Landfill Leachate Treatment Methods and Its Potential for Ammonia Removal and Recovery - A Review

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Abstract. As a fast-developing country, the population, urbanization and industrialization have developed rapidly in Malaysia. The growth in population increases human activities, leading to a rise in the generation of waste. Municipal solid waste in Malaysia is currently estimated to rise from 23,000 tons/day in 2010 to 30,000 tons/day in 2020. Due to its simplicity and low costs, landfilling is the most common method in the country. However, there are various environmental drawbacks associated with landfills that have attracted social and environmental attention in recent decades. One of the key issues is the generation of leachate from the percolation of rainwater by waste disposal in a landfill. Landfill leachate contains many pollutants including ammonia-nitrogen (NH₃-N) which is a particular concern due to its high concentration in leachate. High concentration of ammonia not only causes health and environmental problems but also affects the efficiency of leachate treatment. Therefore, a pre-treatment to remove ammonia is required before downstream treatment to prevent contamination to the surrounding ground and surface water. In general, leachate can be characterized by physico-chemical and biological parameters. Leachate characterization is essential to evaluate the leachate pollution potentials in the landfill site and to determine the treatment methods. Hence, the present review highlights the recent development of landfill leachate treatment methods and its potential for ammonia removal and recovery. Rather than releasing the extracted ammonia directly into the environment that causes air pollution, ammonia from the stripping process can be recovered and used to produce fertilizers. This review also contributes to the body of knowledge of the ammonia stripping treatment in terms of its efficiency and its application for leachate treatment.

1. Introduction
With the increase of population, waste management has become a crucial issue faced in both developed and developing countries, including Malaysia. Various waste disposal approaches were extensively employed to manage waste, including open dumping, sanitary landfill, incineration, composting, dumping, milling, hog feeding, grinding, reduction and anaerobic digestion [1]. Nevertheless, due to its
low cost and simplicity of the disposal method, landfilling is the most common waste disposal method in the country. This method also has proven to be the primary method that has been implemented for many years [2].

The generation of toxic and highly contaminated leachate which contaminates the soil, surface water, groundwater and also causes air pollution is a pressing matter of landfill activity [3]. Landfill leachate is a liquid mixed with several features that render it difficult to treat [1]. It can be defined as highly polluted wastewater which comes from sanitary or landfills caused by rainwater percolation through the landfill site [4]. This hazardous wastewater contains a lot of non-biodegradable organic pollutants, biodegradable organic matters, heavy metals, inorganic salts and a high concentration of ammonia-nitrogen [5].

Leachate management, along with its treatment, is not a simple task. Indeed, the production of highly polluted leachate is one of the key challenges faced in managing landfills since it brings harm to human health and the environment. The management of leachate in any landfill site is necessary to ensure that there will be no contamination to the environment from the discharge of untreated leachate. Presently, solid waste management technology has transformed from conventional to advanced systems which focus on the design, storage capacity and economy feasibility including leachate treatment availability [6]. Leachate management is related to landfill since it is undesirably by-product of landfill sites.

Landfill leachate contains a number of pollutants including ammoniacal-nitrogen (NH$_3$-N) which is a particular concern due to its high concentration in leachate [5,4,1]. A high concentration of ammonia not only causes health and environmental problems, but also affects the efficiency of leachate treatment. Therefore, a pre-treatment to remove ammonia is required before downstream treatment to prevent contamination to the surrounding ground and surface water. Leachate characterization is essential to evaluate the leachate pollution potential of a landfill site and come up with treatment methods. Instead of directly releasing the extracted ammonia into the atmosphere which causes air pollution, ammonia which comes from the stripping process can be used in fertilizer production [7].

This paper provides an overview of the development of landfill leachate treatment methods and its potential for ammonia removal and recovery. The characteristics of leachate from numerous landfills was studied based on recent and past literature. Furthermore, the application of ammonia stripping process for landfill leachate treatment was also presented considering its efficiency as a leachate treatment method.

