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Removal of ammonia from anaerobic co-digestion effluent of organic fraction of food waste and domestic wastewater using air stripping process

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Abstract:

In this study, a continuous ammonium stripping lab-scale model of anaerobic co-digestion effluent from an organic fraction of food waste and domestic wastewater was used to investigate ammonium removal efficiency by air stripping. The effect of initial pH, liquid flow rate, and air-to-liquid ratio on the removal of ammonium from the effluent were examined in experiments. The operating parameters of the trials were established based on calculations from influent and effluent ammonia concentration and the theory of mass transfer. The results indicated that a pH value of 11, liquid flow of 0.25 l/min, and a ratio of air-to-liquid of 2925 gave a >90% ammonia removal efficiency and thus reached the allowable ammonia levels of wastewater discharged into receiving sources. The continuous stripping of nitrogen from anaerobic co-digestion of effluent had a huge significance in the removal of ammonium and recovery of ammonia gas , which aids in eutrophication prevention and fertilizer production.

Keywords: **air-to-liquid ratio, ammonia, anaerobic co-digestion, pH, stripping.**

Classification number: **2.2**

Introduction

For many years, anaerobic digestion has been widely applied to the treatment of wastewater with high biodegradable organic content like waste sludge, an organic fraction of solid waste, as well as to mixtures of wastewater and solid waste [1]. The anaerobic digestion process possesses advantages such as low sludge production, low energy consumption, and high potential recovery of biogases, which can be used for cooking and electricity. However, anaerobic effluent has a high ammonia concentration [1]. Further, ammonium is discharged into receiving bodies from various sources, namely fertilizer [2], landfill leachate [3], pig wastewater [4, 5], and especially in the effluent of an anaerobic co-digestion of a mixture of two or more solid wastes and wastewaters [6]. When discharged into receiving sources, ammonium causes eutrophication, dissolved oxygen depletion, and toxicity to aquatic organisms [7]. Additionally, the penetration of ammonia into ground water causes water contamination and is the cause of blue-skinned disease in children and pregnant women [7]. Because of the risks of untreated ammonia discharge, environmental regulations regarding the allowable limits of ammonia into receiving bodies are becoming more stringent across every country. In Vietnam, the maximum allowable limit of ammonium in drinking water is 3.0 mg/l [8].

Ammonia can be removed from wastewater by biological, chemical, and physicochemical technologies [2]. A biological treatment based on the combination of nitrification-denitrification processes by microorganisms is the most popular method of ammonia removal from wastewater due to low energy consumption, non-secondary pollutants, and non-chemical additives [8]. However, this method is very sensitive to loading shock and toxicity, and is not suitable for anaerobic effluent with low content of organic compounds [1, 9]. Beyond this, oxidation with

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chlorine consumes chemicals and forms by-products [9]. Meanwhile, air stripping is a simple physical separation process using the contact of liquid and air in opposite directions in a tower filled with a different medium. Concentrated gaseous ammonia found in effluent can be recovered and adsorbed by strong acidic solutions (H_2SO_4) for the production of fertilizer [2, 9, 10]. The air stripping process is especially suitable for wastewater with high ammonium and low organic matter, such as the effluent from anaerobic co-digestion processes [6].

The aim of this study, thus, is to study ammonium removal efficiency by air stripping technology in a tower containing a medium of pall rings. The effect of the initial pH, liquid flow rate, and air-to-liquid ratio on ammonium removal are systematically investigated.

Materials and methods

Materials

Wastewater: influent wastewater for the air stripping model was taken from the effluent of the anaerobic co-digestion process in a membrane biological reactor (MF-AnCSTR and MF-UASB**),** which degrades a fraction of the organic food waste and domestic wastewater of an army billet based in Ho Chi Minh city, Vietnam. The characteristics of the influent wastewater from the air stripping process are presented in Table 1.

Table 1. The characteristics of influent wastewater of air stripping model.

