EFFECT OF BED CHARACTERISTICS ON LOCAL LIQUID DISTRIBUTION IN A TRICKLE BED

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Abstract
Gas-liquid flows through packed beds are important to several chemical process applications. While the available CFD models can predict overall liquid hold-up, the prediction of spatial liquid distribution continues to be a challenging task. In the present work, we report experimental and numerical investigations on effect of particle size (2, 4, 8 mm) on local liquid distribution for different liquid flow rates (0 to 0.1 m^3/hr) and gas flow rates (0 to 6 Nm3/hr). The effect of bed porosity distribution and particle wetting characteristics was investigated by creating different bed structures comprised of horizontal and vertical variations of particles of different sizes and wetting characteristics. The CFD model predictions were found to be in a satisfactory agreement with the measurements.

Keywords
Local liquid distribution, Trickle bed, Computational fluid dynamics, High-speed imaging, Porosity

Introduction

Gas-liquid flows through packed beds are important to several chemical process applications. Trickle bed reactors are used extensively in oil industry for hydro-desulphurization of petroleum derivatives. Performance of such packed beds/reactors largely depend on local liquid distribution. Several factors govern local liquid distribution in a trickle bed reactor e.g. particle size/shape and its wetting characteristics, bed structure, fluid flow rates, etc. While several experimental techniques were developed for measurements of local liquid distribution in trickle beds (e.g. x-ray- γ-ray- tomography, magnetic resonance imaging (MRI), etc), the measurements were largely limited to laboratory-scale trickle beds. Therefore, significant research efforts are being made to develop computational fluid dynamics (CFD) based model to simulate local liquid distribution in trickle beds. While several reasearches have validated the CFD models using measured overall pressure drop and overall liquid hold-up, the prediction of spatial liquid distribution continues to be a challenging task. There exists only a few reports on numerical simulations of local liquid distribution and their experimental verification (e.g. Lappalainen et al., 2011; Solomenko et al., 2015; etc.) In the present work, we have performed Eulerian multi-fluid simulations of gas-liquid flow in a trickle bed to understand the effects of particle size/shape, wetting characteristics and different bed structures for different gas and liquid flow rates and verified the predictions of liquid spreading using high-speed imaging experiments.

Experiments and Computational Model

A 3D rectangular column (Height: 120 cm, Width: 40 cm and Depth: 2 cm) was used in the present study. Experiments were performed under ambient conditions using air and water as working fluids. A tracer dye was injected through needles designed to form a single line source and the spread of the tracer was recorded using a high-speed camera. Experiments were performed using non-pre-wetted bed and pre-wetted bed conditions. The effect of particle size (2, 4, 8 mm) on local liquid distribution was investigated for different liquid flows rates (0 to 0.1 m^3/hr) and gas flow rates (0 to 6 Nm^3/hr). The effects of bed porosity distribution and particle wetting characteristics were investigated by creating different bed structures comprised of horizontal and vertical variations of particles of different sizes and wetting characteristics.

Eulerian multi-fluid simulations of gas-liquid flow in a trickle bed were performed using a commercial CFD code. Different porosity distributions were implemented using user defined functions. The phase interaction and capillary pressure models proposed by Attou & Ferschneider (2000) were mapped onto the commercial solver through user defined functions. A transient, pressure based solver was used with QUICK discretization scheme for spatial derivatives and a first order

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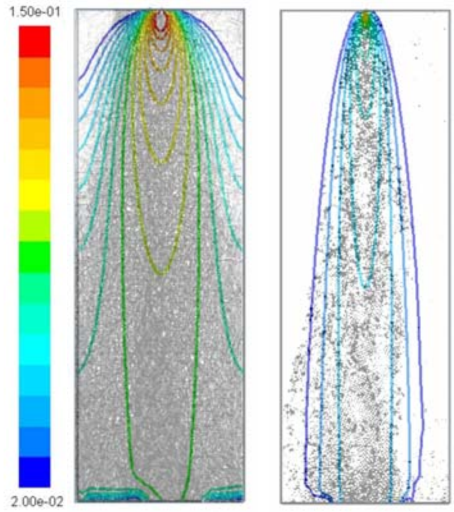
discretization scheme for temporal derivatives. Transient 3D simulations were performed to simulate the local liquid distribution for different gas and liquid flow rates, particle sizes and bed structures considered in the experiments. Further details of numerical schemes, boundary conditions and grid resolution will be provided in the full manuscript.