2. Leachate Characterization
Landfill leachate smells foul and black or brown in colour [8]. It can be characterized through physico-chemical and biological parameters, such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammoniacal nitrogen (NH$_3$-N), Total Kjedhal Nitrogen (TKN), Suspended Solids (SS), Volatile Suspended Solids (VSS) and etc. [9]. These properties may vary widely over time as leachate undergoes organic waste degradation [10]. Since leachate has a complex composition, the water quality of leachate is often produces higher levels of pollutants and biological toxicity [8]. Numerous studies have been done on landfill leachate concerning its impact to the environment [11,12,13]. These studies are mainly concentrated on the leachate characterization and treatment method before being released into the environment.

Another feature of leachate is the variance in the quality and quantity of wastewater from different location and this has been proven to have a significant impact on the characteristics of leachate. According to Wang et al., [8], the concentration of leachate pollutants in Asian countries are discovered to be higher the United States and Europe region. For instance, ammonia nitrogen in leachate from European and American countries is usually less than 1000 mg/L while in Asian countries it is typically
more than 1000 mg/L [8,14,15]. These variations may be related to cultural and behavior differences in different regions. Further, the composition of leachate also dependent upon the age of the landfill leachate. The relationship between the age of landfill leachate and its characteristics are presented in Table 1, which showed that the age of landfill leachate can be divided into three; early age (less than five years old), medium-term (5–10 years old) and stabilized leachate which is identified in the old landfill (more than 10 years old) [8].

### Table 1. Characteristics of landfill leachate within different periods [8]

| Type of leachate | Early | Medium Term | Stabilized/Old |
|------------------|-------|-------------|----------------|
| Age of landfill (years) | <5 | 5–10 | >10 |
| pH (−) | 6.5–7.5 (7.0) | 7.0–8.0 (7.5) | 7.5–8.5 (8) |
| COD (g/L) | 10–30 (15) | 3–10 (5) | <3 (2) |
| BOD/COD (−) | 0.5–0.7 (0.6) | 0.3–0.5 (0.4) | <0.3 (0.2) |
| NH$_4^+$-N (mg/L) | 500–1000 (700) | 800–2000 (1000) | 1000–3000 (2000) |
| COD/NH$_4^+$-N | 5–10 (6) | 3–4 (3) | <3 (1.5) |

*The values in parentheses are typical values.*

When rainwater percolates through the waste landfill, the degraded organic matter of waste which has been dissolved is subjected to physiochemical and biological changes. Early leachate has a high organic content, strong biodegradability and a relatively low concentration of ammonia nitrogen, as shown in Table 1. Meanwhile, a stabilized or old leachate has a high ammonia nitrogen content, low biodegradability, and low carbon-to-nitrogen ratio (COD/NH$_4^+$-N). As for medium-term leachate, the characteristics seem to be in between the early and the old leachate. The difference in characteristics in different age of landfill leachate can be linked to the anaerobic degradation process that happens in landfills. Generally, the anaerobic degradation cycle takes three stages: acid fermentation, intermediate anaerobic step and anaerobic degradation [13].

Acid fermentation occurs in a short time in early leachate. Aerobic activities dominate the process at this point, with a large output of volatile fatty acids (VFAs). Due to lack of oxygen, landfills become more acidic and hence, the biodegradability of young leachate is high [16]. Methanogenic bacteria start to grow during the intermediate anaerobic phase where volatile fatty acids are reduced and ammonia is emitted [17]. Lastly, anaerobic degradation, recognized in the old landfill that produced old leachate, is even more tedious because it is stable and hard to treat biologically [13]. Despite the general characteristics of landfill leachate, site and seasonal factors such as moisture content of waste, landfill design, treatment technology, annual rainfall and temperature may affect the quality of leachate [16].

#### 2.1. Biological Oxygen Demand (BOD)

Water or other liquid that moves into landfill forming leachate contains many organic and inorganic compounds. BOD or Biochemical Oxygen Demand is a characteristic that indicates the amount of dissolved oxygen required by microorganisms (usually bacteria) to decompose organic matter under aerobic conditions. It is practical as an indicator for estimating the amount of organic contamination in a water or waste sample [13]. Microorganisms such as bacteria and fungi feed upon it as organic matter decomposes and it gradually becomes oxidized in combination with oxygen. Therefore, BOD is calculated by quantifying the dissolved oxygen (DO) used in the biochemical oxidation process by these microorganisms.

