

Research article

Combination of Biological and Coagulation Treatments for Sludge Landfill Leachate: A Case Study in Hanoi, Vietnam

Pham Huong Quynh¹, Pham Nguyet Anh^{2*}, Nguyen Thi Thu Phuong¹
and Nguyen Thi Thu Hien¹

¹*HaUI Institute of Technology, Hanoi University of Industry, 298 Cau Dien road, Tu Liem District, Hanoi, Vietnam*

²*Faculty of Chemistry and Environment, Thuyloi University, 175 Tay Son Street, Dong Da District, Hanoi, Vietnam*

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Abstract

Similar to other developing countries, Hanoi, the capital of Vietnam disposes of urban sludge, including sludge from water and wastewater treatment plants, drainage systems, at a landfill. With increasing population growth and urbanization, the volume of generated sludge continues to rise, necessitating proper treatment of the resulting sludge landfill leachate. This study assessed the characteristics of sludge landfill leachate and investigated appropriate treatment methods. The results indicate that the leachate contained high turbidity and TSS levels, along with a substantial organic content, as reflected by an average COD of 222 mg/L and BOD₅ of 110 mg/L. Nitrogen levels were also high, with NH₄⁺ at 102 mg/L and TN at 108 mg/L. Based on these characteristics, the study implemented a combined coagulation and biological treatment approach. The pretreatment of the leachate by coagulation led to COD reduction, thereby reducing the efficiency of the subsequent biological treatment. Therefore, the selected treatment process involved an initial AO (anoxic-oxic) biological treatment using biofilm carriers to remove organic matter and nitrogen, followed by coagulation using PAC at a dosage of 200 mg/L. The treated sludge landfill leachate met local discharge standard of Hanoi. This study provides essential data for designing sludge landfill leachate treatment system in Hanoi, Vietnam.

Keywords: biological treatment; chemical treatment; coagulation; leachate; urban sludge

1. Introduction

The rapid growth of urban populations has led to an increasing demand for water and wastewater treatment, along with the associated sludge management, particularly in developing countries and regions (Khan et al., 2022; Sharma & Jain, 2020). Urban sludge consists of sludge generated from water and wastewater treatment plants and dredged sludge from municipal drainage systems (Kazmi & Furumai, 2005). In Hanoi, Vietnam, the

*Corresponding author: E-mail: anhp@tlu.edu.vn

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volume of dredged sludge from the drainage system is currently substantial, exceeding 240,000 tons per year, with an average annual increase of approximately 5-8% due to continuous urbanization and the subsequent expansion of municipal drainage services. Currently, Hanoi operates seven wastewater treatment plants and more than 20 water supply plants to meet the city's demand for clean water. All sludge from the drainage system and dredging activities is transported to a sludge landfill in the Southern part of Hanoi. By 2030, the total volume of urban sludge generated in Hanoi is estimated to reach approximately 2,000 tons per day (Hanoi Sewerage and Drainage Company, 2023). Similar to solid waste landfilling, sludge landfilling generates leachate containing high concentrations of organic matter, nutrients, suspended solids, heavy metals, and color, posing potential environmental pollution risks if not properly treated (Marin & Rusănescu, 2023; Huan et al., 2024; Valchev et al., 2024; Wang & Qiao, 2024). As urban populations continue to grow and urbanization expands, effective treatment of sludge landfill leachate is crucial to mitigating environmental pollution and protecting public health.

Several methods are available for landfill leachate treatment, with the most commonly employed technologies including biological treatment and physicochemical processes including advanced oxidation, adsorption, and membrane filtration (Mojiri et al., 2021). Coagulation-flocculation has been demonstrated as an effective and economical method for landfill leachate treatment, based on the principle of forming flocs through reactions between coagulants and contaminants (Chen et al., 2024). This process has been shown to achieve removal efficiencies of 93-99.9% for turbidity, 50-94% for color and 54-69% for chemical oxygen demand (COD) (Dhamsaniya et al., 2023). In addition, biological treatment has been proven to be an effective approach for landfill leachate remediation, utilizing microorganisms to convert pollutants into less harmful byproducts such as CO₂, water, and biogas. Due to its high efficiency and cost-effectiveness, biological treatment is widely recognized as a sustainable solution (Ilmasari et al., 2022).

