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LANDFILL GAS FOR ENERGY: ITS STATUS AND PROSPECT IN INDONESIA

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Abstract

Indonesia, a nation with more than 230 million population, is the world's largest archipelagic state located between Asia and Australia continents. In 2000, the production of municipal solid waste (MSW) or refuse in 384 Indonesian cities was about 80,235 tons or 320,940 m^3 per day. Refuse generation is predicted to increase five times by 2020. Waste composition is influenced by external factors, such as geographical location, the population's standard of living, energy source, and weather. Generally, a high percentage of organic matter of refuse is between 61 and 72 per cent by weight. The presence of paper, plastic, glass, and metal ranges from 0.4 to 13 per cent. The current handling of refuse in Indonesia is mostly used the disposal land of unhealthy landfill in the form of open dumping. Around 450 units of open dumping have been in operation in Indonesian big cities. These open dumping landfills cause some problems ranging from odor to health problems. Center of Environmental Technology, BPPT has been preparing to carry out landfill mining both for its compost and gas. The gas sampling must be done first before it is pumped for energy use. The gas is suggested to be utilized for generating energy, for example for electricity. Initial test indicated that the composition of methane gas (CH_4) is around 50%, which is a good enough for energy generation. If the percentage of burnable gas is too low to be used for generating electric energy, it might be mixed with high content of heating value of natural gas (dual fuel system). This paper will present the conditions of open dumping of landfill in Indonesia, and the status and the distribution of its containing gas. From this knowledge of the amount and distribution of landfill gas, it will be analyzed for suggestion how the mined gas will be suitably utilized by the people.

***Keywords**: landfill, municipal solid waste (MSW), refuse, biogas, methane, carbon dioxide, open dumping, reduce, reuse, recycle.*

1. INTRODUCTION[1]

Indonesia, officially called the Republic of Indonesia, is a nation of about 17,500 islands positioned between Asia and Australia continents. It is the world's largest archipelagic state with population more than 230 million people, the world's fourth most populous country. The capital of Indonesia is Jakarta and the country shares land borders with Papua New Guinea, East Timor, and Malaysia, and sea borders with Singapore, the Philippines and Australia.

Indonesia consists of 33 provinces with 450 regencies/cities. The accelerated Indonesian national development has produced not only prosperity but also an environmental impact, especially caused by lack of municipal solid waste (MSW) management and industrial waste treatment.

From 1971 to 1996 (25 year period), the Indonesian population had increased twice, that was 119.20 million people to 198.20 million; respectively. Currently, its population is becoming more than 230 million people. The increased economic activities in the cities have caused the increased number of urbanization from the rural areas.

At present, municipal solid waste (MSW) or refuse management system in Indonesia cannot be separated from the role of the final disposal facilities. Most refuse in Indonesia is disposed into the landfill, and only little of it is reduced, reused and recycled (3R). The common problem faced by Indonesian cities in terms of disposal facility is that the operated landfill for refuse disposal is open dumping system and only a few is controlled landfill system. The open dumping landfill cost cheaper than that of sanitary landfill. With the use of most of all existing open dumping landfill systems, the gaseous collection and recovery facilities are not provided. As a result, the generated landfill gas or often called biogas containing mostly methane (CH_4) and carbon dioxide (CO_2) as a result of biodegradation process of organic matter in the landfill has not been recovered or even measured. This type of system, if it is allowed to operate, will cause the negative impact on the environment due to the green house gas effect of the CH_4 and CO_2 as well as the health effect of other emitted toxic gases. Ventilation for capturing and controlling the generated landfill gas is one of the facilities required by a good and healthy final disposal of *sanitary landfill*. The other important facility required by sanitary landfill is the treatment of liquid waste drainage produced.

Globally, landfill gas consisting of CH_4 and CO_2 is considered as green house gases (GHGs). In 2006, Inter-Governmental Panel on Climate Change (IPCC) reported that emission of CH_4 from refuse management sector contributes 3-4% of the global GHGs emission. The value of Global Warming Potential (GWP) of CH_4 molecule itself is believed to be 21 times of that of CO_2 molecule[1)]. Locally, the uncontrolled biogas production from the landfill has the potency to develop explosion and burning.