Results and Conclusions

Preliminary simulations were performed to understand the effects of grid resolution, boundary conditions and initial bed conditions (pre-wetted vs. non-prewetted). A comparison of predicted and measured liquid distribution showed that it is important to include capillary force model to predict the local liquid distribution correctly (results not shown here). The simulations peformed without and with capillary pressure model showed that average additional momentum source due to capillary foce (~ -100 to +100 $kg/m^2.s^2$ for and 2 mm particles) was approximately of the same order magnitude as that of the liquid-solid interphase momentum exchange.

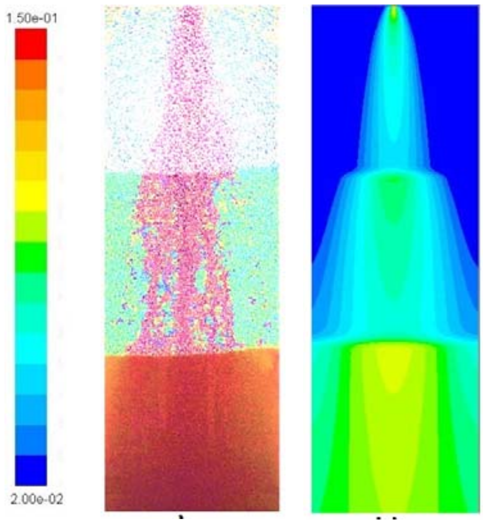
The measuerments and simulations performed for different particle sizes (2, 4, 8 mm) showed the liquid spreding to decrease with increased in particle size (see Figure 1). This can be attributed to decrease in capillary force due to increase in particle size (-100 to +100 $kg/m^2.s^2$ for 2 mm particles vs. -50 to +50 $kg/m^2.s^2$ for 8 mm particles). While the predicted liquid distribution agreed well with the measurements for 8 mm particles, the liquid spreading was over predicted for 2 mm particles in the upper part of the column. In aforemtentioned capillary force model, the wetting efficiency was assumed to be 1. Further simulations are being performed using different wetting efficiencies. Experiments performed at different gas flow rates showed the liquid spreading to decrease with increase in gas flow rates and simulations were able to predict these observed trends correctly (results not shown here).

The effect of bed structure was investigated experimentally and computationally by considering heterogeneous bed structures created using particles of different sizes/shapes and wetting charactertics. For example, the observed and simulated liquid distribution through horizontal layers of 8, 4 and 2 mm particles (axial variation of bed porosity) is shown in Figure 2. The predicted increase in liquid spreading with decrease in particle size was in a satisfactory agreeement with the measurements. Further, the effect of variation of bed porosity in lateral direction and different bed structures comprised of particles of different shape (spherical vs. cylindrical) and wettability characterstics were investigated both experimentally and numerically. The results obtained in the present work will help immensely to understand the effect of bed heterogenity on local liquid spreading and contribute as an important step in extending the CFD models to simulate local liquid distribution in large-scale trickle bed reactors.



(a) (b)

Figure 1: Comparison of experimental and simulated liquid spreading for particle sizes of (a) 2 and (b) 8 mm. The predicted instantaneous liquid volume fraction distribution is shown by line contours whereas the measured liquid spreading is shown in gray color in the background) (Q_L= 0.1 m^3/hr)



(a) (b)

Figure 2: Effect of bed structure on local liquid distribution (a) experiment and (b) predictions (Q_L= 0.1 m^3/hr).

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