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# A dynamic interaction mass transfer model for simulating the mass transfer process in extraction columns

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## Abstract

In this study, the population balance model was used to simulate the steady axial profile of the drop size distribution along the extraction column. Based on the population balance model, a dynamic interaction mass transfer model for simulation of the mass transfer process within extraction columns was developed with only one parameter that needs to be optimized. In comparison with conventional mass transfer models, the dynamic interaction mass transfer model has a theoretical basis and is less empirical because the influence of drop breakage and drop coalescence on the drop size distribution and the mass transfer process were carefully considered.

*Keywords:* Mass transfer model; Dynamic simulation; Extraction column; Population balance model

## 1. Introduction

Mass transfer models, used for extraction columns, are still limited in capturing complex drop interaction behavior, including drop breakage and coalescence. Although population balance models have been well developed to calculate the drop size distribution in extraction columns by considering the drop interaction behavior (Attarakih, Bart, & Faqir, 2004; Coulaloglou & Tavlarides, 1977; Mohanty & Vogelpohl, 1997), conventional mass transfer models ignore drop breakage and coalescence. These mass transfer models include the diffusion model (Sleicher, 1959; Weinstein, Semiat, & Lewin, 1998), the backflow model (Hartland & Mecklenburgh, 1966; Spencer, Hartland, & Steiner, 1981), the forward mixing model (Chartres & Korchinsky, 1975; Qian & Wang, 1992; Tang, Luo, & Wang, 2004) and the combined model (Tang, Luo, & Wang, 2005a). Actually, drop breakage and drop coalescence are too important to be ignored, but the mass transfer model considering the drop interactions can only be found in few papers (Casamatta & Vogelpohl, 1985; Zamponi, Stichlmair, Gerstlauer, & Gilles, 1996).

In this study, the mass transfer process was investigated in a coalescence-dispersion pulsed-sieve-plate extraction column (CDPSEC), which was reported to have 200% throughput and 120% overall mass transfer efficiency over the standard extraction column (PSEC) (Lei, Dai, Shen, & Wang, 1982; Li, Luo, Fei, & Wang, 2000). In improving the PSEC, a special kind of plate made of Teflon, with a wetting ability towards the dispersed phase that is much stronger than the standard steel plate, is inserted into the CDPSEC periodically over the column length. Thus, the droplets of the dispersed phase coalesce when they pass through the Teflon coalescence plates, and then the droplets break up to provide new interface area for mass transfer when they pass through the steel dispersion plates. It is the interface renewal effect, caused by the periodical drop coalescence and dispersion that enhances the mass transfer in the CDPSEC.

In the CDPSEC, the drop interactions are so strong that the mass transfer model should include the drop breakage and drop coalescence effects to describe the mass transfer process as closely as possible. Based on the population balance model, Luo, Li, Tang, and Wang (2004) developed a model to calculate the drop size distribution in the CDPSEC.

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## Nomenclature

| | |
|---|---|
| $a$ | specific surface area ($\mathrm{m^2/m^3}$) |
| $A$ | pulse amplitude (cm) |
| $d$ | drop diameter (m or mm) |
| $d_{43}$ | mean diameter (m or mm) |
| $e$ | free area fraction of the sieve plate |
| $E$ | dispersion coefficient of solute ($\mathrm{m^2/s}$) |
| $f$ | pulse frequency ($\mathrm{s^{-1}}$) |
| $f(d)$ | volumetric probability density function ($\mathrm{m^{-1}}$) |
| $F(i)$ | volumetric fraction |
| $h$ | height (m) |
| $H$ | effective height of the column (m) |
| $k$ | mass transfer coefficient (m/s) |
| $K_{ox}$ | overall mass transfer coefficient based on continuous phase (m/s) |
| $j$ | number of the control volume |
| $l$ | drop class |
| $m$ | constant in relation of equilibrium |
| $n$ | iterative time (min) |
| $N$ | number of drop classes |
| $N_t$ | overall sampling time (min) |
| $N_{ox}$ | number of ‘true’ transfer unit |
| $Pe$ | Peclet number |
| $q$ | constant in relation of equilibrium |
| $R$ | mass transfer of solute per unit cross sectional-area of the column in a differential time d$t$ (mmol/L) |
| $S$ | cross sectional-area of the column ($\mathrm{m^2}$) |
| $t$ | time (min) |
| $u$ | superficial velocity (m/s) |
| $u_d$ | ‘true’ drop velocity (m/s) |
| $w$ | drop breakage probability |
| $We_p$ | Weber drop number |
| $x$ | solute concentration in continuous phase (mol/L) |
| $x_f$ | solute concentration in continuous phase at the stimulus point (mol/L) |
| $x^*$ | equilibrium concentration of solute in continuous phase (mol/L) |
| $y$ | solute concentration in dispersed phase (mol/L) |
| $y_s$ | input solute concentration in dispersed phase (mol/L) |
| $z$ | height (m) |
| $Z$ | dimensionless height |

*Greek symbols*

| | |
|---|---|
| $\beta$ | daughter drop size distribution |
| $\phi$ | holdup of dispersed phase |
| $\gamma'$ | interface tension (N/m) |
| $\varepsilon'$ | interface energy (J) |
| $\rho$ | density ($\mathrm{kg/m^3}$) |
| $\sigma$ | standard deviation of the drop size distribution ($\mathrm{m^{-1}}$) |

*Subscripts*

| | |
|---|---|
| $i$ | drop class |
| $i'$ | drop class |
| $i''$ | drop class |
| $i'''$ | drop class |
| $x$ | refers to continuous phase |
| $y$ | refers to dispersed phase |