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Application of a 4-point optical probe to a Slurry Bubble Column Reactor

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HIGHLIGHTS

- Effect of addition of solids on local gas hold-up and bubble dynamics.
- Effect of size of solids on bubble velocity.
- Liquid side volumetric mass transfer coefficient evaluated.
- Gas–liquid interfacial area estimation in SBCR.

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ABSTRACT

In the present work, a 4-point optical probe (*Xue, J., Al-Dahhan, M., Dudukovic, M.P., Mudde, R.F., 2008a. AIChE J. 54, 350–363*) was applied to a slurry bubble column to assess the effect of solids on bubble dynamics. All experiments were performed in an 8 in. diameter column operated in the churn turbulent regime. Air and water were used as gas and liquid mediums respectively, and the slurry consisted of either 10% [by weight] aluminum oxide catalyst particles with 60 μm average diameter or glass spheres in the 0.3 mm–0.35 mm size range. Local gas hold-up and bubble frequency were reduced in the presence of both solids. However, bubble velocity increased in the presence of aluminum oxide catalyst particles, and is slightly reduced in presence of glass spheres, compared to a system with no solids. The volumetric mass transfer coefficient was lower in the presence of aluminum oxide catalyst particles, and a slight reduction in the gas–liquid interfacial area was observed.

1. Introduction

Uncertainties in oil prices have stimulated renewed worldwide interest in alternative energy sources. Fischer–Tropsch [F–T] synthesis is a well-established gas-to-liquid fuel [GTL] conversion process in which natural gas is first transformed into syngas, and then to a variety of liquid fuels (Davis, 2005; Dry, 2002) [Fig. 1]. Because, the F–T process has been pursued for large scale operations, e.g. Oryx plant of SASOL [~32,400 barrels/day], Pearl plant of Shell [~140,000 barrels/day] (Wood et al., 2012), developing a successful scale-up methodology is crucial if the process is to meet increasing liquid fuel demands. The availability of coal and natural gas has increased the interest in the development of the F–T process. In April 2012, Shell announced a plan to build a GTL plant in Louisiana [140,000 barrels/day] which is similar in scale to its Pearl plant in Qatar; earlier in 2011 SASOL announced a plan to build a GTL facility [96,000 barrels/day] in southwestern Louisiana (Wood et al., 2012). The methanol-to-gasoline [MTG] process of Exxon Mobil is another method for converting synthesis gas to liquid fuels (Yurchak, 1988). In the MTG process, methanol is first synthesized from synthesis gas, which is later converted into gasoline. Slurry Bubble Column Reactor [SBCR] is the preferred reactor for the F–T process and for conversion of synthesis gas to methanol. Hence, successful scale up of the SBCR is the key to commercialization of both the F–T process and the MTG process (Davis, 2002; Krishna and Sie, 2000).

Extensive research has been performed in an attempt to understand the SBCR (Kantarci et al., 2005; Wang et al., 2007), however scaling up an SBCR still remains an art. As pointed out in the recent review, most of the existing scale-up methods are based on similarity of the global parameters (Shaikh and Al-Dahhan, 2013b), which does not completely take into account various

Abbreviations: BC, bubble column; CARPT, Computer Automated Radioactive Particle Tracking; CFD, Computational Fluid Dynamics; CSTR, Continuously Stirred Tank Reactor; CT, Computed Tomography; DME, dimethyl ether; DO, dissolved oxygen; F–T, Fischer–Tropsch; GTL, gas-to-liquid; MTG, methanol to liquid; PIV, Particle Image Velocimetry; SBC, Slurry bubble column

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Notations

a	gas–liquid interfacial area (m^2/m^3)
BC	bubble column
CSTR	Continuously Stirred Tank Reactor
DO	dissolved oxygen
k_La	overall liquid side volumetric mass transfer coefficient
N	the total number of gas–liquid interfaces passing by the probe during the measurement time
R	radius of the column
r	distance from the center of the column
Δt_i	time interval between bubble hitting central tip T_0 and hitting tip T_i (s)
Δt	measurement time (s)
T_i=0, 1, 2, 3	the time interval that Tip i spend in the bubble (s)
v	magnitude of bubble velocity (cm/sec)
x_i, y_i, z_i	the co-ordinates of the tip 1, 2 and 3
ε_g	gas phase holdup
ζ	dimensionless radius
β	the angle between the normal of the bubble's symmetry plane to the probes' axial direction
γ	the angle between the projection of the normal vector on the xy plane to the axis x
θ	the angle of the bubbles velocity vector to the probe's axial direction
ϕ	the angle between the bubble velocity vector and the normal vector of the symmetry plane of the bubble.

