Numerical simulation of micro-mixing in multi-phase stirred tank

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Highlights

- CFD coupled with E-model is extended based on the Eulerian-Eulerian two-fluid method
- Simulation of micro-mixing in multi-phase stirred tank using CFD coupled with E-model
- Satisfactory agreement between predicted segregation index and experimental data

1. Introduction

Multiphase stirred tanks are widely used in process industries as typical reactive-mixing equipments. Especially for the mixing-sensitive chemical process with side-reactions, the quality of target products and the cost for processing are directly associated with the hydrodynamics, mixing and mass transfer characteristics therein. In the presence of insert dispersed phase, the turbulence modulation will influence the reaction process conducting in the bulk phase. Therefore, the micro-mixing models used in multi-phase systems should be added the special characters [1]. However, the widely-used micro-mixing models are proposed aiming at single-liquid phase. It is worth to develop and extend the existing models in case of the inadequate understanding of micro-mixing phenomenon and the vacancy of micro-mixing model for the multi-phase system.

2. Methods

CFD coupled with E-model proposed by Duan et al [2] has been used to predict the effect of micro-mixing in single-phase stirred tank and the predicted results are in good agreement with experimental data. Based on the Eulerian-Eulerian multi-fluid model with using the mixture fraction and its variance, the CFD method combining with the E-model is extended to a two-phase form which is used to simulate the micro-mixing effects on the course of parallel competing chemical reactions in semi-batch gas-liquid and solid-liquid stirred tanks, respectively. The flow field is obtained with the two-phase k-ε turbulent model and a model of variable bubble size is adopted to predict the bubble size distribution for the gas-liquid system.

3. Results and discussion

The stirred tank is the same as that of Hofinger et al. [3]. The normalized segregation index X_{S1} indicates the product distribution of the iodide/iodate reaction coupled with the neutralization reaction system. As shown in Figures 1 and 2, the total exhaustion time at position <2> and the predicted trend of X_{S1} has not a obvious change with the increase of gassing rate with gassing rate, so the turbulent modulation around the position <2> is weak in the presence of sparged air. In addition, the yield of by-product is improved with rising the acid feed concentration which is in agreement with the experimental results. For the solid-liquid stirred tank, as displayed in Figure 3, the effect of the dilute solid concentration (solid phase mass fraction W=0.75%) on the continuous phase is negligible, but the presence of particles significantly dampens the turbulence when the cloud formation is observed at W=1.63% and the segregation index in this case is larger than that in the single-phase system due to the poor micro-mixing.

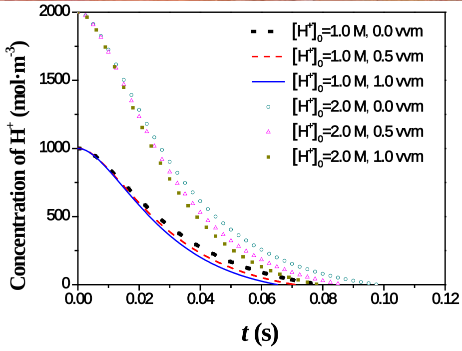

Figure 1. Depletion of the first portion of H+ solution for different acid feed concentrations (σ=50, ε_T =0.4 W/kg, position <2>).

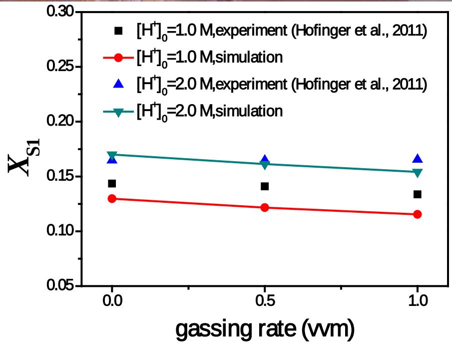

Figure 2. Effect of gassing rate and acid feed concentration on X_{S1} at different mean turbulent energy dissipation rate (σ=50, ε_T =0.4 W/kg, position <2>).

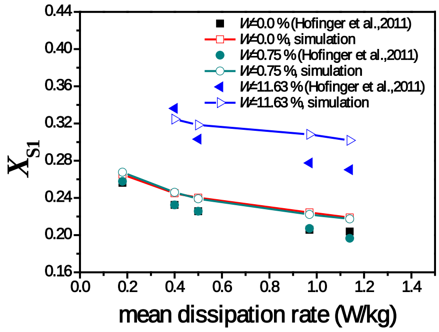

Figure 1. Effect of mean specific energy dissipation rate on X_{S1} for different particle concentrations

4. Conclusions

Compared with experimental data, the multi-phase numerical method shows the satisfactory predicting capability. The trends of predicted segregation index are captured under different solid concentrations, gas flow rates, and so on. For the gas-liquid system, the micro-mixing with feeding reactant near the impeller has no significant improvement. For the solid-liquid system, when the solid cloud is formed at high solid holdups, the reactions proceed more slowly in this almost stagnant zone near the surface.

References

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Keywords

stirred tank; engulfment model; multi-phase micro-mixing; computational fluid dynamics (CFD)