Journal of Environmental Management 91 (2010) 2608–2614

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study

Shuokr Qarani Aziz [a,b], Hamidi Abdul Aziz [a,*], Mohd Suffian Yusoff [a], Mohammed J.K Bashir [a], Muhammad Umar [a]

[a] School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia
[b] Department of Civil Engineering, College of Engineering, University of Salahaddin–Erbil, Iraq

ARTICLE INFO

Article history:
Received 19 January 2010
Received in revised form
13 June 2010
Accepted 19 July 2010
Available online 23 August 2010

Keywords:
Solid waste
Landfill leachate
Semi-aerobic
Intermittently aerated
Anaerobic

ABSTRACT

This study analyzes and compares the results of leachate composition at the semi-aerobic Pulau Burung Landfill Site (PBLS) (unaerated pond and intermittently aerated pond) and the anaerobic Kulim Sanitary Landfill in the northern region of Malaysia. The raw samples were collected and analyzed for twenty parameters. The average values of the parameters such as phenols (1.2, 6.7, and 2.6 mg/L), total nitrogen (448, 1200, and 300 mg/L N-TN), ammonia-N (542, 1568, and 538 mg/L NH_3-N), nitrite (91, 49, and 52 mg/L NO_2^--N), total phosphorus (21, 17, and 19 mg/L), BOD_5 (83, 243, and 326 mg/L), COD (935, 2345, and 1892 mg/L), BOD_5/COD (0.096,0.1124,0.205%), pH (8.20, 8.28, and 7.76), turbidity (1546, 180, and 1936 Formazin attenuation units (FAU)), and color (3334, 3347, and 4041 Pt Co) for leachate at the semi-aerobic PBLS (unaerated and intermittently aerated) and the anaerobic Kulim Sanitary Landfill were recorded, respectively. The obtained results were compared with previously published data and data from the Malaysia Environmental Quality Act 1974. The results indicated that Pulau Burung leachate was more stabilized compared with Kulim leachate. Furthermore, the aeration process in PBLS has a considerable effect on reducing the concentration of several pollutants. The studied leachate requires treatment to minimize the pollutants to an acceptable level prior to discharge into water courses.

1. Introduction

Solid waste disposal methods include open dump, sanitary landfill, incineration, composting, grinding and discharge to sewer, compaction, hog feeding, milling, dumping, reduction, and anaerobic digestion. Sanitary landfill is the most common municipal solid waste (MSW) disposal method due to such advantages as simple disposal procedure, low cost, and landscape-restoring effect on holes from mineral workings (Bashir et al., 2010a; Davis and Cornwell, 2008). However, the production of highly contaminated leachate is a major drawback of this method (Wiszniowski et al., 2007; Kurniawan et al., 2006).

Leachate is liquid formed primarily by the percolation of precipitation water through an open landfill or through the cap of a completed site. Leachates may contain large amounts of organic contaminants measured as chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia, halogenated hydrocarbons suspended solid, significant concentration of heavy metals, and inorganic salts (Foul et al., 2009; Aziz et al., 2009; Renou et al., 2008; Uygur and Kargi, 2004). It is also rich in phenol, nitrogen, and phosphorus. If not treated and safely disposed, landfill leachate could be a potential source of surface and ground water contamination, as it could seep into soils and subsoils, causing severe pollution to receiving waters (Oman and Junestedt, 2008; Lin et al., 2008; Sanphoti et al., 2006; Tatsi et al., 2003). Generally, the risks of the leachate on the natural environment are determined by comparing leachate quality with Malaysia standards.

Presently, there are over 230 landfills in Malaysia, mostly old dumpsites. Most are simply dumping grounds without any environmental protection. The resulting leachate is discharged directly into water courses without any treatment, which can threaten the surrounding ecosystem, particularly in cases where landfills are located upstream of water intakes. This study focuses on characterizing landfill leachate generated from anaerobic and semi-aerobic landfill.

According to Yamamoto (2002) and Matsufuji et al. (1993), in an anaerobic landfill, solid wastes are dumped in an excavated area of a plane field, which is filled with water in an anaerobic condition. Typically, anaerobic sanitary landfills are recognized by its sandwich-shaped cover. On the other hand, semi-aerobic landfills have

* Corresponding author. Tel.: +60 4 5996203; fax: +60 4 5941009.
E-mail addresses: cehamidi@eng.usm.my, cehamidi@yahoo.com (H.A. Aziz).

0301-4797/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2010.07.042

a leachate collection duct. The opening of the duct is surrounded by air, and the duct is covered with small crushed stones. Moisture content in solid waste is small, and oxygen is supplied to the solid waste from the leachate collection duct. The schematic diagram of anaerobic and semi-aerobic (Fukuoka method) landfills is demonstrated in Fig. 1 (JICA, 2005).

A comparison of leachate characteristics at semi-aerobic and anaerobic sanitary landfills in a tropical country such as Malaysia is not available in the literature. This study reviews, analyzes, and compares the results of leachate compositions in two landfills in the northern region, namely, the semi-aerobic Pulau Burung sanitary landfill (PBLS) (unaerated pond and intermittently aerated pond) and the anaerobic Kulim sanitary landfill. Twenty parameters were considered in the present study. The obtained results were compared with data published by previous researchers and the Malaysia Environmental Quality Act 1974 (MDC Sdn. Bhd., 1997). The results are essentially required in order to propose an adequate technique for treating the studied landfill leachate that considers all the measured pollutants.