The combination of coagulation and biological treatment is considered a highly efficient approach for landfill leachate treatment (Mojiri et al., 2021). Coagulation can be applied either before or after biological treatment, depending on the characteristics of the wastewater (Cherni et al., 2021). A study on the treatment of stabilized landfill leachate using coagulation as a pretreatment step, followed by anaerobic biological treatment reported total organic carbon (TOC) and COD removal efficiencies of 70% and 72%, respectively (Yadav & Dikshit, 2016). For the pretreatment of high-strength fresh leachate from municipal solid waste landfill, coagulation followed by a fixed-bed upflow anaerobic filter showed that FeCl₃ achieved the highest COD removal efficiency at 55.4%, compared to other coagulants such as potash alum (KAl(SO₄)₂·12H₂O), ferrous sulfate heptahydrate (FeSO₄·7H₂O), calcium hydroxide (Ca(OH)₂) and bentonite clay (Reddy et al., 2022). The subsequent COD removal in the upflow anaerobic filter was 23.3%. In another study, landfill leachate treatment involving posttreatment by coagulation-flocculation with chitosan and aluminum sulfate following an activated sludge process in a sequencing batch reactor (SBR) demonstrated that aluminum sulfate was the most suitable coagulant (Nascimento et al., 2016). In a separate investigation, co-treatment of landfill leachate with municipal wastewater using a sequencing batch reactor (SBR), followed by coagulation-flocculation with a novel flocculant, i.e., polyacrylamide grafted gum ghatti (GGI-g-PAM) showed that the combined treatment with SBR and alum removed 89% COD, 83% ammonia, 82% nitrate 98% turbidity and 93% TSS (Kumar et al., 2023).

In this study, a combination of coagulation-flocculation and biological treatment was employed to treat the leachate from the sludge landfill in Hanoi, Vietnam. Initially, coagulation was applied as a pretreatment step, followed by biological treatment using various processes, including activated sludge (ACS), biofilm-based aerobic oxidation

(OXM), biofilm-based anoxic treatment (ANM), and the anoxic-oxic process with biofilm carriers (AOM). However, the coagulation pretreatment reduced the COD concentration in the leachate, which negatively impacted efficiency of the subsequent biological treatment. Therefore, this study investigated an alternative approach, applying biological treatment before coagulation, to ensure that the treated leachate meets the QCTDHN 02:2014/BTNMT standard - Hanoi technical regulation on industrial wastewater (MONRE, 2014).

2. Materials and Methods

2.1 Sampling and analysis

The leachate from sludge landfill was sampled on May 19th 2023 and May 26th 2023 to determine its characteristics. COD, arsenic and iron were analyzed by the Standard Methods and other parameters were analyzed by Vietnam standards (TCVN) which are completely equivalent to corresponding methods by the International Organization for Standardization (ISO). All the parameters and analytical methods employed are listed in Table 1.

Table 1. Parameters and analytical methods

No.	Parameters	Analytical Methods	Reference
1.	Turbidity	TCVN 6184:2008 (ISO 7027:1999)	Vietnam Standard (2008a)
2.	pH	TCVN 6492:2011 (ISO 10523:2008)	Vietnam Standard (2011)
3.	BOD ₅ (20°C)	TCVN 6001-1:2021 (ISO 5815-1:2019)	Vietnam Standard (2021)
4.	COD	SMEWW 5220C:2017	APHA/AWWA/WEF (2017)
5.	TSS	TCVN 6625:2000 (ISO 11923:1997)	Vietnam Standard (2000a)
6.	Arsenic (As)	SMEWW 3114B. As:2017	APHA/AWWA/WEF (2017)
7.	Zinc (Zn)	TCVN 6193:1996 (ISO 8288: 1986 (E))	Vietnam Standard (1996)
8.	Iron (Fe)	SMEWW 3111B.Fe:2017	APHA/AWWA/WEF (2017)
9.	Ammonium (NH ₄ ⁺ -N)	TCVN 5988:1995 (ISO 5664: 1984)	Vietnam Standard (1995)
10.	Total Nitrogen (TN)	TCVN 6638:2000 (ISO10048:1991)	Vietnam Standard (2000b)
11.	Total Phosphorus (TP)	TCVN 6202:2008 (ISO 6878:2004)	Vietnam Standard (2008b)
12.	Total Coliform	TCVN 6187-2:2020 (ISO 9308-2:2012)	Vietnam Standard (2020)

2.2 Treatment of sludge landfill leachate

The experiments were initially conducted in batch mode to determine the optimal conditions, followed by continuous experiments.

