AIR STRIPPING FOR AMMONIA REMOVAL FROM LANDFILL LEACHATE IN VIETNAM: EFFECT OF OPERATION PARAMETERS

Tran Tien Khoi1,2, Tran Thi Thanh Thy2,3, Nguyen Thi Ng&2,3, Nguyen Nhat Huy2,3, Nguyen Thi Thu1,2*
1International University, 2Vietnam National University Ho Chi Minh City
3Ho Chi Minh City University of Technology (HCMUT)

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ABSTRACT

Leachate is the wastewater from landfill that contains various pollutants at high concentrations. The treatment of leachate requires a complicated wastewater treatment system including chemical, physico-chemical, biological, and advanced treatment processes. The high ammonia concentration of leachate usually causes inhibition for microorganism in biological treatment. Therefore, it is necessary to remove ammonia from the leachate to lower concentrations to make it suitable for further treatment processes. In this study, we designed an air stripper for removal of ammonia in both synthetic and leachate wastewater. The effects of pH, hydraulic loading rate (HLR), gas/liquid (G/L) ratio, and recirculation of liquid on the ammonia stripping efficiency were investigated. The results show that rising pH from 9 to 12 increased significantly ammonia removal efficiency, irrespective of the changes of G/L or HLR. At both HLR of 57.6 and 172.8 m³/m².day, increase G/L ratio led to the enhanced removal efficiency, getting the highest value of 56% at HLR of 172.8 m³/m².day, pH 12, and G/L of 728. Furthermore, recirculating of leachate improved the stripping efficiency of ammonia up to 99.0% after three hours with the output concentration of 25.2 mg/L. The results from this study hence proved the effectiveness of air stripping as a pre-treatment process for ammonia removal from landfill leachate and suggested suitable operating conditions.

KEYWORDS

Leachate
Landfill
Air stripping
Gas transfer
Ammonia

XỬ LÝ AMONI TRONG NƯỚC RỊ RÁC TỬ BARRIER CHÓN LẤP TẠI VIỆT NAM BẰNG PHƯƠNG PHÁP TÁCH KHÍ: ÁNH HƯỞNG CỦA CÁC THÔNG SỐ VĂN HÀNH

Trần Tiền Khởi*, Trần Thị Thanh Thủy2,3, Nguyễn Thị Ng&2,3, Nguyễn Nhật Huy2,3, Nguyễn Thị Thuý1,2*
1Trường Đại học Quốc tế, 2Đại học Quốc gia Thành phố Hồ Chí Minh,
3Trường Đại học Bách khoa Thành phố Hồ Chí Minh

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Tóm tắt

Nước rỉ rác là nước thải từ bARRIER chốp chứa các thành phần ô nhiễm ở nồng độ cao. Do đó, việc xử lý nước rỉ rác cần một hệ thống phức tạp bao gồm các quá trình hóa học, hóa lý, sinh học và xử lý năng cao. Nồng độ cao của amoniac trong nước rỉ rác ngăn cản sự phát triển của các vi sinh vật trong xử lý sinh học nên cần loại bỏ amoniac xuống nồng độ thấp hơn, tạo điều kiện thuận lợi cho các quá trình xử lý tiếp theo. Trong nghiên cứu này, các nhà khoa học đã loại bỏ amoniac từ nước phải tổng hợp và nước rỉ rác đã được thiết kế và thử nghiệm. Ảnh hưởng của pH, tài trọng thủy lực (HLR), tỷ lệ khí/liquid (G/L), và thời gian tuần hoàn lên hiệu quả tách amoniac đã được nghiên cứu. Kết quả cho thấy việc tăng pH từ 9 lên 12 đã tăng hiệu quả xử lý amoniac đã hệ thống vận hành ở nồng độ tỷ lệ G/L hay HLR khác nhau. Tại HLR bằng 57.6 và 172.8 m³/m².nghy, tăng tỷ lệ G/L năng cao được hiệu quả xử lý, đạt 56% với HLR ở 172.8 m³/m².nghy, pH 12, và G/L 728. Việc tuần hoàn nước rỉ rác đã cải thiện đáng kể hiệu quả tách amoniac, lên tới 99.0% sau ba giờ, đạt nồng độ amoniac đầu ra là 25.2 mg/L. Như vậy, kết quả từ nghiên cứu này đã chứng minh hiệu quả của phương pháp tách khí trong tiến xử lý amoniac từ nước rỉ rác và đề xuất được các điều kiện vận hành phù hợp.