The level of BOD in leachate is dependent on the age of the landfill [13]. Young landfill leachate is commonly characterized by high biochemical oxygen demand (BOD) compared to intermediate and old leachate [18]. The BOD level for old landfills is between 100-200 mg/L, while a young landfill ranged
between 200-30,000 mg/L [13,19]. In young landfill leachate, aerobic activities dominate the cycle and generate a greater number of volatile fatty acids (VFAs), hence contribute to a high level of organic matter. Leachate with a high level of organic matter will also test high for BOD levels. On the other hand, dissolved oxygen in the water decreases as BOD increases since bacteria in the water consume the dissolved oxygen when they decompose organic matter.

2.2. Chemical Oxygen Demand (COD)
Chemical oxygen demand (COD) is one of the essential indexes of landfill leachate. It is a measure of oxygen consumed during decomposition of organic matter and oxidation of inorganic chemicals such as ammonia and nitrite. In other words, it is a measure for calculating the pollutant intensity (organic and inorganic) within the water or wastewater sample [13]. COD is an important water quality parameter because similar to BOD, it can assess the impact of wastewater effluent that will be discharged to the receiving environment (water bodies). COD tests are often used as an alternative to BOD because of the shorter analysis time.

COD declines with the age of the landfill [13]. The COD value of leachate should be less than 400 mg/L prior to its release to the environment as stipulated in the Malaysia Environmental Quality Act 1974 (MEQA). A high COD level indicates a large amount of oxidized organic matter in the sample, which will reduce the level of dissolved oxygen (DO). A decrease in DO can cause anaerobic conditions, which damages aquatic life. Hence, leachate treatment must be carried out to reduce the risk of surface and groundwater pollution.

2.3. Ammoniacal Nitrogen (NH$_3$-N)
Landfill leachate contains a lot of pollutants including ammoniacal-nitrogen (NH$_3$-N) which is a particular concern due to its high concentration in leachate. A high concentration of ammoniacal-nitrogen in the landfill will contribute to a toxic condition in leachate. Hence, it hinders the nitrification process of microorganisms and single biological treatment which results in a low amount of ammonia removal [20]. The permissible limit of ammoniacal-N for domestic effluent discharged from treatment plants imposed by the Department of Environment Malaysia is 5 mg/L. As landfill leachate ages, the concentration of ammonia increases, whilst the biodegradable fraction declines due to the stabilization process [11]. A high concentration of ammonia not only causes health and environmental problems but also affects the efficiency of leachate treatment. Therefore, prior to the downstream treatment process, a pre-treatment to remove ammonia is required to prevent contamination to the surrounding ground and surface water.

2.4. Heavy Metals
In addition to high concentrations of organic matter and ammonia-nitrogen, heavy metals are also the most toxic pollutants in landfill leachate [21]. The metal concentrations in young leachate are usually higher than those in old leachate [22]. Typical metal concentrations in landfill leachate are as follows; Cd (0.0001–0.13 mg/L), Cr (0.0005–0.6 mg/L), Fe (0.08–2100 mg/L), Mn (0.01–65 mg/L), Ni (0.03–3.2 mg/L), Pb (0.0005–1.5 mg/L), and Zn (0.00005–120 mg/L), based on reports [22,23,24].

2.5. Summary on leachate characterization from various landfills
Leachate characteristics depend on the age of the landfills and it can be characterized through physico-chemical and biological parameters. Table 2 summarizes the previous studies on leachate characterization from various landfills. It is clear that scheduled waste landfill (SWL) leachate has slightly alkaline behaviour compared to MSW and semi-aerobic landfill leachate. The BOD$_5$ value and ammonia content are higher for landfill leachate. High ammonia-nitrogen content in leachate,
particularly landfill leachate, causes the leachate to have a high pH level where this condition is not culturally acceptable for the bacteria. Hence, inhibits bacteria growth for the biological treatment process. Liu et al., [25] noted that NH3-N inhibits biodegradation at a concentration of 1500–3000 mg/L. It also can be concluded that landfill leachate has more complex and hazardous properties than MSW landfill leachate and semi-aerobic landfill leachate. Therefore, further studies are needed to provide a better understanding of the characteristics of landfill leachate and treatment methods to remove ammonia-nitrogen before downstream processes.

