Euler-Euler simulation of gas-liquid and gas-liquid-solid airlift reactors: case study

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This contribution is aimed at CFD simulation of hydrodynamics of gas-liquid and gas-liquid-solid airlift reactors using Euler-Euler model. Commercial code Fluent 6.3 is used to solve model equations [1]. Studied cases include gas-liquid rectangular external loop airlift reactor and gas-liquid-solid cylindrical internal and external loop airlift reactor.

Goal

The goal of the work was to compare simulation results with experimental data available in literature.
Horizontal profiles of liquid and bubble velocity and gas holdup were compared with data of Becker et al. [4] in the case of rectangular gas-liquid airlift. Gas holdup and liquid velocity in the riser for different solid loadings were compared with data of Freitas et al. [5, 6] in the case of external and internal gas-liquid-solid airlift.

Model

In Euler-Euler model all involved phases (gas, liquid, (solid)) are treated as interpenetrating continua. There is continuity and momentum equation for each particular phase. Equations for phase q are (see e.g. [1], [2], [3]):

$$\partial(\alpha_q\rho_q)/\partial t + \;.\;(\alpha_q \rho_q \mathbf{u}_q) = 0$$
$$\partial(\alpha_q \rho_q \mathbf{u}_q)/\partial t + \;.\;(\alpha_q \rho_q \mathbf{u}_q \mathbf{u}_q) = -\alpha_q \;\; p - \;.(\alpha_q \tau_q) + \alpha_q \rho_q \mathbf{g} + \Sigma_p \mathbf{F}_{qp}$$

where α_q is volume fraction of phase q, $\mathbf{u}_q$ is velocity, p pressure and $\Sigma_p \mathbf{F}_{qp}$ is sum of forces the other phases p act on phase q, and $\tau_q = \tau_{l,q} + \tau_{t,q}$ is effective stress tensor which contains contributions not only from viscous effects ($\tau_{l,q} = \mu_q (\;\mathbf{u}_q + \;\mathbf{u}_q^T)$) but also from velocity turbulent fluctuations.

These equations are coupled together through pressure, phase volume fractions (which sum to unity) and interphase force terms like drag, lift, added mass and turbulent dispersion force. Closure relations for the interphase forces are needed to solve the equations. These closures are difficult to obtain and their correct form may be unknown especially for higher phase holdup. Related problem is modelling of bubble size distribution since the interphase forces depend on bubble size. Also the turbulent contribution to the stress tensor needs to be modelled. This is usually done with single phase turbulence models such as k-ε extended for multiphase flows.

Simulations

Either steady state or transient simulations were done. Although the flow field is in general unsteady in airlift reactors, the steady state simulations may be useful to estimate total gas holdup and liquid circulation rate at least for lower gas flow rates. Simulations were done in 2D (2D Cartesian – rectangular airlift (Becker), 2D cylindrical (Freitas, internal loop airlift)) and 3D coordinates. The flow field in general is 3D so the 2D simulations may be used only as a first estimate.

Grid and time step independence was tested. Drag, lift, added mass and turbulent dispersion force have been accounted for in the model. Closures based on single bubble case were used. Simulations for different values of lift coefficient were done. Bubble coalescence or break-up were not accounted for in the model, dispersed particles were considered to be all of the same size. Several approaches to modelling of gas-solid interaction were tested. Interactions between gas and solid were either neglected or described in a similar way as gas-liquid interactions or an approach based on kinetic theory applied to granular flows was employed (see [1] for details).

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