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# Removal of hydrophobic volatile organic compounds with sodium hypochlorite and surfactant in a co-current rotating packed bed

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## ABSTRACT

A co-current flow rotating packed bed was applied to remove volatile organic compounds (VOCs) by sodium hypochlorite (NaClO) and surfactant (sodium dodecyl benzene sulfonate, SDBS) from air stream. Xylene was used as a model VOC herein. The effect of pH, concentration of NaClO and SDBS solution, liquid flow rate, gas flow rate and rotational speed on xylene removal efficiency and overall mass transfer coefficient ( $K_Ga$ ) were discussed. Then, a correlation for  $K_Ga$  of the co-current rotating packed bed was proposed by fitting the experimental data of  $K_Ga$  and independent variables of liquid/gas ratio, rotational speed, pH, NaClO concentration and treatment time, which was in good agreement with the experimental data (the deviation  $\leq \pm 30\%$ ).

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## Introduction

Volatile organic compounds (VOCs) emitted from chemical process industries (CPI), automobile exhaust and cooking oil fumes (COFs) have caused serious environmental problems and health concerns, such as photochemical smog, ozone generation, and carcinogenesis. (Atkinson and Arey, 2003; Schauer et al., 2002; Selke et al., 1977; Wei et al., 2014). Many methods (e.g., condensation, membrane separation, catalytic oxidation, absorption and adsorption) have been used for VOC treatment. Among them, absorption has been considered to be a safe, effective and economical method (Chen and Liu, 2002; Li et al., 2015; Parthasarathy and El-Halwagi, 2000; Yang et al., 2011; Yeom et al., 2002). Traditional packed beds are widely used in VOC absorption, however, their poor mass

transfer efficiency and large occupied area lead to high cost in operating, thus the development of the traditional packed beds is largely restricted (Murugesan and Sivakumar, 2002; Silverberg, 1996). As a result, to design a device with high mass transfer, small occupied area and low gas pressure drop are of great importance to response to “process intensification”.

A rotating packed bed (RPB), which was first invented by Ramshaw and Mallinson (Ramshaw and Mallinson, 1981), could enhance the efficiency of mass transfer through tearing liquids into smaller droplets, and thinner films with a centrifugal force to decrease mass transfer resistance and increase gas–liquid interfacial area. RPBs have already been applied to several fields of chemical industry, such as absorption (Lin et al., 2003; Qian et al., 2012; Zhang et al., 2011), distillation (Lin et al., 2002; Wang et al., 2008), stripping

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(Chen et al., 2005; Singh et al., 1992), ozone oxidation (Ko et al., 2011; Zeng et al., 2012), and synthesis of nano-materials (Lin et al., 2012; Sun et al., 2011).

Pressure drop is one of the most important parameters to evaluate the performance of a RPB. Liu et al. (1996) used water–air system to study the pressure drop of a counter-current flow RPB, whose results indicated that the pressure drop in dry bed increased with the rotational speed, but decreased with the rotational speed when liquid was introduced to the rotor. It has been reported by Guo et al. (1997) that the gas pressure drop of a cross-flow RPB in the dry bed was not influenced by the rotational speed, and was proportional to the liquid flow rate, proportional to the square of gas flow rate and also inversely proportional to centrifugal acceleration in wet bed. The study by Li and Hao (2013) indicated that gas pressure drop of a co-current flow RPB increased with the increase of gas flow rate, decreased with the increase of liquid flow rate and rotational speed, it had much lower gas pressure drop when compared with counter-current flow RPB. Therefore, co-current flow RPBs are suitable for treating VOC-containing waste gas with low pressure drop in restaurant cooking fume exhaust and roof exhaust of painting workshop.