2.2.1 Coagulation experiments

In this study, three coagulants were applied: ferric sulfate (FS), aluminum sulfate (AS) and poly aluminum chloride (PAC). The coagulation-flocculation experiments were conducted using a conventional jar test apparatus equipped with six one-liter beakers. For each test, 500 mL of leachate was prepared in each of the six jars. The coagulants were added at different doses to each sample. AS and FS were added at doses of 200, 250, 300 and 350 mg/L, while PAC was dosed at 150, 200, 250 and 300 mg/L. Each coagulation-flocculation test involved rapid mixing at 250 rpm (Palaniandy et al., 2010; Sinha et al., 2004) for 30 s (Daud et al., 2009; Silva et al., 2004), followed by slow mixing at 40 rpm (Tatsi et al., 2003; Silva et al., 2004) for 10 min (Tatsi et al., 2003; Daud et al., 2009).

2.2.2 Biological treatment experiments

The biological treatment of leachate primarily targets the removal of organic matter, ammonium, and total nitrogen. In this study, we evaluated four treatment technologies:

Activated sludge process (ACS): A suspended-growth system where microorganisms are maintained through air diffusion.

Biofilm-based aerobic oxidation (OXM): An aerobic treatment that maintains oxic conditions using moving media.

Biofilm-based anoxic treatment (ANM): An anoxic process that operates with moving media to support biofilm growth.

Anoxic-oxic biofilm process (AOM): A hybrid system combining anoxic and oxic conditions (AO) with biofilm carriers to enhance treatment efficiency.

During the experiments, the dissolved oxygen (DO) levels was controlled within 3-4 mg/L for oxic conditions, and 1-2 mg/L for anoxic conditions. The mixed liquor suspended solids (MLSS) concentration in ACS was maintained at 2,500 mg/L. In the systems involving moving media, microbial concentrations ranging from 5,000 mg/L to 8,000 mg/L. A summary of all experimental conditions is provided in Table 2.

Table 2. Parameters and analytical methods

No.	Technology	Experiment Conditions		
		DO (mg/L)	MLSS (mg/L)	Retention time (h)
1.	Activated sludge (ACS)	3 - 4	2,500	6
2.	Oxidation with moving media (OXM)	3 - 4	5000 - 8000	6
3.	Anoxic condition with moving media (ANM)	1 - 2	5000 - 8000	6
4.	Anoxic + oxic condition with moving media (AOM)	Anoxic: 1 - 2 Oxic: 3 - 4	5000 - 8000	6

3. Results and Discussion

3.1 Characteristics of sludge landfill leachate

The characteristics of sludge landfill leachate in comparison with the Hanoi Technical Regulations on Industrial Wastewater (QCTDHN 02:2014/BTNMT) are summarized in Table 3. The results indicate that, except for heavy metals and total phosphorus (TP), most parameters exceeded the permissible limits specified in QCTDHN 02:2014/BTNMT – Class B which stipulates the concentration limits of parameters in industrial wastewater discharged into water bodies not used for domestic water supply.

The leachate exhibited high turbidity, approximately 2.5 times greater than the regulatory threshold. The leachate also contained high levels of organic matter, suspended solids, ammonium, total nitrogen and coliforms. On average, BOD₅, COD and TSS levels were 2.2, 1.5 and 1.8 times higher than their respective limits. Nitrogen mostly existed in the form of ammonium, with concentration was approximately 10 times greater than the regulated value. Coliforms of the leachate on May 19th were 30 times higher than the threshold and the average coliforms of the samples across two sampling dates were 17 times above the threshold. Heavy metal concentrations remained within allowable limits.

