Jurnal Rekayasa Kimia dan Lingkungan
Vol. 9, No. 4, Hlm. 152 - 157, Desember 2013
ISSN 1412-5064
DOI: http://dx.doi.org/10.23955/rkl.v9i4.1227

Feasibility of In-Situ Aeration of Old Dumping Ground for Land Reclamation

Kelayakan Aerasi In-Situ pada Bekas Pembuangan Sampah untuk Reklamasi Lahan

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Abstract

Dumping grounds are characterized by the absence of engineering controls such as base liners and cover layer. Consequently, these dumping grounds present risks for surrounding resources such as soil, groundwater, and air. The concern for groundwater contamination by leachate from tropical dumping grounds is heightened because of greater amounts of rainfall and subsequent infiltration and percolation through the waste mass. The emergent demand for old dumping grounds reclamation drives the need to employ remediation technologies. Generally, in-situ aeration is a remediation method that promotes aerobic conditions in the later stage of dumping ground. It accelerates carbon transfer, reduces remaining organic load, and generally shortens the post closure period. However, high rainfall in tropical areas straitens this technique. For example, pollutants could be easily flushed out and more energy should be required to overcome hydrostatic pressure. Although heavy rainfall could supply sufficient water to the substrate and accelerate degradation of organic matter, it may inhibit aerobic activities due to limited air transfer. The waste characterization from Lorong Halus Dumping Ground (closed dumping ground in Singapore) showed that the waste materials were stabilized after 22 years closure. According to the Waste Acceptance Criteria set by European Communities Council, the waste materials could be classified as inert wastes. One interesting finding was that leachate layer detected was about of 5 - 8 meter depth, which entirely soaked the waste materials. Hence, the reclamation design and operation should be carefully adjusted according to these characters. Lorong Halus Dumping Ground case study can provide a guideline for other tropical closed landfills or dumping grounds.

Keywords: dumping grounds, *in-situ* aeration, leachate, tropical, land reclamation

Abstrak

Sistem pembuangan sampah terbuka umumnya tidak dilengkapi dengan sistem pengendalian pencemaran seperti lapisan dasar dan lapisan penutup. Akibatnya, sistem pembuangan terbuka ini menimbulkan resiko terhadap kerusakan tanah, air bawah tanah, dan udara. Kekuatiran pencemaran air bawah tanah oleh lindi di pembuangan sampah terbuka di daerah tropis meningkat karena tingginya curah hujan yang dapat berinfiltrasi, dan perkolasi melalui tumpukan sampah. Permintaan reklamasi lahan pembuangan sampah terbuka mendorong kebutuhan teknologi remediasi. Secara umum, aerasi in-situ adalah metode remediasi untuk menciptakan kondisi aerobik pada lahan pembuangan sampah terbuka. Metode ini dapat mengakselerasi degradasi senyawa karbon, mengurangi kandungan bahan organik, dan mempersingkat periode pemeliharaan pasca penutupan untuk mempercepat penggunaan lahan. Namun curah hujan yang tinggi di daerah tropis membatasi penerapan metode ini. Sebagai contoh bahan pencemar dapat terbilas keluar sehingga diperlukan energi yang lebih besar untuk mengembalikan tekanan hidrostatis. Meskipun curah hujan yang tinggi dapat mencukupi kebutuhan air untuk akselerasi degradasi senyawa organik, kondisi ini dapat menghambat aktivitas aerobik karena terbatasnya transfer udara. Karakteristik sampah dari tempat pembuangan terbuka Lorong Halus (tempat pembuangan terbuka di Singapura) menunjukan sampah terstabilisasi 22 tahun pasca penutupan. Berdasarkan kriteria kelayakan yang diatur oleh Masyarakat Uni Eropa material sampah harus tidak reaktif. Salah satu temuan menarik adalah lapisan lindi terdeteksi pada kedalaman sekitar 5 - 8 meter dan membasahi material sampah. Oleh karena itu, desain reklamasi dan desain operasi harus disesuaikan dengan cermat menurut karakternya. Temuan di lahan pembuangan terbuka Lorong Halus dapat menjadi acuan untuk tempat pembuangan sampah tertutup atau terbuka di daerah tropis lainnya.

