Hydrodynamics and Mass Transfer Performance in Modified Rotating Disc Contactor*

Y. D. Wang**, Y. K. Wan, Y. D. Yin and W. Y. Fei,

Solvent Extraction Laboratory, The State Key Laboratory of Chemical Engineering, Department of Chemical Engineering, Tsinghua University, Beijing 100084, P. R. China

Abstract
Velocity fields in a rotating disc contactor(RDC) with single-phase flow have been measured using a Laser Doppler Velocimeter and simulated with computational fluid dynamics software. Simulated velocity profiles are fairly in agreement with the experimental ones. Both experimental and calculated results show that there exist vortices between adjacent rotating discs and between adjacent stator rings in the flow system. The vortex between stator rings enhances mixing and mass transfer in a compartment, while the vortex between discs is the main factor causing axial mixing. In order to suppress the axial mixing thus enhancing the mass transfer efficiency in the extraction column, a modified rotating disc contactor (MRDC) is proposed. Simulated velocity profiles in the new extraction column have shown that the axial mixing between the discs has been effectively eliminated.

Keywords: Extraction; Rotating disc contactor; Computational fluid dynamics; Mass transfer.

1. Introduction

Liquid-liquid extraction is a main separation technology in process industries. Rotating disc contactor (RDC) is one of the major extraction columns which has been widely used in petroleum refining, chemical and metallurgical industries for its high throughput, low investment, easy operation and maintenance. But due to the limit of its structure, mass transfer efficiency of commercial RDC is low, especially for very low interfacial tension systems, namely, the axial back-mixing is sever. Axial mixing is undesirable forward and back mixing of the continuous and dispersed phases as they pass through the extraction column. The ideal structure is pure plug flow of the two phases as they pass each other in the column, which maximises the concentration driving force. The more of axial mixing, the greater the falloff in driving force. The effect of axial mixing is seen as concentration "jumps" at either end of extractor. These jumps move the equilibrium and operating lines closer together, thus reducing concentration driving force and increasing the stage requirement in the extractor[1]. Some reports [2] showed that 60~75% of its height is used to compensate the decrement of mass transfer efficiency, and some commercial size RDC just has 3 theoretical stages [3]. Therefore, it becomes an imperative research task to improve the mass transfer efficiency of RDC, strive for high capacity while minimising axial mixing. A lot of works [4,5] had been done on RDC by chemical engineering researchers. These works can be divided into two classes, one is about the mass

* Project supported by the National Natural Science Foundation of China (No. 29836130) and China National Petrochemical Corporation (No. X598026).

** To whom all correspondence should be addressed.

transfer performance and hydrodynamics such as throughout capacity drop diameter distributions, flooding velocities with varied systems and RDC scales. The main objective of this category is to seek for the optimal operating conditions and design method for RDC. Many correlations had been presented in literature, but when system or column scale changed, the use of these correlations was quite limited. Another class is to optimise the structure of RDC, several modified RDCs, such as asymmetric rotating disc extractor(ARD)[6] , the enhanced coalescence column(EC)[7] , self-stabilising high performance extractor(SHE)[8] ,open turbine rotating disc contactor(OTRDC)[9] were presented. However, major change in RDC's inner structure was needed in order to achieve better mass transfer performance, usually with the expense of throughout capacity decrease.

Computational Fluid Dynamics (CFD) has been applied in automobile and aerospace industries successfully for decades. Its use in chemical engineering concentrates mostly on stirred tank [10]. Velocity field measurements by LDV and numerical simulations using CFD have been performed by Weiss and Bart[11], Bart et al.[12], Rieger et al.[13][14] in a small column with a diameter of 150 mm. Xu and Fei[15] measured velocity profiles in a rotating disc contactor with a diameter of 100 mm. Up till now, most of the velocity fields measurement has been done with small column diameters. Since two-phase flow in a RDC is very complicated, the majority of the experimental measurements of the velocity fields were in a single phase, mostly, the measurement media is water. Although two phase flow fields have been done[14], there are still some uncertainties in the two phase flow measurements. There is no report on velocity field measurements in pilot-scale and on modifying the inner structure of the RDC so as to change the flow pattern and increase the mass transfer performance.