2. Materials and methods

2.1. Site characteristics

PBLS is situated within the Byram Forest Reserve at 5°24′ N Latitude, 100° 24′ E Longitude in Penang, Malaysia, approximately 20 km southeast of Penang Island (Aghamohammadi et al., 2007). The total landfill site area is 63.4 ha, but only 33 ha is currently operational in receiving 2200 ton of solid waste daily. The depth of solid waste is between 10 and 30 m. This site was developed as a semi-aerobic sanitary landfill Level II by establishing a controlled tipping technique in 1991(landfill age >10 years). In 2001, it was upgraded to a sanitary landfill Level III by using controlled tipping with leachate recirculation (Aziz et al., 2004a). This site has a natural marine clay liner. It was developed semi-aerobically and is one of only three sites of its kind in Malaysia. PBLS produces a dark black-green liquid, which can be classified as stabilized leachate with high concentrations of COD and ammonium and a low BOD_5/COD ratio (Mohajeri et al., 2010; Bashir et al., 2009; Halim et al., 2009).

The Kulim Sanitary Landfill is situated in the town of Kulim, Kedah, Malaysia. Its geographical coordinates are 5°23′ N and 100°33′ E. It is surrounded by a palm oil plantation. The total area of the landfill is 56 ha, and receives about 240 ton of municipal solid wastes daily. The depth of solid waste is approximately 20 m. This landfill is equipped with leachate collection facilities. This open dumping site started operating in 1996 (landfill age >10 years) and was upgraded to a sanitary landfill in 2006.

Pulau Burung and Kulim landfills are situated in the North West coast of Peninsular Malaysia which has a tropical climate. The climate is warm and humid during the year. Temperatures range from 21 °C to 32 °C, relative humidity ranging from 70% to 90%, and the average annual rainfall of the area is 2670 mm. The characteristics of solid waste at Pualu Burung and Kulim landfills are illustrated in Table 1.

2.2. Leachate sampling

Leachate samples were collected from the PBLS and Kulim landfill in the northern region of Malaysia. Two samples were taken from the semi-aerobic PBLS, one for the unaerated pond (old leachate) and the other for the intermittently aerated pond (young leachate). One sample was taken from the anaerobic Kulim landfill. The samples were collected from May to November 2009, were immediately transported to the laboratory, and were stored in a cold room at 4 °C prior to use for experimental purposes to minimize biological and chemical reactions.

2.3. Leachate characterization

The samples were characterized in terms of phenols, total nitrogen, ammonia-N, nitrate-N, nitrite-N, total phosphorus, orthophosphorus, BOD_5, COD, BOD_5/COD, pH, EC, turbidity, color, total solids, SS, total iron, zinc, total coliform, and *Escherichia. coli*. The parameter measurements were conducted thrice according to the

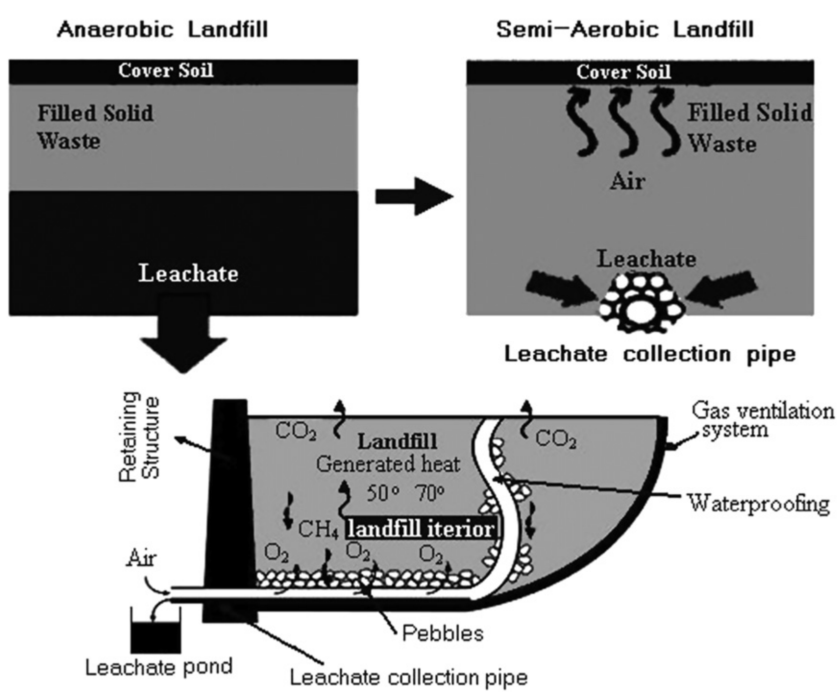

Fig. 1. Schematic diagram of anaerobic and semi-aerobic landfill.

Table 1
Characteristics of solid waste in Pulau Burung and Kulim landfills.

Waste characteristics	Pulau Burung (amount, %)	Kulim (amount, %)
Food	40	45
Plastic	22	24
Paper	10.5	7
Metals	2.5	6
Glass	3.25	3
textile	3.5	–
Others	18.25	15
Total	100	100

Standard Method of Water and Wastewater (APHA., 2005). The obtained parameters values were compared with the data published by previous researchers and the Environmental Quality Act of Malaysia 1974.

3. Result and discussion

Table 2 shows the characterization of leachate and the range and average values for the mentioned parameters at each leachate pond at the semi-aerobic PBLS (unaerated and intermittently aerated) and the anaerobic Kulim landfill.

3.1. General characteristics

3.1.1. Phenols

Many kinds of phenols are in leachate. Forty-one types were measured in three MSW landfill sites in Japan (Kurata et al., 2008). In this research, the 4-aminoantipyrine method was used to measure phenols by determining all ortho- and meta-substituted phenols or naphthols (but not para-substituted phenols). The minimum values of phenols at PBLS (unaerated and intermittently aerated) and Kulim landfill were 0.35, 2.85, and 1 mg/L, respectively. The maximum values were 2.07, 10.5, and 5.25 mg/L, respectively. Typical phenols concentration in both iron foundry waste leachate and paper mill sludge leachate were 0.118 and 0.0011–4.5 mg/L, respectively (Bagchi, 1990). Al-Harazin et al. (1991) investigated the start-up of Sequencing Batch Reactor (SBR) to treat phenol-bearing wastewater. They documented phenol concentrations to be as high as 800 mg/L.