phenomena at the meso-scale and the micro-scale. Thus, the performance of the reactor in the plant differs from its performance in the lab scale or pilot plant. Hence, a multi-scale modeling approach should be followed for reliable scale up of SBCRs. Such an approach is summarized in Fig. 2 and requires understanding of the micro-scale and meso-scale processes. By reducing empiricism, multi-scale approach provides insight into complexities of the overall process, and enhances the reliability of the overall model. Chen has elegantly demonstrated how a multi-scale approach can be used for predicting the performance of pilot scale reactor (Chen et al., 2004, 2005). In a complete 3D Euler–Euler model, he implemented the population balance approach, where the bubble population balance equation was solved along with the flow field. In churn turbulent flow, the bubble break up rates, which were estimated based on models that considered break up of a single bubble in mildly shearing or elongation flow fields, had to be enhanced 10-fold in order to match experimental results. This need for adjustment demonstrates that even after taking into account a detailed mechanistic model, the overall model still needed the support of experimental data to be useful for design purposes. Along with the CFD approach of Chen, phenomenological models have been successful in predicting liquid and gas phase mixing, both in lab-scale bubble columns, and in pilot scale reactors during dimethyl ether [DME] synthesis (Chen et al., 2006; Gupta et al., 2001a, 2001b). Although there are no fitting parameters in these models, they are not yet fully predictive, because input parameters such as gas holdup profile and average bubble size, are needed. Hence, in current experimental research in reaction engineering, advanced measuring techniques, such as CARPT, PIV, CT and optical probe technique are used to capture phenomena occurring at various time and length scales (Jain et al., 2014; Lau et al., 2013; Lee and Dudukovic,

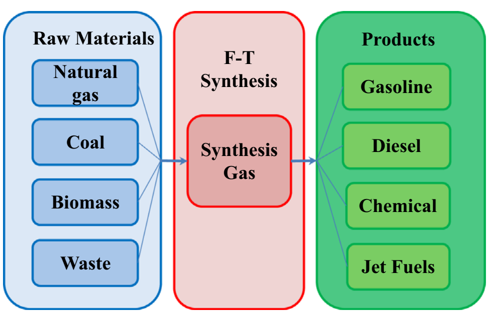

Fig. 1. F–T synthesis.

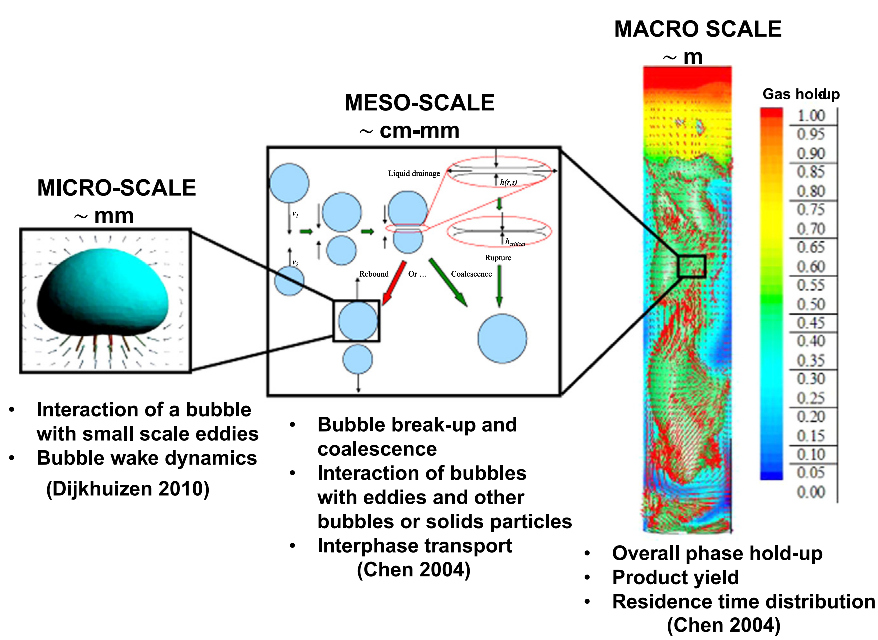

Fig. 2. Multi-scale approach in SBCR.(The figure reproduced by the permission of Elsevier, 2004 Chen et al.)