In this study, tangential and axial velocity fields in a pilot-scale RDC have been measured and simulated using CFD software. Our specific objective is to get a deep understanding of the flow pattern inside a RDC. We try to locate the areas where axial mixing happens and how to eliminate them by modifying the inner structure of the RDC.

Table 1 RDC structure parameters for LDV measurements

Parameter	Symbols	Value(m)	Parameter	Symbols	Value(m)
RDC Inner diameter	D_T	0.29	Stator ring inner diameter	D_R	0.19
Rotating disc diameter	D_r	0.174	Compartment height	H_C	0.078
Shaft diameter	D_S	0.014	Column height	H_T	0.46

2 Experimental

A pilot-scale RDC was designed and constructed with four compartments, its parameters are showed in Table 1. The column was made of glass pipe and inner parts were made of aluminum, the rotating discs and shaft was driven by a 0.2kw motor and its speed was controlled by a speed regulator from 0-1500±2 rpm. A photoelectric speed detector measured the rotation speed. The measuring system used was TSI9100-3 Laser Doppler Velocimeter (LDV), a single channel LDV system signal processor is 1980B and later is replaced with QSP LDA processor. A schematic diagram of the measuring system is shown in Figure 1. A circulation flow system was installed with the flow in on the top of the column and out at the bottom of the column, the flow rate is controlled by a valve and measured by a rotameter from 0-1.6M^3/hr. The pipeline of the flow system was cooled in order to maintain constant temperature of the fluid. The system is so designed to simulate the single phase flow of pure water with and without throughput. Fine polystyrene particles are added as seedling particles to increase the signal intensity. To reduce reflecting light, all the inner parts of the RDC are blackened, and a backscatter collection method is adopted for the limit of structure.

Doppler signals received were processed using model 1980B Counter-type signal processor as well as QSP LDA processor.

3 Mathematical Model

Steady state, axial-symmetric Navier-Stokes equations written for an incompressible Newtonian fluid in steady state flow were used. The calculations were done with the commercial CFD package of PHOENICS.

4 Results and Discussion

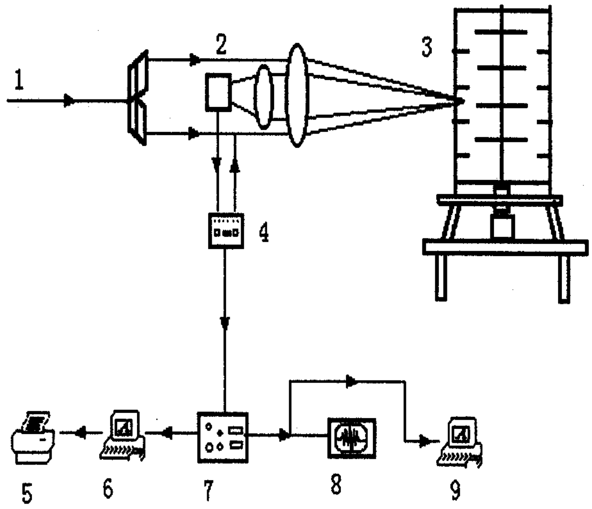
The vortexes between rotating discs are the main factors caused axial back mixing which should be eliminated for the benefit of higher mass transfer efficiency. A modified rotating disc contactor (MRDC) is, therefore, proposed as shown in Fig.2. MRDC is different to the traditional RDC in that a perforated rotating disc is added at the stator ring level. The disc is perforated so that the throughput capacity of MRDC can be kept nearly as high as the RDC. Numerical simulations have been performed with MRDC. Simulated flow pattern of MRDC indicates that the vortex between the rotating discs has been effectively eliminated. Hydrodynamic and mass transfer experiments were carried out in both MRDC and RDC. The extraction column was 0.1 m diameter and contained 35 rotating discs. The effective column height was 1.0 m, rotating disc diameter 0.06 m, stator ring diameter 0.07 m, central shaft diameter 0.015 m, stainless steel disc and stator plate thickness 0.0012 m. In the case of MRDC experiments, perforated discs were installed between every two rotating discs. Continuous phase was deionised water having a density of 1000 kg/m^3 and viscosity of 1.610 mPa·s. Dispersed phase was 6%(by weight) succinic acid in n-octanol having a density of 876.2 kg/m^3 and viscosity of 3.925 mPa·s. The results shown in Fig. 3 indicates that mass transfer efficiency increased by 25 to 40% compared to conventional RDC while throughput capacity is only 1~3% lower than that of conventional RDC (Fig. 4).