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* Corresponding author. Email: ntthay@hcmiu.edu.vn
1. Introduction

Leachate is a type of wastewater generated in landfills, formed by leakage of rainwater into landfills or due to the available moisture of waste accumulated in the bottom layer of landfill and seepage through the soil. In general, there are four main components in leachate, including (i) organic compounds such as dissolved organic substances, volatile fatty acids (acetic, propionic, butyric compounds), fulvic acid, humic acid, etc.; (ii) main inorganic ions: Ca$^{2+}$, Mg$^{2+}$, Na+, K+, NH$_4^+$, Fe$^{2+}$, Mn$^{2+}$, Cl, SO$_4^{2-}$, and HCO$_3^-$; (iii) heavy metals: Cd$^{2+}$, Cr$^{3+}$, Cu$^{2+}$, Pb$^{2+}$, Ni$^{2+}$, and Zn$^{2+}$; (iv) xenobiotic organic compounds: aromatic compounds, phenols, pesticides, chlorinated aliphatics, plastics, etc. and oil-derived components of fuel: benzene, toluene, xylene, etc. Among these components, ammonia nitrogen is one of the pollutants of concern because its concentration is very high (800-5210 mg/L), even in leachate from old landfills [1]. The total ammonia nitrogen (TAN) up to 1000 mg/L can inhibit microbial activity, reducing the effectiveness of the biological based processes [2], [3]. Because it is generated from waste, leachate is very toxic and difficult to be handled, causing serious environmental pollution. It is known that with a certain amount of leachate absorbed into the soil, this wastewater can contaminate groundwater while if it follows into the canal, the water environment can be deteriorated. Therefore, leachate must be thoroughly treated before being discharged into the environment. To solve the problem of pollution from leachate, many technologies have been studied and applied, such as biological (anaerobic and aerobic), chemical-biological (Fenton-anaerobic-aerobic, and stripping-anaerobic-aerobic), physical, chemical oxidation, and membrane technologies.

Several studies have reported that air stripping is successful in removing ammonia from landfill leachate and many other wastewaters [4],[9], such as those from the fertilizer industry [10], pig slurry [11], [12], anaerobic digestion effluent [13], [14] or source-segregated food waste [15]. The effectiveness of ammonia removal obtained in these studies was in the range of 90 to 99%. Ozturk et al. [6] used air-stripping to treat ammonia in leachate at the optimum pH of about 10, 11, and 12. The results showed that after 2 hours of aeration, the ammonia removal was 72% at pH 12 while it was nearly 20% at pH 10 and 11. Under continue aeration for the next 24 hours, the ammonia removal was at 45, 80, and 85% after 6, 12, and 17 hours, respectively [6]. In addition, Marttinen et al. [16] also used air-stripping tower with a 1.1-liter PVC column (6 cm in diameter and 40 cm high) filled by plastic materials, to remove ammonia from leachate. Experiments were performed at pH 11 at temperatures of 6, 10, and 20 °C and a flowrate of 2 or 10 L/h for 0, 6, and 24 hours. In the 24-hour test, the highest ammonia removal of 89% was achieved at pH 11, 20 °C and a gas flowrate of 10 L/h [5]. Furthermore, most studies on air stripping relied on small stripping units in which air was bubbled at flow rates of 1.2 to 300 L/h and only a small volume of leachate (0.8-4 L) was treated [5]-[7], [11], [17]-[19]. The ratio of G/L (m$^3$/m$^3$) varied for each reference which was 50-150 [9], 45-200 [20], 1250 to 2000 [21], 3480 [22], and 2000-6000 [23].

