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The effects of a surfactant on mean drop size in a mixer-settler extractor

Amir Khakpay, Hossein Abolghasemi, Ali Salimi-Khorshidi*

Chemical Engineering Department, University of Tehran, Enghelab Street, Tehran 11365/4563, Iran

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ABSTRACT

In this experimental study, the presence effect of Aniline surfactant on mean drop size, D_{32}, was investigated in a horizontal mixer-settler. For this purpose, two series of experiments were conducted in a single stage mixer-settler on the liquid–liquid dispersion of a toluene–water system. At first, the effects of the impeller speed and the holdup on the drop size distribution were examined without Aniline. Afterwards the same investigation was performed in the presence of Aniline. For both experimental series, a new modified correlation for D_{32} was presented. The results revealed that D_{32}, in the absence of Aniline, depended on the impeller speed with a power low function, having an exponent of −1.208 and being in agreement with the Hinze-Kolmogorov's theory. In the presence of Aniline, a greater reduction in D_{32} was observed when the impeller speed increased. Moreover, the increasing rate of D_{32} diminished with the increase in the holdup.

1. Introduction

Solvent extraction is a selective and powerful separation technology, finding applications in a broader range of fields than the past. The interfacial properties control the hydrodynamics of extraction. Small increases in the surfactant level dramatically reduce the interfacial tension and the lower interfacial tension results in smaller drop sizes and increased carryover. Thus, the interfacial properties control not only the hydrodynamics in a liquid dispersion but also the rate of extraction. On the other hand, the interfacial properties were influenced by some pollutants, such as the surface-active agents [1,2].

The drop size and the mass transfer are strongly affected by the surfactants in the extraction equipment. The surfactants exist in the equipment in the form of pollutants. One type of these pollutants is created when the equipment is lubricated. The materials that are used for the lubrication of the equipment are a type of pollutants [3,4]. These materials, an example of which is Aniline, often have an aromatic basis.

The complex behavior of hydrodynamics within the extraction columns makes it difficult to determine the mass transfer characteristics and to analyze the extraction behavior. However, a mixer-settler-type extraction column has better characteristics than the types of the extraction columns [5–8]. The main advantages of this equipment are: strong operational loads, easy operation and maintenance, and simple start-up. The effect of agitation on throughput is small, because the dispersed drops coalesce within the settler [9–11].

It should be noted that, in this paper, D_{32} was analyzed during the steady-state time-run of emulsification. This paper presents the results of drop size measurements in liquid–liquid emulsions, where the surfactant Aniline was employed in order to stabilize the emulsion at different surfactant concentrations. Furthermore, the effect of the impeller speed and the holdup on drop size with and without surfactant was studied. Finally, for emulsions with and without surfactant, two empirical correlations are presented.

A large amount of work is carried out to study the effect of the impeller speed and the holdup on the drop size distribution in liquid–liquid emulsions in stirred vessels, such as the mixer-settler extractor. In most of these works, the Hinze-Kolmogorov's theory was used to predict the impeller speed dependence [4,12,13]. According to the Hinze-Kolmogorov's theory, in the inertial range of turbulence spectrum, only the energy-containing eddies, whose size is smaller than the drop size, may cause the drop breakup. Such models lead to a decreasing power function of the maximum stable diameter as a function of the average turbulent energy dissipation, with an exponent equal to −0.4, or in an equivalent way as a function of the impeller rotation speed with an exponent equal to −1.2. As a matter of fact, the Sauter mean diameter of the distribution follows the same trend [14]. Hence, one obtains the classical relation between the mean diameter and the impeller Weber number:

$$\frac{D_{32}}{D_I} \propto We^{-0.6} \qquad \text{with } We = \frac{\rho_c N^2 D_I{}^3}{\sigma} \tag{1}$$

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* Corresponding author. Tel.: +98 21 66967791.
E-mail address: a_salimi2001@yahoo.com (A. Salimi-Khorshidi).

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where D_{32} is the Sauter mean diameter, D_I is the impeller diameter, σ is the interfacial tension, N is the impeller speed, and ρ_c is the continuous phase density.

Calabrese et al. used a semi-empirical approach to develop various correlations for the maximum stable drop diameter for drops with a wide range of viscosity. The following equation was proposed for a low to moderate dispersed phase viscosity [8,15]:

$$\frac{D_{32}}{D_I} = C_1 We_I^{-0.6}\left(1 + C_2 V_I \left(\frac{D_{32}}{D_I}\right)^{1/3}\right)^{0.6} \quad \text{with } V_I = \frac{\mu_d N D_I}{\sigma} \qquad (2)$$

where C_1 and C_2 are constants and μ_d is the dispersed phase viscosity.

The effect of the holdup on drop size has also been investigated and the results are often presented under the form of an increasing linear of the holdup [16]:

$$\frac{D_{32}}{D_I} = C_1(1 + C_2\phi)We_I^{-0.6} \qquad (3)$$

where C_1 and C_2 are constants and Φ is the holdup.