4 Conclusion

Single phase velocity profiles in a pilot-scale rotating disc contactor have been measured using LDV and simulated by CFD software for both flow and non-flow systems. The simulated results agree fairly well with the experimental ones. There is a significant difference on flow pattern between the two systems. The vortexes occurred between the compartments are the main causes of axial mixing which has a significant effect on mass transfer efficiency in a RDC. To eliminate these vortexes and improve the mass transfer efficiency, A modified RDC (MRDC) is proposed. The experimental and simulated results have shown that vortexes between the compartments can be effectively removed and mass transfer efficiency increased by 25 to 40% with MRDC.

References

[1] R. W. Cusack and P. Fremeaux, Chem. Eng. (New York), March(1991)132.
[2] T. Misek, V. Rod, in Recent Advance in Solvent Extraction, Pergamon, New York,(1971),197.
[3] S. Y. Ju , R. W. Pike, The Can. J. of Chem. Eng. , 68 (1990) 3.
[4] W. J. Korchinsky, Rotating Disc Contactor in J. C. Godfrey and M. J. Slater , Eds. Liquid-liquid Extraction Equipment, John Wiley & Sons, (1994) 247.
[5] Z. Li, W. Fei et al., Liquid-liquid Extraction Process and Equipment, Atomic Energy Press, Beijing, (1993) 478.
[6] T. Misek, et al., Brit. Chem. Eng. 15(2)(1970) 202.
[7] L. Steiner, S. Hartland, Chem. Rundsch ,13(1980) 256.
[8] W. Gaubinger, Ger. Chem. Eng. , 6(1983) 74.
[9] J. W. Zhu, Chem. Eng. Technol., 14(1991) 167.
[10] A. Brucato, et al., Chem. Eng. Sci. 53(21)(1998) 3653.
[11] C. Weiss, H-J. Bart, Proceedings of ISEC'93, New York: Elsevier Applied Science Pub. Ltd., 1993, 2: 1191.
[12] H-J Bart, G, Husung, R. Marr, C. Weiss, 11th Inter. Congr. Chem. Eng. Chem. Equip. Des. Auto., CHISA'93, 1993, 29 Aug. to 3 Sept., Praha, Czech, A1-A11.
[13] R.Rieger, Computers Chem. Eng., 18(1994) s229.
[14] R. Rieger., H. –J.Bart, R. Marr, et al., Computers Chem. Eng. , 20(12) (1996) 1467.
[15] H. Q. Xu, W. Y. Fei, J. Experimental Mechanics(in Chinese), 10(4)(1995) 316.
[16] H. I. Rosten and D. B. Spalding, Shareware PHOENICS Beginner's Guide---CHAM Report number TR100.



1. He-Ne Laser. 2. Photomultiplier. 3. RDC column. 4. Frequency shifter. 5. Printer. 6. HP computer. 7. Signal processor. 8. Oscilloscope. 9 IBM computer.