Currently there are around 460 open dumping landfills in Indonesia that are not supported with suitable gas ventilation system. The refuse generation rate in Indonesia is around 0.5 to 0.65 kg/person/day, and 60–70% of it is biodegradable material[2)]. From several research data indicated that only about 40-60% of generated refuse in each city of Indonesia is sent to the legal landfill, and the rest of it is illegally disposed and openly burned at area close to community backyard. Only very little refuse is reduced, reused and recycled. In order to regulate the refuse management in Indonesia it is required regulation in the form of Law. Up to until now, there has not been officially available such a law that can be used for guiding the refuse management in Indonesia. However, the draft of that kind of law has actually been prepared by the Government of Indonesia and it has now being reviewed and finalized by Legislator. Hopefully, by the end of 2007 the draft will finally be approved by Legislative Body as an official Law of municipal solid waste management in Indonesia. One of the important content of the drafted Law said that since five years to come after it is officially signed and enforced, all the existing open dumping landfills must be closed and changed with sanitary ones. If it is implemented, the ventilation infrastructure of the gas of the sanitary landfill must be provided. The handling system of environmentally friendly landfill gas is needed for open dumping landfills after their closure. Then, the design and implementation of new sanitary landfills must be carried out, instead. Due to the important benefit of landfill methane gas (CH_4) to be converted into electric energy or other forms of energy use, as well as for

CDM program, the gas measurement from the existing landfill in Indonesia is now necessary to be carried out.

Research on how high the biogas generation from Indonesia landfills has rarely been done. Only several Indonesian and foreign institutions have carried out the research on the purpose of clean mechanism development (CDM) program. However, they have not done direct measurement of the emitted gas but by estimation from the carbon content of the existing compost. Meanwhile in this year 2007, the Center of Environmental Technology, BPPT has prepared to carry out the direct landfill gas measurement. At first, the landfill at Piyungan, Yogyakarta has been chose as a starting point. In the following years the Center will cooperate with the Research and Development Agency, Ministry of Public Work to extend the landfill gas measurement to other landfills around the country in order to gain enough data for knowing how the potential of the landfill gas is. Thus, it is necessary to report in this event the results of initial measurement in terms of the potential and distribution of the landfill gas in Indonesia.

2. FORMATION AND COMPOSITION OF LANDFILL GAS

Landfill gas generation and composition is influenced by several factors such as waste composition, availability of oxygen, water content, pH, availability of nutrients, size and compactness of the waste. Waste composition will determine the content of nutrients whereas pH and redox potential will importantly contribute on gas generation. The process to generate landfill gas is actually microbiological decomposition of organic material.

Degradation process of organic material of the refuse results gases consisting mostly of the mixture between CH_4 and CO_2 (also called biogas or landfill gas). The simplified reaction of the degradation is shown in the following equation[3].

$$\begin{aligned} &Organic\ waste + H_2O + nutrient \xrightarrow{microbes} \\ &CH_4 + CO_2 + NH_3 + H_2S + \\ &biomass + heat + resistant\ organic matter \end{aligned}$$

The microbial degradation of the refuse organic matter takes very slow in which CH_4 and CO_2 generation follows a first order decay model. At relatively stable condition, CH_4 generation rate depends upon the carbon content of the refuse. Consequently, the amount of CH_4 in the landfill will be high in the beginning years and gradually goes down afterwards. The first order decay emission model of the landfill gas is formulated as the following equation [4].

$$V_t = V_0\ e^{-kt}$$

where;

V_t = gas generation rate at time t (g/s)

V_0 = gas generation rate at time 0 (g/s)

t = time (s)

k = degradation constant of first order decay

= $0,69/\ t_{1/2}$

$t_{1/2}$ = half-life time (s)

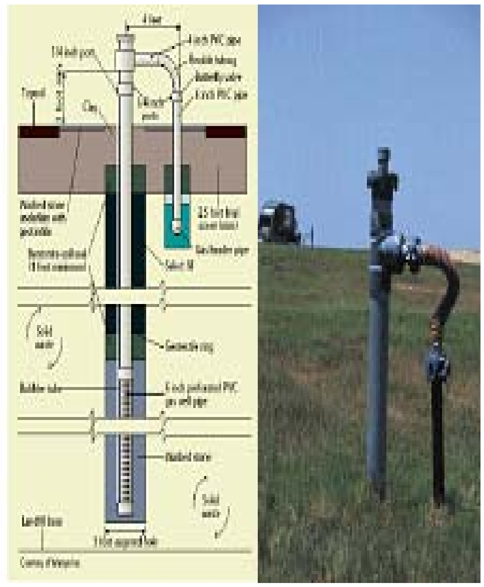
Landfill condition in Indonesia is mostly wet because of rain as well as its composition of 60-70 per cent degradable organic material. It is hypothetically predicted that refuse landfill in Indonesia is very potential in generating a high enough concentration of methane gas.

