A Novel Method for Evaluation of the Flow Field Effects on Mean Drop Size in a Multiphase CFB

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ABSTRACT

Prompt evaporation of injected liquid drops near the injectors locating in the FCC unit riser reactor has considerable impacts on the gas–solid mixing phenomena. To investigate influencing various parameters on the injected liquid species in the riser, conservation equations are primarily needed. A novel model to predict droplet mean diameter (DMD) due to computing penetration depth of the jet flowing through the riser was proposed. The proposed model is able to indirect predict DMD based on direct computation of spray tip penetration (STP). The model has been validated by some empirical correlations. In this study, influencing gas superficial velocity, liquid injection velocity, jet angle and nozzle diameter on DMD were investigated. The results for both concurrent and counter-current flows showed that the decrease of jet angle and injection velocity improves DMD. In addition, increasing orifice diameter (as a structural parameter) arising mean drop size can decline performance of atomizing. It also displayed close agreement between the model predictions and experimental data. In this work, the measurement error associated with STP was determined up to 2.7 mm, and the mean relative error with respect to detecting STP is 4.3%.

KEYWORDS
Droplet Mean Diameter, FCC Riser Reactor, Fluidized Bed, Jet Angle, Liquid Injection, Spray Tip Penetration (STP)

1. INTRODUCTION

Liquid jet issuing through the gas-solid flow and spray formation plays a key role in circulating fluidized beds (CFB). Various industrial processes comprising Fluidized catalytic cracking (FCC) unit, scrubbing, and polymerization are samples of multi-phase systems, which are widely used. In whole processes, the liquid jet injecting through the field flow is evaporated due to both contacting hot solid particles and pressure reduction after discharging liquid species from nozzle orifice.

Until now, there are numerous studies on different injection systems. Al-Omari investigated the kerosene droplet vaporization and mixing the vapor with air in a 90-bended duct and then, the results were compared with a straight duct. They showed that the bend angle results in increasing droplet heat up, and produced vapors (Al-Omari, 2008). Alipchhnkov et al. used a three-fluid model of two-phase medium. They concluded that droplets diameter derived from experiments reveals agreement with current correlations (Alipchenkov, Zaichik, Zeigarnik, Solov’ev, & Stonik, 2002). Prommersberger used a lean premixed pre-vaporized (LPP) to simulate a spray. They compared
their results with the experimental data and illustrated that high velocity air flow brings out weak agreement with experimental results, due to secondary breakup which are not considered by the model (Prommersberger, Maier, & Wittig, 1998). Tolpadi et al. investigated the spray model coupled with a combustion model, where a quasi-steady droplet vaporization approach was utilized. They validated their model with a single droplet. According to their conclusion, the applied model reveals earlier vaporization and higher temperature (Tolpadi, Aggarwal, & Mongia, 2000). Silverman et al. considered interactions between multi-droplet and offered a model to analyze interactions. They considered both evaporation and motion of spray simultaneously, in their model (Silverman & Sirignano, 1994). Buchanan showed that convection heat transfer is much higher than radiation heat transfer in FCC risers, where the riser reactors are modeled by considering this significant fact (J Scott Buchanan, 1994). Zhu developed a model to indicate that the evaporation depth decreases due to increasing temperature of ambient and solid phase as well as particle holdup (Zhu, Wang, Liu, & Fan, 2001). Kouremenous et al. offered three regimes including the sheet, breakup, and droplet portion for liquid jet by focusing on spray (Kouremenos Dimitrios, Pantzas Christos, Panagakis Georgios, & Krikkis Rizos, 1995).

Gavaises et al. used a 3-D model to investigate influencing collision of droplets discharging from parallel nozzles. They validated their work with phase Doppler anemometer (PDA). They concluded that the collision has a great impact on the droplet size (Gavaises, Theodorakakos, Bergeles, & Brenn, 1996). Babinsky reviewed three methods to model drop size distribution namely the empirical method, the maximum entropy method and the discrete probability function (Babinsky & Sojka, 2002). Sellens used maximum entropy to show that the drop size distribution is similar to empirical distribution and velocity distribution is Gaussian (Sellens, 1989). Li et al. used their experimental data to validate maximum entropy approach. In spite of velocity distribution results, the size distribution has satisfied the experimental results (X. Li et al., 1991). So far, few studies have been published on three-phase computational fluid dynamics modeling and hydrodynamic simulation of fluidized beds due to the complexity and difficulty of the problems and models. Two approaches are commonly used comprising Eulerian approach based on interpenetrating multi-fluid formulation, and Lagrangian approach that solves the motion equations for the dispersed phase (Martinez, Sánchez, Ancheyta, & Ruiz, 2010).

During the past few years, a number of models based on CFD have been developed for various flow systems comprising gas-liquid, liquid-solid, and gas-solid (Cheung, Yeoh, & Tu, 2007); (Jiradilok, Gidaspow, & Breault, 2007; Panneerselvam, Savithri, & Surender, 2009). Lagrangian approach is not numerically tractable, when the dispersed phase occupies a large volume fraction of the bed. Numerous experimental investigations have been conducted to unveil the complex hydrodynamics of multi-phase fluidized beds. The necessity of study on phase holdup and transport properties for recognizing flow regime structure lead to develop a new model for co-current fluidized bed (Muroyama & Fan, 1985). In addition, particle image velocimetry (PIV) is a profitable technique to study some hydrodynamic characterizations in the riser (He, Yi, Zhao, Tian, & Chen, 2011; Liu, Wang, & Fu, 2011; Pan, Wang, & Zhang, 2009; Tang & Jiang, 2012; Yang & Jiang, 2012).

In addition, increasing orifice diameter can decrease the performance of atomizing and arise mean drop size as one of the most important dependent parameters. To investigate the influence of the flow characteristics on size of liquid drops discharging from a nozzle several experiments for calculation of liquid jet penetration depth evaporating were conducted. Some parameters play a key role on spray tip penetration (STP) and producing smaller size droplets. Several independent parameters comprising the gas superficial velocity, the liquid injection velocity, positive and negative jet angles, and nozzle orifice diameter are reported in this work. Adjusting these parameters can improve atomization conditions of liquid species. The results of warm experimental tests can be used for enhancing fluid catalytic cracking reactions and efficient performance of other operational cases.

The aim of present work is to perform simulations associated with independent variables involving in a three-phase fluidized bed. In this study, based on bed hydrodynamic conditions, influencing
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