| Landfill Type      | Sites                      | Parameters | Reference |
|-------------------|----------------------------|------------|-----------|
| MSW landfill      | Alor Pongsu Landfill Site, Perak, Simpang Renggam Landfill Johor SWL site | pH BOD5 COD Ammonia Total Iron | [13] |
| MSW landfill      | 8.13 196 3,852 1,241 N/A  | [26] |
| SWL landfill      | 8.1 170 1993 982 N/A | [1] |
| SWL landfill      | 9.31 2,053 4,127 2,267 0.29 | [4] |
| Semi-aerobic landfill | Pulau Burung Landfill Site, Penang | 8.29 227 NA 1,890 5.41 | [5] |

3. Leachate Treatment Methods
Leachate from landfills can be a significant source of pollution of surface and groundwater due to its toxicity. Hence, before being discharged into the environment, landfill leachate must be appropriately treated and properly disposed [5,19]. The treatment of landfill leachate is dependent on leachate composition and the natures of organic matter present [27]. In general, there are two methods in leachate treatment namely biological method and other is the combination of both chemical and physical methods.

3.1. Chemical & Physical Method
Chemical and physical methods are applied before the biological approach [5]. Coagulation-flocculation is one of the major chemical treatment methods used for landfill leachate [1,28,29]. In this method, a colloidal suspension of the particles destabilizes with coagulants causing the particles to agglomerate with flocculants. Then, it will accelerate separation and subsequently clarify the effluents. There are many factors that can affect the efficiency such as the coagulant/flocculants type and dosage, pH, retention time, mixing speed and time [30]. Hence, the optimization of these factors may influence the efficiency of the coagulation-flocculation process [31]. The most widely used coagulant for leachate treatment are lime (calcium hydroxide), ferum chloride, aluminum sulphate and polychlorinated aluminium [30]. As for physical methods, adsorption, membrane filtration, sedimentation and air stripping are the most commonly used method for the treatment of landfill leachate [1]. Generally, for
matured or stabilized leachate, physical-chemical treatment methods that are unfavorable for young leachate treatment are recommended.

3.2. Biological Method

Biological treatment is a common treatment as it is both economically and technically feasible compared to others. The key biological approaches used in combination for treating leachate from landfills are including aerobic, anaerobic, and anoxic processes [1]. In general, biological processes are favored for treating leachate with a high biodegradable value ratio BOD/COD. However, with the lowered effectiveness of biological processes, physico-chemical methods could be viewed as better options [19, 24].

4. Aeration/Air Stripping

Aeration or air stripping method is technically feasible for complex characteristics of leachate with high ammonia concentration [7]. It is the most implemented method to treat leachate in ammonia removal. Ammonia stripping is a mass transfer mechanism involving the transfer of dissolved substances by physical action when liquid water is in contact with ammonia-free air [1]. Volatile organic compounds will be separated from the aqueous solution during air stripping and the two phases in contact will maintain equilibrium within the air stripping reactor. The treated gas may be absorbed into a strong acid such as sulphuric acid or flowed directly into the air.

Several factors may influence the efficiency of air stripping including the concentration of ammonia, temperature, pH, contact time /stripping time, volatile material characteristics, turbulence in gases and liquid phases, types of packing materials and the surface area-to-volume ratio [32]. Previous studies have shown that leachate requires a pH value of 11 to undergo ammonia removal by air stripping to cause the chemical equilibrium to shift to the right which is towards the direction of gaseous ammonia (NH₃) [7]. Referring to Equation 1, ammonium ion and free ammonia concentrations are pH-dependent. Ammonium and hydrogen ions are dominant species at lower pH levels, but pH increases shift to the right and increase the free ammonia concentration. The ammonia removal is insignificant when pH is beyond the value of 13 [32]. At pH 11, a large number of ammonium ions are all in the form of NH₃ gas, leading to higher removal of ammonia.

