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Mass transfer performance in an asymmetric rotating disc contactor

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ABSTRACT

The volumetric overall mass transfer coefficients have been measured in a pilot scale asymmetric rotating disc contactor of 113 mm diameter for the toluene–water–acetone system. The experiments are carried out for both mass transfer directions. The effects of operational variables such as rotor speed and continuous and dispersed phase velocities on mass transfer performance are investigated. The results show that the column performance is strongly dependent on agitation speed but only slightly dependent on phase velocities. An empirical equation for prediction of overall continuous phase Sherwood number is proposed based on Reynolds number and dispersed phase holdup for each mass transfer direction. Good agreement between prediction and experiments is found for all operating conditions.

1. Introduction

Liquid–liquid extraction is now an important separation process in the chemical industry and a key step for hydrometallurgical production of strategic metals, treatment of dilute waste for metal recovery, processing of nuclear fuels, and biochemical separations. Due to industrial success of solvent extraction, more than 25 kinds of liquid–liquid contactors have developed and extensively investigated (Blass et al., 1986). The rotating disc contactor (RDC), as one of the major extraction columns, has been widely used in petroleum refining and chemical industries on account of its simplicity in construction, high throughput, and low power consumption. However, its low performance is its major disadvantage (Morís et al., 1997). The deterioration in performance arises from two undesirable effects resulting from mechanical agitation: (1) the entrainment of small droplets and (2) an increase in axial mixing. Therefore, it has become imperative research task to improve the mass transfer performance of the RDC. Several research works have been done to optimize the RDC structure in order to improve its performance (Wang et al., 2002). Asymmetric rotating disc contactors (ARDC) are widely used in the different industries due to the dual advantage of high mass transfer rates and reduced axial mixing in both phases. In this extractor, a shaft carrying the agitator discs is mounted off-centre, and two sets of staggered stator plates are provided, connected by a vertical segmental baffle. By this means, the mixing chambers are enclosed, and are connected to one another via openings on each side of the vertical baffle leading to chambers in which partial coalescence occurs (Kadam et al., 2009).

The design of an extraction column requires the determination of two independent parameters, viz. (i) the cross-sectional area required to accommodate the desired flows without flooding and (ii) the height of the column required to achieve the desired performance. In early design procedures, ideal plug flow conditions were assumed in both phases for the estimation of height required for a given separation. However, it is now widely accepted that axial mixing in one or both phases can result in an increase in the height required to achieve the desired separation Pratt and Stevens (1992). The state of the art for the design of an extraction column is to use diffusion or backflow model, where one parameter accounts for all deviations from the ideal plug flow conditions (Bart et al., 2008). The reliability of the design of an extraction column depends upon the correlations used for prediction of overall mass transfer coefficient (Outili et al., 2007). Although the ARDC has been used effectively for a number of separation processes, limited data are available from the literature on the performance of asymmetric rotating disc contactors. Consequently, in this work the volumetric

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Nomenclature

d	droplet diameter (m)
d_{32}	Sauter mean drop diameter (m)
D	molecular diffusivity ($m^2\,s^{-1}$)
D_c	column diameter (m)
D_R	rotor diameter (m)
e	fractional free cross-sectional area (–)
E_c	continuous phase axial mixing frequency ($m^2\,s^{-1}$)
g	acceleration due to gravity ($m\,s^{-2}$)
h_c	compartment height (m)
H	effective height of the column (m)
k_c	continuous phase mass transfer coefficient ($m\,s^{-1}$)
k_d	dispersed phase mass transfer coefficient ($m\,s^{-1}$)
K_{oc}	overall continuous phase mass transfer coefficient ($m\,s^{-1}$)
N	rotor speed (s^{-1})
N_{ox}	number of true transfer unit (–)
P	Péclet number = HV/E (–)
Pe_c	continuous phase Péclet number = $d_{32}V_s/D_c$ (–)
Re	Reynolds number = $d_{32}V_s\rho_c/\eta_c$ (–)
Sc_c	continuous phase Schmidt number = $\eta_c/(\rho_c D_c)$ (–)
Sc_d	dispersed phase Schmidt number = $\eta_d/(\rho_d D_d)$ (–)
Sh_c	continuous phase Sherwood number = $k_c d_{32}/D_c$ (–)
Sh_d	dispersed phase Sherwood number = $k_d d_{32}/D_d$ (–)
Sh_{oc}	overall continuous phase Sherwood number = $K_{oc}d_{32}/D_c$ (–)
V	superficial velocity ($m\,s^{-1}$)
$\bar{V}_c$	continuous phase true velocity ($V_c/(1-x_d)$) ($m\,s^{-1}$)
V_s	slip velocity ($m\,s^{-1}$)
x_d	dispersed phase holdup (–)
x	mass fraction of acetone in continuous phase (–)
x^*	equilibrium mass fraction of acetone in continuous phase corresponding to dispersed phase
y	mass fraction of acetone in dispersed phase

