International Journal of Environmental Engineering – IJEE
Volume 1: Issue 2 [ISSN 2374-1724]
Publication Date : 25 June 2014

Ammonium bicarbonate draw solution reuse in forward osmosis process

Chinnawat Traisupachok[1], Sutha Khaodhiar[2], Jirachote Phattaranawik[3] and Vasimon Ruanglek[4]

Abstract— **Membrane technology is one of the advance wastewater treatment processes with an aim for treated wastewater reuse. Forward osmosis is the membrane process in which the trans-membrane transport was driven by osmotic pressure of draw solution. Ammonium bicarbonate is one of the chemicals that can be utilized as draw solution because of its high solubility and osmotic pressure properties. Recovery concentration unit in forward osmosis desalination system is necessary for draw solution reuse. In this study, thermal process was chosen for ammonium bicarbonate removal. Heated at 60℃ was provided to the synthetic draw solution with initial ammonium bicarbonate concentration between 0.05 to 0.5 M, and then ammonium bicarbonate concentration was measured on an hourly basis. The result indicated that heat can't completely removed ammonium- bicarbonate. The addition of air bubble can increase the removal efficiency to 40 – 70 %. The optimal heating time is five hour and the additional heating doesn't significantly effect on the removal efficiency. Ammonium bicarbonate is removed as CO_2 and NH_3 gas which can be recovered at 84.3% efficiency of removal**

Keywords*— *Water reuse, Forward osmosis, Ammonium bicarbonate

I. Introduction

Membrane is an advance technology for wastewater treatment and reuse.The efficiency of the membrane system depends on porosity size of membrane. It can be classified as: 1.Microfiltration (MF) 2.Ultrafiltration (UF) 3.Nanofiltration (NF) and 4. Reverse osmosis (RO) [1] Normally, Microfiltration and Ultrafiltration are used in the tertiary treatment process for suspended solids organics and germs removal or can be used as pretreatment unit for nanofiltration and reverse osmosis system.

Chinnawat Traisupachok[1] is with the Department of Environmental Engineering, Chulalongkorn University, Thailand

Sutha Khaodhiar[2] is with the Department of Environmental Engineering, Chulalongkorn University, Thailand,

Jirachote Phattaranawik[3] is with the SCG Chemicals Co.Ltd.,Sukumvit Rd, Map-ta-Phut, Rayong, 21150, Thailand

Vasimon Ruanglek[4] is with the SCG Chemicals Co.Ltd.,Sukumvit Rd, Map-ta-Phut, Rayong, 21150, Thailand

Forward osmosis (FO) or Direct osmosis is the osmotic driving force system owing to property as reverse osmosis membrane. It can be applied to most solutions except water. One side of membrane is low concentration feed solution and the other side is high concentration draw solution. The osmotic driving force is proportion to the different of concentration between feed and draw solution. Feed solution concentration increases while draw solution concentration decreases when the system is operated. The benefits of forward osmosis, compared with the reverse osmosis process, are similar membrane property as reverse osmosis can be used, low pressure and low electricity consumption, less dependent on pump, similar treated water quality as reverse osmosis, and less fouling [2].

Draw solution is an important composition in forward osmosis. It is the driving force of the system. Previous studies used many chemical as draw solution, for example, sulfur dioxide [4, 8] aluminiumsulfate [5] sugar [6, 7] glycine [7] potassium nitrate [8] Magnetic nanoparticle [9] and Methylimidazole–based [10].In this study ammonium bicarbonate is used as draw solution because it has high osmotic pressure and high solubility and can be recovery by heating process.

Used draw solution, low concentration, is normally sent to recovery unit to separate water and ammonium bicarbonate for reuse propose. They are many methods, such as precipitation, heating or reverse osmosis [3, 11] that can be used to remove ammonium bicarbonate. In this study heating process is selected. Previous study indicated that heating at 60℃ can change ammonium bicarbonate to ammonia gas and carbon dioxide, however, the appropriate heating time is unclear. Therefore the objectives of this study are 1.To find the optimum heating time 2. To evaluate the efficiency of ammonium bicarbonate removal by heating at 60℃ 3. To determine the capability to collect ammonium bicarbonate for reuse as draw solution.

