3D STEADY STATE RISER SIMULATIONS USING FILTERED GAS-SOLID MOMENTUM TRANSFER MODELS

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INTRODUCTION

To account for meso-scale phenomena in coarse grid simulations, Reynolds stress terms appearing in the filtered gas-solid flow equations have to be modeled. Filtered models for the gas-solid momentum transfer are focused on and possible approaches are discussed. Three-dimensional steady-state simulations of developing flow in the bottom section of a riser in which the solid phase is accelerated by the gas phase are carried out to investigate the impact of using filtered gas-solid momentum transfer models.

ANALYSIS OF FILTERED GAS-SOLID MOMENTUM TRANSFER MODELS

The gas-solid momentum transfer consists, on the one hand, of the drag force and, on the other hand, of the acoustic gas-solid interaction force, i.e. the distribution of the gas phase pressure gradient over the phases. Effective interphase momentum transfer coefficient closure models have been proposed for the filtered drag force [1]. For the filtered acoustic gas-solid interaction force, Zhang and VanderHeyden proposed a generalized added mass closure model [2], introducing a generalized added mass coefficient. The closure models for the filtered gas-solid momentum transfer proposed so far are analyzed with a mixture speed of sound test. Whereas the closure terms in filtered models may alter the calculated mixture speed of sound at frequencies higher than the filter frequency, they should not alter the calculated mixture speed of sound at frequencies lower than the filter frequency. The mixture speed of sound test shows an acceptable behavior for the generalized added mass approach.

Theoretically, it was shown that a generalized added mass appears directly from the filtered acoustic gas-solid interaction force and that it corresponds to a redistribution of the filtered gas phase pressure gradient over the phases [3]. This direct contribution scales according to the mean square of the solid volume fraction fluctuations. A second, indirect contribution to the generalized added mass term from the filtered acoustic gas-solid interaction term was shown to be statistically significant, but one order of magnitude smaller than the direct contribution. With decreasing filter frequency, the distribution of the filtered gas phase pressure gradient over the phases may shift from volume fraction based to mass fraction based. The restriction to mass fraction based is in accordance with Newton's second law of motion. A further quantification of the maximum generalized added mass effect as a function of the filter frequency is obtained from the mixture speed of sound test. It is shown that a large generalized added mass coefficient, as previously reported by Zhang and VanderHeyden [2], is justified only in case the filter frequency is low (< 20 Hz), i.e. if the grid is, either spatially or temporally, sufficiently coarse.

3D STEADY STATE RISER SIMULATIONS

The steady state simulations of the bottom acceleration section of a riser that are carried out have a sufficiently low filter frequency to verify the impact of a generalized added mass based filtered gas-solid momentum transfer model assuming a large generalized added mass effect. As well with the non-filtered model as with the filtered generalized added mass based model, a core-annulus flow pattern develops. The steady state riser simulations reveal, however, a different gas-solids acceleration behavior using the non-filtered model and the filtered generalized added mass based model. With the non-filtered model, the gas phase is immediately decelerated to the solid phase velocity upon contact with the slower moving solid phase. More downstream both phases accelerate jointly. Hence, the gas-solid slip is seen to be small, even in the bottom mixing and acceleration zone of the riser where it is the most pronounced. With the filtered generalized added mass based model, the gas phase hardly decelerates upon contact with the slower moving solid phase, in agreement with experimental observations by Gillandt et al. [4], resulting in a much higher initial slip velocity. More downstream, as the solids accelerate, the slip velocity decreases.

CONCLUSIONS

A generalized added mass approach for a filtered description of gas-solid momentum transfer is supported by theory, a mixture speed of sound test, and simulations. For sufficiently low filter frequencies, i.e. sufficiently coarse spatial or temporal grids, the generalized added mass effect may be dominant. Three-dimensional steady-state simulations of the bottom acceleration section of a riser reveal the importance of using filtered gas-solid momentum transfer models.

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