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THE REMOVAL OF DISSOLVED AMMONIA FROM WASTEWATER THROUGH A POLYPROPYLENE HOLLOW FIBER MEMBRANE CONTACTOR

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ABSTRACT

This study aims to evaluate the effectiveness of a polypropylene hollow fiber membrane contactor in removing dissolved ammonia in wastewater using sulfuric acid solution as an absorbent. In the ammonia removal experiments, wastewater and absorbent solutions flowed through the shell side and the lumen side of the contactor, respectively. The *p*H of wastewater, rate of circulation and ammonia initial concentration were operating variables which influenced the efficiency of the removal process. The efficiency of ammonia removal increases with the wastewater *p*H level when it is at the same circulation rate and time. In addition, the increase in the circulation rate of the wastewater will increase the efficiency of ammonia removal and the overall mass transfer coefficient. Meanwhile, the efficiency of ammonia removal and the overall mass transfer coefficient decreased with initial ammonia concentration in the wastewater solution.

Keywords: Ammonia; Efficiency of ammonia removal; Mass transfer; Polypropylene

1. INTRODUCTION

Industrialization processes will increase proportionately with the wealth factor in a country; however, industrialization also has negative impacts on the environment. One of these negative impacts is environmental pollution. Ammonia in wastewater is an example of industrial waste. Ammonia can be considered as a corrosive material and can harm human body tissue (El-Bourawi et al., 2007). Ammonia removal is very important in reclaiming industrial wastewater. Ammonia is usually treated by conventional processes, such as in pack tower aeration, by biological treatment or adsorbed as ammonium ions onto zeolites. Application of the ammonia removal process generally depends on many factors, namely the level of contamination, plant safety and regulatory considerations, as well as the availability of sources of heat and chemicals (Xie et al., 2009).

There are many conventional methods to remove ammonia from wastewater, but most of these methods consume large amounts of energy for operation (Bonmatí & Flotats, 2003). There are some unconventional methods to remove ammonia from wastewater, such as: contact glow discharge electrolysis (Saksono et al., 2013), ammonia stripping through a hollow fiber membrane contactor (Mandowara & Bhattacharya, 2009), membrane distillation

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(Ding et al., 2006; Xie et al., 2009), vacuum membrane distillation (Ding et al., 2006; El-Bourawi et al., 2007), combination membrane and ozone processing (Kartohardjono et al., 2012a), and combination membrane, ozone and nonthermal plasma (Kartohardjono et al., 2012b). This study aims to evaluate the performance of a polypropylene membrane contactor in removing dissolved ammonia from wastewater using a sulfuric acid solution as an absorbent. In this study we will examine the effects of *p*H, the circulation rate and the initial ammonia concentration in the wastewater solution on the efficiency of removal and the overall mass transfer coefficient.

2. MATERIALS AND METHODS

In this study, membrane contactors are made of polypropylene with a surface area of 1.4 m^2 (based on the outside fiber diameter) provided by the Liqui-Cell Company (1.7×8.75 Mini Module®). Figure 1 shows the schematic diagram of the experimental setup. The wastewater containing ammonia was formulated by dissolving a given amount of ammonium sulphate into distilled water, which will be used as wastewater solution in the experiment. A Sodium Hydroxide solution (purchased from Merck) was introduced to the wastewater to adjust the wastewater *p*H level. Meanwhile, the absorbent solution used in the experiment was a solution of 0.1 M H_2SO_4 (purchased from Merck). The wastewater solution was delivered to the membrane contactor through the shell side, whilst the solution of 0.1 M H_2SO_4 was pumped through the lumen fiber using a peristaltic pump (Longer WT600-2J). Wastewater was analyzed every 15 minutes to measure the ammonia concentration with an ammonia meter (Martini Instruments Mi 4500.)

Equation 1 can be used to calculate the efficiency of ammonia removal,

$$\%R = \frac{C_0 - C_t}{C_0} x100\% \tag{1}$$

where C_0 and C_t are the concentration of ammonia in the feed solution (mg/L) at an initial rate and at time *t*, respectively. Furthermore, Equation 2 can be used to determine the overall mass transfer coefficient, K_{OV}, based on experimental results:

$$ln\left(\frac{C_t}{C_0}\right) = \frac{Q}{V}\left[exp\left(-\left(\frac{K_{OV}aL}{v_L}\right) - 1\right)\right]t \tag{2}$$

where *Q* and *V* are the wastewater circulation rate and the volume of wastewater in the reservoir, respectively. Meanwhile, *a*, *L* and v_L are the membrane specific area, fiber length and wastewater velocity in the membrane contactor, respectively.

