Population balance modeling using class and quadrature-based moment methods with application to bubbly flows

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Multi-phase flows with a continuous and a distinct disperse phase are essential in a variety of industrial applications, e.g., in chemical engineering or in nuclear safety research. These flows are usually polydisperse, i.e., the disperse phase exhibits a size distribution. In case of bubbly flows, the size distribution and its statistical moments are highly influenced by the overall heat- and mass transfer rates as well as the flow structure, e.g., during the transition from the homogeneous to the heterogeneous regime in bubble columns. Temporal and spatial changes of the size distribution can be described with a transport equation for the number density function (NDF), i.e., the population balance equation (PBE).

Two popular Eulerian methods to solve the PBE are the method of classes and the family of Quadrature Based Methods of Moments (QBMM). Both approaches have been applied in CFD before, e.g., for simulations of stirred tanks, spray behavior or soot formation. However, OpenFOAM offers no capabilities in this regard.

While the Quadrature Method of Moments (QMOM) - the basic QBMM approach - tracks only the moments of the NDF, class methods track the shape of the NDF directly by means of discretization. An extended version of QMOM, called EQMOM, allows reconstructing the NDF using a set of kernel density functions. All three approaches are implemented into the OpenFOAM library and validated against analytical solutions. A comparison for pipe flow and bubble column cases using appropriate coalescence and breakup models shows the accuracy and performance of each method.

Furthermore, it is known for bubbly flows that the velocity of the disperse phase is generally size dependent and the bubbles may separate spatially. An extreme case is the lift force, which governs the lateral migration of bubbles in a liquid shear field and changes its sign at a critical diameter. This effect is not covered by the general two-fluid or Euler-Euler approach. Partially, this can be taken into account using a multi-fluid solver, by splitting the disperse phase into velocity groups with fixed boundaries. An alternative approach is to include the velocity as an internal coordinate into the PBE, which gives the generalized PBE (GBPE). Using a size-conditioned velocity approach, the GBPE can be solved within the
QBMM framework. Thereby, a continuous information about the dependency of velocity on size can be obtained. The work presents first results and comparisons between the two approaches.