3.1.2. Total nitrogen

The total nitrogen values for collected leachate samples ranged between 200, 700, and 100 mg/L, and 700, 1800, and 600 mg/L at PBLS (unaerated and intermittently aerated) and Kulim landfill, respectively. A wider range (428.2–4368.2 mg/L) was reported for mineral oil landfill leachate with different ages in China (Ziyang et al., 2009), which confirms the present results.

3.1.3. Ammonia-N

The average values of ammonia-N (measured as NH_3-N) for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill were 542, 1568, and 538 mg/L, respectively. Weiner and Matthews (2003) found similar values (500 mg/L) in their study, while other researchers reported results of 1400, 283–2040, and 1200 mg/L, respectively (Aghamohammadi et al., 2007; Rushbrook and Pugh, 1999; Bagchi, 1990). The ranges of 10–800 and 20–40 mg/L were from new and mature landfills, respectively (Tchobanoglous et al., 1993). Typically, the existence of high levels of pollutants such as ammonia-N in landfill leachate over a long period of time is one of the most critical problems usually encountered by landfill operators (Bashir et al., 2010a; Aziz et al., 2004a). This high concentration of untreated ammonia leads to motivated algal growth, decreased performance of biological treatment systems, accelerated eutrophication, promoted dissolved oxygen depletion, and increased toxicity of living organisms in water bodies (Aziz et al., 2004a; Jokela et al., 2002). Bashir et al. (2010a) mentioned that ammonia removal has become an important concern in leachate since its level continues to be dangerous and poisonous over long periods.

3.1.4. Nitrate

For nitrate, ranges of 900–3200, 2900–7900, and 400–2600 mg/L NO_3^--TN were recorded for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill,

Table 2
Characteristics of raw leachate at Pulau Burung and Kulim landfills.

No.	Parameter	Semi-aerobic Pulau Burung site				Kulim site		Standard B
		Unaerated		Intermittently aerated		Anaerobic		Discharge limit[b]
		Range	Average[a]	Range	Average[a]	Range	Average[a]	
1	Phenols (mg/L)	0.35–2.07	1.2	2.85–10.5	6.7	1–5.25	2.6	–
2	Total nitrogen (mg/L N-TN)	200–700	483	700–1800	1200	100–600	300	–
3	Ammonia-N (mg/L NH_3-N)	360–730	542	1145–2150	1568	130–1039	538	–
4	Nitrate-N (mg/L NO_3^--N)	900–3200	2200	2900–7900	5233	400–2600	1283	–
5	Nitrite-N (mg/L NO_2^--N)	44–270	91	20–120	49	30–60	52	–
6	Total phosphorus (mg/L PO_4^{3-}-TNT)	10–43.0	21	10.0–25	17	8.0–40	19	–
7	Ortho-Phosphorus (mg/L PO_4^{3-} mv)	84–274	141	94–210	159	57–197	94	–
8	BOD_5 (mg/L)	67–93	83	146–336	243	135–476	326	50
9	COD (mg/L)	600–1300	935	1680–4020	2345	630–2860	1892	100
10	BOD_5/COD	0.051–0.12	0.096	0.036–0.186	0.124	0.088–0.35	0.205	0.5
11	pH	8.05–8.35	8.20	8.14–8.37	8.28	6.93–8.26	7.76	5.5–9
12	Electrical conductivity (ms/cm)	10.14–13.630	12.17	21.500–22.500	22.10	5.250–13.92	8.55	–
13	Turbidity (FAU)	600–3404	1546	149–211	180	490–4500	1936	–
14	Color (Pt Co)	1944–4050	3334	2310–4390	3347	1950–7475	4041	–
15	Total solids (mg/L)	5138–7404	6271	8860–11084	9925	4520–10568	6336	–
16	Suspended solids (mg/L)	906–2220	1437	374–1372	837	232–1374	707	100
17	Total iron (mg/L Fe)	2–29.5	7.9	0.9–8.8	3.4	0.6–11.4	5.3	5
18	Zinc (mg/L Zn)	0–3	0.6	0.01–2	0.5	0–1	0.2	1
19	Total coliform	–	–	–	<50	$(0.77–0.85) \times 10^4$	0.81×10^4	–
20	*E. Coli*	–	–	–	0.00	$(0.18–0.22) \times 10^4$	0.20×10^4	–

[a] Average value of six samples.
[b] Standard B of the Environmental Quality (Sewage and Industrial Effluents) Regulations 1979, under the Environmental Quality Act of Malaysia, 1974 (MDC Sdn. Bhd., 1997).

respectively. Smaller average values of 14.2 and 14.6 mg/L were recorded by Aghamohammadi et al. (2007) and Salem et al. (2008), respectively. Typical nitrate values of 25 and 5–10 mg/L were recorded for new (less than two years) and mature landfills (greater than 10 years), respectively (Tchobanoglous et al., 1993). Bagchi (1990) reported that the overall range of nitrate in leachate is up to 250 mg/L.

3.1.5. Nitrite

The nitrite figures for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill varied from 44–270, 20–120, and 30–60 mg/L NO_2^--N, respectively. At PBLS, a range of 20–110 mg/L similar to that published by Aghamohammadi et al. (2007) was obtained. Ranges of 0.1–500 and 0.1–20 mg/L were recorded for the transition phase (0–5 years) and acid-formation phase (5–10 years), respectively (Kostova, 2006).