Table 3. Characteristics of sludge landfill leachate

No.	Parameters	Unit	Sampling Date		Ave. ± S.D.	QCTDHN 02:2014/BTNMT – Class B
			May 19 th 2023	May 26 th 2023		
1.	Turbidity	Pt-Co	122	131	125±6	50
2.	pH	-	6.8	6.72	6.76±0.06	5.5 - 9.0
3.	BOD ₅ (20°C)	mg/L	111	108	110±2	50
4.	COD	mg/L	232	211	222±15	150
5.	TSS	mg/L	181	173	177±6	100
6.	Asen (As)	mg/L	0.021	0.016	0.019±0.004	0.1
7.	Kẽm (Zn)	mg/L	0.15	0.21	0.180±0.042	3
8.	Sắt (Fe)	mg/L	1.34	2.11	1.725±0.544	5
9.	Ammonium (NH ₄ ⁺ - N)	mg/L	107.1	98.3	102.7±6.2	10
10.	TN	mg/L	110.1	106.7	108.4±2.4	40
11.	TP	mg/L	2.16	3.22	2.69±0.75	6
12.	Coliforms	CFU/100mL	1.5×10 ⁵	1.8×10 ⁴	8.4×10 ⁴ ±9.4×10 ¹⁰	5,000

Note: Ave. ± S.D.: average±standard deviation

CFU: Colony forming unit

QCTDHN 02:2014/BTNMT: Hanoi Technical Regulation on Industrial Wastewater - Class B stipulates the concentration limits of parameters in industrial wastewater discharged into water bodies not used for domestic water supply.

In comparison with municipal solid waste landfill leachate, it can be observed that landfill leachate generally contains higher concentrations of specific pollutants. COD level

in landfill leachate typically ranges from 5,000 mg/L to over 10,000 mg/L, depending on landfill age (Mojiri et al., 2021). In older landfills, the COD concentration tends to be lower, and the BOD₅/COD ratio decreases, as most of the biodegradable organic matter has been decomposed, indicating the stabilization of the landfill. Furthermore, ammonium concentration and color in landfill leachate are often elevated. For example, a study conducted in Malaysia reported ammonium concentrations between 1,070 and 1,300 mg/L (Ghafari et al., 2010) while Mojiri et al. (2021) reported values around 400 mg/L. The color of landfill leachate was observed to range from 3,640 to 4,100 Pt-Co (Ghafari et al., 2010). However, the total suspended solids (TSS) concentration in landfill leachate, reported as 38-96 mg/L in Malaysia (Ghafari et al., 2010) and 55±27 mg/L at the Wrocław landfill (Wdowczyk & Szymańska-Pulikowska, 2021), was lower than that measured in sludge landfill leachate in this study, which was recorded at 177±6 mg/L.

The BOD₅/COD ratios of the sludge landfill leachate on the two sampling days were 0.47 and 0.51, respectively, which fall within 0.3-0.8, indicating suitability for biological treatment processes (Tchobanoglous et al., 2003). Considering the leachate characteristics, the treatment strategy focused on removing turbidity, organic matter (represented by BOD₅ and COD), TSS, ammonium, and total nitrogen through the application of combined physicochemical and biological treatment methods.

3.2 Pretreatment of sludge landfill leachate by coagulation followed by biological processes

Since the leachate contains high TSS content, there is a need of TSS removal before the leachate enters biological treatment (Tchobanoglous et al., 2003). Here, we applied coagulation with FS, AS and PAC. Figure 1 presents TSS and COD removal efficiencies by 3 coagulants. The results show that FS provided 70.2-75.4% of TSS removal at FS concentrations of 200, 250, 300 and 350 mg/L. As the FS concentration increased, the TSS treatment efficiency decreased. By observations, the leachate after coagulation with FS turned yellow, which significantly affected the quality of the treated effluent. At the same dosage as FS, AS showed its higher efficiency in removing TSS, ranging between 74.6-78.1%. In general, the coagulation performance of the FS was lower than that of the AS. For both AS and FS, the change in coagulant dosages had almost no significant effect on the TSS removal efficiency from leachate. Another research that applied FS and AS for the treatment of stabilized leachate from municipal solid waste landfill in the USA showed that the coagulation performance of FS was higher than that of AS (Comstock et al., 2010).