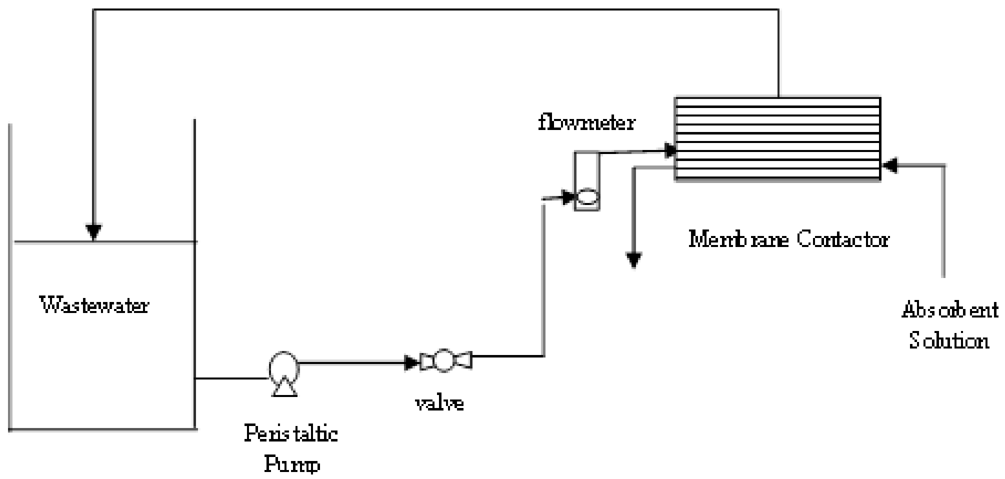


Figure 1 Schematic diagram of experimental setup

3. RESULTS AND DISCUSSION

The effects of the *p*H level of the wastewater on the removal efficiencies and the overall mass transfer coefficients using an initial ammonia concentration of 772 ppm are illustrated in Figures 2 and 3, respectively.

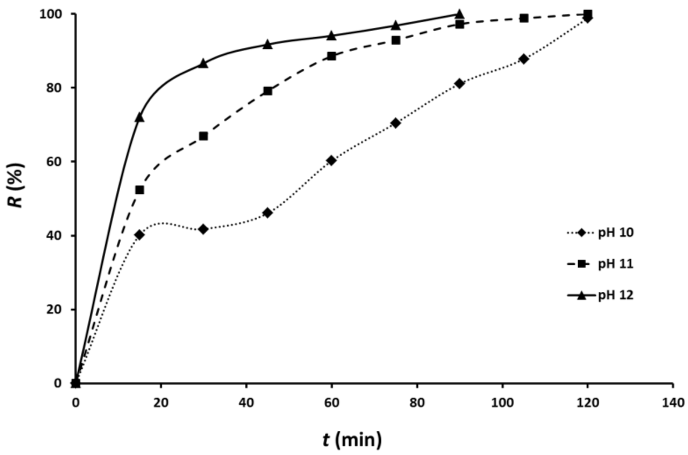


Figure 2 Ammonia removal efficiency profiles at various wastewater *p*H

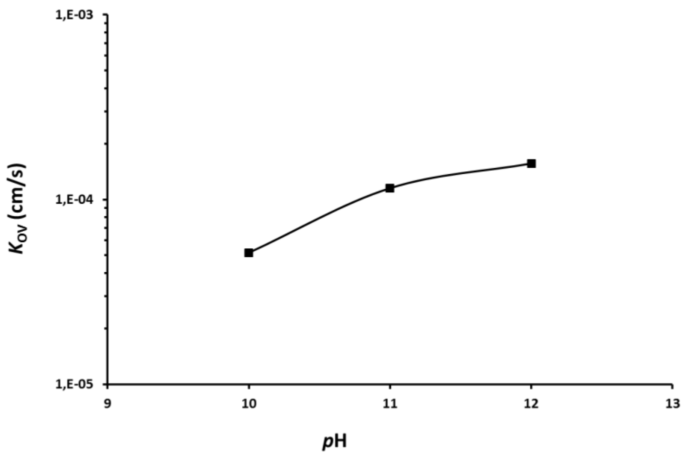


Figure 3 The effects of wastewater *p*H on the overall mass transfer coefficients, K_{OV}

