

ELECTRICAL CAPACITANCE TOMOGRAPHY ANALYSIS OF NON-CONDUCTING ORGANIC FLUID-SOLID MIXING WITH GAS-ENTRAINMENT IMPELLER

Bawadi Abdullah, Chirag B. Dave, Tuan-Huy Nguyen, Cyrus G. Cooper and Adesoji A. Adesina*

Reactor Engineering & Technology Group, School of Chemical Sciences and Engineering, The University of New South Wales, NSW 2052 Australia

Summary

This study investigated changes in dispersed phase holdup with varying the stirring speed (200-1200 rpm) in non-Newtonian organic fluids using electrical capacitance tomography (ECT) technique. Experiments were carried out in a 0.8 L stirred tank reactor equipped with an air-entrainment impeller. Air and alumina particles were used as dispersed phases while glycerol and paraffin oil were used as the continuous liquid phases. The dispersed phase holdup profile exhibited a sigmoid-shape with respect to the impeller Reynolds (Re_i) number, and a suitable correlation describing mixing in both 2- and 3-phase systems were developed. The associated parameters were related to particle (gas bubbles or solid entities) clustering process and the physicochemical properties of the organic fluids.

Keywords

Multiphase analysis, Multiphase and particulate reactors

Introduction

Process characterisation using tomographic techniques is particularly attractive in the investigation of complex multiphase flow operations in order to obtain reliable correlations for optimal design and scale-up purposes. Tomography provides visualisation of the interaction between different phases by generating cross-sectional images using electrical signals corresponding to changes in the component distribution within the vessel with the aid of reconstruction algorithms¹. The electrical signals are typically based on resistance or capacitance measurement depending on whether the fluid medium is aqueous or organic respectively.

Electrical capacitance tomography (ECT) has been used in previous studies to probe phase hold-up distribution in gas-liquid and gas-liquid-solid bubble column reactors commonly using paraffin oil and air as the continuous and dispersed phases respectively². Current ECT technology has capability to capture up to 100 frames per second for a 12-electrode system. As part of a larger program on Fischer-Tropsch synthesis in a stirred tank reactor, the present study examines the hydrodynamics of the gas-liquid-solid (catalyst) system using paraffin oil and glycerol as representative liquid phases. In particular, stirring was conducted with a gas-entrainment impeller to improve gas conversion (for reactive systems) and to

reduce the power consumption per unit volume as demonstrated in a recent study³. Furthermore, the resulting data may be used for comparative interpretation of the mixing behaviour in bubble column FT reactors with that obtained in mechanically-agitated stirred system.

Experimental Setup and Methodology

The stirred vessel was made from a flat-bottomed acrylic (polymethyl methacrylate) cylinder with inner diameter (T) of 90 mm and height of 190 mm. Liquid volume was held constant during the experimental run at 1.4T (0.8 L). The vessel was equipped with an axial gas-entrainment impeller made of polypropylene. The impeller blades were bevelled at 45° with $D = 0.56T$ and located at the distance of 0.67T above the vessel bottom. Gas entrainment impeller was used in this study due to its ability to continuously recirculate gas from the head-space above the liquid to the impeller. A partial vacuum was generated at the tips of the impeller blades upon stirring, drawing gas in from the twin openings near the top of the shaft and sucked into the continuous liquid phase through dispersion ports located at the blade tips (three parallel holes with diameter of 0.035T per blade tip). The reactor vessel was also fitted peripherally with baffles in the form

* Corresponding author. Tel.: +61 2 9385 5268; Fax: +61 2 9385 5966 Email: A.Adesina@unsw.edu.au

of 8 PVC rods to prevent fluid-vortex formation and promote better mixing.

The ECT sensor unit is a 12-electrode belt fitted to the vessel exterior. The sensor was connected to a dual tomography unit, M3000 module, supplied by Industrial Tomography Systems, Manchester, UK for data collection. Data analysis was carried out using the ITS M3000 Tool Suite installed on a personal computer. The software utilises a non-iterative algorithm based on linear back-projection method.

Results and Discussion

Experimental runs were conducted for gas-liquid and gas-liquid-solid operations using impeller speed ranging from 200 to 1200 rpm for 4 different alumina particle loadings (6.25, 12.5, 18.75 and 25 g L⁻¹). The dispersed phase holdup was determined from Maxwell-Hewitt equation⁴.