\[ \text{NH}_4^+ \rightleftharpoons \text{NH}_3 + \text{H}^+ \] (1)

Calcium hydroxide [Ca(OH)₂] is often used as pH adjustments in the air stripping systems. The advantage of using NaOH including avoiding the scaling which requires regular maintenance. Table 3 concludes that air stripping has a high-efficiency rate in treating landfill leachate since most of the studies shown 80% and above of removal efficiency. Landfill shows a lower efficiency compared to other types of landfill and this might be due to the complex characteristics of its leachate. However, Hanira et al., [1] exhibited a quite impressive removal efficiency results for both raw leachate and diluted leachate (76% and 80% respectively) with aeration time of 12 hours. Thus, this suggests that ammonia stripping is feasible in removing ammonia from landfill leachate.
Table 3. Previous studies on ammonia removal from leachate using aeration / ammonia stripping method.

| Type                        | pH | Temperature | Air flow rate | Air-liquid ratio | Aeration time | Removal efficiency | References |
|-----------------------------|----|-------------|---------------|------------------|---------------|--------------------|------------|
| Landfill leachate           | 11 | 25 °C       | 7 L/min       | -                | 18 hours      | 85% ammonia        | [33]       |
| Scheduled waste landfill    | -  | -           | -             | 70               | 8 hours       | 76% ammoniacal-nitrogen, 55% turbidity, 34% colour and 46% phosphate | [1]        |
| (Raw leachate)              |    |             |               |                  |               |                    |            |
| Scheduled waste landfill    |    |             |               |                  | 70            | 12 hours           |            |
| (Diluted leachate)          |    |             |               |                  |               |                    |            |
| MSW landfill                | 9  | 60 °C       | 2 L/min       | -                | 7 hours       | 96.7% ammonia       | [20]       |
| Municipal sanitary landfill | 11 | 25 °C       | 75 L/min      | 50               | 72 hours      | 88% of total ammoniacal nitrogen, 82% of colour and 70-90% of heavy metals (Zn, Fe and Mn) | [7]        |

5. Ammonia Recovery Through Absorption

The reverse of the air stripping process is known as the absorption process. High ammonia concentrations from the stripping process favor absorption process in acid solution and can be used in fertilizer production [7]. Absorption is also suggested to reduce air pollution from the mass transfer of stripped ammonia from the liquid to the gaseous phase [7, 34]. This method, on the contrary, includes the transformation of gaseous pollutants into a liquid phase. Acidic solutions are widely used to neutralize ammonia whereby ammonia is extracted as an ammonium salt [35]. However, the application of air stripping followed by ammonia recovery (absorption) has been recorded in detail only in a few studies [7]. In certain scenarios, no information on the efficacy of ammonia recovery was given or which absorbent was used. Table 4 shows that the efficiency of the absorption process on ammonia is quite high (80-99.9%) and H2SO4 solutions are commonly used as an absorbent.
Table 4. Previous study on ammonia recovery through absorption and its application

| Type                | Site                        | Absorption media | Recovery Efficiency | Application | References |
|---------------------|-----------------------------|-------------------|---------------------|-------------|------------|
| Municipal Solid Waste | Northern Italy              | H₂SO₄             | N/A                 | Fertilizer  | [36]       |
| Municipal sanitary landfill | Sao Carlos, Brazil       | H₂SO₄ solution    | 80%                 | Fertilizer  | [7]        |
| Plant waste         | India                       | Phosphoric acid   | N/A                 | N/A         | [37]       |
| Wastewater           | China                       | N/A               | 99.9%               | N/A         | [38]       |

6. Conclusion and Outlook

As there is a number of methods available for landfill leachate treatment, the most suitable process for individual landfill must be selected by considering the characteristics of leachate. It is also important to take into account all factors that may influence the efficiency of the treatment methods. With the decreased effectiveness of biological processes, physico-chemical methods are also viewed as better options in treating landfill leachate. The production of ammonia nitrogen (N-NH₃) in leachate is potentially one of the issues with landfill management. Indeed, ammonia removal from leachate is particularly difficult due to the complex characteristics of leachate. Currently, conventional disposal processes are poor in efficiency or high in cost, which makes it difficult to apply them for leachate treatment. Hence, the design and process of each method and its parameters should be pursued and optimized to aid the wastewater treatment industry. Future research should also be explored and focus on enhancing the leachate treatment method.