In Vietnam, different technologies for ammonia removal from landfill leachate have been investigated, including partial nitrification and denitrification in SBR [24], chemical precipitation [25] for Nam Son landfill leachate, combining the anoxic and attached growth processes at Phuoc Hiep landfill [26], completely autotrophic nitrogen-removal over nitrite - SBR process for Go Cat Landfill leachate [27], electrocoagulation and bio-filter for Nam Son Leachate [28], [29], and Fenton process followed by coagulation for Quang Hanh landfill [30]. Though the application of air stripping for ammonia removal in leachate has been reported from some research around the word, such research is rarely found in Vietnam, except for one report with limited information about the roles of respective treatment processes of pH adjustment with CaCO$_3$, air stripping, activated sludge, coagulation using FeCl$_3$, Fenton oxidation, sand filtration, and chlorine disinfection processes in Phuoc Hiep and Go Cat landfills [31]. Therefore, the
objective of this study was to apply a pilot air stripping tower with Kaldnes packing material for removal of ammonia from synthetic leachate and the leachate collected from Go Cat Landfill.

2. Materials and methods

2.1. Synthesis of wastewater and leachate collection

Artificial wastewater was made from ammonium chloride (NH₄Cl) in tap water at different NH₄⁺ concentrations. Real leachate was collected from Go Cat Landfill (Bình Hưng Hòa Ward, Bình Tân District, Ho Chi Minh City). According to [27], this leachate is characterized as an old landfill leachate which was closed since 2007. The concentrated leachate was taken directly from the collection tank while the leachate diluted by rainwater was collected at storage pond.

2.2. Air stripping unit

An air stripping tower was designed with a 2 m high tube and a diameter of 0.09 m (Table 1). Kaldnes rings (25×25 mm) made of Polyvinyl Chloride with a specific surface area of 250 m²/m³ were used as the packing material in the tower. The height of packing material was 1.80 m. The tower was operated in batch mode at room temperature. As shown in Figure 1, the wastewater was conveyed by a dosing pump from the wastewater tank to the top of the tower. At this point the leachate was distributed evenly through the packing material and simultaneously contacted with air stream driven from the outside by an air blower. The treated wastewater was collected in a tank and its ammonia concentration was measured. In state#3 (Table 2), the treated wastewater was recirculated back to the inlet while samples were regularly taken for ammonia analysis.

| Parameter                     | Unit | Value |
|-------------------------------|------|-------|
| Diameter                      | m    | 0.097 |
| Height                        | m    | 2     |
| Height of packing material    | m    | 1.8   |
| Air blower                    |      |       |
| - Flow                        | m³/h | 3200  |
| - Power                       | HP   | 2     |
| - Pressure column             | Pa   | 1000  |
| Water pump                    |      |       |
| - Pressure column             | mH₂O | 2.5   |
| - Flow                        | m³/h | 40    |

Figure 1. Schematic diagram of the air stripping tower: (1) wastewater tank, (2) dosing pump, (3) frame, (4) air blower, (5) wastewater distribution system, (6) packing material, (7) column, (8) treated wastewater tank, (9) treated wastewater outlet, and (10) wastewater inlet.
2.3. Operating the tower

During the operation, it is necessary to control parameters pH and gas/liquid ratio (G/L) so that NH$_4^+$ in wastewater can be converted into NH$_3$ gas. pH of leachate was adjusted to 9, 10, 11, and 12 by slowly adding 30% NaOH solution. The pH raising process must take place slowly to prevent rising NH$_3$ too fast. G/L was controlled by air and water flowrates in which water flowrate was adjusted by throttle valve while air flowrate was monitored by an anemometer.

| Stage   | Type of wastewater | Liquid flowrate (L/min) | G/L ratio (m$^3$/m$^2$.day) | Average NH$_4^+$ in wastewater (mg/L) | pH               |
|---------|--------------------|-------------------------|------------------------------|--------------------------------------|-----------------|
| #1      | Synthetic wastewater | Q = 0.3 (L/min) (HLR = 57.6) | G/L = 1802                   | 3300, 3000, 1400, 500                 | pH: 9, 10, 11, 12. |

Leachate

| Stage #2 | Leachate | Q = 0.9 (L/min) (HLR = 172.8) | G/L = 312                   | 3780                                  | pH: 9, 10, 11, 12. |

Leachate

| Stage #3 | Synthetic wastewater | Recirculating 15, 30 min, 1, 2 and 3 h; (HLR = 172.8) | G/L = 728                   | 3080                                  | pH: 12 |

Leachate

| Stage #3 | Synthetic wastewater | Recirculating 15, 30 min, 1, 2 and 3 h; (HLR = 172.8) | G/L = 728                   | 2520                                  | pH: 12 |

