

# An improved dynamic combined model for evaluating the mass transfer performances in extraction columns

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## Abstract

Dispersed phase droplet behavior research is very important for the design and scaling up of extraction columns. Recently, the droplet velocities at high holdup were found to be uniform, which means the conventional concept of forward mixing needs correction. The drop size distribution only influences the mass transfer coefficients and not the residence time distribution of droplets. In this work, an improved dynamic combined model considering the influence of drop size distribution has been developed, by which the axial mixing can be easily evaluated using a one-dimension search. A typical experimental system of 30% tributyl phosphate (TBP) (in kerosene)-nitric acid–water with interfacial tension of 0.00995 N/m was used to investigate the mass transfer performances in a coalescence-dispersion pulsed-sieve-plate extraction column (CDPSEC) with 150 mm in diameter. The two-point dynamic method was used to obtain the stimulus–response curves. With these results, the axial mixing in the CDPSEC was evaluated. The calculated results showed that the response curves could be predicted by the dynamic combined model with a deviation less than 0.001. This model has marked advantages over previous models in literature because of its accuracy, simple boundary conditions, and single parameter optimization.

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*Keywords:* Extraction column; Mass transfer model; Coalescence-dispersion; Drop size distribution and drop velocity

## 1. Introduction

In the past, it has been very difficult to establish accurate models that describe the mass transfer process in extraction columns because of the complexities of liquid–liquid two-phase flow. The simplified mass transfer models, including the diffusion model and back-flow model developed in the 1950s' (Danckwerts, 1953; Sleicher, 1959) assumed the axial mixing of the two phases as the main reason for the lowering of extraction efficiency. For the purpose of simplification, uniform distribution of droplets instead of probability distribution was used in these models. However, the influence of drop size distribution is too important to be ignored. Since Olney (1964) firstly reported that the drop size distribution might have significant effect on the

extraction efficiency, some investigations (Misek and Marek, 1970; Chartres and Korchinsky, 1975; Levenspiel and Fitzgerald, 1983) have showed that the influence of the dispersion coefficient or the backflow ratio of the dispersed phase can be neglected compared with that of the drop size distribution. Luo (1993) found that the concentration profiles along the extraction column varied slightly even though the dispersion coefficient of the dispersed phase changed significantly when the mass transfer performances were evaluated by the diffusion model. Thus, the influence of forward mixing was introduced into the modeling of liquid–liquid extraction processes, and is considered as the result of droplet residence time difference dependence on drop size distribution. Qian and Wang (1992) developed a model by considering both forward drop mixing and coalescence-redispersion of droplets in extraction columns. Zhu et al. (1994) developed a model by taking into account forward mixing and backflow of the dispersed phase.

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It is important to note that many previous mass transfer models are applied to simulate the steady-state concentration profiles along the extraction columns. Although the steady-state models are stable and accurate, they are rarely applicable because of their high expenses and accurate sampling requirement of the two phases in the large-scale extraction columns. Thus, the dynamic-state models based on the stimulus–response principle were developed (Steiner et al., 1978; Lei, 1985; Luo, 1993). Luo (1993) proved that the dynamic-state models had adequate stability and accuracy. Li et al. (2004) improved upon the early single-point sampling dynamic model to avoid the non-ideality. In this model, a two-point sampling method is used by taking one sampling point as the stimulus point and the other as the response point. Tang et al. (2004b) developed a dynamic forward mixing model with two-point sampling method to evaluate the mass transfer performances and axial mixing in extraction columns.