Therefore, it can be stated that with the same impeller speed, the increase of the volume fraction of the dispersed phase results in larger drops in the mixer. This trend has been observed with low or high coalescence rates [16–18].

There are several correlations that predict mean drop size in stirred vessels. Most correlations were derived for systems with low interfacial tension. Coulaloglou et al. have derived a correlation for mean drop size as follows [19]:

$$\frac{D_{32}}{D_I} = 0.081(1 + 4.47\phi)We_I^{-0.6} \qquad (4)$$

Another correlation was derived by Calabrese et al. [19]:

$$\frac{D_{32}}{D_I} = 0.053(1 + 4.42V_i)^{0.6}We_I^{-0.6} \qquad (5)$$

$$V_i = \left(\frac{\mu_d N D_I}{\sigma}\right)\left(\frac{\rho_c}{\rho_d}\right)^{1.2}\left(\frac{D_{32}}{D_I}\right)^{1.3} \qquad (6)$$

where ρ_d is the dispersed phase density.

Masberant et al. have derived a correlation for nickel chloride/tributyl phosphate [14]:

$$\frac{D_{32}}{D_I} = 0.28(1 + 0.92\phi)We_I^{-0.6} \qquad (7)$$

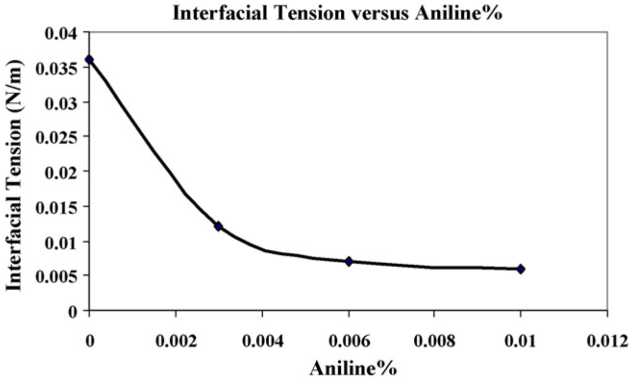

Fig. 1. Interfacial tension for various Aniline concentrations.

Moreover, Godfrey et al. have derived a correlation for systems with high interfacial tension. This correlation is presented below [19,20]:

$$\frac{D_{32}}{D_I} = 0.053(1 + 55.125\phi^{0.825})We_I^{-0.6} \qquad (8)$$

The spiral type of the impeller has not been used in the mixer-settler by other researchers. Therefore, our research group decided to use the spiral impeller to recognize the effect of this mixer type on D_{32}.

2. Experimental

2.1. Materials

The liquid–liquid system used for the experiments was toluene–water. Distilled water (density = 996 kg/m^3, viscosity 9.6×10^{-4} Pa s) and toluene (density = 870 kg/m^3, viscosity 5.7×10^{-4} Pa s, purity >99%, product of Merck Co.) were used as the continuous phase and the dispersed phase, respectively. The interfacial tension for the toluene/water system is 0.036 N/m. Moreover, Fig. 1 shows the interfacial tension for several concentrations of Aniline in the toluene/water system, which was utilized in our experiments. Fig. 1 was drawn based on results of the measurements performed by the Wilhelmy plate method using a Kruss digital tensiometer K10T (Hamburg, Germany).

Throughout our experimental measurements, only one surfactant was employed, Aniline, (density = 1030 kg/m^3, purity >99%) that was purchased from the Merck Co.

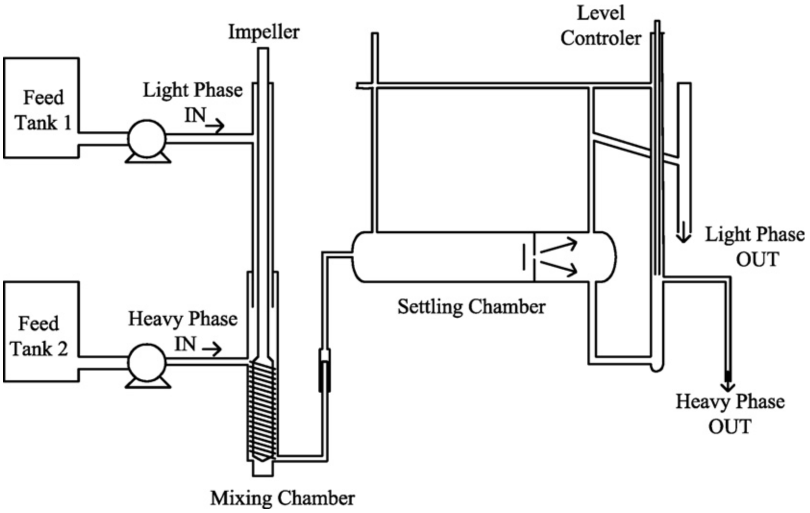

Fig. 2. Schematic diagram of the mixer-settler.