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LOCAL STATIC HOLD-UP IN A ROTARY SIEVED DISC CONTACTOR FOR A BUTYL ACETATE-WATER SYSTEM

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ABSTRACT

Considering the importance of liquid static holdup in liquid-liquid extraction columns, a novel experimental approach for predicting the mentioned parameter in a rotary sieved disc contactor has is presented in this research. One chemical system without mass transfer was used, in which distilled water and butyl acetate were employed as the continuous and the dispersed phase, respectively. The static holdup has been measured using the draining method. Based on the experimental results, one correlation was proposed to predict the static holdup as a function of stage position in the column and rotating speed in the form of Reynolds numbers and also the dimensionless mother drop size. Changes in static holdup caused by each factor have been discussed and graphically illustrated. It was revealed that an increase in mother drop size will cause the growth of static holdup, while the rise of rotating speed will decrease the amount of static holdup. Furthermore, it was proven that static holdups in upper positions in the column are less than those in the lower positions.

Keywords: Hold-up; Mother drop size; Rotary Sieved Disc Contactor; Static hold-up

1. INTRODUCTION

The Rotary Disc Contactor (RDC) is an agitated column developed for liquid extraction by the Royal Dutch / Shell group (Reman & Olney, 1955). Its advantages over the other devices are its high throughput, low power consumption, low cost, simplicity in construction, flexibility of operation, and ease of maintenance. These attributes have made it more commonly used than packed and spray column types (Kamath & Subba, 1985; Laddha & Degaleesan, 1976; Zhang et al., 1981; Slater & Goldfrey, 1994).

Krishnaiah et al. (1967) suggested that Rotary Sieved Disc Contactors (RSDCs) are more suitable for use in systems with low interfacial tension. Moreover, the height of a transfer unit (HTU) for the RSDC is much lower than that of the RDC. Also, the drop size is controlled by the size of the holes on the discs and this is uniform. Furthermore, the RSDCs have better mass transfer efficiency and controllability in comparison with the RDC (Soltanali, 2007).

There are three distinct kinds of motion for liquid in an RDC: (1) axial flow of two phases resulting from the difference in densities; (2) radial flow of two phases resulting from the

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centrifugal field near the rotor axis; (3) centripetal flow resulting from contact with the wall of the column (Reman & Olney, 1955).

It is important to study the hydrodynamics, such as the axial dispersion, hold-up and characteristic velocity, in order to achieve the best scale-up and design for extraction contactors (Moris et al., 1997). The present study examines the important static holdup parameter on an RSDC.

There are three types of holdup as follows: Static holdup is the ratio of the volume of the dispersed phase trapped under rotors and stators to the active column volume, which is equal to the combined volume of the dispersed phase and the continuous phase. Dynamic holdup is the ratio of the volume of the dispersed phase that crosses the active column height to the active column volume. Total holdup is the sum of the static and dynamic holdups. The Dispersed Phase holdup can be expressed as the volumetric fraction of the two phases as follows in Equation 1 (Treybal, 1963):

$$\Phi = \frac{v_d}{v_d + v_c} \tag{1}$$

The Dispersed Phase total holdup must be predicted in order to calculate the column diameter and it is necessary to calculate the interfacial area per unit volume and slip velocity (Napeida et al., 2009). Moris et al. (1997) showed that the maximum value for the holdup is at the middle of the RDC column.

There are a lot of researches and publications in the field of total and dynamic hold up (Attarakih et al., 2006; Kulkarni et al., 2007; Schmidt et al., 2006). However, in spite of this fact that static holdup has an important role on drop coalescence, residence time and interfacial area, a few works have been carried out in this area (Westerterp et al., 1984; Yin et al., 2002; Molavi et al., 2011).

In current work, an experimental approach has been conducted to investigate the local static holdup in an RSDC column as a function of mother drop size, stage position and rotating speed, which was not studied before. The results of this study may be helpful in calculation and design of the column.

2. EXPERIMENTS

2.1. Chemical System

One liquid-liquid system has been used in this work. Distilled water was used for the Stagnant Continuous Phase and butyl acetate was used for the Dispersed Phase. Table 1 shows the physical properties of the chemical system.

2.2. Apparatus

Figure 1 shows schematic of the RSDC. This glassy column consists of 21 stages and is 120 cm in height. The dimensions of the RSDC are shown in Table 2. It has a central rotating shaft with equidistant sieved discs mounted on it. Each disc is positioned in the middle of each compartment, which is defined as the space between two stators. The rotating speed is controlled by a digital drive motor and turbulence was varied by changing the speed of rotation.

