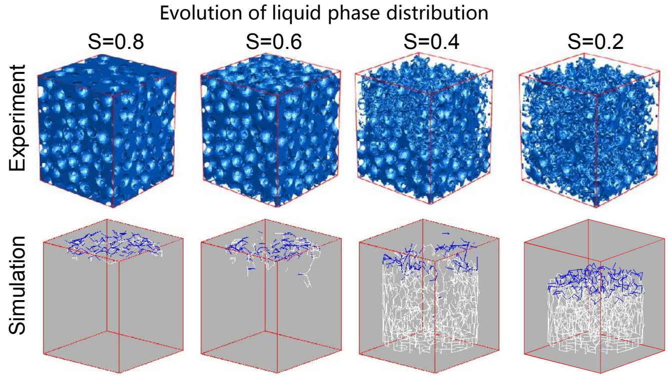
Pore Network Model

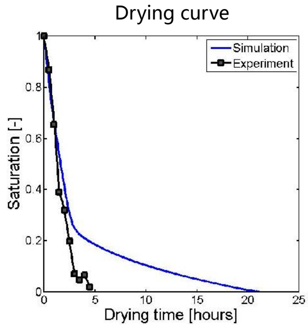
- Input: center coordinates and radii of particles
- Segmentation of the void space of particle packing by Voronoi tessellation
- Elimination and node-merging for small pores
- Pores and nodes are identified
- Boundary layer, which is responsible for vapor diffusion
- Drying model: capillary liquid pumping, vapor diffusion, viscosity and gravity effects



Results and Discussion

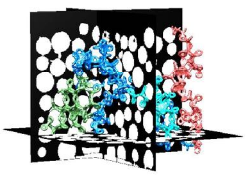
X-ray tomography experiment and pore network simulation





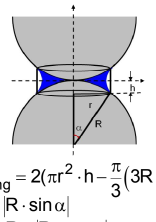
- Pore network model predicts well the first drying period.
- Drying time is overestimated by the pore network simulation.
- Discrepancy in simulation and experiments may be due to the absence of film effect in the model.

Morphology of liquid rings (films)



At low saturation, the liquid phase remains connected through **annular liquid rings** around the particle-particle contact points, providing the liquid to the aggregate surface.

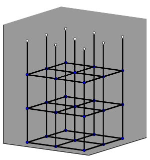
Ring geometry



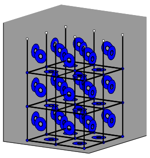
$$V_{ring} = 2(\pi r^2 \cdot h - \frac{\pi}{3}(3R - h) \cdot h^2)$$
$$r = |R \cdot \sin\alpha|$$
$$h = R - |R \cdot \cos\alpha|$$

Model incorporation of liquid rings

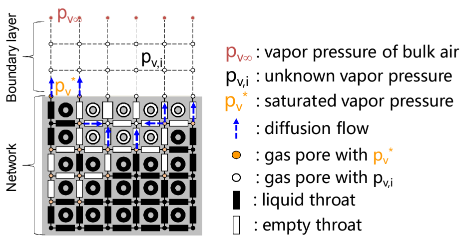
Geometrical elements for representation of the void space:
Cylindrical throats: large pore space
Annular rings: small pore space at vicinity of contact points between particles



Previous pore network



New pore network with liquid rings



- There is no vapor diffusion in the network until a ring starts to dry.
- In a cluster, only throats can be emptied; rings can only empty if they are isolated.

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