Fig. 2 demonstrates the variation of total nitrogen, ammonia, nitrate, and nitrite at Pulau Burung (unaerated and intemittently aeration) and Kulim landfills, respectively. Biological nitrogen removal is usually accomplished via nitrification and denitrification processes. Nitrification is the biological oxidation of ammonia to nitrite and then to nitrate form; while denitrification is a process in which nitrate is reduced to nitrogen gas by microorganisms in the absence of dissolved oxygen (Spagni and Marsili-Libelli, 2009). As can be seen in Fig. 2, the nitrate value at Pulau Burung (intermittently aeration) is very high compared with the other sites. This may be due to the nitrification process which is resulted by the assistance of aeration.

3.1.6. Total phosphorus

Maximum values for total phosphorus at PBLS (unaerated and intermittently aerated) and Kulim were 43, 25, and 40 mg/L PO_4^{3-}-TNT, while the minimum were 10, 10, and 8 mg/L PO_4^{3-}-TNT, respectively. For new and mature landfills, similar ranges of 5–40 and 5–10 mg/L were recorded, respectively (Tchobanoglous et al., 1993). The same range of 0.62–34.9 mg/L was published by Ziyang et al. (2009) for landfill leachate in China. The result (39 mg/L) of Aghamohammadi et al. (2007) confirms this study's results.

3.1.7. Ortho-phosphorus

Phosphorus in wastewater is predominantly present in the form of (ortho) phosphates, with a minor fraction of organic phosphate mainly in proteins. In biological treatment systems, most organic phosphates are mineralized (Cervantes et al., 2006). Ortho-phosphorus values of leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill varied at 84–274, 94–210, and 57–197 mg/L, respectively. According to Tchobanoglous et al. (1993), the typical values of ortho-phosphorus for new and mature landfills are 20 and 4–8 mg/L, respectively; the present values obtained were greater than (not ready) those reported. A smaller range of 0.19–34.29 mg/L for landfill leachate was published by Ziyang et al. (2009).

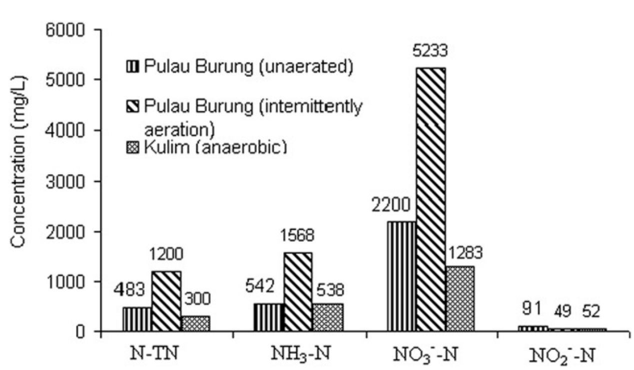

Fig. 2. Concentrations of nitrogen compounds in the landfill leachates.

3.1.8. BOD_5

BOD_5 is the most widely used parameter of organic pollution applied to both wastewater and surface water. The determination of BOD_5 involves measuring dissolved oxygen used up by microorganisms in the biochemical oxidation of organic matter. The standard five-day BOD_5 value is commonly used to determine the amount of organic pollution in water and wastewater (Metcalf and Eddy INC., 2003). In this study, the maximum range of BOD_5 135–476 mg/L was recorded at the Kulim landfill, while the minimum range was 67–93 mg/L recorded at the unaerated PBLS. BOD_5 varies with the age of the landfill. Tchobanoglous et al. (1993) provided two different ranges, 2000–30,000 and 100–200 mg/L, for new and mature landfills, respectively. The present values of BOD_5 agree with those previously recorded (Salem et al., 2008; Aghamohammadi et al., 2007; Aziz et al., 2007; Rushbrook and Pugh, 1999; Bagchi, 1990). Greater BOD_5 value (99–13,900 mg/L) was observed by Canziani et al. (2006); this high variation in BOD_5 value was not due to biochemical processes inside the mass of wastes, but due to the leachate collection systems where the subsurface drainage was active only for the duration of wet weather (Canziani et al., 2006). According to Malaysian standards, the permissible level of BOD_5 is 50 mg/L. Measured BOD_5 values greater than the permissible level of 50 mg/L were also reported in other studies (Abu foul, 2007; Aghamohammadi et al., 2007; Aziz et al., 2007).

3.1.9. COD

The average COD values for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill were 935, 2245, and 1892 mg/L, respectively. The pervious COD values indicate that the leachate in PBLS and Kulim landfill can be classified in methanogenic phase. In this phase, the COD value ranges between 500 and 4500 mg/L (Christensen et al., 2001). According to Kostova (2006), the present COD results are remain within the range of leachate characteristics in methane fermentation phase. The COD values recorded by Jokela et al. (2002) agree with the present COD values. Greater COD values were reported by other researchers (Zhong et al., 2009; Ziyang et al., 2009; Salem et al., 2008; Canziani et al., 2006; Weiner and Matthews, 2003; Rushbrook and Pugh, 1999). This difference in COD values may be due to: landfill design, solid waste composition, climate conditions, site characteristics, and landfill age (Christensen et al., 2001). In the current study, the observed COD values are considerably high. Classically, the toxicological effects of non-biodegradable organic substances (measured as COD) in landfill leachate onto the ecosystem have been presented by Renou et al. (2008) and Christensen et al. (2001). Therefore, further treatment needs to be carried out before discharging, to meet the standard B of the Environmental Quality Regulations 1979, under the Environmental Quality Act of Malaysia, 1974. Where as the effluent COD should be less than 100 mg/L.