References

[1] Hanira N M L, Hasfalina C M, Rashid M, Luqman C A and Abdullah A M 2017 Effect of dilution and operating parameters on ammonia removal from scheduled waste landfill leachate in a lab-scale ammonia stripping reactor IOP Conference Series: Mat. Sc. and Eng. 206
[2] Ogunmakinde O E, Sher W and Maund K 2019 An assessment of material waste disposal methods in the Nigerian construction industry Recycling 4
[3] Naveen B P and Sivapullaiah P V 2020 Solid waste management: Current scenario and challenges in Bengaluru Sust. Sew. Sludge Management
[4] Sani A, Rashid M, Hanira N and Hasfalina C M 2014 The influence of pH on the removal of ammonia from a scheduled waste landfill leachate Jurnal Teknologi Sc. and Eng. 68 pp 25–28
[5] Halim A A, Aziz H A, Johari M A M, Ariffin K S and Bashir M J K 2012 Semi-aerobic landfill leachate treatment using carbon-minerals composite adsorbent. Env. Eng. Sc. 29 pp 306–312
[6] Kamaruddin M A, Yusoff M S, Rui L M, Isa A M, Zawawi M H and Alrozi R 2017 An overview of municipal solid waste management and landfill leachate treatment: Malaysia and Asian perspectives. Env. Sc. and Poll. Research 24 26988–27020
[7] Ferraz F M, Povinelli J and Vieira E M 2013 Ammonia removal from landfill leachate by air stripping and absorption Env. Tech. 34 pp 2317–2326
[8] Wang K, Li L, Tan F and Wu D 2018 Treatment of landfill leachate using activated sludge technology: A review

[9] Fulazzaky M A 2013 Measurement of biochemical oxygen demand of the leachates. *Env. Monitor. and Assess.* 185 pp 4721–4734

[10] Ahmed F N and Lan C Q 2012 Treatment of landfill leachate using membrane bioreactors: A review *Desalination* 287 pp 41-54

[11] Abood A R, Bao J, Abudi Z N, Zheng D and Gao C 2013 Pretreatment of nonbiodegradable landfill leachate by air stripping coupled with agitation as ammonia stripping and coagulation-floculation processes *Clean Tech. and Env. Policy* 15 pp 1069-1076

[12] Shiva Kumar G, Bharadwaj J, Lakshmi Sruthi P and Chandra Sekhar M 2016 Removal of ammonia nitrogen (NH4-N) from landfill leachate by chemical treatment *Indian J. of Sc. and Tech.* 9

[13] Zakaria S N F and Aziz H A 2018 Characteristic of leachate at Alor Pongsu Landfill Site, Perak, Malaysia: A comparative study *IOP Conference Series: Earth and Env. Sc.* 140

[14] Lau I W, Wang P and Fang H 2001 Organic removal of anaerobically treated leachate by Fenton coagulation *J. of Env. Eng.* 127 pp 666-669

[15] Wu J J, Wu C C, Ma H W and Chang C C 2004 Treatment of landfill leachate by ozone-based advanced oxidation processes *Chemosphere* 54 pp 997-1003

[16] Rathnayake W A and Herath G B 2018 A review of leachate treatment techniques *The 9th International Conf. on Sustainable Built Env.* pp 7–106

[17] Naveen B P, Sivapullaiyah P V and Sitharam M 2014 Characteristic of a municipal solid waste landfill leachate Proceedings of Indian Geotechnical Conference pp 18-20

[18] Li W, Zhou Q and Hua T 2010 Removal of organic matter from landfill leachate by advanced oxidation processes: A review *International J. of Chem. Engineering*

[19] Aziz S Q, Aziz H A, Yusoff M S, Bashir M J and Umar M 2010 Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study *J. of Env. Manag.* 91 pp 2608–2614