As mentioned above, many previous models must assume the droplet velocity when they are used to evaluate the mass transfer performances of extraction columns. Measuring the droplet velocity in extraction columns under the operating conditions of the high holdup is very difficult for the low light transmission of the experimental system. In literature, the terminal velocities of droplets obtained by single drop experiments were used to represent the ‘true’ drop velocities under the practical operation. This approximate treatment leads to a residence time distribution of droplets, which is dependent on the drop size distribution, for droplets with difference sizes are of different terminal velocities in single drop experiments. However, the interaction of droplets in drop swarms is neglected, so the approximate treatment is not reasonable especially for the practical operating conditions with the high holdup. Kentish et al. (1997) indirectly proved that the ‘true’ drop velocities tended to be uniform under the high holdup despite the drop size distribution. In our previous work, a new type of measurement technique was developed to measure the drop size distribution and ‘true’ drop velocity in a coalescence–dispersion pulsed–sieve–plate extraction column (CDPSEC) by the infrared laser probe (Tang et al., 2005). The experimental results showed that the ‘true’ drop velocities are uniform when the holdup is high.

In this study, an improved dynamic combined model applying the two-sampling point method is developed to evaluate the mass transfer performances in a CDPSEC based on the investigations of drop size distribution and ‘true’ drop velocity in our previous work. The CDPSEC was reported to be 200% throughput and 120% overall mass transfer efficiency over the standard extraction column (PSEC) (Lei et al., 1982; Li et al., 2000). Improving upon the PSEC, a special kind of plate made of Teflon, called the ‘coalescence plate’, whose wetting ability to the dispersed phase is much stronger than the standard steel plate, called the ‘dispersion plate’, is inserted into the CDPSEC periodically. The droplets of the dispersed phase coalesce when they pass through the coalescence plates, and then break up to provide

the new interface area when they pass through the dispersion plates. It is this interface renewal effect, caused by the periodical drop coalescence and dispersion that enhances the mass transfer performance in the CDPSEC.

## 2. Experimental set-up

The CDPSEC is composed of a glass section, 150 mm in diameter, with an effective height of 2 m. The plate spacing is 25 mm. Lei (1981) proved that the CDPSEC performed best with a coalescence plate inserted every fourth plate. This combination of plates was applied in this work. The experimental set-up is shown in Fig. 1 and the plate specifications have been described in our previous work (Tang et al., 2004a; Li et al., 2000). Along the column, two sampling points were arranged with 1 m in distance and the upper point was located about 150 mm below the top of the effective section of the column.

The experimental system is 30% tributyl phosphate (TBP) (in kerosene)–nitric acid–water and the organic phase is the dispersed phase. The physical properties of the experimental system are shown in Table 1. The distribution relationship of HNO<sub>3</sub> in the two phases at room temperature can be expressed in a linear equation of  $x^* = 4.279y + 0.168$ . The dispersed phase holdup is measured by volumetric replacement method.

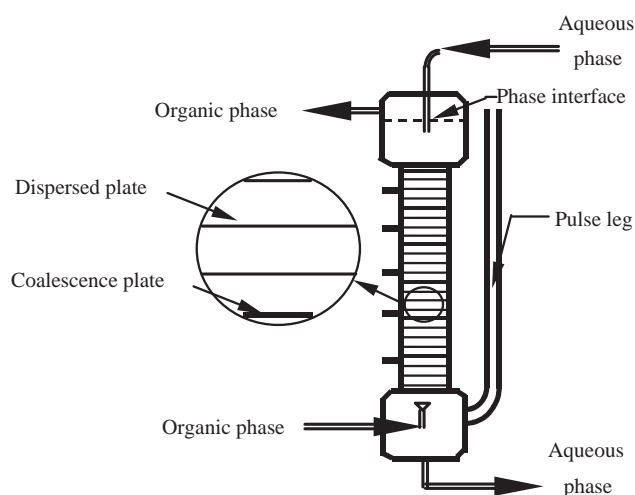


Fig. 1. Experimental set-up.

Table 1  
Physical properties of the experimental system (25 °C)

	Density (kg/m <sup>3</sup> )	Viscosity (Pa s)	Interfacial intension (N/m)
Continuous phase	998.0	0.00105	0.00995
Dispersed phase	835.0	0.00209	

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