Table 1 Physical properties of liquid-liquid system at T = 25ºC

Materials	Name	ρ_c $\left(Kg/m^3\right)$	ρ_d $\left(Kg/m^3\right)$	μ_c $(mpa.s)$	μ_d $(mpa.s)$	γ $\left(mN/m\right)$
Butyl acetate-water	W-B	996	875	0.87	0.67	12.4

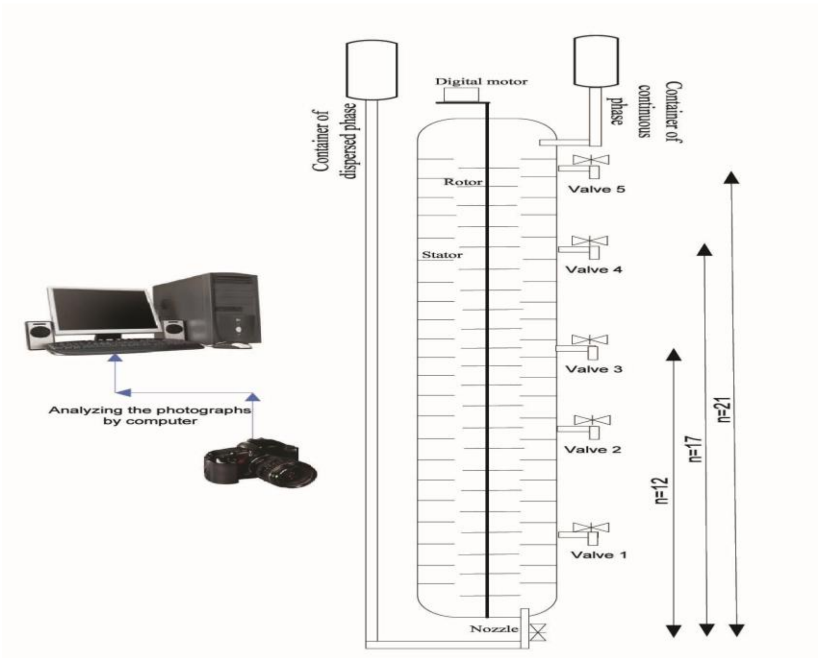

Figure 1 Schematic of the RSDC

Table 2 RSDC dimensions

Inner diameter of column (mm)	91
Inner diameter of stator (mm)	61
Outer diameter of rotor (mm)	45.5
Hole diameter on rotor (mm)	3
Compartment High (mm)	27.8
Disc thickness (mm)	1
Shaft diameter (mm)	14
Column height (m)	1.20

2.3. Experimental Procedure

Testing can be carried out in 6 stages:

1. Saturate the continuous phase (distilled water) with the dispersed phase (butyl acetate) and saturate the dispersed phase with the continuous phase.
2. Fill the containers of the dispersed and continuous phases (Figure 1) with the corresponding liquids.
3. Fill the column up to the fifth valve with the aqueous phase.
4. Add the dispersed phase to the aqueous phase drop-by-drop through a nozzle (0.4 mm internal diameter) installed at the bottom of the column.

5. Control rotating speed using the digital motor drive for testing at rotating speeds of 2.5, 3.75 and 5 rps.
6. After achieving stabilized condition in the column, calculate the mother drop size (drops in the bottom of column, just above the nozzle tip).

Shut down motor and close nozzle valve simultaneously. In order to measure the static holdup, collect samples from five valves according to the draining procedure described by Molavi et al. (2011).

3. RESULTS AND DISCUSSION

The effects of rotating speed, stage position and also mother drop size on local static holdup of a RSDC have been investigated. The results have been presented in the following.

3.1. Rotating Speed

Figure 2 shows liquid trapped under the rotors between Valves 2 and 3 versus rotor speed. It is clear that the static holdup decreased as the rotor speed increased, indicating an inverse relationship between static holdup and rotor speed. Figure 3 also depicts a decreasing trend for static holdup versus rotor speed. Indeed by increasing the rotating speed, the centrifugal force that dispersed the drops throughout the column increased. Therefore, the drops are moving upward in the column rather than gathering under the rotors and stators. Kasatkin et al. (1962) and Napeida et al. (2009) have presented correlations in which rotating speed with reverse effect on static holdup have been considered.