[20] Campos J C, Moura D, Costa A P, Yokoyama L, Araujo F V, Cammarota M C and Cardillo L 2013 Evaluation of pH, alkalinity and temperature during air stripping process for ammonia removal from landfill leachate. *J. of Env. Sc. and Health* 48 pp 1105-1113

[21] Dan A, Oka M, Fujii Y, Soda S, Ishigaki T, Machimura T and Ike M 2017 Removal of heavy metals from synthetic landfill leachate in lab-scale vertical flow constructed wetlands *Sc. Of the Total Env.* pp 584–585, 742–750

[22] Öman C B and Junestedt C 2008 Chemical characterization of landfill leachate-400 parameters and compounds. *Waste Manag.* 28 pp 1876–1891

[23] Baun D L and Christensen T H 2004 Speciation of heavy metals in landfill leachate: A review. *Waste Manag. Res.* 22 pp 3–23

[24] Renou S, Givaudan G, Poulain S, Dirassouyan F and Moulin P 2008 Landfill leachate treatment: Review and opportunity *J. of Haz. Mat.* pp 150, 468

[25] Liu J, Luo J, Zhou J, Liu Q, Qian G and Xu Z P 2012 Inhibitory effect of high strength ammonia nitrogen on bio-treatment of landfill leachate using EGSB reactor

[26] Zailani L M, Amdan N S M and Zin N S 2018 Characterization of leachate at Simpang Renggam Landfill Site, Johor, Malaysia. In IOP Conf. Ser. Earth Environ. Sci. 140 pp 012053

[27] Mandal P, Dubey B K and Gupta A K 2017 Review on landfill leachate treatment by electrochemical oxidation: Drawbacks, challenges and future scope *Waste Manag.* 6 pp 250-273

[28] Chiang L Chang J and Chung C 2001 *Environ. Eng. Sci.* 18 pp 369-378
[29] Ahn D H, Yun-Chul C and Won-Seok C 2002 J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng. 37 pp 163-173
[30] Rui L M, Daud Z and Latif A A 2012 Treatment of leachate by coagulation-flocculation using different coagulants and polymer: A Review. International J. on Adv. Sc., Eng. And Information Tech. 2 pp 114
[31] Amor C, De Torres-Socías E, Peres J A, Maldonado M I, Oller I, Malato S and Lucas M S 2015 Mature landfill leachate treatment by coagulation/flocculation combined with Fenton and solar photo-Fenton processes J. of Haz. Mat. pp 286, 261-268
[32] Guo J S, Abbas A A, Chen Y P, Liu Z P, Fang F and Chen P 2010 Treatment of landfill leachate using a combined stripping Fenton, SBR, and coagulation process J. of Haz. Mat. 178 pp 699–705
[33] Smaoui Y, Bouzid J and Sayadi S 2019 Combination of air stripping and biological processes for landfill leachate treatment Env. Eng. Research 25 pp 80–87
[34] USEPA–United States Environmental Protection Agency 1995 Control and pollution prevention options for ammonia emissions. Research Triangle Park (NC): Environmental Protection Agency
[35] Bonmatí A and Flotats X 2003 Air stripping of ammonia from pig slurry: Characterisation and feasibility as a pre- or post- treatment to mesophilic anaerobic digestion Waste Manag. 23 pp 261–272
[36] Raboni M, Torretta V, Viotti P and Urbini G 2013 Experimental plant for the physical chemical treatment of groundwater polluted by municipal solid waste (MSW) leachate, with ammonia recovery. Revista Ambiente & Agua 8 pp, 22-32
[37] Vijay K M and Prabhakar R 1988 Ammonia removal and recovery from urea fertilizer plant waste Env. Tech. Letters 9 pp 655-664
[38] Beylier M R, Blauvelt A, Yan P, Li M, Wei G, Li H, Gao Z, Lopez M V, Schreiber F, Hu B L, Shen L, Lian X, Zhu Q, Liu S, Huang Q, He Z, Geng S, Cheng D Q, Lou L P and Gao Z 2015 Treatment of manure landfill leachates by anammox process. Applied and Env. Microbiology 3 pp 562–570