Greek symbols

σ	interfacial tension ($N\,m^{-1}$)
$\Delta\rho$	density difference between phases ($kg\,m^{-3}$)
η	viscosity (Pa s)
ρ	density ($kg\,m^{-3}$)
κ	viscosity ratio (–)

Subscripts

c	continuous phase
d	dispersed phase
x	x-phase (continuous phase in present case)
y	y-phase (dispersed phase in present case)

Superscripts

*	equilibrium value
°	inlet to column

overall mass transfer coefficients have been measured experimentally for the commonly recommended toluene–water–acetone system in a pilot scale ARDC. The influence of operating variables including agitation speed, as well as the continuous and dispersed phase velocities on the mass transfer performance is investigated. Experimental results are compared with Kumar and Hartland (1999) correlations and new correlations are developed so that the overall mass transfer coefficient can be accurately predicted.

2. Experimental

A pilot scale asymmetric rotating disc column was used in the present work. The main column section consisted of a 1430 mm long glass tube of 113 mm internal diameter, enclosing a stock of 36 discs mounted on a vertical shaft and driven by an electronic motor via a variable speed gear box. A settler of 168 mm diameter at each end of the column permitted the liquids to coalesce and decant separately. All internals in the column were made of AISI 316 stainless steel. The interface level at the top of the column was controlled automatically by an optical sensor. A solenoid valve (normally closed type) was provided at the outlet stream of the aqueous phase. When the interface location was going to change, the optical sensor sends a signal to the solenoid valve and aqueous phase was allowed to leave the column by opening the diaphragm of the solenoid valve. The organic phase was allowed to leave the column via overflow. A scheme of the ARDC pilot scale unit used in the present study is shown in Fig. 1. The dimensions of the extraction column used in the present study are given in Table 1.

Toluene–acetone–water liquid system was used in this work. This system has been adopted as *Recommended Test System* by the European Federation of Chemical Engineering (E.F.C.E.). The physical properties of the studied system are given in Table 2. Liquid–liquid equilibrium data of the system were taken from Míšek et al. (1985). All experiments were performed with solute concentrations of approximately 3.5 wt%.

The aqueous and organic phases were saturated before fed into the column in order to prevent miscibility effects from interfering with dispersed phase holdup and drop size measurements. When starting a run, the rotor speed was adjusted to the desired value and, after filling the column with the continuous phase, the dispersed phase was introduced. The interface location was then maintained at the desired height, and the system was allowed to reach steady state. For all

Table 1 – Dimensions of the pilot plant ARDC.

Column diameter (m)	0.113
Rotor diameter (m)	0.042
Column working height (m)	1.43
Compartment height (m)	0.033
No. of compartments (–)	36

Table 2 – Physical properties of the two phases for the toluene–acetone–water system (20 °C) (Míšek et al., 1985).

Physical property	Toluene–acetone–water
ρ_c (kg/m^3)	994.4–995.7
ρ_d (kg/m^3)	864.4–865.2
η_c (mPa s)	1.059–1.075
η_d (mPa s)	0.574–0.584
σ (mN/m)	27.5–30.1
D_c ($m^2\,s^{-1}$)	$1.09–1.14 \times 10^{-9}$