Leachate

*HLR: hydraulic loading rate

Three stages of operation were designed as given in Table 2. The stage#1 was conducted in order to find the relation between input NH$_4^+$ concentrations (in both synthetic and real leachate), pH and removal efficiency. For the stage #2, effect of two hydraulic loading rates (57.6 and 172.8 (m$^3$/m$^2$.day)) and different G/L ratios on ammonia removal efficiency from real leachate was evaluated. In final stage (stage #3), the tower was operated at optimum values of HLR, G/L, pH found from previous stages and the liquid phase was recirculated at different periods of time (15 and 30 minutes; 1, 2 and 3 hours). Total liquid volume in this stage was 5 L for both synthetic wastewater and leachate.

2.4. Chemicals and parameters analysis

NH$_4$Cl, acid boric, acids, and bases used in this study were purchased at analytical grade. pH of wastewater was measured by Hanna Hi 8424 while the air flowrate was measured by an anemometer (Manometer Testo 435). Ammonia concentration in wastewater was analyzed according to Standard Methods 4500 NH3 B with duplicates for each analysis.

3. Results and discussion

3.1. Effect of pH and initial NH$_4^+$ concentration on NH$_4^+$ removal efficiency

Relationship between pH, initial ammonia concentration, and efficiency of ammonia removal in artificial wastewater and leachate is illustrated in Figure 2. As can be seen from Figure 2(a), NH$_4^+$ remove efficiency was increased obviously when pH increased and initial NH$_4^+$ concentration reduced. The highest efficiencies achieved at pH of 12 were 79, 70, 64, and 48%, corresponding to the initial concentrations of 500, 1400, 3000 and 3300 mg/L. According to reaction (1), this trend is reasonable because of rising pH led to the shift of the equilibrium of the reaction to produce more NH$_3$ into gas phase.

\[ \text{NH}_4^+ \leftrightarrow \text{NH}_3 + \text{H}^+ \] (1)
The dependence of removal efficiency on pH of leachate was similar to that of synthetic wastewater, with the highest amount of NH$_4^+$ stripped out at pH 12. This optimum pH was consistent with the results of pH value found by Ozturk, et al. [6] and Marttinen, et al. [16]. However, increasing initial NH$_4^+$ concentration of leachate from 3405, 3606 and 4032 mg/L resulted in the increasing of removal efficiency from 45, 46, and 58% at pH 12, respectively. This trend differed from that of synthetic wastewater which can be explained based on the free ammonia amount available in leachate but not in synthetic wastewater. As calculated via the equation (2) [32], leachate contained about 1-5% of free ammonia (FA) and the leachate with a higher ammonia concentration contains a higher FA content which was easily released at the pH of greater than 9. Therefore, the leachate with higher input concentration of NH$_4^+$ could achieve a higher removal efficiency.

$$\text{FA} = \frac{C_{\text{NH}_4^+} \times 10^{pH}}{k_b + 10^{pH}}$$

(2)

Where $C_{\text{NH}_4^+}$ is ammonia concentration in leachate and $k_b = \exp \left( \frac{6,344}{273 + t} \right)$.

### 3.2. Effect of hydraulic loading rate and gas/liquid ratio on NH$_4^+$ removal efficiency

The results achieved from the operation of stage #2 are illustrated on Figure 3. This experiment was conducted with two hydraulic loading rates (HLR) of 57.6 and 172.8 m$^3$/m$^2$.day, pH ranged from 9 to 12, at different G/L ratios. To increase G/L ratio, we used a fixed wastewater flowrate while increased air flowrate (Table 2).

In consistent with the results from Section 3.1, the increase of pH from 9 to 12 significantly increased the removal efficiency of NH$_4^+$, irrespective of the changes of G/L or HLR, getting the highest values at pH 12. Under pH 12 and the HLR of 57.6 m$^3$/m$^2$.day, increase G/L ratio from 936 to 1630 led to the increase of removal efficiency, i.e. from 40 to 54%. This is explained based on the Equation (3) [23]. Accordingly, when G/L increases, concentration of ammonia in the output (C$_e$) will reduce or removal efficiency will increase. At this point, the working line shifts to the equilibrium line. However, the removal efficiency was unchanged when we further increased G/L ratio from 1630 to 2815 (i.e. 54 and 54%, respectively).
\[(G/L) = \left(\frac{P_T}{H}\right) \times \left(\frac{C_0 - C_e}{C_0}\right)\]  

(3)

Where \(H\) is Henry’s constant for ammonia, \(P_T\) is total pressure, \(C_0\) and \(C_e\) is the input and output concentrations of ammonia, \(G/L\) is the minimum ratio of gas and liquid.

