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Use of axial dispersion model for determination of Sherwood number and mass transfer coefficients in a perforated rotating disc contactor

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ABSTRACT

The mass transfer process in a perforated rotating disk contactor (PRDC) using a toluene–acetone–water system was investigated. The volumetric overall mass transfer coefficients are calculated in a PRDC column. Both mass transfer directions are considered in experiments. The influences of operating variables containing agitation rate, dispersed and continuous phase flow rates and mass transfer in the extraction column are studied. According to obtained results, mass transfer is significantly dependent on agitation rate, while the dispersed and continuous phase flow rates have a minor effect on mass transfer in the extraction column. Furthermore, a novel empirical correlation is developed for prediction of overall continuous phase Sherwood number based on dispersed phase holdup, Reynolds number and mass transfer direction. There has been great agreement between experimental data and predicted values using a proposed correlation for all operating conditions.

1. Introduction

Mass transfer performance of a system is an inseparable part of many chemical engineering operations in two-phase systems. Solvent extraction (SE) is one of these chemical operations which applied in an enormous number of industrial systems. The solvent extraction process can be conducted in a number of different extraction columns. These extraction columns are divided into non-agitated and agitated extraction columns [1,2]. The rotating disk contactor (RDC) is one of the most important agitated extraction columns. This type of extraction column has been widely used in chemical industries and petroleum refining due to its high throughput, low investment, low energy consumption, and easy operation and maintenance [3]. However, this extraction column has some limitations due to its structure. There have been some drawbacks including severe axial back mixing and inappropriate drop distribution which cause a reduction in the mass transfer efficiency of commercial RDCs, particularly for low interfacial tension systems. Both the continuous and dispersed phases as they pass through the extraction column can affect axial mixing [4,5]. For these reasons, modified RDCs are developed to overcome the mentioned issues. Perforated rotating disk contactor is one of these modified extraction columns that leads to the enhancement in the mass transfer performance of a system. PRDC extraction column is considered as a subset of the RDC extraction column with improved structure, for instance, the RDC with sieved disks [6,7]. Better drop dispersion, lower bond drops, more contact time and at the last count, the higher mass transfer are the advantages of PRDC extraction column in comparison to RDC extraction column [8]. Furthermore, low operating expenses, easy manufacturing in the industrial scale compared to other agitated columns, and easy scale up to commercial scale are the other plus points of PRDC extraction columns. Sieved disks were apparently more appropriate to liquid–liquid systems with low interfacial tension [9]. Based on the obtained experimental results [9], the height of the transfer unit for the sieved disk extraction columns is much lower than that of the rotating disk extraction columns. PRDCs are also used by Fan *et al.* [10] for phenol removal using liquid membrane separation. According to their conclusion, the mass transfer performance of sieved disk extraction columns is much better than that of the RDC [10]. Wang *et al.* [5] investigated how the perforations on disks cut the droplets and disperse them in the continuous phase. The droplet size in the PRDC extraction column can be controlled using holes on sieved disks and is rather uniform. Thus, it is expected that the extraction column with sieved disks has suitable mass transfer performance and controllability compared to the rotating disk extraction column [5].

The design and scale up of an extractor need the calculation of two independent parameters including the cross-sectional area and the height of the column. The first one is required to accommodate the desired flows without flooding and the second one should be determined

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to reach the appropriate performance of extraction columns. Ideal plug flow conditions were considered in continuous and dispersed phases for the calculation of the height needed for a separation system in early design and scale-up procedures. However, it is now accepted that axial mixing in the extraction column for one or two phases can lead to the enhancement of the required height for reaching desired separation [11]. Using a diffusion or backflow model for design and scale-up is now developed for determination of the height of the extraction column. In this method one parameter is considered for all deviations from the ideal plug flow conditions [12]. As a result, widespread availability of reliable correlations for calculation of mass transfer coefficients is required to develop an extraction column design. On the other hand, determining mass transfer coefficient in an extractor is difficult due to significant uncertainty. Although the PRDC was applied appropriately for a number of separation processes, limited experimental data are available from the literature on the mass transfer performance of PRDC extraction columns.

In the current study, the volumetric overall mass transfer coefficients of a pilot scale perforated rotating disk contactor have been determined. A thorough research was carried out for calculation of operating variable effects which include disk rotational speed, flow rates of continuous and dispersed phase on mass transfer performance of the extraction column for a water–acetone–toluene liquid–liquid system. Additionally, experimental results are compared with Kumar and Hartland [13] correlations and new correlations are developed so that the overall mass transfer coefficient can be precisely foreseen.