Meanwhile, the efficiency of TSS removal by PAC showed the highest results as compared to FS and AS. The TSS removal efficiency using PAC reached 87.3-97.4% at PAC dosages of 150, 200, 250 and 300 mg/L. These results were consistent with the findings of Ghafari et al. (2010), in which AS and PAC were applied to treat partially stabilized leachate, demonstrating that PAC exhibited superior performance in the removal of turbidity, color and TSS. Similarly, in another study on the treatment of leachate from a landfill in Malaysia, PAC achieved a higher TSS removal efficiency of 92% compared to tapioca starch, which only reached 35% under optimal conditions (Azizan et al., 2020). Furthermore, our results revealed that when increasing the PAC dosage from 150 mg/L to 200 mg/L, the efficiency of TSS treatment rose from 87.3% to 96.5%; while increasing the PAC dosages beyond 200 mg/L, the efficiency of TSS treatment did not increase much. To balance treatment performance and cost efficiency, a PAC concentration of 200 g/mL was selected as the appropriate concentration for TSS removal under the conditions of this study.

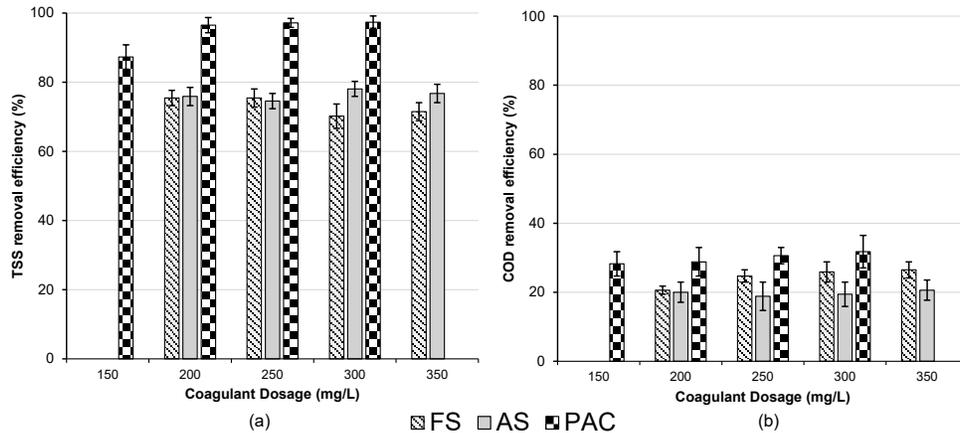


Figure 1. Removal efficiencies of TSS (a) and COD (b) versus coagulants type and dosages

As illustrated in Figure 1(b), coagulation effectively also reduces the leachate's COD. Notably, PAC demonstrated superior performance, achieving COD removal efficiencies of 28.2-31.8%, compared to 20.6-26.5% with FS and 18.8-20.6% with AS. These results were consistent with a previous study on the pretreatment of young landfill leachate using coagulation, which reported approximately 26% of COD removal (Marañón et al., 2008). Similarly, Azizan et al. (2020) reported that PAC achieved a 37% COD removal efficiency when treating aged leachate in Malaysia. However, our findings differ from those of Ghafari et al. (2010), who observed that while PAC demonstrated the highest efficiency in improving the physical characteristics of partially stabilized leachate, it was less effective in COD removal (Ghafari et al., 2010). Based on our study, a PAC dosage of 200 mg/L is recommended as the optimal coagulant for sludge landfill leachate treatment, resulting in treated leachate with TSS and COD concentrations of 8 mg/L and 121 mg/L, respectively.

Following coagulation, the wastewater was treated by biological treatment. Figure 2 illustrates the removal efficiencies of COD, NH_4^+ , and TN using various biological treatment methods, including ACS, OXM, ANM, and AOM. The detailed data of the experiment is presented in Table 4. The research results indicate that, overall, biofilm-based treatment technologies exhibited higher efficiency than conventional suspended activated sludge systems. Additionally, combined anoxic-oxic (AO) configurations yielded higher pollutant removal compared to single-stage aerobic or anoxic treatment. This can be attributed to the enhanced biofilm growth, superior biomass content, and the formation of microbial films with significantly higher microbial densities compared to suspended activated sludge (Tchobanoglous et al., 2003). Notably, aerobic biofilm-based processes, particularly OXM, demonstrated better COD and ammonia removal compared to both aerobic and anoxic processes (Tchobanoglous et al., 2003; Hao et al., 2022). The anoxic process utilizing biofilm carriers (ANM) exhibited lower nitrification and denitrification efficiencies, as evidenced by reduced NH_4^+ and TN removal efficiencies compared to ACS and OXM. However, the leachate treated by all biological processes still contained high levels of total nitrogen in the range of 42.3-75.7 mg/L and ammonium in the range of 14.9-24.0 mg/L (Table 4), which failed to meet the local discharge standard QCTDHN 02:2014/BTNMT – class B. The results can be explained as coagulation-flocculation process consuming about 30% of COD which was an essential carbon source for the subsequent biological treatment that included nitrification and denitrification (Tchobanoglous et al., 2003).