3.1.10. BOD_5/COD ratio

The BOD_5/COD average ratios for the collected leachate samples were 0.096, 0.124, and 0.205 at PBLS (unaerated and intermittently aerated) and Kulim landfill, respectively. About 0.11 of BOD_5/COD average ratio was observed in Pulau Burung leachate by Mohajeri et al. (2010). Results ranged from 0.043 to 0.67 have been published by previous researchers and confirm the present ranges of BOD_5/COD (Bashir et al., 2009; Salem et al., 2008; Aghamohammadi et al., 2007; Aziz et al., 2007; Canziani et al., 2006; Weiner and Matthews, 2003). Generally, the BOD_5/COD of young leachate is greater than that derived from stabilization. The low BOD_5/COD ratio indicates that the leachate is stable and difficult to be degraded further biologically (Jokela et al., 2002). Therefore, physico-chemical treatment techniques are particularly recommended for treatment of stabilized leachate (Ghafari et al., 2010; Bashir et al., 2010b; Kurniawan et al., 2006).

3.1.11. pH

The pH figures for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill varied at 8.05–8.35, 8.14–8.37, and 6.93–8.26 respectively. The present pH figures agree with those in previous studies (Zhong et al., 2009; Salem et al., 2008; Bagchi, 1990). A lower pH range of 6.8–7.5 was recorded by Jokela et al. (2002). pH varies according to the age of landfills. For new landfills, pH values are 4.5–7.5; for mature landfills, pH varies from 6.6–7.5 (Tchobanoglous et al., 1993). The measured pH values are within the allowed limit (5.5–9) of the Environmental Quality Act 1974 of Malaysia (Abu foul, 2007; Aghamohammadi et al., 2007; Aziz et al., 2007).

3.1.12. EC

The maximum values of EC for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill were 13.63, 22.5, and 13.92 m s/cm, while the minimum values were 10.14, 21.5, and 5.25 m s/cm, respectively. This was confirmed by the results obtained by Bashir et al. (2010a), Ziyang et al. (2009), Salem et al. (2008), and Bagchi (1990) which were 22250–25060, 6380–41,500, 28,560, and 480–72,500 μs/cm, respectively.

3.1.13. Turbidity

Ranges of 600–3404, 149–211, and 490–4500 FAU were recorded for turbidity at PBLS (unaerated and intermittently aerated) and Kulim landfill, respectively. The leachate at the Kulim landfill contains higher turbidity than in the others. For the semi-aerobic (intermittently aerated) leachate at PBLS, two different turbidity ranges, 418–420 and 268–502 FAU, were obtained by researchers (Ghafari et al., 2010; Aghamohammadi et al., 2007). Turbidity values of unaerated leachate are higher than those of intermittently aerated leachate and are higher for anaerobic than for semi-aerobic. This can be attributed to the effectiveness of aeration process that can reduce the concentration of turbidity. Also, because of the fact that the designed semi-aerobic landfill can leads to improve the quality of leachate (Aziz et al., 2004a).

3.1.14. Color

The minimum values of color at PBLS (unaerated and intermittently aerated) and Kulim landfill were 1944, 2310, and 1950 Pt Co, respectively, while the maximum values were 4050, 4390, and, 7475, respectively. For the semi-aerobic PBLS (intermittently aerated leachate), similar ranges were recorded by previous researchers at 3640–4100 and 4000–4560 Pt Co (Ghafari et al., 2010; Aghamohammadi et al., 2007). However, about 4250–5700 Pt Co was recorded by Bashir et al. (2010b). According to Aziz et al. (2007), the presence of high concentration of color in landfill leachate is due to the presence of high organic substances. Typically, stabilized landfill leachate contains a high molecular weight substances i.e., humic and fulvic compounds which are not easily degradable (Renou et al., 2008; Kurniawan et al., 2006). Nevertheless, in Malaysia, there is no specific standard limitation for color concentration at landfill leachate before discharged.

3.1.15. Total solids

Total solids represent dissolved and SS. The average values of total solids at PBLS (unaerated and intermittently aerated) and Kulim landfill were 6271, 9925, and 6336, respectively. The sum of total dissolved solids and total SS (TSS) of typical leachate ranged from 586–195,900 mg/L (Bagchi, 1990). The present values remain within this range. A smaller figure of 1140 mg/L was recorded by Salem et al. (2008).

3.1.16. SS

The values of SS ranged between 906, 374, and 232 mg/L, and 2220, 1372, and 1374 mg/L, respectively, at PBLS (unaerated and intermittently aerated) and Kulim landfill. The typical ranges of TSS in leachate for new and mature landfills are 200–2000 and 100–400 mg/L, respectively (Tchobanoglous et al., 1993). A wider range of 2–140,900 mg/L was recorded for typical leachate by Bagchi (1990). Smaller SS values of 133, 38–96, 78–80 mg/L were reported at semi-aerobic PBLS leachate (intermittently aerated) by previous researchers (Bashir et al., 2009; Ghafari et al., 2010; Aghamohammadi et al., 2007). Aeration has an affect of decreasing SS in leachate. However, the obtained SS values are greater than the acceptable Malaysian standard level (100 mg/L).

3.1.17. Total iron

Total iron values varied at 2–29.5, 0.9–8.8, and 0.6–11.4 mg/L for PBLS (unaerated and intermittently aerated) and Kulim landfill leachate, respectively. In PBLS, about 0.32–7.5 mg/L of iron was recorded by Aziz et al. (2007), while 6.1–19 mg/L was measured by Aghamohammadi et al. (2007). However, a greater value of 500 mg/L was published by Weiner and Matthews (2003). Total iron concentration in leachate in both sites is higher than the allowed limit (5 mg/L). Aziz et al. (2004b) reported that iron concentration in landfill leachate is typically associated with iron-base material waste, such as construction materials, paints, pigments, color compounds, polishing agents and electrical materials. According to Revans et al. (1999), the concentrations of heavy metals (such as iron) in methanogenic phase are normally lower than the concentrations in acidogenic phase.