For the case of HLR of 172.8 \(m^3/m^2\).day and \(G/L\) ratio of 312, 543 and 728, the removal efficiency was slightly changed from 50, 52, to 56%, respectively, which is in consistent with the results of [13, 21]. We hence selected HLR of 172.8 \(m^3/m^2\).day, \(G/L\) ratio of 728 at pH 12 due to the induced highest removal efficiency and wastewater treatment capacity. The \(G/L\) ratio of 728 in this study was higher than those from [9] (i.e. 50-150), [20] (i.e. 45-200) but smaller than the values applied in [21] (i.e. 1250-2000), [22] (i.e. 3480), and recommended in [23] (i.e. 2000-6000).

3.3. Effect of recirculation on \(NH_4^+\) removal efficiency

The results from the previous sections showed that the \(NH_4^+\) removal efficiency from the air stripping tower ranged from 48-79% for synthetic wastewater and 45-58% for leachate. To enhance the stripped amount of ammonia, recirculation of wastewater (5 L) was applied. As can be seen from Figure 4, operation with the artificial wastewater at initial \(NH_4^+\) concentration of 3080 mg/L could yield the efficiency from 90% at 15th minute to 99% at the 120th minute. At the same time, the \(NH_3\) concentration calculated in the gas phase decreased considerably from 1297 to 179 mg/m³. A similar trend of change in removal efficiency was found for the leachate containing 2520 mg/L of ammonia, from 81% at 15th minute to 99% at 120th minute. The \(NH_4^+\) output concentration was 25.2 mg/L which is approximately equal to the allowable value in column B (i.e. 25 mg/L) from national technical regulation on wastewater of the solid waste landfill sites (QCVN 25:2009/BTNMT). This efficiency is higher compared to those obtained from previous studies, e.g. 98% with the operation time of 4 to 9 days [20], 95.5% for 3 hours [22]. During this period, the \(NH_3\) concentration dropped from 956 to 97 mg/m³, but was still higher than the value recommended in air quality – maximum allowable concentration of hazardous substances in ambient air (i.e. 0.2 mg/m³, TCVN 5938:2005) or the allowable value given in national technical regulation on industrial emission of inorganic substances and dusts (i.e. 50 mg/m³, column B, QCVN 19: 2009/BTNMT).

Though pH adjustment improved significantly the \(NH_4^+\) removal efficiency but this step consumes chemicals and requires the neutralization of the wastewater after the treatment to
facilitate the next treatment steps. For the rainwater diluted leachate with a low concentration of NH$_4^+$ (442 mg/L), we further tested the air stripping without pH adjustment and found the removal efficiency was 8, 18, 40, 74, and 91% at 15th, 30th minute, 1st, 2nd, and 3rd hour, respectively. Hence, recirculating the leachate could be considered as an effective pretreatment step improved the removal efficiency.

![Figure 4](image-url)  
**Figure 4.** Effect of recirculation time on NH$_4^+$ removal efficiency from artificial wastewater and leachate (error bars present standard deviations, n = 3)

### 4. Conclusions

In this study, air stripping for ammonia removal in synthetic wastewater and leachate was investigated under various operating conditions of pH, initial ammonia concentration, hydraulic loading rate, gas to liquid ratio, and recirculating time. As a result, the increase of pH from 9 to 12 led to the significant increase of ammonia removal efficiency, irrespective of the changes of G/L or HLR, with the highest ammonia stripping achieved at pH12. For both hydraulic loading rates of 57.6 and 172.8 m$^3$/m$^2$.day, rising G/L ratio resulted in the improvement of removal efficiency, up to 56%. Under the HLR of 172.8 m$^3$/m$^2$.day, pH 12, G/L of 728 with liquid recirculation, the leachate containing ammonia at 2520 mg/L was stripped out 99% of ammonia for three hours. The final concentration of ammonia was 25.2 mg/L which is about equal to the allowable value from the discharging standard of leachate. The results from this study hence proved the effectiveness of air stripping in ammonia removal from leachate and the optimum operating conditions were suggested. Further investigation is needed for recovery the amount of ammonia stripped and released into gas phase so that this gas stream can meet the requirement to discharge into the air.