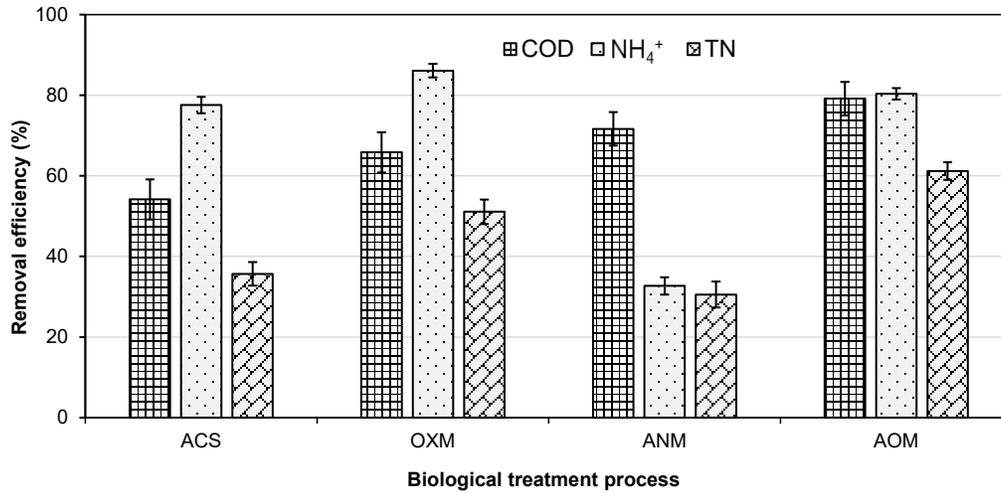


Figure 2. Biological treatment of the sludge landfill leachate after coagulation with PAC; ACS: activated sludge, OXM: oxic condition with moving media, ANM: anoxic condition with moving media, AOM: anoxic-oxic condition with moving media

Table 4. Pretreatment of sludge landfill leachate by coagulation followed by biological processes. COD, NH₄⁺ and TN of the effluent after biological processes. Experiment conditions: Influent: COD = 120 mg/L; NH₄⁺ = 107 mg/L; TN = 109 mg/L

Parameter	Unit	ACS	OXM	ANM	AOM	QCTDHN 02:2014/BTNMT – class B
COD	mg/L	55±6	41±6	34±5	25±5	150
NH ₄ ⁺	mg/L	24±2.2	14.9±1.8	72±2.3	21.0±1.5	10
TN	mg/L	70.1±3.2	53.3±3.3	75.7±3.5	42.3±2.4	40

Note: QCTDHN 02:2014/BTNMT: Hanoi Technical Regulation on Industrial Wastewater - Class B stipulates the concentration limits of parameters in industrial wastewater discharged into water bodies not used for domestic water supply.

3.3 Posttreatment of sludge landfill leachate by coagulation after biological processes

In standard wastewater treatment protocols, coagulation-flocculation is conventionally employed as a pre-treatment step to remove TSS and color prior to biological treatment. However, our research revealed that in the case of leachate with low organic matter content, the coagulation-flocculation process resulted in a substantial COD reduction of approximately 30%, which is comparable to findings from another study reporting a 35% COD removal efficiency using coagulation pretreatment (Reddy et al., 2022). This COD depletion affects the efficacy of subsequent biological treatment, particularly concerning the removal of COD, total nitrogen (TN), and ammonia (NH₄⁺). To mitigate the necessity