3.1.18. Zinc

The average values of zinc for PBLS (unaerated and intermittently aerated) and Kulim landfill leachate were 0.6, 0.5, and 0.2 mg/L, respectively. Greater values (2.06, 0.1–1.8, and 50 mg/L) were reported by previous researchers (Aghamohammadi et al., 2007; Aziz et al., 2007; Weiner and Matthews, 2003). According to Malaysian standards, the concentration of zinc in the landfill leachates is within the acceptable level (1 mg/L). The observed decrease of zinc concentration in leachate is due to the age of landfill where leachate becomes more stabilizers. Habitually, the main source of heavy metals such as zinc in leachate is from raw waste industry. Actually, to date, most of the implemented treatment process in landfill leachate focuses on the removal of organic compounds and ammonia because of its high concentration. However, removal of metals from leachate is not really practiced in the field, especially in Malaysia (Aziz et al., 2004b).

3.1.19. Total coliform and E. coli

Coliforms are defined as including all aerobic and facultative anaerobic, non-spore, forming, and gram-stain negative rods that ferment lactose with gas production within 48 h of incubation at 35 °C (McGhee, 1991; Viessman and Hammer, 1985). The organisms originating from the intestinal tract of warm-blooded animals are called *E. coli* (Bartram and Balance, 1996). The PBLS contained a negligible number of total coliform (<50), and no *E. coli* was found primarily because of a high salt concentration of 14%, as recorded by Umar et al. (2009). The activity of *E. coli* is known to be inhibited by salt concentrations higher than 9% (Tassoula, 1997). The Kuala Sepetang landfill contains a higher concentration of total coliform and *E. coli* ranging at 0.12×10^4–0.16×10^4 and 0.11×10^4,

Table 3
Concentration of some leachate characteristics at different phases (Kostova, 2006).

Leachate Constituents	Transition phase (0–5 years)	Acid-formation phase (5–10 years)	Methane fermentation phase (10–20 years)	Final maturation phase (>20 years)
BOD_5	100–11000	1000–57000	100–3500	4–120
COD	500–22000	1500–71000	150–10000	30–900
TOC	100–3000	500–28000	50–2200	70–260
Ammonia	0–190	30–3000	6–430	6–430
NO_2^--N	0.1–500	0.1–20	0.1–1.5	0.5–0.6
TDS	2500–14000	4000–55000	1100–6400	1460–4640

respectively. The Kulim landfill had the highest concentration of total coliform and *E. coli*, ranging between 0.77 and 0.85×10^4 and 0.18×10^4 to 0.22×10^4, respectively. No standards are available for total coliform and *E. coli* concentrations for discharged wastewaters. Variations in the concentrations of these organisms are probably due to the characteristics of waste, landfill age, and waste handling practices at landfill sites.

3.2. Leachate phases and treatment

Typically, the concentration of leachate parameters changes with the age of the leachate. The phases of leachate are transition (0–5 years), acid-formation (5–10 years), methane fermentation (15–20 years), and final maturation (greater than 20 years). According to Aziz et al. (2007), the age of the landfill is one of the main factors that affect leachate characteristics. The concentrations of some leachate characteristics such as BOD_5, COD, TOC, ammonia-N, NO_2^--N and TDS in different phases are presented in Table 3 (Kostova, 2006). Tchobanoglous et al. (1993) classified new landfills as less than two years old and mature landfills as more than 10 years old. Generally, as a landfill becomes older, the biological decomposition of the deposited wastes shifts from a relatively shorter initial period to a longer decomposition period, which has two distinct sub-phases: acidic and methanogenic. Leachates from these distinct stages contain different constituents; therefore, young leachates tend to be acidic due to the presence of volatile fatty acids. In the current study, the observable parameters concentrations showed considerable variation in leachate characteristics. Actually, this is due to the effects of local climatic conditions on the leachate quality and quantity where Pulau Burung and Kulim landfills are under humid condition with a high intensity of rainfall. Typically, the characteristics of leachate are different from time to time; numerous factors can influence the leachate characteristics such as climatic conditions, solid waste composition, precipitation, bacterial activity, and landfill site characteristics. This study shows that the pollutants concentrations in Kulim landfill leachate are slightly higher than those measured in PBLS. However, this low different is due to the age of both landfill (>10 years). PBLS leachate generated from unaerated landfills can be characterized by methanogenic conditions (stabilized leachate) due to its high pH (>8.2), low BOD_5 concentration, and low BOD_5/COD ratio of 0.096 (Kulikowska and Klimiuk, 2008). The high strength of COD in stabilized leachate indicates that leachate contains humic and fulvic acid, which are not easily degradable. The high amount of ammonia in the methanogenic phase has been identified as a very toxic substance to microorganisms, which typically inhibits the biological degradation process. Thus, biological activity shifts to relative dormancy. Currently, physico-chemical treatment processes such as chemical oxidation, chemical precipitation, coagulation-flocculation, activated carbon adsorption, and membrane processes have been found to be very suitable in removing refractory matters from stabilized leachate. Moreover, physico-chemical treatments can be used as a refining step for biological treatment. However, due to the observed complicated characteristics of Pulau Burung and Kulim leachates, it is very difficult to comply with the desired standard discharge limits by using a single physico-chemical treatment method. Consequently, a combination of different physico-chemical processes or combinations between physico-chemical and biological processes are strongly recommended.