### REFERENCES

[1] P. Kjeldsen, M. A. Barlaz, A. P. Rooker, A. Baun, A. Ledin, and T. H. Christensen, "Present and long-term composition of MSW landfill leachate: a review," *Critical reviews in environmental science and technology*, vol. 32, pp. 297-336, 2002.

[2] A. Lopez, M. Pagano, A. Volpe, and A. C. Di Pinto, "Fenton’s pre-treatment of mature landfill leachate," *Chemosphere*, vol. 54, pp. 1005-1010, 2004.

[3] D. Shiskowski and D. Mavinic, "Biological treatment of a high ammonia leachate: influence of external carbon during initial startup," *Water Research*, vol. 32, pp. 2533-2541, 1998.

[4] K. C. Cheung, L. M. Chu, and M. H. Wong, "Ammonia stripping as a pretreatment for landfill leachate," *Water, air, and soil pollution*, vol. 94, pp. 209-221, 1997.

[5] S. Martinen, R. Kettunen, K. Sormunen, R. Soimasuo, and J. Rintala, "Screening of physical–chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates," *Chemosphere*, vol. 46, pp. 851-858, 2002.
[6] I. Ozturk, M. Altinbas, I. Koyuncu, O. Arikan, and C. Gomec-Yangin, "Advanced physico-chemical treatment experiences on young municipal landfill leachates," *Waste Management*, vol. 23, pp. 441-446, 2003.

[7] A. Ž. Gotvajn, T. Tišler, and J. Zagorc-Končan, "Comparison of different treatment strategies for industrial landfill leachate," *Journal of Hazardous Materials*, vol. 162, pp. 1446-1456, 2009.

[8] L. Jurczyk, J. Koc-Jurczyk, and A. Masloň, "Simultaneous Stripping of Ammonia from Leachate: Experimental Insights and Key Microbial Players," *Water*, vol. 12, p. 2494, 2020.

[9] F. M. Ferraz, J. Povinelli, and E. M. Vieira, "Ammonia removal from landfill leachate by air stripping and absorption," *Environmental Technology*, vol. 34, pp. 2317-2326, 2013.

[10] V. K. Minocha and A. P. Rao, "Ammonia removal and recovery from urea fertilizer plant waste," *Environmental Technology*, vol. 9, pp. 655-664, 1988.

[11] A. Bonnati and X. Flotats, "Air stripping of ammonia from pig slurry: characterisation and feasibility as a pre-or post-treatment to mesophilic anaerobic digestion," *Waste Management*, vol. 23, pp. 261-272, 2003.

[12] L. Zhang, Y.-W. Lee, and D. Jahng, "Ammonia stripping for enhanced biomethanization of piggery wastewater," *Journal of hazardous materials*, vol. 199, pp. 36-42, 2012.

[13] S. Guštin and R. Marinšek-Logar, "Effect of pH, temperature and air flow rate on the continuous ammonia stripping of the anaerobic digestion effluent," *Process safety and environmental protection*, vol. 89, pp. 61-66, 2011.

[14] X. Lei, N. Sugiuara, C. Feng, and T. Maekawa, "Pretreatment of anaerobic digesting effluent with ammonia stripping and biogas purification," *Journal of hazardous materials*, vol. 145, pp. 391-397, 2007.

[15] M. Á. De la Rubia, M. Walker, S. Heaven, C. J. Banks, and R. Borja, "Preliminary trials of in situ ammonia stripping from source segregated domestic food waste digestate using biogas: Effect of temperature and flow rate," *Bioresource technology*, vol. 101, pp. 9486-9492, 2010.

[16] S. K. Marttinen, R. H. Kettunen, K. M. Sormunen, R. M. Soomasuo, and J. A. Rintala, "Screening of physical-chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates," *Chemosphere*, vol. 46, pp. 851-858, 2002.

[17] M. Cotman and A. Ž. Gotvajn, "Comparison of different physico-chemical methods for the removal of toxicants from landfill leachate," *Journal of Hazardous Materials*, vol. 178, pp. 298-305, 2010.