3. MEASUREMENT METHOD

Measurement of landfill gas rate is best done continuously in a long enough time and through a collection and ventilation system prepared before the landfill is discharged. Since all Indonesian landfills are open dumping and there is no collection and ventilation system, the extraction well at the point of measurement is first made. The piping system to vent the emitted gas is then installed. After that, the gaseous measurement is performed through extraction well ventilation pipe either passively or actively (with the support of induced vacuum pump). Landfill gas concentration and composition as well as temperature and humidity are measured by a portable gas analyzer. Several secondary data are required to support the result of the measurement, such as (i) volume of the refuse, (ii) composition and characteristic of the refuse, (iii) sampling point of the gaseous measurement, and (iv) operational data of landfill.

The technique used for landfill gas measurement done by the Center follows US-EPA method-2E. Basically, the landfill gas measurement is done through a passive system which the driving force uses the pressure of its gases inside the landfill, or through an active system which the driving force uses the help of the induced vacuum pump or blower. The vertical venting pipe is prepared either with PVC, HDPE, fiberglass or SS with 100-150 mm diameter. The gas is normally sucked via a sampling port pipe of 12 to 18 mm diameter. The perforated venting pipe is circularly covered with gravel with final cover layer of 12 to 30 cm depth of clay. During the sampling, the condensate trap is required to avoid the damage of the gas analyzer due to moisture. The typical gas recovery well is shown in the Figure 1.

Before landfill gas recovery is carried out, its concentration must be measured in order to decide whether or not it is feasible to be mined and recovered. Therefore, it needs to set up an appropriate sampling train with a standard sampling method. Portable and continuous gas analyzer that is capable to measure CH_4, CO_2, O_2 in per cent is employed. For landfill without gas recovery infrastructure, the drilling into the landfill as deep as the thickness of the refuse layer is also carried out. Then perforated pipe with enough diameter is inserted for inflowing the gas. The perforated pipe circulated with gravel is performed in order to protect the blocking by refuse particles. The schematic diagram of the perforated pipe connected with the gas sampling train is given in Figure 2.



(a) (b)

Figure 1. (a) Cross-section of gas pipe collector. (b) Picture of LFG recovery well[5)]

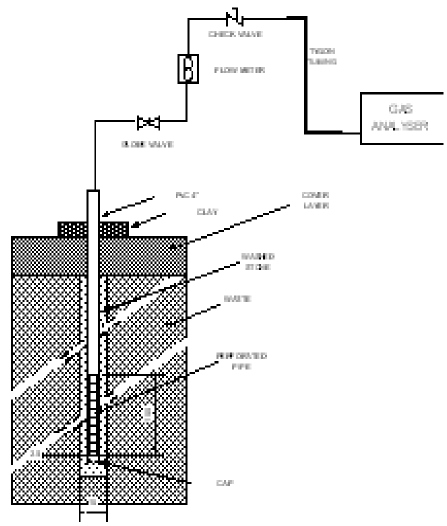


Figure 2. The sampling train lay out of the landfill gas measurement.

Since the LFG ventilation is not provided in the open dumping landfill in Indonesia, the gas measurement is carried after it has been bored in order to place the piping of vented gas. The typical landfill boring activity is shown in the Figure 3.

Figure 3. Picture of boring activity for inserting gas venting pipe.

The gas analyzer used for CH_4, CO_2 and O_2 measurement is Eagle portable one as shown in Figure 4.

Figure 4. Eagle portable gas analyzer.

4. MEASUREMENT RESULTS

Landfill gas generation in Indonesia is actually very promising comparing with that in subtropical countries. However, due to open dumping landfill system used with no gas recovery infrastructure prepared at the beginning of the development, the rate of the gas generation fluctuates from one place to another and from one time to another time. The following table shows the measured rate of landfill gas at several landfill locations.

