EGU General Assembly 2022

EGU22-4837, updated on 15 Aug 2022
https://doi.org/10.5194/egusphere-egu22-4837
EGU General Assembly 2022

Validation and calibration of gas flow experiments with numerical simulations

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The success of the Rosetta mission to comet 67P/Churyumov–Gerasimenko has revolutionized our view of comets, while opening a plethora of new questions. In order to find the answers to them and harness the full potential of the new data, an international consortium named "Cophylab – Comet Physics Laboratory" (Cophylab.space) was launched in 2018. In this project several experiment campaigns were initialized to study cometary properties in a controlled environment. The idea was to isolate individual properties and processes in dedicated laboratory experiments. One of the experiment campaigns was designed to characterize gas flow properties of dry porous materials in a first step, with the aim of developing a model that improves our understanding of the outgassing of comets.

Before the initial model is extended to consider the sublimation of volatile components, it needs to be validated by alternative methods, such as numerical simulations. For this purpose, we chose the finite element method, to test the combination of the Darcy and Knudsen flow model, which was used in the preceding study.

Our approach was to use the results of the experiment as input in the simulations and compare the output with the measurements. This comparison confirmed the validity of the model and its assumptions. In particular, the sample is assumed to be homogenous and isotropic on a macroscopic scale, so that it can be described by a set of averaged parameters. While this description is relatively accurate for samples with well-defined grain shapes (e.g. spherical glass beads), significant discrepancies occur for inhomogeneous materials such as lunar, Asteroid or Martian analogues.

We investigated various aspects that were initially neglected in the evaluation of the measurements, such as channel building in the sample, boundary effects and non-ideal geometry of the experimental setup, which will be complemented by inhomogeneities that occur naturally in random close packing or ballistic deposition samples. Furthermore, we assessed the models range of applicability through a thorough review of the different flow regimes encountered in the measurements. Our findings indicate that boundary effects, as well as non-ideal geometry have a significant influence particularly in samples with larger grains. For finer grained samples on the other hand, inhomogeneities are the most probable cause for discrepancies. The grain size also plays an important role regarding the flow regime and its corresponding parameters.

The work for this study was performed in the framework of a master’s thesis, as part of the Cophylab project, which is funded by the D-A-CH program (DFG GU1620/3-1 and BL 298/26-1 / SNF 200021E 177964 / FWF I 3730-N36)