Parameter	Unit	Concentration	
		MF-AnCSTR	*MF-UASB*
pH	-	7.0±0.82	7.37±0.33
N-NH_4^+	mg/l	150±12.09	152±13.45
TN	mg/l	163.90±17.04	171.34±24.08
COD	mg/l	81.02±2,50	85.02±2.76
TSS	mg/l	5.91±2.37	8.71±2.48

Chemicals: all chemicals used in this study were purchased from Merck. The acidic and alkaline solutions used to adjust the pH to desired values were prepared as follows: the 1 M NaOH solution was prepared by dissolving of 41.667 g NaOH in 1000 ml of deionized water. The 1 M H_2SO_4 solutions was diluted from 14 ml of concentrated 98% H_2SO_4 solution in 500 ml of deionized water. The 5 M H_2SO_4 solution was prepared by diluting 70 ml of concentrated 98% H_2SO_4 in 500 ml of deionized water. This acidic solution was used to neutralize the gaseous ammonia output of the air stripping model.

Experimental setup

The laboratory-scale air stripping system: a plastic column (PAC) manufactured by the Binh Minh Company (Vietnam) was used for the design of the air stripping experiments. The column diameter and height was 11.4 cm and 130 cm, respectively. The column was filled with plastic spring carriers (size 2 cm x 3 cm) and the height of plastic carriers in the column was 75 cm. The air and liquid flows were continuously introduced into the air stripping column along the opposite direction of the carrier layer. The wastewater was adjusted to the desired pH and contained in 10-l tank. The wastewater was pumped at a pre-determined flow to the top of the column and was sprayed over the packing surface through a shower. The air was introduced into the bottom of the column by a fan with a capacity of 2.2 kW, the current strength of 7.8 A with a frequency of 50 Hz. The air was blown through the packing material. The ammonia containing output air was released at the top of the column and was adsorbed into a tank containing 5 M H_2SO_4. The scheme of the laboratory-scale ammonia stripping system is described in Fig. 1.

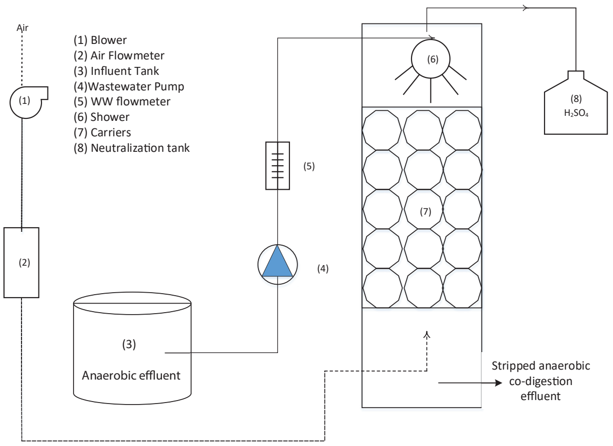


Fig. 1. The scheme of the lab-scale ammonium stripping system for treatment of anaerobic co-digestion effluent.

Determination of parameters for design of the air stripping model: the parameters of the air stripping model were calculated using mass transfer theory for the removal of NH_4^+-N (from 150 to 10 mg/l of QCVN 14:2008/BTNMT, column B) with 10 l volume of wastewater at 25±1°C.

The amount of air required to reduce the ammonia concentration from 150 to 10 mg/l in treated wastewater was calculated based on the text "Wastewater engineering: treatment and resource recovery" [11]. The parameters obtained for the design of the air stripping model are presented in Table 2.

Table 2. The parameters for design the air stripping to treat ammonium in anaerobic effluent.

Parameter	Unit	Value
Provided air flow	l/min	650
Provided liquid flow	l/min	50
Air-to-liquid ratio	-	2000-6000:1
Diameter of column	mm	114
Height of packing	m	0.75
Height of column	m	1.3
Mass transfer coefficient	1/s	0.0125

The influent and effluent ammonia concentrations were determined according to the standard method by the APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation) [12]. The pH was measured by a WTW pH meter 304.

Operating condition: the air stripping (AS) method used to treat the anaerobic co-digestion effluent was continuously operated to assess the effect of initial solution pH, liquid flow and air-to-liquid ratio on ammonium removal efficiency in anaerobic co-digestion effluent with packing column. The detailed operating conditions of the model were as follows:

The effect of solution pH on ammonia stripping was conducted by changing the pH values from 8 to 12 at an air flow rate of 650 l/min, wastewater volume of 10 l, and contact time of 25 min, under a constant influent ammonia concentration of 150±20 mg/l. The stripping process was examined over 15 experiments, where each of the 15 experiments were triplicated for each set of operating conditions.