Kata kunci: aerasi *in-situ,* daerah tropis, lindi, pembuangan terbuka, reklamasi lahan

1. Introduction

Landfill is still the most popular disposal route for the majority of solid waste, due to its low cost and ease of operation. However, landfilling is fundamental. First, traditional landfills require long-term aftercare, which is a heavy financial and environmental burden. Second, landfills are aesthetically unpleasant and result in considerable wastage of land. Therefore, landfill reclamation is increasingly attracting attention. The foremost concern about landfill rehabilitation is the health and safety issue of the future users on the reclaimed land. Prior to any redevelopment work, contaminant cleanup measures should be carried out to allay the health and safety risks from landfill. Remediation approaches include landfill capping, landfill gas venting, leachate pump and treat, landfill mining, in situ aeration, etc.

Unlike the “end of pipe” techniques, in situ aeration reduces polluting potential of the decaying waste. During in-situ aeration, air is compressed into the waste layer through gas injection wells. After the oxygen is utilized by the microbes, the exhausted gas is collected and treated. Under aerobic condition, increased waste decomposition, accelerated settlement, reduced leachate strength and enhanced carbon discharge via gas phase could be achieved (Ritzkowski *et al*., 2006). The aeration cost could be offset by earlier reuse, less strict requirement for subsequent capping and sealing system, and lower expenditure with decontamination (Heyer *et al*., 2005).

In our case study, Lorong Halus Dumping Ground (LHDG) is the largest closed dumping ground in Singapore. In the past, it was allocated on the boundaries of towns and villages. However, due to population growth and urbanization, it has been engulfed by rapid development. In small and densely populated Singapore, LHDG represents a significant portion of vacant urban land for further development. A research project was launched in 2010 to develop and demonstrate complementary technologies for rapid LHDG reclamation. In situ aeration recommended a promising technique to accelerate waste stabilization, which could pave the way for potential redevelopment into commercial, industrial, or even residential use. However, a comprehensive site characterization is necessary before any reclamation work. The objective of this study was to characterize LHDG waste stability, and to investigate the feasibility of in situ aeration on site. Also, this paper addresses technical challenges including leachate management.

2. Method

2.1. Application Site

The dumping ground was broken into 5 different segments according to different operational periods. The development of complementary technologies and subsequent test bedding and demonstration will be conducted at Phase III plot of the LHDG (Figures 1 and 2). Phase III covers an area of 44 hectares, with the operational lifetime from 1983 to 1989. It was formerly a mangrove swamp, with Sungei Serangoon meandering through it. As an uncontrolled dump site, it has no liner or leachate collection system in place. Due to the operation of incinerators in 1979 and infrastructure expansion in the late 1970s, the main component of deposited waste gradually shifted from domestic wastes to inorganic wastes, which includes construction and demolition (C&D) waste and incineration bottom ash.

2.2. Material Characterization

The waste material collection from LHDG was through field drilling from 23rd July 2011 to 28th August 2012. Seven boreholes (designated BH1 to BH7) with a termination depth of 30 m were drilled in order to characterize the subsurface soil layers, subsurface liquid (leachate) and landfill gas. Solid samples collected from field work were stored in cooler boxes on site and transported to the laboratory. After material collection, the boreholes were converted into monitoring wells (designated MW1 to MW7) for further monitoring. Also, leachate samples were withdrawn from the seven monitoring wells and then transferred to lab for further analysis. In-situ measurements of landfill gas quality were conducted concurrently at the end of leachate sampling by portable gas analyzer.

2.3. Analysis

Leachate samples were analyzed including pH, ammonia nitrogen (NH_3-N), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) values. All analyses were performed according to the relevant methods described in the Standard Methods of APHA. The gas composition (CO_2, CH_4, and O_2) in the headspace was measured as a volume percentage by using a landfill gas analyzer (Sewerin, Multitech 520).

