Experimental and modeling evaluation of droplet size in immiscible liquid-liquid stirred vessel using various impeller designs

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Abstract

The present study investigates the effects of impeller design and dispersed phase volume ratio on mean droplet sizes in an immiscible liquid-liquid stirred vessel through experimental and modeling approaches. Various impeller designs including conventional and new impeller designs were employed to cover both radial and axial flow impellers. The microscopic method associated with image processing tools was used for the droplet size analysis. The results showed the hydrofoil impeller produced the largest drop sizes while the double-curved blade turbine produced the smallest drop sizes, corresponding to about 37% difference. Increasing the dispersed phase volume ratio from 1% to 10% increased the $d_{50}$ by approximately 20–40%. Adaptive neuro-fuzzy inference system based on fuzzy C–means (ANFIS-FCM) clustering algorithm was used to develop a model to predict drop sizes, and its validation and accuracy were examined by comparing the results to the experimental data. The results also proved the superior prediction capability of the ANFIS-FCM method over the empirical correlations for the most cases.

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1. Introduction

Liquid-liquid mixing in stirred vessels and mixing of two immiscible liquids in the turbulent-flow condition is typical processes in various chemical, pharmaceutical, petroleum and food process applications. Examples of liquid-liquid mixing in industrial processes include polymerization, emulsification, and solvent extraction. In all these cases, drop size distribution is amongst the most significant parameters to evaluate the dispersion stability and the efficiency of the system operation. Furthermore, it plays a key role to generate interfacial areas in order to determine the mass transfer rate between the phases in liquid-liquid systems [1–3]. Smaller drop sizes become more beneficial in mass transfer processes where they generate larger interfacial and mass transfer areas around the impeller area compared to drops with larger size [4,5]. The drop size distribution has consequences of the dynamic equilibrium between the drop breakup and coalescence [6,7].

Fundamentally, drop breakage is initiated by the collision between droplets and eddies whereas coalescence is caused by the collision between droplets [8].

In the meantime, mechanical agitation systems are utilized as ordinary tools for mixing processes [9–13]. It is well-known that the input parameters such as the impeller type, dispersed phase volume fraction, agitation speed, and fluids physical properties influence droplet sizes and consequently, the interfacial areas. The literature clearly states that the increase in dispersed phase holdup causes faster coalescence rate due to higher collision rates and rheological changes and therefore, longer contact intervals for droplets [10]. Thus, a suitable design for mixing systems needs to expand knowledge on mechanical properties and fluid properties to control the drop size and uniformity of the distribution [11].

There are few studies systematically comparing the mean drop sizes produced by different designs of impellers. In fact, most of the reported experiments in liquid-liquid dispersion have been accomplished with Rushton turbine [14–16]. Although using different designs of impellers has been receiving interest recently, available data are still limited [11,14,16,17]. Drop size study in a highly dilute liquid-liquid system was carried out by Zhou and Kresta [18] with a Rushton turbine and three axial flow impellers without any reports on the comparison between the impellers.