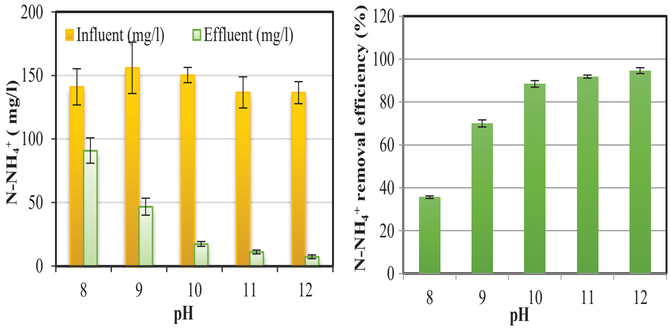
The experiments used to evaluate the effect of the liquid flow on ammonia stripping were conducted by changing the influent liquid flow rate between 0.25 l/min, 0.5 l/min, 0.75 l/min, and 1.0 l/min at pH of 11 with air flow rate of 650 l/min, wastewater volume of 10 l and contact time of 25 min under a constant influent ammonia concentration of 150±20 mg/l. All the samples were analysed in triplicates.

The effect of the air-to-liquid ratio was conducted over 15 experiments, where each experiment was triplicated for each set of operating conditions. The air-to-liquid ratio was varied from 0, 2084, 2260, 2632, and 2925 at a pH of 11 with an air flow of 650 l/min, wastewater volume of 10 l and contact time of 25 min with influent ammonia concentration of 150±20 mg/l.

Results and discussion

Effect of pH on ammonia stripping

The pH solution was chosen based on the theory of air stripping by George Tchobanoglous, et al. (2014) [11]. The effect of initial pH on ammonia stripping is presented in Fig. 2.



(A) (B)

Fig. 2. (A)The influent and effluent ammonium and (B) ammonium removal efficiency at various initial pH values.

Figure 2 indicates that effluent ammonium decreased when pH was increased from 8 to 12. The removal efficiency of ammonium reached 35.64±0.75, 70.02±1.67, 88.39±1.54, 91.87±0.68, and 94.61±1.35% corresponding to a pH of 8, 9, 10, 11, and 12, respectively. At pH 11 a high removal efficiency was found and reached QCVN 14:2008/BTNMT. Thus, a pH of 11 was chosen for the next experiments.

It can be seen that the pH value had the most significant effect on the conversion efficiency of $N\text{-}NH_4^+$ into gaseous $N\text{-}NH_3$. A low efficiency of 35.64±0.75% was obtained at pH 8. The removal efficiency quickly rose to 91.87±0.68% and 94.61±1.35% at pH 11 and 12, respectively, corresponding with a $N\text{-}NH_4^+$ concentration of effluent of 11.12±1.46 mg/l and 7.30±1.52 mg/l, respectively, which reached the permitted standard discharge amounts for receiving sources. This result agrees with research conducted by Guštin and Marinšek-Logar (2011) [6]. That study reached its highest ammonia removal efficiency of anaerobic digestion effluent at a pH between 10.5-11.

Effect of contact time on ammonia stripping

The change of ammonium as a function of contact time is demonstrated in Fig. 3. It can be seen from Fig. 3 that the ammonium removal efficiency at an initial pH of 8 did not change with contact time. However, the removal efficiency of $N\text{-}NH_4^+$ gradually increased at pH of 11 with increasing contact time until it became constant at 25 min.