The increase in the pH level of wastewater will increase both the efficiency of ammonia removal and the overall mass transfer coefficient at the same circulation time. Equation 3 shows that the ammonia in an aqueous solution occurs as volatile ammonia molecules NH_3 and NH_4^+ ions. The volatile ammonia molecules can be diffused in the membrane pores from the watsewater side to the absorbent in the lumen fiber. Therefore, in the experiment we must manipulate the condition as shown in Equation 3 to produce a high amount of volatile ammonia molecules, which can be conducted by adjusting the pH and the temperature of wastewater (El-Bourawi et al., 2007). The increase in pH level of the wastewater will increase the species of the hydroxyl radical OH^- in the solution and this will force the equilibrium reaction in the formation of volatile ammonia ($NH_{3(g)}$) in the wastewater side, which in turn will increase the efficiency of ammonia removal and the overall mass transfer coefficient. Figure 2 also shows that at the pH level of 11 and 12 in wastewater, ammonia can be removed entirely from the wastewater after 90- and 120-minute circulation times, respectively. Meanwhile, at a pH level of 10 in the wastewater there is still a small amount of ammonia in the wastewater (9.12 ppm) after a 120-minute circulation time.

$$NH_{3(g)} + H_2O_{(l)} \leftrightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)} \quad (3)$$

Figure 4 and Figure 5 show the effects of the initial concentration of ammonia on the efficiency of the ammonia removal and the overall mass transfer coefficient, respectively.

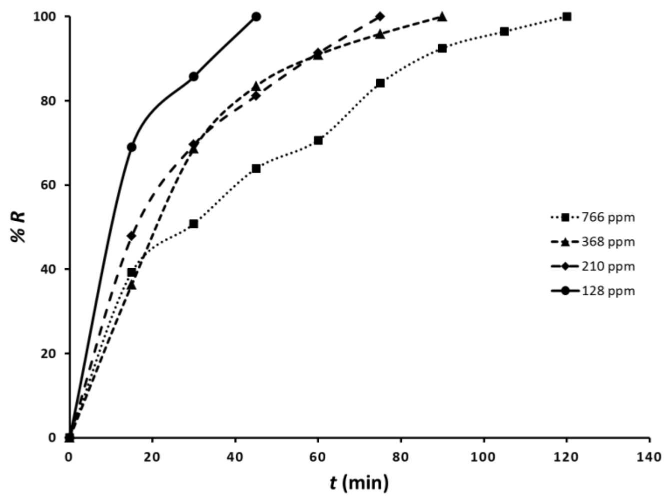


Figure 4 Ammonia removal efficiency profile at various initial ammonia concentrations

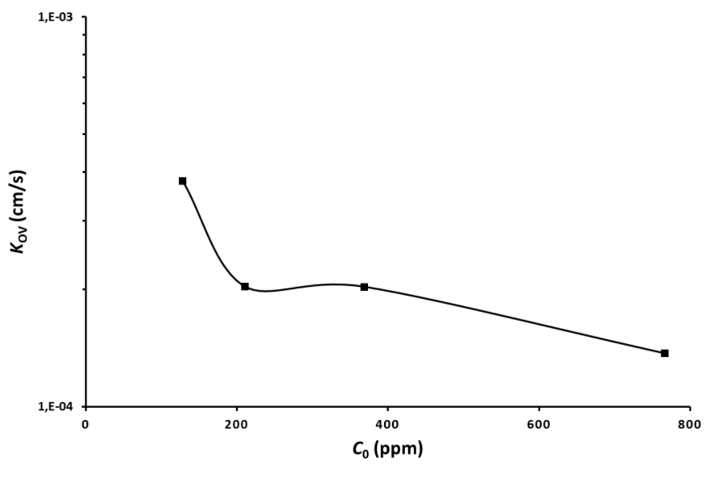
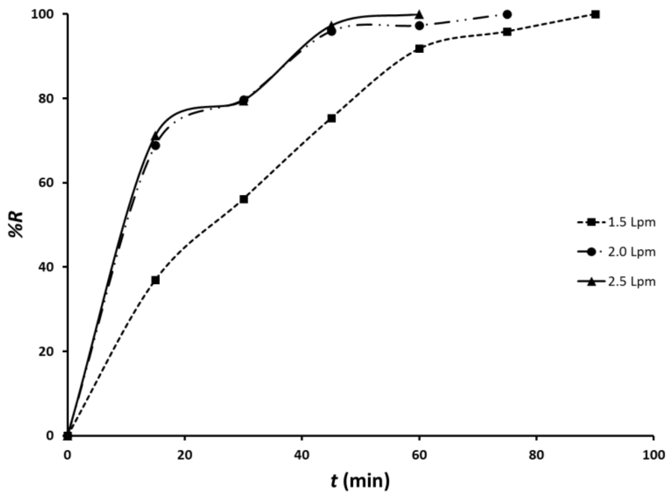