The biological stability of solid waste was one of the main issues related to the evaluation of the long-term emission potential and environmental impacts of landfill. Apart from measuring the composition of landfill gases and the strength of leachate, analysis of waste biostability was also carried out through respiration index experiment (RI_4) and leaching test. According to Binner's study, the waste fraction < 20 mm was representative for biological parameters (respiration activity, gas-production potential) and leaching (Binner and Zach, 1999). The waste materials were sieved and the fraction < 20 mm was used for the tests.

RI_4 (mg O_2/g DM) is defined as the cumulative oxygen consumption in 4 days, which was measured by Oxitop IS 6 system (WTW). Fifty gram dry material (DM) was put into the reaction bottle, and wetted to optimized water content (50%). The sample was stirred at a constant temperature (20°C) for 4 days. The CO_2 produced by microbiological activity was removed by sodium hydroxide tablets. The negative pressure resulted from oxygen utilization was recorded by Oxitop controller.

Leaching tests were conducted at liquid to solid ratio (L/S) of 10. A tested sample, with a dry weight of 0.900 kg was put into the reaction bottle. The volume of leaching fluid was added according to calculations. The sealed reaction bottle was then agitated for 24 ± 0.5 h. The eluate was filtered through 0.4 μm membrane filter and stored at 4°C for future analysis. Ion chromatography was used for analysis of common anions (F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, and Br^-) (Dionex). The analyses of Ni, Cd, Pb, As, and Zn were carried out in a inductively coupled plasma (ICP-MS).

Figure 1. Location of LHDG

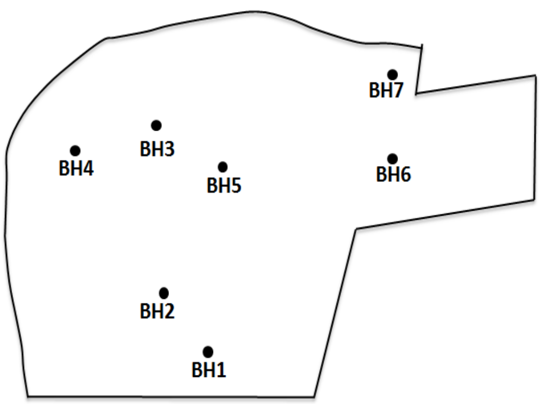

Figure 2. Location of 7 boreholes in LHDG Phase III

3. Results and Discussion

3.1. Respiration Index (RI_4) and Leaching Test

The results for RI_4 and leaching test are tabulated in Table 1. European Communities Council has set out the criteria for the acceptance of the waste in inert, non-hazardous and hazardous landfill (European Commission, 2003). Most values from the leaching tests were below the target values of inert waste. Although the Cl^- and SO_4^{2-} were slightly higher than the target values of inert waste, they were far below the target values of non-hazardous waste. Therefore, it can be safely concluded that the LHDG waste can be classified as inert waste.

Termination criteria of in situ aeration are used to define an endpoint of aeration practice (Ritzkowski *et al.*, 2006). The limit value for RI_4 is set to 5 mg O_2/g DM, and the eluate criteria resemble the Appendix II of the German Waste Disposal regulation (AbfAblV, 2001). All the values of the detected parameters were below the relative threshold. This indicates that the readily biodegradable organic materials had already been decomposed in the previous stage. Moreover, the residual non-biodegradable or slowly biodegradable organic materials in LHDG were beyond the capability of in situ aeration.

3.2. Field Data

The global parameters in leachate and gas are listed in Table 2. Carbon dioxide (CO_2) and methane (CH_4) are the principal gases produced during the anaerobic decomposition of the organic solid waste components. The concentration of CO_2 and CH_4 is 60% and 40% in typical methanogenic phase. The gas concentration in MW1~MW4 was into the range for the typical data in a matured landfill. Since the gas generation rate around MW5~MW7 was quite low, oxygen intrusion via atmosphere began. That was also the main reason of high oxygen level in those three boreholes.