[18] M. Nurisepehr, S. Jorfi, R. R. Kalantary, H. Akbari, R. D. C. Soltani, and M. Samaei, "Sequencing treatment of landfill leachate using ammonia stripping, Fenton oxidation and biological treatment," *Waste Management & Research*, vol. 30, pp. 883-887, 2012.

[19] A. Silva, M. Dezotti, and G. L. Sant’Anna Jr, "Treatment and detoxification of a sanitary landfill leachate," *Chemosphere*, vol. 55, pp. 207-214, 2004.

[20] H. A. P. dos Santos, A. B. de Castilhos Júnior, W. C. Nadaleti, and V. A. Lourenço, "Ammonia recovery from air stripping process applied to landfill leachate treatment," *Environmental Science and Pollution Research*, vol. 27, pp. 45108-45120, 2020.

[21] R. Alam and M. D. Hossain, "Effect of Packing Materials and Other Parameters on the Air Stripping Process for the Removal of Ammonia from the Wastewater of Natural Gas Fertilizer Factory," *Journal of Water Resource and Protection*, vol. 01, pp. 210-215, 2009.

[22] V. Leite, S. Prasad, W. Lopes, J. Sousa, and A. Barros, "Study on ammonia stripping process of leachate from the packed towers," *Journal of Urban and Environmental Engineering*, vol. 7, pp. 215-222, 2013.

[23] Metcalf and I. Eddy, *Wastewater engineering: treatment and reuse*, Fourth edition / revised by George Tchobanoglous, Franklin L. Burton, H. David Stensel. Boston: McGraw-Hill, 2003.

[24] V. Y. Hoang, H. Jupsin, V. C. Le, and J. L. Vasel, "Modeling of partial nitrification and denitrification in an SBR for leachate treatment without carbon addition," *Journal of Material Cycles and Waste Management*, vol. 14, pp. 3-13, 2012.

[25] M. K. Nguyen and T. Q. T. Hoang, "Chemical Precipitation of Ammonia and Phosphate from Nam Son Landfill Leachate, Hanoi," *Iranian (Iranica) Journal of Energy & Environment*, vol. 3, pp. 32-36, 2012.

[26] T. T. N. Dieu, T. T. Canh, and J. L. Vasel, "Removal of cod and nitrogen in Leachate by using combined Anoxic/attached-growth bioreactor," *Proceedings Sardinia 2017/ Sixteenth International Waste Management and Landfill Symposium*, S. Margherita di Pula, Cagliari, Italy, 2017.
[27] L. Son, N. Dan, P. Nhat, L. Tam, T. Sang, and L. Thanh, "Application of CANON-SBR process for ammonium removal from old municipal old landfill leachate," *Science & Technology Development Journal - Science of The Earth & Environment*, vol. 3, pp. 46-55, 2019.

[28] L. Khai, "Study on leachate treatment after electrocoagulation process by bio-filter system: a case study in Nam Son landfill, Ha Noi," *Vietnam Journal of Science and Technology*, vol. 55, p. 251, 2018.

[29] T. S. Le, N. M. Dang, and D. T. Tran, "Performance of coupling electrocoagulation and biofiltration processes for the treatment of leachate from the largest landfill in Hanoi, Vietnam: Impact of operating conditions," *Separation and Purification Technology*, vol. 255, 2021, Art. no. 117677, doi: https://doi.org/10.1016/j.seppur.2020.117677.

[30] N. T. Dung, B. Van Thanh, and N. N. Huy, "A study on the application of Fenton process followed by coagulation for treatment of landfill leachate," *Vietnam Journal of Chemistry*, vol. 58, pp. 792-797, 2020.

[31] S. Soda, D. Fujii, D. A. M. Ike, and V. Nguyen Trung, "Leachate treatment processes improve water quality in waste landfills in Ho Chi Minh City," *Proceedings of the Annual Conference of Japan Society of Material Cycles and Waste Management*, vol. 27, p. 551, 2016.

[32] A. C. Anthonisen, R. C. Loehr, T. B. S. Prakasam, and E. G. Srinath, "Inhibition of Nitrification by Ammonia and Nitrous Acid," *Journal (Water Pollution Control Federation)*, vol. 48, pp. 835-852, 1976.