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

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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 2.5 mg/L), total nitrogen (448, 1200, and 300 mg/L N-TN), ammonia-N (542, 1568, and 538 mg/L NH₃-N), nitrite (91, 49, and 52 mg/L NO₂⁻-N), total phosphorus (21, 17, and 19 mg/L), BOD₅ (83, 243, and 326 mg/L), COD (935, 2345, and 1892 mg/L), BOD₅/COD (0.096, 0.1124, 0.205%), pH (8.20, 8.28, and 7.76), turbidity (1546, 180, and 3034 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 (Wiszniewski 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 (BOD₅), 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...
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°23’ 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 BOD5/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 Pulau 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, BOD5, COD, BOD5/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.](image-url)
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-aminopyrimidine 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 0.35, 2.85, and 1 mg/L respectively (Bagchi, 1990).

#### 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 NH3-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 NO3-TN were recorded for leachate at PBLS (unaerated and intermittently aerated) and Kulim landfill.
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 NO2-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 intermittently aerated) 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 aerated) 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 PO4-P, 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).

3.1.8. BOD5

BOD5 is the most widely used parameter of organic pollution applied to both wastewater and surface water. The determination of BOD5 involves measuring dissolved oxygen used up by microorganisms in the biochemical oxidation of organic matter. The standard five-day BOD5 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 BOD5 135–476 mg/L was recorded at the Kulim landfill, while the minimum range was 67–93 mg/L recorded at the unaerated PBLs. BOD5 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 BOD5 agree with those previously recorded (Salem et al., 2008; Aghamohammadi et al., 2007; Aziz et al., 2007; Rushbrook and Pugh, 1999; Bagchi, 1990). Greater BOD5 value (99–13,500 mg/L) was observed by Canziani et al. (2006); this high variation in BOD5 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 BOD5 is 50 mg/L. Measured BOD5 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 previous COD values indicate that the leachate in PBLs and Kulim landfill can be classified in methaneogenic 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. BOD5/COD ratio

The BOD5/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 BOD5/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 BOD5/COD (Rash 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 BOD5/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).

### 3.11. 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 (Aziz et al., 2004a).

### 3.11.14. Color

The presence of high concentration of color in landfills Pt Co was recorded by Bashir et al. (2010b). According to Aziz et al. (2004a), color 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$^4$.

### 3.11.15. 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).

### 3.11.16. 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 SS 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).

### 3.11.17. Total iron

Total iron values varied at 2–29.5, 0.9–8.8, and 0.6–114 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.

### 3.11.18. 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).

### 3.11.19. 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 reported 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$^4$. 

### 3.11.2. 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, 6380–41500, 28560, and 480–72500 µs/cm, respectively.

### 3.11.3. Turbidity

Ranges of 600–3400, 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).

### 3.11.4. 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 (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.
According to Aziz et al. (2007), the age of the land handling practices at landfills is probably due to the characteristics of waste, landfills, and variations in the concentrations of these organisms are 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), 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 BOD₅, COD, TOC, ammonia-N, NO₃-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: acid 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 difference 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 BOD₅ concentration, and low BOD₅/COD ratio of 0.096 (Kuikowska 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 of the semi-aerobic PBLS (unaerated), which may due to the landfill’s age. Moreover, Pulau Burung leachate demonstrates low biodegradability (BOD₅/COD = 0.096) compared with Kulim leachate (BOD₅/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.

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