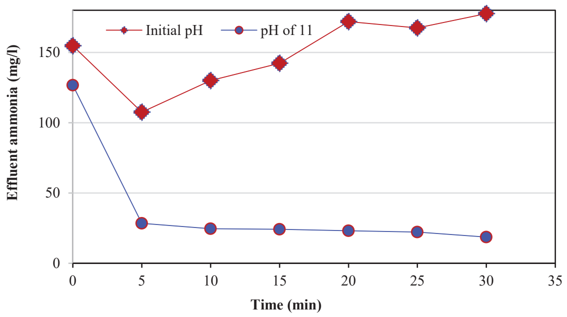
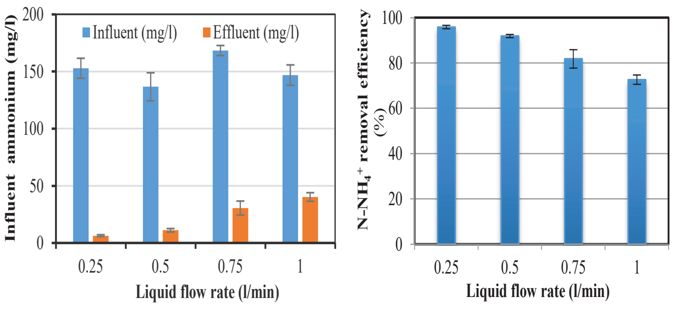


Fig. 3. Contact time dependence of ammonium concentration at initial pH and pH of 11.

Figure 3 also indicates that the contact time had an insignificant effect on ammonia removal efficiency. The N-NH_4^+ concentration reached 156.68, 29.51, 23.75, 17.12, 14.64, and 12.02 mg/l, respectively, at contact times of 0, 5, 10, 15, 20, and 25 min. The ammonia removal efficiency reached its maximum at a contact time of 25 min and pH of 11, and met the allowable limit of N-NH_4^+ (QCVN 14:2008/BTNMT, column B). Thus, a pH of 11 and contact time of 25 min was chosen for the next experiments.

Effect of liquid flow rate on ammonia stripping

The influent and effluent ammonium concentration and removal efficiency of the air stripping system are presented in Fig. 4. Fig. 4A illustrates that effluent ammonium increased when the liquid flow rate increased. The effluent ammonium was 6.38±0.77, 11.12±1.46, 30.51±6.16, and 40.25±3.84 mg/l corresponding to a liquid flow rate of 0.25, 0.5, 0.75, and 1.0 l/min, respectively. Fig. 4B shows a N-NH_4^+ removal efficiency of 95.80, 91.87, 81.81, and 72.59% when the liquid flow rate increased from 0.25 to 1.0 l/min, respectively.



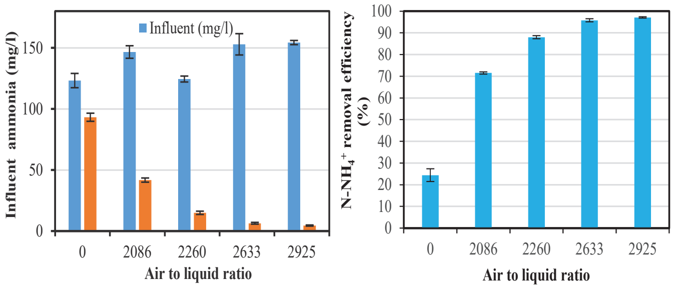
(A) **(B)**

Fig. 4. (A) The influent and effluent ammonium and (B) ammonium removal efficiency at various of liquid flow rates.

The removal efficiency decreased from 95.80 to 72.59% when the flow rate (Q_L) increased from 0.25 to 1.0 l/min. These results may be due to the decrease in liquid hydraulic retention time and stripping factor, resulting in a decrease in removal efficiency for air stripping [2]. The results were similar to the results obtained by Yuan, et al. (2016) [9] when using a rotating packed bed to strip ammonia from ammonia-rich wastewater.

Effect of air-to-liquid ratio on ammonia stripping

Figure 5 shows the effect of the air-to-liquid ratio (Q_G/Q_L) (from 0 to 2925) on ammonia stripping. As illustrated in Fig. 5, Q_G/Q_L had a significant effect on ammonia removal efficiency. The removal efficiencies obtained were 24.38±2.96, 71.51±0.53, 88.00±0.68, 95.80±0.75, and 97.08±0.34% at Q_G/Q_L values of 0, 2086, 2260, 2633, and 2925, respectively. The removal efficiency reached a maximum at Q_G/Q_L of 2925. The results showed that with increasing Q_G/Q_L, the removal efficiency also increased.



(A) **(B)**

Fig. 5. (A) The influent and effluent ammonium and (B) ammonium removal efficiency at various air-to-liquid ratios.