Table 1. Waste characterization (results of eluates and biological tests) and criteria

Sources		R14 MgO_2/g DM	Leaching Test													
			mg/L								μg/L					
			F-	Cl	NO_2^-	NO_3^-	SO_4^{2-}	Br^-	NH_4^+	COD	Cd	Cr	Cu	Pb	Zn	Ni
BH1-T	8-9m	0.82	0.27	19.18	0.24	0.15	61.50	0.00	0.10	72.00	2.02	4.13	21.35	19.33	43.09	7.49
BH1-B	12-13 m	0.03	0.17	11.41	0.00	0.00	509.49	0.20	1.21	44.00	1.54	3.44	11.87	20.93	17.93	4.37
BH2-T	12-13m	0.93	0.28	39.96	0.00	0.00	884.27	0.81	10.50	108.00	2.53	4.44	45.45	20.26	110.26	5.58
BH2-B	15-17m	0.95	0.48	150.95	0.00	0.00	403.98	0.54	5.80	117.00	1.48	1.78	26.74	3.85	59.52	3.38
BH3-T	9-10m	0.64	0.32	43.89	0.44	3.54	100.58	0.00	4.41	157.00	NA	3.12	106.13	18.86	23.54	4.71
BH3-B	14.5-15m	0.22	0.59	204.60	0.00	2.09	508.00	0.00	74.40	449.00	0.65	5.64	267.73	41.69	458.06	31.07
BH4-T	6-7m	1.76	0.19	21.04	0.17	0.71	230.03	0.51	14.80	46.00	2.47	5.77	26.39	13.47	43.95	18.02
BH4-B	11-12.5m	1.13	0.28	39.31	0.00	0.53	368.46	0.34	15.40	65.00	1.58	3.90	18.44	15.85	36.52	4.49
BH5-T	11-11.5m	N.A.	0.26	32.31	0.23	1.48	223.89	0.74	5.76	55.00	0.73	1.10	22.42	3.68	13.48	4.61
BH5-B	15-15.5m	0.34	0.13	22.53	0.40	2.19	96.29	0.00	7.02	51.00	0.19	0.77	42.75	9.40	14.45	4.57
BH6-T	8-9m	N.A.	0.24	10.13	2.35	25.46	62.39	0.00	5.18	43.00	0.13	0.51	14.45	2.78	9.32	6.35
BH6-B	11-12m	0.65	0.35	7.93	0.00	0.40	160.93	0.00	0.09	15.00	0.40	0.38	8.84	0.31	14.77	5.27
BH7-T	9-10m	0.64	0.25	119.90	17.92	17.78	129.83	0.66	1.12	50.00	1.42	0.91	12.42	N.D.	31.53	4.14
BH7-B	11-12m	0.45	0.25	290.42	0.00	0.80	213.68	1.40	11.80	124.00	3.89	17.40	39.21	0.27	29.19	26.89
Aeration Termination		5.00							200.00		100.0	100.0	5000.0	1000.0	5000.0	1000
Inert[b]			0.90	72.00			90.00				4.0	50.0	200.0	50.0	4000.0	40.0
Non-hazardous[b]			13.50	1350.0			1800.0				1000	10000	50000	10000	50000	10000

[a]Criteria of termination of in situ aeration measures, which were proposed by Ritzkowski *et al* (2006)
[b]Limit values for waste acceptable at this class of landfills, which were proposed by European Council (1999)

Table 2. Field data from seven boreholes

Well No	MW1	MW2	MW3	MW4	MW5	MW6	MW7
CH_4 %	50.3	61.2	68.8	61	0.6	0.3	18.1
CO_2 %	27.3	40.3	16.1	39.8	0.1	0.4	0.2
O_2 %	4	0.1	0.9	0.11	15.2	20	16.5
pH value	6.8	7	6.7	6.9	8.8	7	6.8
BOD (mg/L)	32.2	20.4	5.46	21.6	7.38	7.78	11.6
COD (mg/L)	310.1	380.1	N.D.	300.1	60	N.D.	210
BOD/COD	0.10	0.05	0	0.07	0.12	0	0.05