4. Conclusions

Twenty parameters of landfill leachate were investigated in this study for two different landfill sites in the northern part of Malaysia to compare semi-aerobic and anaerobic landfill leachate quality. The results are necessary to formulate a suitable technique for treatment. In this study, aeration has a significant effect on reducing the concentration of several contaminants in PBLS leachate. Therefore, the concentration of these contaminants from leachate collected from the intermittently aerated pond is less than that collected from the unaerated pond. The strength of leachate contaminants at the anaerobic Kulim landfill is greater than that at the semi-aerobic PBLS (unaerated), which may due to the landfill's age. Moreover, Pulau Burung leachate demonstrates low biodegradability (BOD_5/COD = 0.096) compared with Kulim leachate (BOD_5/COD = 0.205). Due to its characteristics, the studied leachate requires treatment to minimize the pollutants to a desirable level prior to discharge into water courses by using a physico-chemical process or a combination of different treatment processes.

References

Abu foul, A.E.M., 2007. Physical-chemical treatment of stabilized leachate using limestone, activated carbone and zeolite. PhD thesis. School of Civil Engineering, University Sains of Malaysia (USM), Malaysia.

Aghamohammadi, N., Aziz, H.A., Isa, M.H., Zinatizadeh, A.A., Nasrollahzadeh, S.H., Ghafari, S., 2007. Performance of a powdered activated carbon (PAC) augmented activated sludge process treating semi-aerobic leachate. Int. J. Environ. Res. 1, 96–103.

Al-Harazin, I.M., Nakhla, G.F., Farooq, S., 1991. Start-up of sequencing batch reactors for toxic wastewater treatment. J. Environ. Sci. Health A 26, 673–687.

APHA., 2005. Standard Methods for the Examination of Water and Waste Water, twenty first ed. American Public Health Association, Washington, DC.

Aziz, H.A., Adlan, M.N., Zahari, M.S.M., Alias, S., 2004a. Removal of ammoniacal-nitrogen ($N-NH_3$) from municipal solid waste leachate by using activated carbon and lime stone. Waste Manag. Res. 22, 371–375.

Aziz, H.A., Yusoff, M.S., Adlan, M.N., Adnan, N.H., Alias, S., 2004b. Physico-chemical removal of iron from semi-aerobic landfill leachate by limestone filter. Waste Manag. 24, 353–358.

Aziz, H.A., Alias, S., Adlan, M.N., Asaari, F.A.H., Zahari, M.S.M., 2007. Colour removal from landfill leachate by coagulation and flocculation processes. Bioresour. Technol. 98, 218–220.

Aziz, H.A., Daud, Z., Adlan, M.N., Hung, Y.-T., 2009. The use of polyaluminium chloride for removing colour, COD and ammonia from semi-aerobic leachate. Int. J. Environ. Eng. 1, 20–35.

Bagchi, A., 1990. Design, Construction, and Monitoring of Sanitary Landfill, first ed. John Wiley & Sons, Inc, New Jersey.

Published on behalf of UNESCO, WHO and UNEP by E&FN Spon an imprint of. In: Bartram, J., Balance, R. (Eds.), Water Quality Monitoring. A Practical Guide to the

Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. Chapman & Hall, 2–6 Boundary Row, London SE1 8HN, UK.

Bashir, M.J.K., Isa, M.H., Kutty, S.R.M., Awang, Z.B., Aziz, H.A., Mohajeri, S., Farooqi, I.H., 2009. Landfill leachate treatment by electrochemical oxidation. Waste Manag. 29, 2534–2541.

Bashir, M.J.K., Aziz, H.A., Yusoff, M.S., Adlan, M.N., 2010a. Application of response surface methodology (RSM) for optimization of ammoniacal nitrogen removal from semi-aerobic landfill leachate using ion exchange resin. Desalination 254, 154–161.

Bashir, M.J.K., Aziz, H.A., Yusoff, M.S., Huqe, A.A.M., Mohajeri, S., 2010b. Effects of ion exchange resins in different mobile ion forms on semi-aerobic landfill leachate treatment. Water. Sci. Technol. 61, 641–649.

Canziani, R., Emondi, V., Garavaglia, M., Malpei, F., Pasinetti, E., Buttiglieri, G., 2006. Effect of oxygen concentration on biological nitrification and microbial kinetics in a cross-flow membrane bioreactor (MBR) and moving-bed biofilm reactor (MBBR) treating old landfill leachate. J. Memb. Sci. 286, 202–212.

Cervantes, F.J., Pavlostathis, S.G., Van Handeel, A.C., 2006. Advanced Biological Treatment Processes for Industrial Wastewaters-Principles and Applications, first ed. IWA Publishing, UK.

Christensen, T.H., Kjeldsen, P., Bjerg, P.L., Jensen, D.L., Christensen, J.B., Baun, A., Albrechtsen, H.-J., Heron, G., 2001. Biogeochemistry of landfill leachate plumes. Appl. Geochem. 16, 659–718.

Davis, M.L., Cornwell, D.A., 2008. Introduction to Environmental Engineering. International Edition, fourth ed. McGraw Hill, New York.

Foul, A.A., Aziz, H.A., Isa, M.H., Hung, Y.-T., 2009. Primary treatment of anaerobic landfill leachate using activated carbon and limestone: batch and column studies. Int. J. Environ. Waste Manag. 4, 282–298.

Ghafari, S., Aziz, H.A., Bashir, M.J.K., 2010. The use of poly-aluminum chloride and alum for the treatment of partially stabilized leachate: a comparative study. Desalination 257, 110–116.

Halim, A.A., Aziz, H.A., Johari, M.A.M., Ariffin, K.S., Hung, Y.-T., 2009. Removal of ammoniacal nitrogen and COD from semi-aerobic landfill leachate using low-cost activated carbon?zeolite composite adsorbent. Int. J. Environ. Waste Manag. 4 (3–4), 399–411.

A practical Guide to Landfill Management in Pacific Island Countries. In: Inland-Based Waste Disposal, vol.1, 2005. Japan International Cooperation Agency (JICA).

