# Application of Large Eddy Simulation-Immersed Boundary Volume Penalization Method for Heat and Mass Transfer in Granular Layers

**Authors :** Artur Tyliszczak, Ewa Szymanek, Maciej Marek

**Abstract :** Flow through granular materials is important to a vast array of industries, for instance in construction industry where granular layers are used for bulkheads and isolators, in chemical engineering and catalytic reactors where large surfaces of packed granular beds intensify chemical reactions, or in energy production systems, where granulates are promising materials for heat storage and heat transfer media. Despite the common usage of granulates and extensive research performed in this field, phenomena occurring between granular solid elements or between solids and fluid are still not fully understood. In the present work we analyze the heat exchange process between the flowing medium (gas, liquid) and solid material inside the granular layers. We consider them as a composite of isolated solid elements and inter-granular spaces in which a gas or liquid can flow. The structure of the layer is controlled by shapes of particular granular elements (e.g., spheres, cylinders, cubes, Raschig rings), its spatial distribution or effective characteristic dimension (total volume or surface area). We will analyze to what extent alteration of these parameters influences on flow characteristics (turbulent intensity, mixing efficiency, heat transfer) inside the layer and behind it. Analysis of flow inside granular layers is very complicated because the use of classical experimental techniques (LDA, PIV, fibber probes) inside the layers is practically impossible, whereas the use of probes (e.g. thermocouples, Pitot tubes) requires drilling of holes inside the solid material. Hence, measurements of the flow inside granular layers are usually performed using for instance advanced X-ray tomography. In this respect, theoretical or numerical analyses of flow inside granulates seem crucial. Application of discrete element methods in combination with the classical finite volume/finite difference approaches is problematic as a mesh generation process for complex granular material can be very arduous. A good alternative for simulation of flow in complex domains is an immersed boundary-volume penalization (IB-VP) in which the computational meshes have simple Cartesian structure and impact of solid objects on the fluid is mimicked by source terms added to the Navier-Stokes and energy equations. The present paper focuses on application of the IB-VP method combined with large eddy simulation (LES). The flow solver used in this work is a high-order code (SAILOR), which was used previously in various studies, including laminar/turbulent transition in free flows and also for flows in wavy channels, wavy pipes and over various shape obstacles. In these cases a formal order of approximation turned out to be in between 1 and 2, depending on the test case. The current research concentrates on analyses of the flows in dense granular layers with elements distributed in a deterministic regular manner and validation of the results obtained using LES-IB method and body-fitted approach. The comparisons are very promising and show very good agreement. It is found that the size, number of elements and their distribution have huge impact on the obtained results. Ordering of the granular elements (or lack of it) affects both the pressure drop and efficiency of the heat transfer as it significantly changes mixing process.

**Keywords :** granular layers, heat transfer, immersed boundary method, numerical simulations
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