A higher air-to-liquid ratio enhances the gas flow leading to a reduction in mass transfer resistance and, thus, a promotion ammonia stripping efficiency [13]. Moreover, the ammonia stripping efficiency increase due to increasing Q_G/Q_L was found using the same volume of wastewater, 10 l, placed in a separate area, and under a fixed liquid flow rate of 0.25 l/min. At a higher air flow rate, a higher velocity is produced that breaks down the liquid-gas interface and easily pushes out the ammonia gas from the wastewater [9].

Conclusions

The lab-scale air stripping system used in these experiments has successfully removed ammonium from anaerobic co-digestion effluent. The results indicated that the initial pH of wastewater had the most significant effect on ammonia stripping efficiency. A pH value of 11 gave the highest ammonia removal efficiency. Similarly, a higher air-to-liquid ratio increased the ammonia removal efficiency due to a reduction in the mass transfer resistance between the liquid-gas interface. This study has huge significance in the removal of ammonia from ammonia-rich wastewaters and anaerobic co-digestion effluent, and contributes to the prevention of eutrophication and promotes environmental protection. The gaseous ammonia obtained from the stripping effluent can be recovered to produce fertilizer for agriculture. Thus, this study has opened up new prospects for the protection of the environment and nutrient recovery from wastewater.

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The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] C. Bougrier, J.P. Delgenes, H. Carrere (2006), "Combination of thermal treatments and anaerobic digestion to reduce sewage sludge quantity and improve biogas yield", *Environmental Protection*, **84**, pp.280-284.

[2] M-H. Yuan, Y-H. Chen, J-Y. Tsai, C-Y. Chang (2016a), "Removal of ammonia from wastewater by air stripping process in laboratory and pilot scales using a rotating packed bed at ambient temperature", *Journal of the Taiwan Institute of Chemical Engineers*, **60**, pp.488-495.

[3] K-C. Cheung, L-M. Chu, M-H. Wong (1997), "Ammonia stripping as a pretreatment for landfill leachate", *Water Air Soil Pollution*, **94**, pp.209-216.

[4] P-H. Liao, A. Chen, K-V. Lo (1995), "Removal of nitrogen from swine manure wastewaters by ammonia stripping", *Bioresource Technology*, **54**, pp.17-20.

[5] M. Laureni, J. Palatsi, M. Llovera, A. Bonmati (2013), "Influence of pig slurry characteristics on ammonia stripping efficiencies and quality of the recovered ammoniumsulfate solution", *Journal Chemistry Technology Biotechnology*, **88**, pp.1654-1662.

[6] S. Guštin, R. Marinšek-Logar (2011), "Effect of pH, temperature and air flow rate on the continuous ammonia stripping of the anaerobic digestion effluent", *Process Safety and Environmental Protection*, **89**, pp.61-66.

[7] L.J. Ding, X.L. An, S. Li, G.L. Zhang, Y.G. Zhu (2014), "Nitrogen loss through anaerobic ammonium oxidation coupled to iron reduction from paddy soils in a chronosequence", *Environmental Science Technology*, **48**, pp.10641-10647.

[8] QCVN 01:2009/BYT, *National Technical Regulation on Drinking Water Quality*.

[9] M-H. Yuan, Y-H. Chen, J-Y. Tsai, C-Y. Chang (2016b), "Ammonia removal from ammonia-rich wastewater by air stripping using a rotating packed bed", *Process Safety and Environment Protection*, **102**, pp.777-785.

[10] N. Değermenci, O-N. Ata, E. Yildız (2012), "Ammonia removal by air stripping in a semi-batch jet loop reactor", *Journal of Industrial and Engineering Chemistry*, **18**, pp.399-404.

[11] George Tchobanoglous, et al. (2014), *Wastewater Engineering: Treatment and Resource Recovery*, McGraw-Hill: ISBN 0073401188.

[12] APHA (American Public Health Association), AWWA (American Water Works Association) and WEF (Water Environment Federation) (1998), *Standard Methods for the Examination of Water and Wastewater*, 20th ed., Washington D.C.

[13] X. Quan, F. Wang, Q. Zhao, T. Zhao, J. Xiang (2009), "Air stripping of ammonia in water-sparged aerocyclone reactor", *Journal of Hazardous Material*, **170**, pp.983-988.