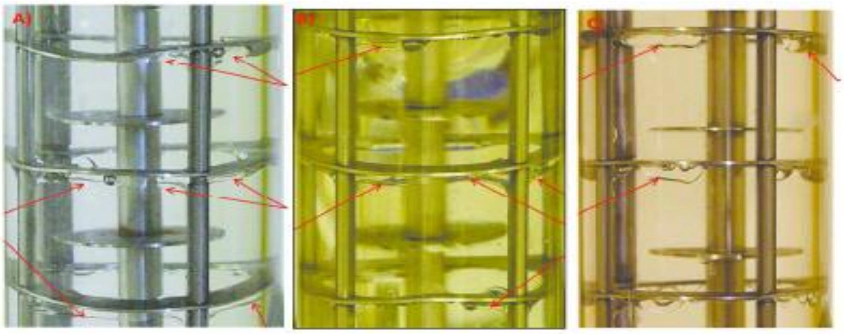

Figure 2 Static holdup under rotors and stators between valve 2 and 3 at: (a) 2.5 rps; (b) 3.75 rps; (c) 5 rps

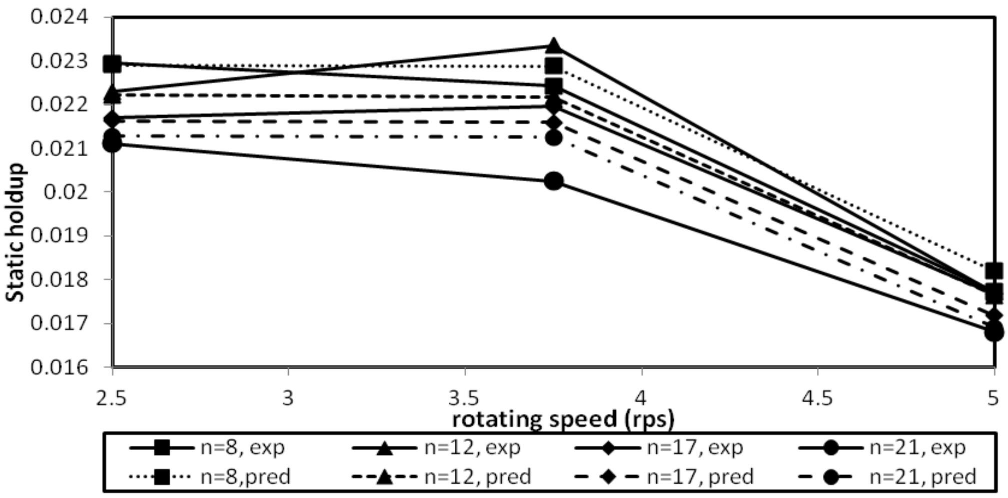

Figure 3 Local static holdup versus rotating speed for water-butyl acetate system at a constant stage position

3.2. Stage Position

Figure 4 shows the effect of stage position on local static holdup. As the stage position increased, the local static holdup decreased. Since the first stages were closer to the source of drop formation, the local static holdup in this area is greater than at the top of the column. The diagram shows a mild slope, indicating that the stage position has much less influence on static holdup than rotating speed, especially in high rotating speeds. Molavi et al. (2010) have worked on the effect of stage position on holdup in the RDC. It was inspiring that this factor was analyzed and considered in this research.