2. Experimental

2.1. PRDC pilot scale unit

A pilot scale unit of a perforated rotating extraction column was constructed. Internal diameter of the perforated rotating disk contactor is 113 mm and it has 43 stages. The accessory equipment contains storage tanks, pumps and rotameters. The rotor shaft carries sieved disks with a diameter of 0.07 m and drilled with 30 holes of 0.015 cm diameter. All internal parts of the column and the blade impellers were made of AISI 316 stainless steel. The blade impellers are mounted on a shaft, which is driven by an electric motor via a variable speed gear box. An optical sensor was used to interface the location of two phases at the top of the extraction column which was automatically controlled. Centrifugal pumps (Penax model) were used to circulate both liquid phases through the column. A schematic of the PRDC pilot-scale unit used in this study is depicted in Fig. 1. The geometrical data of the investigated extraction column are given in Table 1.

2.2. Liquid–liquid system

All experiments were conducted at ambient temperature, using a liquid–liquid system according to the recommendations of the European Federation of Chemical Engineering [14]. The system was toluene–acetone–water. Distilled water was used as continuous phase in all experiments. The physical properties of this system are given in Table 2. Liquid–liquid equilibrium data of the system was taken from

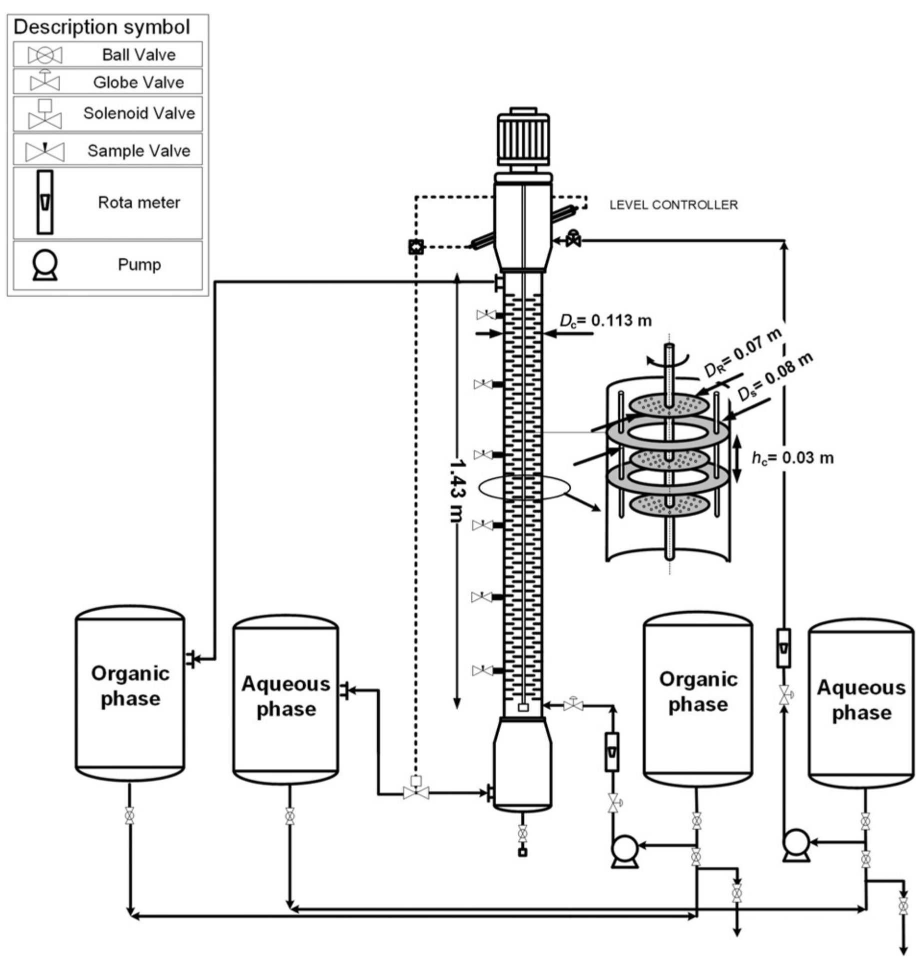

Fig. 1. A schematic diagram of the perforated rotating disk contactor (PRDC).