for external organic matter supplementation, a series of biological treatment experiments were conducted without coagulation with PAC. The comparison of COD, NH_4^+ and TN removal efficiencies across different biological treatment processes is illustrated in Figure 3 and detailed results of the biological treatment are presented in Table 5. The results indicate that nitrification was more effective under oxic conditions, with NH_4^+ removal efficiencies of 74.6% for ACS, 84.6% for OXM, and 93.9% for AOM, compared to only 28.8% under anoxic conditions (ANM). Denitrification was most effective in AOM, making it the only process capable of efficiently removing both NH_4^+ and TN. This is because the AO process integrates both nitrification and denitrification, enabling the removal of not only ammoniacal nitrogen but also TN through the recirculation of nitrified liquid (Wang et al., 2018). The treated leachate contained average concentration of 6.3 mg/L of NH_4^+ and 20.4 mg/L of TN (Table 5), corresponding to removal efficiencies of 93.9% and 82.5%, respectively. AO technology, when combined with moving media, demonstrated high efficiency in nitrogen removal.

The results also show that all biological processes effectively removed COD, achieving compliance with the local discharge standard. COD removal efficiencies ranged from 79.5% to 91%, resulting in effluent COD concentrations between 22 mg/L and 50 mg/L (Table 5), with the highest removal efficiency observed in AOM. This can be attributed to the consumption of a certain amount of carbon as an electron donor in the denitrification process (Tchobanoglous et al., 2003). Based on these findings, AOM was selected as the most suitable treatment for sludge landfill leachate in this study.

However, TSS levels after all biological processes did not meet the required standard. The post-treatment of average TSS concentrations for ACS, OXM, ANM and AOM were 136 mg/L, 141 mg/L, 143 mg/L and 150 mg/L (Table 5), corresponding to removal efficiencies of 25%, 23%, 21% and 18%, respectively. These results were attributed to the high proportion of non-biodegradable components within the suspended solids, which were difficult to remove during biological treatment. It is likely that only a small fraction may be partially removed through adsorption and attachment to sludge flocs.

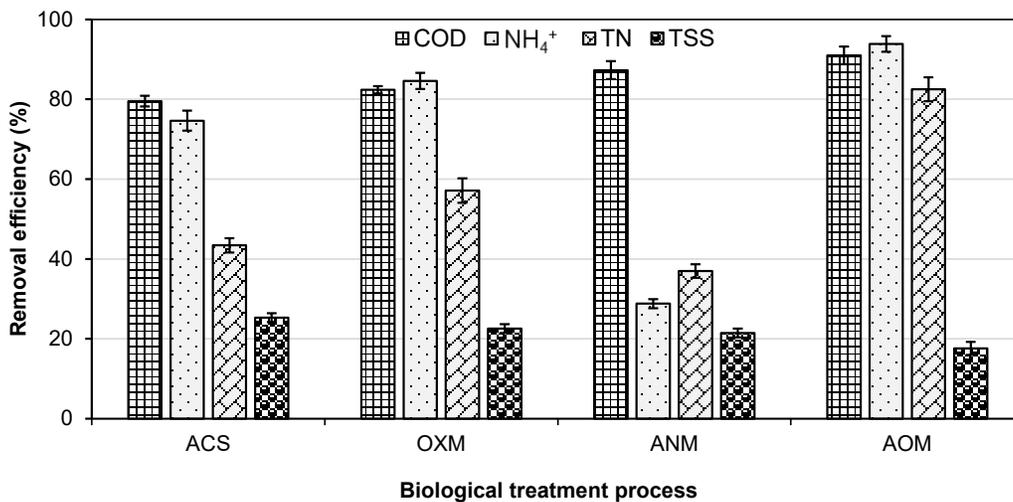


Figure 3. Biological treatment of the sludge landfill leachate; ACS: activated sludge, OXM: oxic condition with moving media, ANM: anoxic condition with moving media, AOM: anoxic-oxic condition with moving media

Table 5. Post-treatment of sludge landfill leachate by coagulation after biological processes. COD, NH₄⁺, TN, and TSS of the effluent after biological processes. Experiment conditions: Influent: COD = 244 mg/L; NH₄⁺ = 103 mg/L; TN = 117 mg/L; TSS = 182 mg/L

Parameter	Unit	ACS	OXM	ANM	AOM	QCTDHN 02:2014/BTNMT – class B
COD	mg/L	50±3	43±2	31±5	22±5	150
NH ₄ ⁺	mg/L	26.0±2.5	15.8±2.1	73.0±1.2	6.3±2.0	10
TN	mg/L	66.0±2.1	50.0±3.6	73.5±2.0	20.4±3.5	40
TSS	mg/L	136±2	141±2	143±2	150±3	100

Note: QCTDHN 02:2014/BTNMT: Hanoi Technical Regulation on Industrial Wastewater - Class B stipulates the concentration limits of parameters in industrial wastewater discharged into water bodies not used for domestic water supply.

