Modelling liquid spreading in trickled packed beds

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Introduction

Modelling two-phase flow in an unstructured packed beds, even for isothermal and non-reacting conditions, seems to be one of the most challenging fluid mechanics problems. Complex geometry, locally unpredictable flow patterns, mutual interactions between all (solid, gas and liquid) phases make the flow description extremely difficult. Various concepts have been proposed in the source literature to provide reasonable solutions. In their review paper Wang et al. [1] discussed different approaches to the subject including those with limited applications (e.g. packed beds composed of spheres) up to methods allowing to accurately predict pressure drop, liquid holdup and even liquid spreading intensity for various packing element types.

In principle the specific characteristics of the packed bed are introduced into the flow governing equations by the source terms in momentum equation, which may take different forms and depend on numerous parameters. In a recent paper of Solomenko et al. [2] the very good agreement between experimental measurements (γ-ray tomography) and the simulation results was obtained with the use of an Euler-Euler 2-fluid model taking into account the capillary and mechanical mechanisms with adequately chosen model constants. However, all the Eulerian-type models allow to predict the flow statistics only, losing its local nonuniformities resulting from realistic geometry of packed bed manifested by spatial variations of bed porosity. That in turn may lead to significant variations of flow velocities and liquid holdup and thus influence all the processes (heat and mass transfer) built on flow hydrodynamics. This drawback of Euler-Euler approach can be overcome by Volume of Fluid (VOF), being a surface tracking technique. However, its application requires the precise definition of flow boundaries (i.e. packed bed geometry) which makes it very expensive computationally and restricts its applicability to small segments or periodic regions [1].

Volume of Fluid – Eulerian approach

In the present paper a combined VOF-Eulerian two-fluid simulation strategy was applied to the two-phase countercurrent flow in a random packed bed composed of Raschig rings. The realistic packed bed geometry was generated numerically using the in-house code [3], which then could serve as geometrical constraints for the liquid flow simulation with the use of VOF model. As an outcome the probability distribution function (PDF) of velocity vector orientation angle was determined, which then could be implemented into a 2-fluid Euler-Euler multiphase model of packing column [4] developed in Ansys Fluent environment.

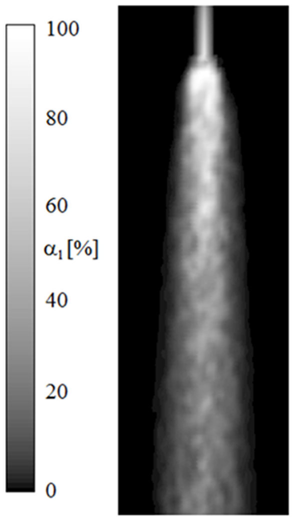

Fig. 1: Instantaneous liquid volume fraction distribution in a packed bed. White colour corresponds to liquid while black one to gas phase.

The velocity vectors were generated in random way, however, satisfying both the PDF of vector orientation as well as the cross section averaged liquid loads. Using this procedure the flow structure could be recovered in a way reflecting the realistic geometrical constraints, i.e. local nonuniformities of the flow velocity and volume fraction fields. In Fig.1 the sample distribution of the liquid volume fraction is presented for the case when water is injected from centred fine-diameter distributor. One can easily notice the irregular flow structure manifested by varying greyscale intensity reflecting liquid accumulations and zones with significantly reduced water content. The variations of liquid volume fraction around the expected (Eulerian) level influence a gas velocity field which in turn may lead to increased pressure drop. Taking the reacting flow conditions into account the solution of the flowfield in such a form allows for more precise calculations of local heat and mass transfer being actually related (in nonlinear manner) to volume fractions and compositions of counterflowing phases.

The presented VOF-Euler simulation strategy has been shown to provide the adequate description of the trickling flow and the liquid spreading in an unstructured packed bed in reasonable time. The speeding up of the procedure was achieved by implementation of velocity vector distribution instead of detailed flow modelling in a realistic packed bed geometry. The model is intended to be applied for the simulation of reacting flows, in particular to simulate the carbon dioxide capture by chemical absorption, i.e. one of the most common post-combustion carbon capture and storage (CCS) technologies.

References

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