II. Materials and Method

A. *Materials*

In this paper, Ammonium bicarbonate, reagent grade, was purchased from Ajax Finechem Pty Ltd. Ammonium bicarbonate concentrations of 0.05 M 0.1 M 0.2 M 0.3 M 0.4 M and 0.5 M (3,950 mg/l 7,900 mg/l 15,800 mg/l 23,700 mg/l 31,600 mg/l and 39,500 mg/l) was prepared by dissolving ammonium bicarbonate powder in DI water in 1 L volumetric flask.

B. *Experimental equipment for thermal process*

The experimental equipment for heating consists of water bath which can control temperature at 60℃. (BUCHI Heating bath, model B-490) (Figure 1.). Ammonium bicarbonate was contained in the flask. Bubbling tube connected to aerator (aquarium air pump) was used to add air to the solution. Reflux unit was set at the top of the flask to reduce water loss. Gas rubber tube with one end submerge in to DI water was used to collect outlet gas. (BUCHI Rotavapor, model R-200)

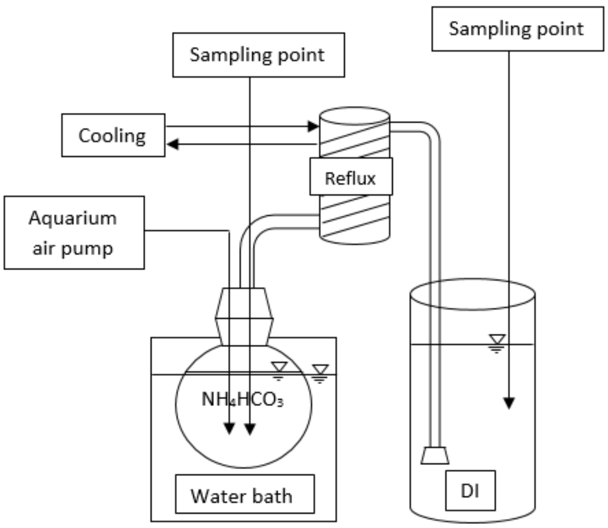

Figure 1. Schematic of heating process

C. *Sampling and Method*

The samples were collected before and after heating and bubbling (Figure 1.) on an hourly basis to determine ammonium bicarbonate concentration and pH. The ammonium bicarbonate was measured as nitrogen form by conductivity meter (Inolab, model 740, WTW TERMINAL). pH meter (DENVER Instrument, model UB-10, ultrabasic) was used for pH measurement. pH is used to indicate form of bicarbonate (pH about 7-9)[12] According to the theory, the backward reactions occur at temperatures of around 38-60 °C but the forward reactions are dominant at room temperature. Ammonium carbamate (NH_2COONH_4) is formed by the reaction of carbon dioxide and ammonia in the dry condition under room temperature and a pressure of 1 atm. while under moist air the hydration product of ammonium carbonate ($(NH_4)_2CO_3$) or ammonium bicarbonate (NH_4HCO_3) are the dominant forms. The time for react is about 60 seconds. [13]

$$NH_3\,(g) + CO_2\,(g) + H_2O\,(g) \leftrightarrow NH_4HCO_3\,(s) \quad (1)$$

$$NH_3\,(l) + CO_2\,(g) + H_2O\,(l) \leftrightarrow NH_4HCO_3\,(s) \quad (2)$$

$$2NH_3\,(g) + CO_2\,(g) + H_2O\,(g) \leftrightarrow (NH_4)_2CO_3\,(s) \quad (3)$$

$$2NH_3\,(l) + CO_2\,(g) + H_2O\,(l) \leftrightarrow (NH_4)_2CO_3\,(s) \quad (4)$$

$$2NH_3\,(l) + CO_2\,(g) \leftrightarrow NH_2COONH_4\,(s) \quad (5)$$

$$NH_2COONH_4\,(s) + H_2O\,(g) \leftrightarrow (NH_4)_2CO_3\,(s) \quad (6)$$

III. Results

A. *Heating and bubbling*

The result indicates that ammonium bicarbonate can't be removed by either heating or bubbling. Despite temperature is one of the factors effecting on ammonia solubility, the concentration wasn't changed with addition heat or bubble. The removal efficiency significantly increases when both heating and air bubbling were applied together (Figure 2.).