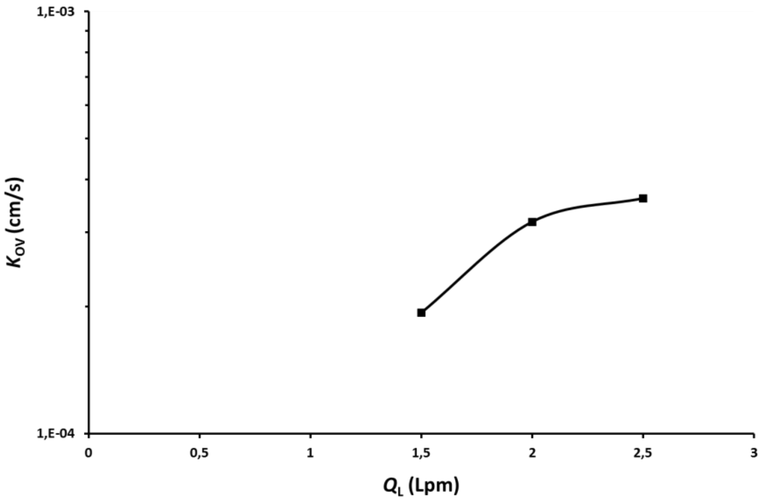
Figure 5 The effects of the initial concentration of ammonia, C_0, on the overall mass transfer coefficients, K_{OV}

Experimental results, which were conducted at a *p*H level of 11 in wastewater and a circulation rate of 1 Liter per minute (Lpm) show that the increase in the initial concentration of ammonia will decrease the efficiency of ammonia removal and the overall mass transfer coefficient. Increasing the initial concentration of ammonia in the wastewater will increase the membrane contactor load to reduce the ammonia content in the wastewater, thus decreasing the efficiency of ammonia removal and the overall mass transfer coefficient. Figure 5 shows that a 100% removal efficiency is achieved at 45-, 75-, 90- and 120-minute circulation times for the initial ammonia concentration in the wastewater of 128, 210, 368 and 766 ppm, respectively.

Figures 6 and 7 show the effects of the circulation rate of wastewater on the efficiency of ammonia removal and the overall mass transfer coefficient, respectively, where the experiments were run using the *p*H level of wastewater and an initial ammonia concentration of 11 and 220 ppm, respectively.



Figures 6 Ammonia removal efficiency profile at various wastewater circulation rates



Figures 7 The effects of the circulation rate of watswater, Q_L, on the overall mass transfer coefficients, K_{OV}

The efficiency of ammonia removal and the overall mass transfer coefficient increased with an increase in the wastewater circulation rate due to the liquid boundary layer near the membrane wall in the wastewater phase. This boundary layer becomes thinner as the wastewater circulation rate increases and reduces the mass transfer resistance (Ashrafizadeh & Khorasani, 2010). This phenomena indicate that the resistance of mass transfer in the wastewater boundary layer cannot be neglected in the range of wastewater circulation rates applied in this study (Hasanoğlu et al., 2010). Figure 6 shows that 100% removal efficiency is achieved at 90-, 75- and 60-minute circulation times for wastewater circulation rates of 1.5, 2.0 and 2.5 Lpm, respectively.

4. CONCLUSION

This study was conducted to determine the effects of the *p*H level of wastewater, initial ammonia concentration in wastewater and wastewater circulation rate on the efficiency of ammonia removal and the overall mass transfer coefficient in the hollow fiber membrane contactor. Wastewater containing ammonia and an absorbent solution flowed through the membrane contactor to the shell and lumen sides, respectively. The initial concentration of ammonia, wastewater circulation rate and *p*H are influential variables related to the efficiency of ammonia removal and the overall mass transfer coefficient. Experimental results show that the efficiency for ammonia removal and the overall mass transfer coefficient increased by increasing the *p*H and the flowrate of wastewater. Meanwhile, the efficiency for removal of ammonia and the overall mass transfer coefficient decreased by increasing the initial concentration of ammonia in the wastewater.

5. ACKNOWLEDGEMENT

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