Jokela, J.P.Y., Kettunen, R.H., Sormunen, K.M., Rintala, J.A., 2002. Biological nitrogen removal from municipal landfill leachate: low-cost nitrification in biofilters and laboratory scale in-situ denitrification. Water. Res. 36, 4079–4087.

Kostova, I., 2006. Leachate from Sanitary Landfills—Origin, Characteristics, Treatment. University of Architecture, Civil Engineering and Geodesy, "Iskar's Summer School"-Borovetz, 26–29 July.

Kulikowska, D., Klimiuk, E., 2008. The effect of landfill age on municipal leachate composition. Bioresour. Technol. 99, 5981–5985.

Kurata, Y., Ono, Y., Ono, Y., 2008. Occurrence of phenols in leachates from municipal solid waste landfill sites in Japan. J. Mater. Cycles Waste Manag. 10, 144–152.

Kurniawan, T.A., Lo, W.H., Chan, G.Y.S., 2006. Physico-chemical treatments for removal of recalcitrant contaminants from landfill leachate. J. Hazard. Mater. 129, 80–100.

Lin, L., Lan, C.Y., Huang, L.N., Chan, G.Y.S., 2008. Anthropogenic N_2O production from landfill leachate treatment. J. Environ. Manage. 87, 341–349.

Matsufuji, Y., Hanashima, M., Nagano, S., Tanaka, A., 1993. Generation of greenhouse effect gases from different landfill type. Eng. Geol. 34, 181–197.

McGhee, T.J., 1991. Water Supply and Sewerage, sixth ed. McGraw-Hill, Inc., USA.

MDC Sdn. Bhd., 1997. Laws of Malaysia-Environmental Quality Act 1974 and Regulations, fourth ed. Kuala Lumpur, Malaysia.

Metcalf and Eddy INC., 2003. Wastewater Engineering-Treatment and Reuse, fourth ed. Mc Graw-Hill, Inc.

Mohajeri, S., Aziz, H.A., Isa, M.H., Bashir, M.J.K., Mohajeri, L., Adlan, M.N., 2010. Influence of fenton reagent oxidation on mineralization and decolorization of municipal landfill leachate. J. Environ. Sci. Health A 45, 692–698.

Oman, C.B., Junestedt, C., 2008. Chemical characterization of landfill leachates—400 parameters and compounds. Waste Manag. 28, 1876–1891.

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P., 2008. Landfill leachate treatment: review and opportunity. J. Hazard. Mater. 150, 468–493.

Revans, A., Ross, D., Gregory, B., Meadows, M., Harries, C., Gronow, J., 1999. Long term fate of metals in landfill. Sardinia, 99, Seventh International Waste Management and Landfill Symposium, 4–7 October, 1, pp. 199–206.

Rushbrook, P., Pugh, M., 1999. Solid waste landfills in middle-and lower-income countries- a technical guide to planning, design, and operation. World bank technical paper no.426.

Salem, Z., Hamouri, K., Djemaa, R., Allia, K., 2008. Evaluation of landfill leachate pollution and treatment. Desalination 220, 108–114.

Sanphoti, N., Towprayoon, S., Chaiprasert, P., Nopharatana, A., 2006. The effects of leachate recirculation with supplemental water addition on methane production and waste decomposition in a simulated tropical landfill. J. Environ. Manage. 81, 27–35.

Spagni, A., Marsili-Libelli, S., 2009. Nitrogen removal via nitrite in a sequencing batch reactor treating sanitary landfill leachate. Bioresour. Technol. 100, 609–614.

Tassoula, E.A., 1997. Growth possibilities of E.coli in natural waters. Int. J. Environ. Stud. 52, 67–73.

Tatsi, A.A., Zouboulis, A.I., Matis, K.A., Samaras, P., 2003. Coagulation-flocculation pretreatment of sanitary landfill leachates. Chemosphere 53, 737–744.

Tchobanoglous, G., Theisen, H., Vigil, S., 1993. Integral Solid Waste Management Engineering Principles and Management Issues, first ed. Irwin/McGraw- Hill., USA.

Umar, M., Aziz, H.A., Yusoff, M.S., 2009. Enumeration of total coliform and E.coli in landfill leachate: a review. The 1st Regional Conference on Geo-Disaster Mitigation and Waste Management, Kuala Lumpur, 3–4 March, Malaysia.

Uygur, A., Kargi, F., 2004. Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor. J. Environ. Manage. 71, 9–14.

Viessman Jr., W., Hammer, M.J., 1985. Water Supply and Pollution Control, fourth ed. Happer &Row, Publishers, NewYork.

Weiner, R.F., Matthews, R., 2003. Environmental Engineering, fourth ed. Butterworth Heinemann.

Wiszniowski, J., Surmacz-Gorska, J., Robert, D., Weber, J.-V., 2007. The effect of landfill leachate composition on organics and nitrogen removal in an activated sludge system with bentonite additive. J. Environ. Manage. 85, 59–68.

Yamamoto, O., 2002. Solid waste treatment and disposal experiences in Japan. In: Proceedings of International Symposium on Environmental Pollution Control and Waste Management (EPCOWM'2002), Tunis, pp. 417–424.

Zhong, Q., Li, D., Tao, Y., Wang, X., He, X., Zhang, J., Zhang, J., Guo, W., Wang, L., 2009. Nitrogen removal from landfill leachate via ex situ nitrification and sequential in situ denitrification. Waste Manag. 29, 1347–1353.

Ziyang, L., Youcai, Z., Tao, Y., Yu, S., Huili, C., Nanwen, Z., Renhua, H., 2009. Natural attenuation and characterization of contaminants composition in landfill leachate under different disposing ages. Sci. Total. Environ. 407, 3385–3391.