$$\phi_D = \frac{\left(2 + \frac{\varepsilon_C}{\varepsilon_D}\right) \left(1 - \frac{\varepsilon_M}{\varepsilon_D}\right)}{\left(1 - \frac{\varepsilon_C}{\varepsilon_D}\right) \left(2 + \frac{\varepsilon_M}{\varepsilon_D}\right)} \quad (1)$$

where ε_C is the permittivity of the continuous phase (liquid), ε_D is the permittivity of dispersed phase, and ε_M is the measured permittivity of the mixture obtained from pixel-averaged cross-sectional ECT data. Figs. 1 and 2 reveal that in both the gas-liquid and gas-liquid-solid mixtures with paraffin oil and glycerol; the dispersed phase holdup increased with Re_1 , with a characteristically sigmoid shape. Thus, the data may be described by the relation:

$$\phi_D = \phi_0 + \phi_{D,max} \left[1 - \exp(-\tau_{dpp} (Re_1 - Re_{1,cr}))\right]^\gamma \quad (2)$$

where ϕ_D is the overall dispersed phase holdup, γ is the particle clustering activity in the liquid phase due to inter-particle forces and τ_{dpp} is a dimensionless dispersed phase mixing time constant. However, $Re_{1,cr}$ is the minimum impeller Reynolds number for the onset of air entrainment in the liquid phase and estimated from the Sawant-Joshi correlation as 390 and 500 for our vessel configuration and mixing using glycerol and paraffin oil respectively⁵. Nonlinear regression analysis of the data yielded estimates of $\gamma=1$, $\tau_{dpp}=6 \times 10^{-4}$ (for air-glycerol) and $\gamma=2$, $\tau_{dpp}=1 \times 10^{-4}$ (for air-paraffin oil). However, for the 3-phase system, γ and $\phi_{D,max}$ are dependent on the solid loading, w , as $\gamma = \gamma_0 e^{-k/w}$; $\phi_0 = \phi_{00} w^n$ and $\phi_{D,max} = \phi_{D,max0} w^m$ while τ_{dpp} was essentially constant (3×10^{-3} and 5×10^{-4} for glycerol and paraffin oil) over the solid loading range used.

The physical significance of these parameters and their estimates are discussed in the full length paper.

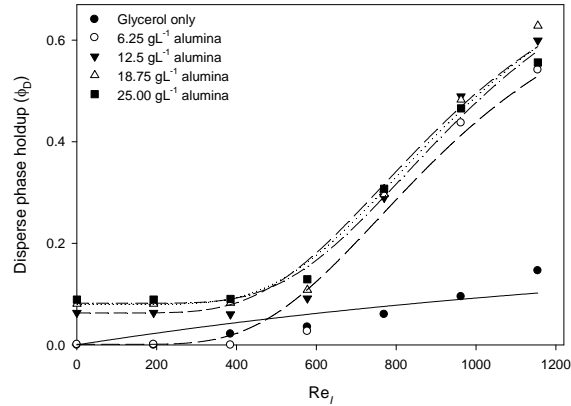


Fig. 1. Dispersed holdup (ϕ_D) for different solid loadings as a function of stirring speed for glycerol

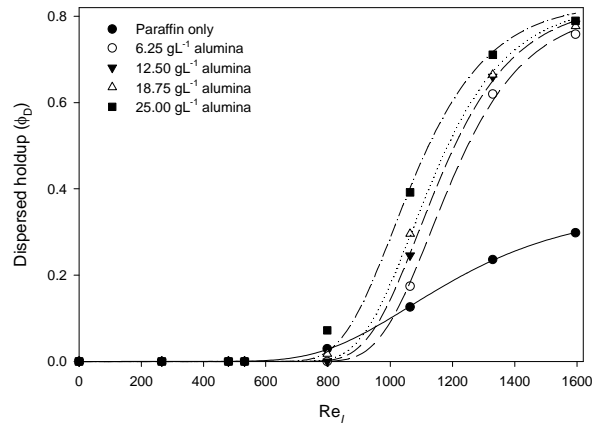


Fig. 2. Dispersed holdup (ϕ_D) for different solid loadings as a function of stirring speed for paraffin

References

- (1) Bennet, M. A.; West R. M.; Luke, S. P.; Williams, R. A. The investigation of bubble column and foam processes using electrical capacitance tomography. *Minerals Eng.* **2002**, *15*, 225
- (2) Gamio, J. C. Castro; J.; Rivera, L.; Alamilla, J.; Garcia-Nocetti, F.; Aguilar, L. Visualisation of gas-liquid two phase flows in pressurised pipes using electrical capacitance tomography. *Flow Measurement and Instrumentation* **2005**, *16*, 129
- (3) Abdullah, B.; Dave, C. B.; Nguyen, T. H.; Cooper, C. G.; Adesina, A. A. Hydrodynamics of Multiphase Stirred Tank Reactor using Electrical Resistance Tomography. *Proceedings of the 8th World Congress of Chemical Engineering*, Montreal, Quebec, Canada **2009**
- (4) Tortora, P.; Ceccio, R.; Steven L.; Trujillo, S. M.; O'Hern, T. J.; Shollenberger, K. A. Capacitance measurements of solid concentration in gas-solid flows. *Powder Technol* **2004**, *148*, 92
- (5) Sawant, S. B.; Joshi, J. B. Critical impeller speed for the onset of gas induction in gas-inducing types of agitated contactors *The Chemical Engineering Journal* **1979**, *18*, 87