Based on the research findings, the AO technology with biofilm carriers (AOM) was selected for sludge landfill leachate treatment. Although AOM technology was possible to remove organic matter and nitrogen, the treated effluent still contained a high level of TSS that did not meet the discharge standards, requiring further treatment by coagulation.

Suspended solids (SS) in sludge landfill leachate consist of insoluble organic matter that remains suspended in wastewater. After biological treatment, a portion of the SS adheres to biological flocs, while another portion, along with microbial cells, is discharged with the effluent. The leachate sludge is typically carbon-deficient and nitrogen-rich, which accelerates microbial growth but reduces the ability of the cells to form stable flocs. As a result, many microbial cells fail to aggregate into flocs and are discharged with the effluent, leading to SS concentrations similar to those before biological treatment. The TSS concentration before biological treatment was 182 mg/L, which slightly decreased to 150 mg/L after treatment using the AOM process. Since the characteristics of the SS did not significantly change, our study did not conduct further testing with FS or AS, but instead selected PAC at the previously determined optimal conditions. The effluent from AOM underwent coagulation using PAC at a dosage of 200 mg/L with rapid mixing at 250 rpm for 30 s, followed by slow mixing at 40 rpm for 10 min. After coagulation, the TSS concentration in the leachate was reduced to 5 mg/L, achieving a 97% TSS removal and meeting the local standard QCTDHN 02:2014/BTNMT – class B.

Finally, the treatment was carried out continuously. The results of this continuous operation are presented in Table 6, demonstrating high treatment efficiency and confirming that the treated sludge landfill leachate met local discharge standards.

4. Conclusions

This study assessed the characteristics of leachate from sludge landfill and evaluated wastewater treatment technology to ensure compliance with local discharge standards in Hanoi, Vietnam. The leachate quality analysis revealed high concentrations of pollutants, primarily TSS, organic matter, ammonia, total nitrogen, and total coliforms. Treatment of sludge leachate by coagulation resulted in COD reduction of approximately 30%, which subsequently limited the efficiency of biological treatment, particularly for nitrogen removal.

Table 6. Continuous treatment of sludge landfill leachate by anoxic-oxic with moving media (AOM), followed by coagulation with poly aluminium chloride (PAC)

No.	Parameter	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)	QCTDHN 02:2014/BTNMT – class B (mg/L)
1.	COD	250	25	90.0	150
2.	NH ₄ ⁺	98.7	8.0	91.9	10
3.	TN	114.6	22.3	80.5	40
4.	TSS	175	5	97.1	100

Note: QCTDHN 02:2014/BTNMT: Hanoi Technical Regulation on Industrial Wastewater - Class B stipulates the concentration limits of parameters in industrial wastewater discharged into water bodies not used for domestic water supply.

Therefore, the study proposed biological treatment prior to TSS treatment. Among the biological processes investigated—ACS, OXM, ANM, and AOM—the AO technology with media (AOM) demonstrated the highest treatment efficiency for COD and nitrogen removal. The effluent concentrations of COD, NH₄⁺ and TN following AOM treatment were 22 mg/L, 6.3 mg/L, and 20.4 mg/L, corresponding to removal efficiencies of 91%, 93.9%, and 82.5%, respectively. After AOM treatment, the leachate underwent coagulation with PAC at a dosage of 200 mg/L, achieving a 97% TSS removal efficiency. The findings of this study contribute to the development of an effective sludge landfill leachate treatment for Hanoi, Vietnam.

5. Acknowledgements

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6. Authors' Contributions

Pham Huong Quynh designed research, supervised, and wrote original draft; Pham Nguyet Anh designed research, wrote original draft, reviewed and edited the manuscript; Nguyen Thi Thu Phuong performed research; analyzed data, and wrote original draft; Nguyen Thi Thu Hien performed research, analyzed data, and wrote the original draft.

7. Conflicts of Interest

The authors declare no conflict interest.

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