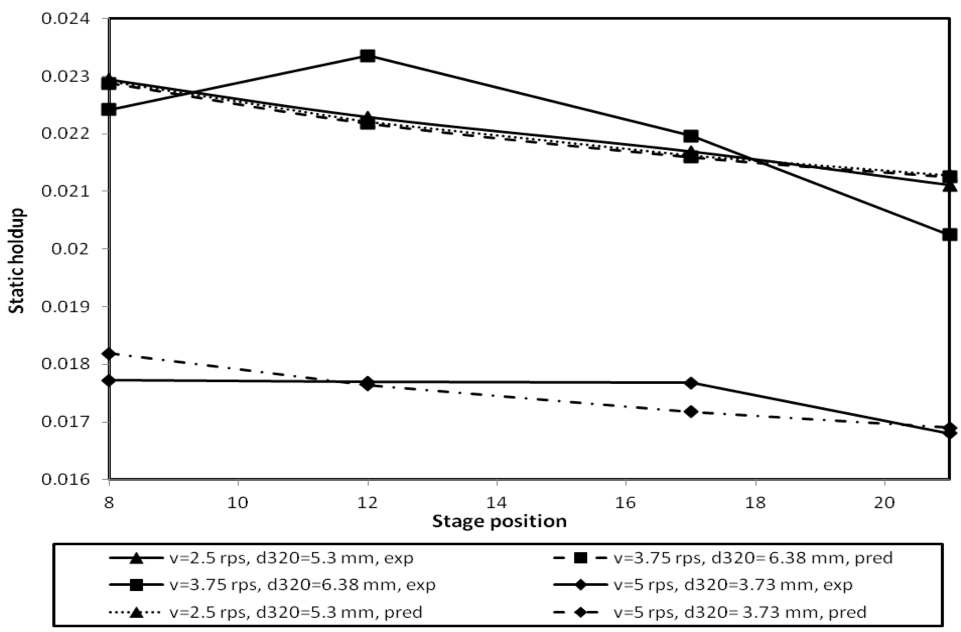

Figure 4 Local static holdup versus stage position for water-butyl acetate system at different rotor speeds

3.3. Mother Drop Diameter

The presence of static holdup in the column means drops would coalesce with the trapped liquids under rotors and stators and make bigger drops. The mother drop is the drop that is generated from the nozzle (Behzad et al., 2015).

Photos and videos were used to measure the size of the mother drops using AutoCAD software. An optional reference point, such as disc thickness, was used for comparison. A total of 6-13 drops were monitored for the first position (below Valve 1) to increase accuracy. The mean drop diameter was calculated as shown in Equation 2:

$$d_{32} = \frac{\sum n_i d_i^3}{\sum n_i d_i^2} \quad (2)$$

Figure 5 shows local static holdup versus mother drop diameter and indicates that static holdup increases as the mother drop size increased. The results show that, a larger mother drop increases the probability of the dispersed phase collecting under the stators. This is more obvious at the bottom of the column (in lower stage positions).

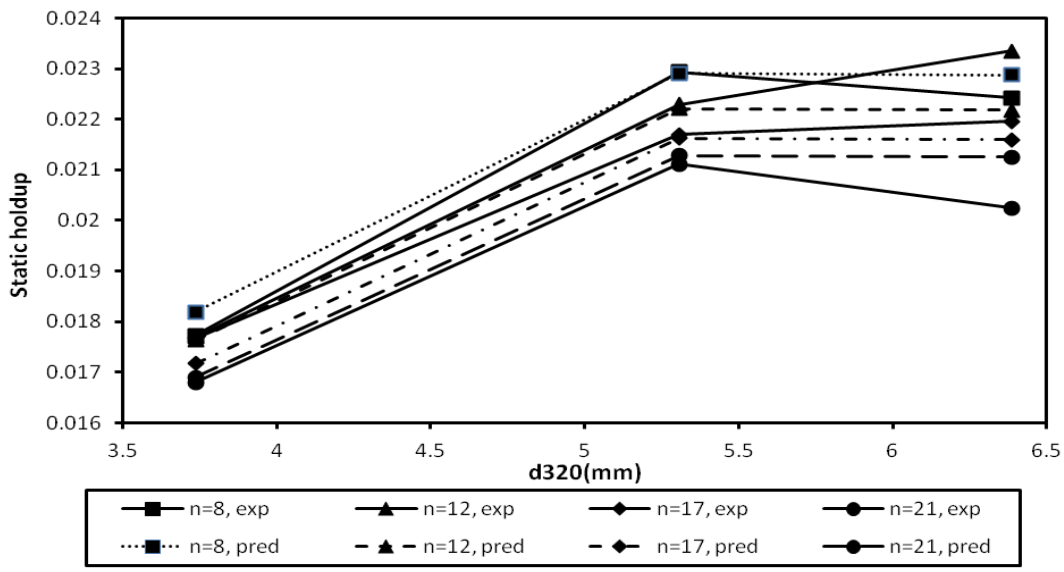

Figure 5 Local static holdup versus mother drop size for water-butyl acetate system at a constant stage position

3.4. Proposed Correlation

The previous studies shown in Table 1 have found the total holdup to be a function of dimensionless factors such as the physical properties of the two phases, rotating speed and column specification. Molavi et al. (2010) added the stage position and mother drop size to their correlation for RDC. These factors were also assessed in the present study. Rotating speed and physical properties were considered in the form of a Reynolds number. The correlation for local static holdup of one chemical system is shown in Equation 3:

$$\Phi = 0.19 \times \left(\frac{d_{320}}{H_s}\right)^{0.34} \times \mathrm{Re}^{-0.16} \times n^{-0.07} \tag{3}$$

where $\mathrm{Re} = \frac{\rho_c D_R^2 N}{\mu_c}$, it is worth noting that, no published correlation for static holdup of an RSDC was found in the literature. Therefore, no comparison is possible.