Fig.1. Schematic diagram of LDV measuring system

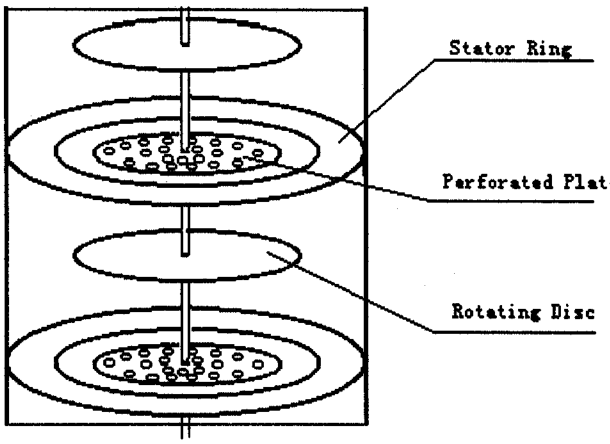


Fig.2 Schematic diagram of MRDC

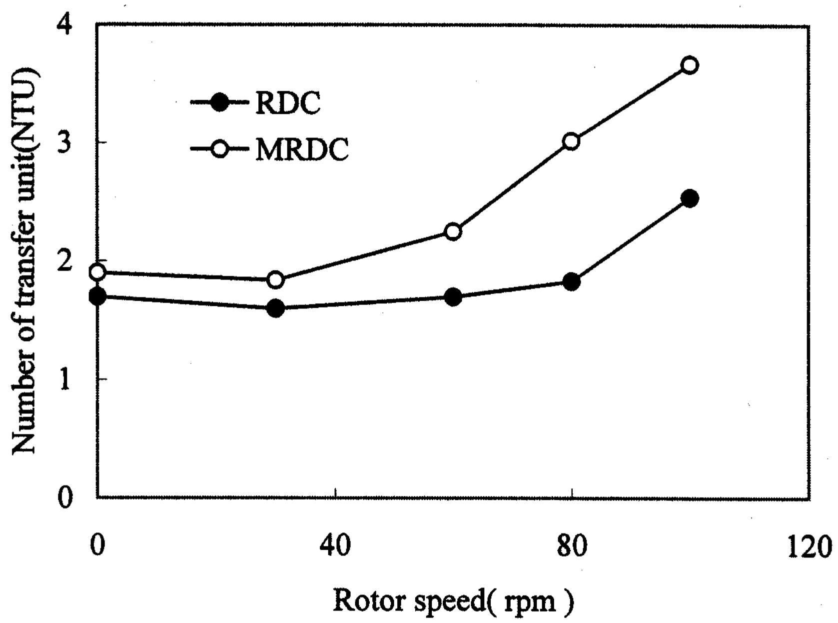


Fig.3 Mass transfer comparison between MRDC and RDC($Vd=Vc=1.67x10^{-5}m^3/s$)

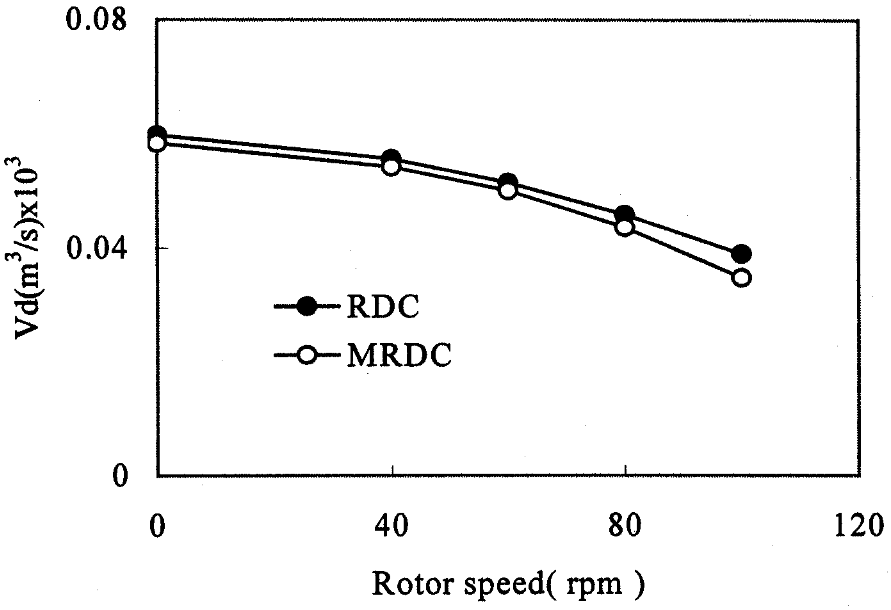


Fig.4 Throughput capacity comparison between MRDC and RDC($Vc=1.67x10^{-5}m^3/s$)