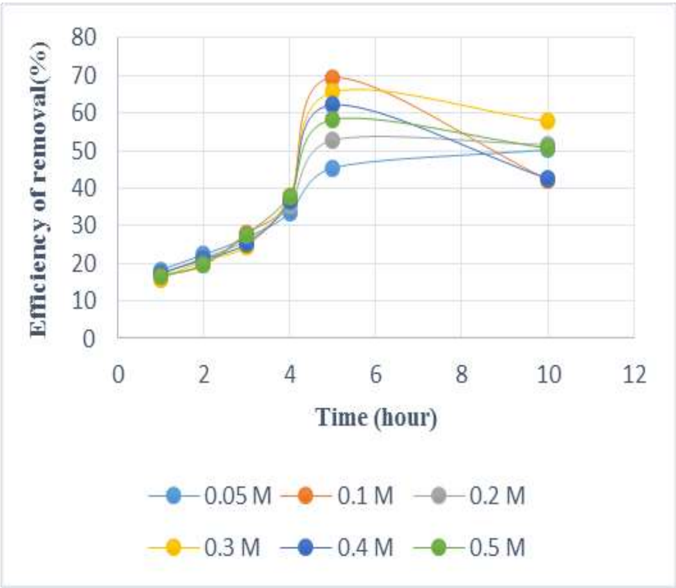

Figure 2. Ammonium bicarbonate removal efficiency at variable time when both heating and air bubbling were applied.

B. *Heating time*

Heating couldn't effectively remove ammonium bicarbonate from the solution and the additional air bubbling was required. Figure 2 indicates that the ammonium bicarbonate removal efficiency increase from 10-20% during the first hour to 40-70% at end of the fifth hour. The concentration was relatively constant after 5 hours.

C. *pH*

The initial pH of ammonium bicarbonate and DI water are around 7.9 and 6.7. After 5 hours of heating and bubbling, pH of both used and recovered draw solution was increase to 9. At pH around 7-10, carbon dioxide reacts with water and become to bicarbonate. Bicarbonate reacts with NH_4^+ to form ammonium bicarbonate at room temperature.

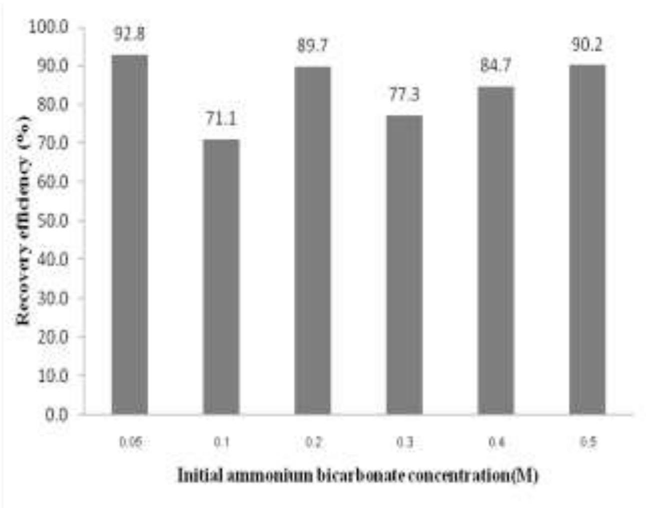

Figure 3. Ammonia and carbon dioxide gas recovery efficiency

D. *Removal and recovery efficiency*

According to the theory, ammonium bicarbonate is decomposed to NH_3 and CO_2 gas when heated. After heating and bubbling, It was found that the ammonium bicarbonate removal efficiency of the system after 5 hours is in the range between 40 -70 %, (average 53.9 %). NH_3 and CO_2 are gas which can be recovered and dissolved to ammonium bicarbonate again, similar to stripping column. However, there are many factors that effect on the removal efficiency such as NH_3 loss and CO_2 trapped. Recovery efficiency was 70 - 90% in this study (Figure 3.). To increase removal and recovery efficiency, contact time to form ammonium bicarbonate and temperature should be increased. The contact time for react should be about 60 s [13].