Table 1. Results of LFG measurements at several locations in Indonesia

No.	Location	LFG Vol.Rate (m^3/d)	CH_4 conc. (%)
1	Sukamiskin, West Java	2.508 to 4.669	77.02 to 88.38
2	Grenjeng, West Java	1.996 to 12.581	67.44 to 70.68
3	Benowo, East Java	2.245 to 15.723	51.29 to 58.5
4	Jelekong, West Java	3.742 to 6.967	56.40 to 56.90
5	Leuwigajah, West Java	5.116 to 10.676	55.4 to 55.7
	Range	*1.996 to 15.723*	*51.29 to 88.38*
	Average	*6.623*	*63.71*

For open dumping landfills of Sukamiskin and Grenjeng (West Jawa), the gas was measured when they were 3 year old whereas for open dumping landfill of Jelekong (West Java) the measurement was taken when it was 5 year old. At the age between 5 and 10 years, the landfill gas generation in the tropical region usually reaches the highest and stable production. At Sukamiskin (West Java) landfill for instance, one gas ventilation piping was employed to vent the dumped refuse of about 31,860 m^3. With water content of about 57% and estimated compactness of 50% tons/m^3 results in about 6,850 tons of dry weight refuse. As given in the Table 1 the LFG volumetric rate from Sukamiskin landfill was between 2.508 and 4.669 m^3/day. Thus, the calculated LFG production at Sukamiskin landfill was between 3.66 and 6.82 x 10^{-4} L gas/day kg dry basis refuse.

Meanwhile at Grenjeng landfill, for one

ventilation piping was used to vent about 4650 m^3 of dumped refuse. Considering that the refuse compactness factor and water content are the same as those at Sukamiskin landfill, the dry weight of the refuse was calculated about 1000 tons. Stating from the Table 1 that the LFG volumetric rate at Grenjeng was 1.996 to 12.581 m^3/day therefore the LFG productivity was about 1.996 – 12.581x10^{-3} L gas/day kg dry basis refuse. The higher LFG productivity of Grenjeng landfill than that of the Sukamiskin was probably due to the leachate recirculation applied and older refuse age at Grenjeng landfill. Another factor that contributed in the result might be the higher ambient temperature at Grenjeng landfill (coastal area) than that at Sukamiskin (mountain area).

Results of the LFG measurements conducted from those two landfills might be able to be used for estimating the LFG productivity from other landfills, particularly those located at Western Java area. Currently in West Java, Banten and Jakarta provinces there are about 44 open dumping landfills with total area of about 342 hectares. The landfill areas range from 2 (two) hectares till 100 hectares[6)]. With the assumption of landfill depth was around 20 m the total volume of refuse in Western Java landfills was 684,000 m3. Using the same compactness factor and the water content of landfill refuse as previous calculation, this results about 147,060 Tons of dry weight refuse. If the average LFG productivity of Grenjeng landfill is used to estimate, the total LFG productivity of Western Java landfills will be 290 till 1850 m3 LFG/day. If the average active LFG generation is 5 (five) years, the total emitted LFG from Western Java is then 535,700 till 3,376,550 m^3 LFG/day. It is noted that the average concentration of CH_4 is 63% and CO_2 is 37%.

Calculation of LFG in 17 cities of Indonesia has also been done by the World Bank through estimating the rate of the refuse production as shown in Table 2.

From that calculation the World Bank at least gives general description how potential the methane generation from Indonesian landfill. Table 2 shows the estimation done by the World Bank on refuse produced, methane gas emitted, and electricity generated. It also indicates that at least there are 5 (five) cities in Indonesia that their landfills are potential in generating LFG that might be utilized for energy[7)]. Those are Jakarta, Bandung (West Java), Surabaya (East Java), Palembang (South Sumatera), and Medan (North Sumatera).