Among numerous reports of RPBs, counter-current flow and cross-flow RPBs have been widely applied for VOC absorption (Chen et al., 2008; Chiang et al., 2012; Hsu and Lin, 2011, 2012; Lin and Chien, 2008; Lin et al., 2006, 2009). However, co-current flow RPBs were rarely reported for VOC absorption despite its obvious merit that low pressure drop is demanded. Moreover, the fresh absorption liquid in the reported RPB-systems was exhausted after gas–liquid mass transfer and no more recycling, resulting in a huge equipment with at least two liquid tanks and not full utilizing of absorption liquid. Accordingly, in the view of process intensification and cost-effect, design of a co-current RPB with recycling of absorption liquid in a circulating liquid tank can simplify the equipment and reduce energy consumption, which may be more suitable for industrial application.

In this work, a novel co-current flow RPB with a circulating liquid tank was designed and applied for xylene absorption. Sodium hypochlorite (NaClO) and surfactant (sodium dodecyl benzene sulfonate, SDBS) were used as oxidant and absorbent (Cheng and Hsieh, 2010). Xylene removal efficiency (E) and

overall mass transfer coefficient ( $K_G a$ ) were discussed with the effect of pH, concentration of NaClO and SDBS solution, liquid flow rate, gas flow rate and rotational speed. In addition, a correlation for  $K_G a$  of the co-current RPB was proposed by fitting the experimental data of  $K_G a$  and independent variables of liquid/gas ratio, rotational speed, pH, NaClO concentration and treatment time. The results in this paper casted some light on applying co-current RPB for waste gas treatment which demands low pressure resistance.

## 1. Materials and methods

### 1.1. Chemicals

The pH was adjusted by sulfuric acid ( $H_2SO_4$ , 96%) purchased from Beijing Chemical Works. NaClO (10%) was obtained from Tianjin Guangfu Fine Chemical Research Institute. SDBS ( $C_{12}H_{25}SO_3Na$ , SDBS) was purchased from Tianjin Fuchen Chemical Reagents Factory.

### 1.2. Reactor

In this work, the co-current flow RPB equipped with random stainless steel wire mesh packing has an inner radius of 3.2 cm, an outer radius of 11.0 cm, and an axial height of 6.5 cm. The rotor is fixed into a cylindrical circulated liquid tank, which has a diameter of 36 cm, a height of 25 cm and a total volume of 25 L. The liquid distributor consists of a tube which contains four set of holes, and each set has three holes of 0.4 cm diameter with 0.6 cm distance between holes in a vertical direction. A baffle is introduced near the rotor to make the liquid which came out from rotor fall into the bottom of the liquid tank and mix with fresh liquid, then pump into the rotor again.

### 1.3. Experimental section

Fig. 1 briefly describes the experimental process of xylene treatment. A high purity nitrogen stream (99.99%) of a low flow rate passed through a bubbler containing xylene, which was diluted to a desired concentration (120 ppmv) by compressed

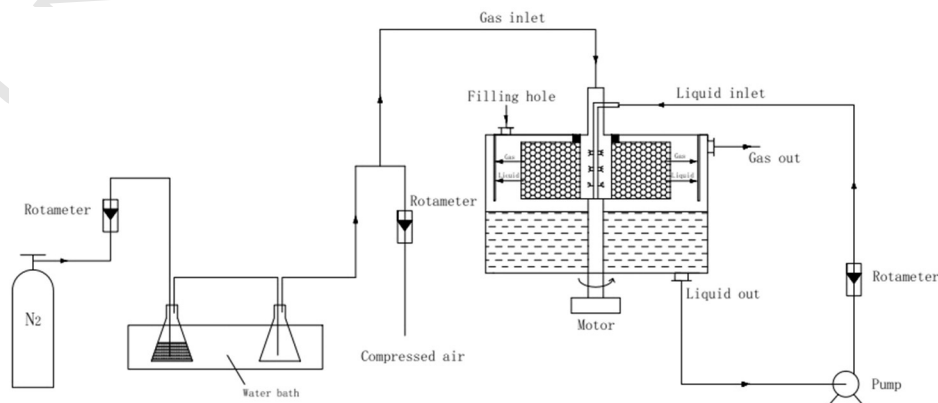


Fig. 1 – Schematic diagram of a co-current RPB for VOC treatment. RPB: rotating packed bed; VOC: volatile organic compound.

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