In Figures 3 to 5, the results of local static holdups calculated using the proposed correlation have been presented. Figure 6 shows the holdups calculated using the proposed correlation versus experimental values. The Absolute Average Relative Error (AARE) was 1.80%, while the standard deviation (σ) was 1.75% for this correlation as calculated by Equations 4 and 5:

$$AARE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_{\exp}(i) - y_{pred}(i)}{y_{\exp}(i)}\right| \tag{4}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left[\left|\frac{y_{\exp}(i) - y_{pred}(i)}{y_{\exp}(i)}\right| - AARE\right]^2}{N-1}} \tag{5}$$

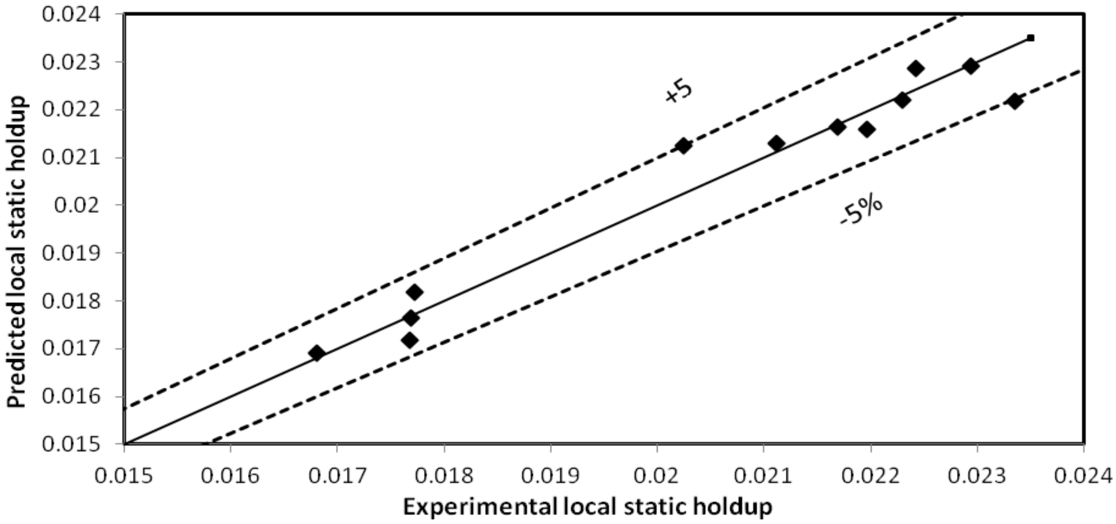

Figure 6 Calculated local static holdup versus experimental local static holdup

4. CONCLUSION

Considering the fact that static holdup has an important role on drop coalescence, residence time, interfacial area and general efficiency of the mass transfer columns, an experimental investigation has been performed on the static holdup of a rotary sieved disc contactor (RSDC). The static holdup has been measured using a draining method and one correlation has been proposed to calculate local static holdup in an RSDC for the water-butyl acetate chemical system. The correlation incorporates rotating speed, stage positions and mother drop size. The results showed that rotating speed and stage position increase local static holdup while mother drop diameter increased. These effects are shown in the form of negative and positive powers in the correlation. AARE and standard deviation were calculated to be 1.80% and 1.75%, respectively, which demonstrates the accuracy of the proposed correlation.

5. ACKNOWLEDGEMENT

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6. NOMENCLATURE

Roman Symbols

AARE	Absolute average relative error
D	Column diameter (mm)
D_R	Rotor diameter (mm)
D_S	Stator diameter (mm)
d_{320}	Average mother drop size (mm)
d_{32}	Sauter mean diameter (mm)
F_r	Froude number
G	Acceleration due to gravity (m/s^2)
H	Colum height (m)
H_S	Compartment height (m)
n	Stage position
N	Rotating speed (rpm)
Re	Reynolds number
V	Superficial velocity (m/s)
We	Weber number

Greek letters

Φ Local hold-up
ρ Density (kg/m^3)
$\Delta\rho$ Density difference (kg/m^3)
γ Interfacial tension (mN/m)
μ Viscosity (mPa.s)
σ Standard deviation
v Volumetric flow rate (m^3/s)

Subscripts

c Continuous phase
d Dispersed phase
pred Predicted

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