Table 2. Estimation of LFG Potential in Big Cities in Indonesia

No	City	MSW (ton/y) Million	CH_4 emission (m^3/year) Million	Electricity (MW)
1	Medan	0.7	27	5
2	Pekanbaru	0.3	11	2
3	Padang	0.4	16	3
4	Jambi	0.2	7	1
5	Palembang	0.6	23	5
6	Lampung	0.4	15	3
7	Jakarta	3.5	140	29
8	Bandung	0.8	32	7
9	Semarang	0.5	21	4
10	Yogyakarta	0.1	5	1
11	Surabaya	0.8	33	7
12	Denpasar	0.2	9	2
13	Pontianak	0.2	7	1
14	Banjarmasi n	0.2	7	2
15	Samarinda	0.2	9	2
16	Balikpapan	0.2	6	1
17	Makassar	0.5	19	4

Source : World Bank (2005)

5. DISCUSSION AND CONCLUSION

There are around 460 open dumping landfills in Indonesia and if their generated methane gas can be recovered it will be a big potential to utilize this methane gas for energy. This will then be a good opportunity to include them in the clean mechanism development (CDM) program under the waste management sector. Utilization of landfill methane gas will be interesting alternative in managing municipal solid waste in Indonesia.

Several measurements of landfill gas performed by researchers from different institutions even though not yet perfectly give representative data, it basically indicates that Indonesian LFG have high potency to be converted to energy use forms, such as electricity and gas fuel for cooking. Besides, the LFG recovery and utilization reduce the green house gases effects due to the burning of CH_4 gas of LFG. As known that CH_4 has green house gas effect factor 21 time than that of CO_2. It means that if we burn CH_4 even though it becomes green house gas of CO_2, the effect on the global warming is 21 time less than if it releases into the atmosphere. This is why that the activity to recover and to utilize the LFG for energy is considered to be as one of the clean development mechanism (CDM) programs. The fact more than 60% of LFG consists of CH_4 and therefore to use it will be benefit due to additional energy and reduction on GHG effect.

Based on calculation of Danish CDM Project Development in Indonesia the feasible value for CDM landfill where the amount of refuse disposed in the landfill is 150 tons/day or about 430 m^3/day. If this criteria is used, of the 44 Western Java landfills, the only landfill with 10 ha or larger area will be the feasible landfill for CDM project.

In Indonesia however, the majority of the landfills are open dumping systems. If the landfill is sanitary one as required in the draft of law regarding Indonesia MSW management it will be much higher potential for LFG to be recovered and utilized than that at current condition.

Indonesian climate that is hot for whole year supports the development of biodegradation process for methane generation. If the current available 460 landfills are not controlled and utilized their LFG they will be sources of GHGs. Methane concentration of LFG so far being measured is very high (65%) which is considered to be a burnable gas. Therefore to use it, there is no need additional fuel for mixing to be a burnable gas.

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Appendix 1. List of MSW generation in several cities of Indonesia

No	City	Number of Population	Population Growth Rate (%)	Population Density (Person/Ha)	Waste Generation(l/capita/d)	Total Waste Generation (m^3/d)
1	Bandung	2,232,624	0.20	133	3.95	8,826
2	Denpasar	542,553	4.05	35	0.73	330
3	Jakarta	7,471,866	0.20	112	3.55	26,521
4	Makassar	1,173,107	1.27	67	3.02	3,546
5	Medan	2,006,014	1.50	76	2.71	5,436
6	Palembang	1,338,793	2.65	33	6.50	8,700
7	Semarang	1,389,421	1.43	37	2.52	3,500
8	Surabaya	2,740,490	2.38	84	3.17	8,700
9	Balikpapan	500,406	1.02	10	2.26	1,128
10	Lampung	800,490	2.66	41	1.25	1,000
11	Banjarmasin	574,259	0.34	80	1.65	947
12	Bekasi	2,005,899	4.10	95	2.39	4,800
13	Bogor	750,250	2.40	63	2.83	2,124
14	Depok	1,204,687	3.70	59	0.64	766
15	Yogyakarta	519,936	1.74	160	3.02	1,571
16	Surakarta	552,542	0.48	125	1.83	1,009

Appendix 2. Composition of MSW in Indonesian Cities

No	Type of Waste	Composition (%)			
		Semarang	Surabaya	Jakarta	Bandung
1	Organic	61.95	71.85	68.12	63.52
2	Plastic	13.39	12.45	11.08	4.90
3	Paper	12.36	7.60	10.11	10.42
4	Textile	1.55	0.90	2.45	1.70
5	Rubber	0.5	0.90	0.55	4.90
6	Metal	1.8	0.54	1.90	0.95
7	Glass	1.72	1.94	1.63	1.45
8	Others	6.83	3.82	4.12	12.16