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Effect of packing on drop swarms extraction of high viscosity solvents☆

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Abstract

The terminal velocity and mass transfer coefficients of drop swarms of high viscosity solvents were investigated to study the effect of viscosity on drop behavior in a column packed with super mini ring (SMR) packing. The experimental column was equipped with a multi-channel precise syringe pump and a computerized video imaging system. Cyanex 923S kerosene solutions of different concentrations were used as experimental systems, and their viscosities are ranged from 1.2 to 53.7 mPa S. The effect of drop size and viscosity on the mass transfer coefficient, K_{od}, has been studied. It is clear from the results that K_{od} decreases sharply with the increase of viscosity, whereas drop size only has a little effect on K_{od}. The SMR packing increases K_{od} significantly up to 100%. Calculations with well-known literature equations cannot predict our experimental data, thus a model considering the interfacial mobility was provided to predict K_{od} of high viscosity solvents. The model has an adjustable parameter easily obtained from experimental data and fits the experimental data well. A modified Klee–Treybal equation describing terminal velocity under mass transfer conditions was also proposed in this paper.

Keywords: High viscosity solvent; Drop swarms; Terminal velocity; Mass transfer coefficients; Super mini ring packing

1. Introduction

Solvent extraction has been widely used in petrochemical, pharmaceutical, hydrometallurgical and environmental industries. Although many researchers consider that extraction is a fully mature technology lacking in potential for further improvement, there are still many questions that need to be solved urgently. One of them is to design commercial extractors safely with low costs. Nowadays, the scale-up of extractors still depends on large quantities of pilot experiments, which is expensive and time-consuming.

Measuring mass transfer coefficients by single drop experiments is a promising method to solve the above problem. Researchers (Laddha and Smith, 1976; Blass et al., 1986; Slater, 1994; Kumar and

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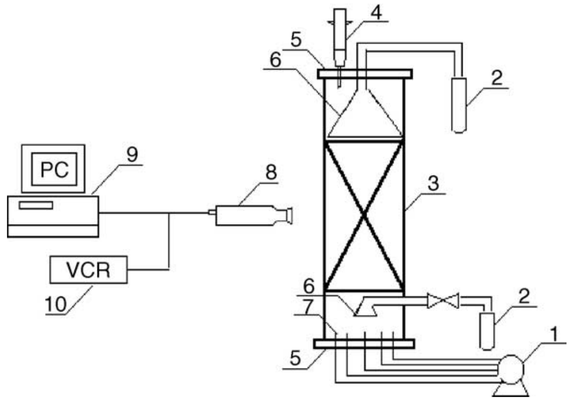

Fig. 1. A schematic diagram of experimental apparatus. 1, Multi-channel syringe pump; 2, sampling tube; 3, extraction column; 4, syringe; 5, flange; 6, funnel; 7, needle; 8, video camera; 9, PC computer; 10, video tape recorder.

Hartland, 1999) have presented extensive studies on mass transfer to single drops, and proposed theoretical and empirical equations to evaluate mass transfer coefficients. However, most of the equations are restricted to their experimental conditions and have a narrow range of applicability. Besides this, single drop experiments cannot consider the interaction of drops which affects mass transfer significantly in practical columns. Drop swarm experiments were designed in our group to overcome the limitation of single drop experiments. In the experiment, ten drops of the solvent were produced simultaneously by a multi-channel pump and these drops have interactions similar to that in commercial column. Therefore, drop swarm processes are closer to what happens in real columns.

It is well-known that packings can enhance mass transfer by decreasing axial dispersion, increasing drop breakage probability and enhancing surface renewal. However, there is still a lack of direct evidence on whether packings can increase the mass transfer coefficients of a single drop. Only regular packings were used to investigate this aspect (Mao et al., 1995; Hoting, 1996) and the conclusions are inconclusive. The super mini ring (SMR) is a newly developed random packing with elaborately geometric design. Studies (Fei et al., 1993) showed that the SMR has superior extraction characteristics than many commercial types of packing. The effect of the SMR on mass transfer is still not well understood. To study its influence on mass transfer is one aim of the paper.

Several new high viscosity solvents have been developed and applied successfully in hydrometallurgy and petrochemical industries recently. These solvents have favorable thermodynamics properties, however, their mass transfer coefficients are very low due to high viscosity. Diluents or higher extraction temperature have to be used in industry to enhance their mass transfer, however, these operations will cost more energy and make an extraction process more complicated. Mass transfer can be enhanced by introducing energy into the extraction system, but experiments showed that agitation has only a little influence on the mass transfer coefficients of high viscosity solvents. Therefore, it is necessary to find new methods to increase the mass transfer coefficients of high viscosity solvents.

Terminal velocity and mass transfer coefficients of drop swarms were measured with high viscosity solvents in this paper. The effect of drop size, viscosity and the SMR packing on mass transfer was studied. A new mathematical model was proposed to predict mass transfer coefficients of high viscosity solvents.

Table 1
Physical properties of six experimental systems (18 °C)

Phases	ρ (kg m^{-3})	μ ($\times 10^3$ Pa S)	σ ($\times 10^3$ N/m)	D ($\times 10^{10}$ m^2/s)	m
Water/HAc (0.2 M)	1001.5	1.07		10.96	
15% Cyanex 923S–kerosene (system I)	760.0	1.20	12.20	12.17	0.76
30% Cyanex 923S–kerosene (system II)	789.2	3.23	10.80	7.66	1.74
50% Cyanex 923S–kerosene(system III)	816.9	6.36	10.03	4.21	2.64
70% Cyanex 923S–kerosene (system IV)	848.8	13.79	10.20	1.94	3.45
80% Cyanex 923S–kerosene (system V)	854.5	26.58	10.04	1.15	3.57
100% Cyanex 923S (system VI)	881.7	53.65	10.02	0.63	4.65