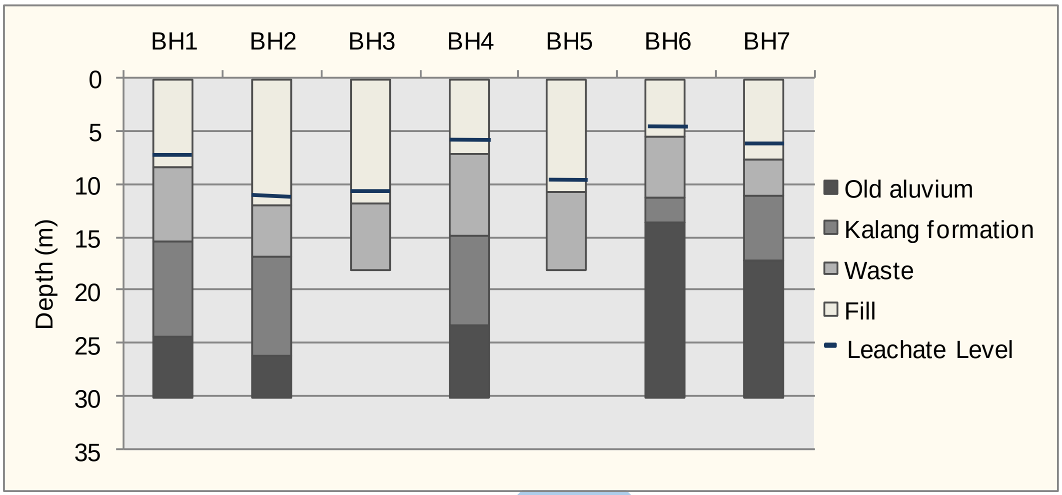

Figure 3. Subsurface soil profile and leachate level in 7 boreholes of LHDG

After more than two decades of post-closure, it was highly unlikely that LHDG was still in the active period. This can be inferred by the neutral pH of the leachate. Furthermore, the BOD/COD ratio was less than 0.10 suggesting that it was moving towards stabilization, since the BOD/COD ratio is often in the range of 0.05 to 0.2 in the mature landfill (Tchobanoglous *et al.*, 2003). It is believed that the rate of landfill gas generation will be diminished gradually, but it can last decades. Meanwhile, the leachate accumulates humic and fulvic acids, which are difficult to further process biologically. Hence, collection and treatment measure-ments should be continuously conducted, although the substrate left is slowly biodegradable.

3.3. Implication

Several successful in situ aeration projects have been reported worldwide, especially in European countries (Cossu *et al.*, 2003; Jacobs *et al.*, 2003). Laboratory simulation and full-scale in situ aeration systems have provided useful information on the performance and procedures of aeration technique (Rich *et al.*, 2008). However, there have been no studies on the application of in situ aeration in tropical area.

In addition, Figure 3 presents the LHDG different layers of subsurface soil and leachate level in each of the 7 boreholes. The waste depth was in a range of about 5 to 12 m depth. Below the waste layer, the soil profile changes from Kallang followed by Old Alluvium formation. The Kallang formation consists of both marine and terrestrial deposits that are found in onshore incised valleys, offshore and coastal areas. Old Alluvium is made of gravel and loose quartz-feldspar sand with infrequent findings of weak sandstone and conglomerate (Pitts, 1984).

The entire waste layer was soaked by the elevated leachate level. The leachate mounded up to the fill layer (the mixture of sand, clay, and gravel). This leachate mounding was mainly caused by low hydraulic conductivity of underlying clay (5x 10^{-5} cm/s) and heavy annual rainfall (2400 mm/year) (MW report, 1997; Tan *et al.*, 2007). In order to employ in situ aeration technique in tropical landfill, specific research is needed on the implementation of in situ aeration on leachate mounding landfills. Future work is focused on the effects of leachate mounding on in situ aeration performance for tropical climate and waste conditions.

4. Conclusion

The waste materials collected from LHDG were characterized. The results from RI_4 and leaching test showed that the buried materials were inert and stabilized. Moreover, low BOD/COD ratio (< 0.1) in the leachate were also indicative of advanced waste decomposition. LHDG as well as most dumping grounds in tropical area are exposed to high precipitation, which results in leachate mounding problems. Elevated leachate level could increase lateral seepage and cause problems during in situ aeration. For this purpose, future study will be on the leachate mounding during in situ aeration of closed tropical landfills.

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