IV. Conclusions

This study demonstrated the efficiency of ammonium bicarbonate removal and recovery for forward osmosis recovery unit. Simultaneous heating at 60 °C and air bubbling can increase rate of ammonium bicarbonate removal from the solution. The optimal removal and recovery efficiency are 53.9% and 84.3% respectively. The suitable heating and bubbling time is 5 hours. pH of recovered draw solution was around 9, in which ammonium bicarbonate is the dominant form?

Acknowledgment

This work was financially supported by CU graduate school thesis grant of Chulalongkorn University. The technical support from Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University, and SCG Chemicals Co.Ltd., Sukumvit Road, Map-ta-Phut, Rayong, 21150, Thailand are also acknowledged.

References

[1] Wintgens, T., Melin, T., Schäfer, A., Khan, S., Muston, M., Bixio, D. and Thoeye, C. 2005. The role of membrane processes in municipal wastewater reclamation and reuse. Desalination 178: 1 – 11

[2] Junyou, Z. 2011. Forward Osmosis Membrane Bioreactor for Water Reuse. Master's thesis, Department of Civil and Environmental Engineering National University of Singapore.

[3] Cath, T.Y., Childress, A.E.and Elimelech, M. 2006. Forward osmosis: Principles, applications, and recent developments. Journal of Membrane Science 281: 70–87

[4] Batchelder, G.W. 1965. Process for the demineralization of water. United State Patent. Available from: http://www.freepatentsonline.com/3171799.pdf [2012, Sep 18]

[5] Frank, B.S. Desalination of sea water [online]. United State Patent. Available from: http://www.freepatentsonline.com/3670897.pdf [2012, Sep 18]

[6] Kravath, R.E. and Davis, J.A. 1975. Desalination of sea water by direct osmosis. Desalination 16: 151 - 155

[7] Stache, K. 1989. Apparatus for transforming sea eater, brackish water, polluted water or the like into a nutritious drink by means of osmosis. United State Patent. Available from: http://www.freepatentsonline.com/4879030.pdf [2012, Sep 18]

[8] McGinnis, R. 2002. Osmotic desalination process. United State Patent. Available from: http://www.freepatentsonline.com/7560029.pdf [2012, Sep 18]

[9] Ling, M.M., Wang, K.Y. and Chung, T.S. 2010. Highly Water-Soluble Magnetic Nanoparticles as Novel Draw Solutes in Forward Osmosis for Water Reuse. Industrial and Engineering Chemistry Research 49: 5869 -5876

[10] Yen, S.K., Haja N., F.M., Su, M., Wang, K.Y. and Chung, T.S. 2010. Study of draw solutes using 2-methylimidazole-based compounds in forward osmosis. Journal of Membrane Science 364: 242-252

[11] McCutcheon, J.R., McGinnis, R.L.and Elimelech, M. 2005. A novel ammonia-carbon dioxide forward (direct) osmosis desalination process. Desalination 174: 1 – 11

[12] Chi, A., Hu, Y., Zhu, G., Xu, S., Zhou, Z. and Xu, Z. 2003. Solution-Chemistry Analysis of Ammonium Bicarbonate Consumption in Rare-Earth-Element Precipitation. METALLURGICAL AND MATERIALS TRANSACTIONS B VOLUME 34B : 611 - 617

[13] Bai, H. and Yeh, A.C. 1997. Removal of CO2 Greenhouse Gas by Ammonia Scrubbing. United State Patent. Available from: http://pubs.acs.org/doi/pdfplus/10.1021/ie960748j [2013, Aug 23]

About Author (s)

This paper study about optimal time for heating efficiency of removal and efficiency of recovery thermal recovery unit of forward osmosis process because draw solution is ammonium bicarbonate that can be separated by heating