LOCATIONAL DIFFERENCES OF GASEOUS EMISSION EFFECTS FROM A SEMI-AEROBIC LANDFILL

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LOCATIONAL DIFFERENCES OF GASEOUS EMISSION EFFECTS FROM A SEMI-AEROBIC LANDFILL

by

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
BOD	-	Biochemical oxygen demand
COD	-	Chemical oxygen demand
ELR	-	Effect of lapse rate
EPA	-	Environmental Protection Act
eV	-	Electronvolt
GDP	-	Gross domestic product
GLM	-	General Linear Model
GWP	-	Global warming potential
IPCC	-	Intergovernmental Panel on Climate Change
IR	-	Infra red
LER	-	Light emitting resistor
MEWC	-	Ministry of Energy, Water and Communication
MHLG	-	Ministry of Housing and Local Government
MP	-	Monitoring Point
MPPP	-	Majlis Perbandaran Pulau Pinang
MPSP		Majlis Perbandaran Seberang Perai
MSW	-	Municipal solid waste
MSWM	-	Municipal solid waste management
NIMBY	-	Not in my backyard
NMOC	-	Non methane organic compound
PBLS	-	Pulau Burung Landfill Site
PID	-	Photoionization Detector
SS	-	Sums of square
TLV	-	Threshold limit value
TVOC	-	Total volatile organic compound
UNDP	-	United Nations Development Programme
UV	-	Ultraviolet
VOC	-	Volatile organic compounds
WHO	-	World Health Organisation

PERBEZAAN LOKASI BAGI KESAN PEMBEBASAN GAS TAPAK PELUPUSAN SAMPAH SEPARA-AEROBIK

ABSTRAK

Gas tapak pelupusan sampah merupakan campuran metana (CH_4), karbon dioksida (CO_2) dan sejumlah kecil gas lain yang berbau termasuk ammonia (NH_3) dan hydrogen sulfida (H_2S). Masalah utama yang berkaitan dengan tapak pelupusan sampah di Malaysia adalah bau dari dekomposisi sampah, lalat, kutu dan air larut lesap dari tapak pelupusan sampah ke sungai terdekat. Menyedari pentingnya, kesan gas tapak pelupusan sampah, satu kajian kesan gas tapak pelupusan sampah ke atas manusia telah dijalankan. Empat juzuk gas tapak pelupusan sampah (CH_4, CO_2, CO dan H_2S) dipantau dari 15 Disember 2009 hingga 11 Januari 2010, selama tempoh 28 hari. Asas kajian adalah pemantauan gas tapak pelupusan sampah dan penilaian persepsi penduduk berkaitan impak tapak pelupusan sampah ke atas mereka. Kajian telah dilakukan di Tapak Pelupusan Sampah Pulau Burung (PBLS) dan penilaian sikap di antara pekerja dan penduduk tinggal kira-kira lapan km sekeliling tapak. Berbeza bahagian tapak pelupusan sampah mengandungi sampah berbeza umur, iaitu dua, enam dan lapan tahun. Kepekatan empat juzuk gas tapak pelupusan sampah (CH_4, CO_2, CO dan H_2S) diukur pada lima masa setiap hari, selama tempoh 28 hari pemantauan. Tiga belas titik sampel tersebar atas bahagian yang berbeza umur yang dikaji. Analisis diskriptif, ANOVA dan model linear umum menunjukkan kepekatan kesemua juzuk dari sampah lapan tahun adalah kurang. Ini kerana sampah berusia lapan tahun berada dalam tahap pengoksidaan. Sampah berusia dua dan enam tahun, berada pada tahap pembentukkan gas metana, menghasilkan lebih banyak kepekatan semua gas ini. Model linear umum menunjukkan CH_4, CO_2, dan H_2S adalah dipengaruhi oleh umur tapak pelupusan sampah. Sejumlah 507 responden ditemu ramah dan menjawab soalan kaji selidik. Masalah utama dihadapi oleh kedua-dua, pekerja PBLS dan penduduk berdekatan ialah bau. Mereka yang tinggal dalam lingkungan 1-1.9km daripada tapak pelupusan sampah menganggap pencemaran udara, bunyi bising, bau dan lalat adalah satu isu. Responden tinggal jauh dari tapak pelupusan sampah (>7km) tidak setuju yang mereka mengalami isu alam sekitar yang kurang baik. Permonitoran VOC dan H_2S, sebagai timbalan untuk bau, menunjukkan bahawa kepekatan tidak berkurangan dengan jarak. Kepekatan adalah tinggi di jarak lebih jauh kerana pelbagai sumber bau busuk di dalam kawasan. Model penyebaran Gaussian digunakan untuk mengkaji penyebaran gas berbau busuk di Nibong Tebal. Data permonitoran dan data sebenar memberi perbezaan yang kecil dalam kepekatan gas berbau busuk. Oleh kerana itu, dapat disimpulkan, model Gaussian dapat digunakan dalam kajian kesan gas tapak pelupusan sampah.

LOCATIONAL DIFFERENCES OF GASEOUS EMISSION EFFECTS FROM A SEMI-AEROBIK LANDFILL

ABSTRACT

Landfill gas is a mixture of methane (CH_4), carbon dioxide (CO_2) and small quantities of other odorous gas including ammonia (NH_3) and hydrogen sulphide (H_2S). The major problem associated with landfill sites in Malaysia are odour from waste decomposition, flies, vermin and leachate into nearby water body from the landfill. Recognizing the importance of landfill gas, the study investigated the effect of landfill gas on human being. Four landfill gas constituents (CH_4, CO_2, CO and H_2S) were monitored from 15 December 2009 until 11 January 2010, a period of 28 days. The basic of the research was the monitoring of landfill gas and an assessment of the perceptions of residents concerning the impact of the landfill upon them. The research was undertaken at Pulau Burung Landfill Site (PBLS) and attitude assessed amongst the employees and residents living around eight km surrounding the site. Different section of the disposal site contained waste of different ages, namely two, six and eight years. The concentration of the four constituents of landfill gas (CH_4, CO_2, CO and H_2S) was measured at five times per day over a 28 day period (15 December 2009 till 11 January 2010). Thirteen sampling points spread over the different age sections were studied. Descriptive analysis, ANOVA and general linear model analysis showed the concentrations of all constituents from eight years waste was less. This is because waste of this age was in the oxidation phase. Two and six year old waste, being at methanogenesis stage, produced much higher concentrations of these gases. ANOVA showed that CH_4, CO_2 and H_2S emissions were highest from two year old waste. General linear model analysis showed that CH_4, CO_2 and H_2S emissions are influenced by the age of the landfill. A total of 507 respondents were interviewed and answered the questionnaire. The major problem faced by both the PBLS employees and nearby residents is odour. Those living within 1-1.9 km from the landfill considered air pollution, noise, odour and flies to be an issue. Respondents living the furthest from the landfill (>7km) did not agree that they experienced adverse environmental issues. Monitoring of VOCs and H_2S, as surrogates for odour, showed that concentration did not decrease with distance. Concentration is high at further distances because of the multiple sources of odour in the area. Gaussian dispersion modeling was used to study the dispersion of odourous gas at Nibong Tebal. The monitoring data and actual data gave small differences in the concentration of odourous gases. Therefore, it is concluded that Gaussian modeling can be used in the study of landfill gas effect.

CHAPTER 1

INTRODUCTION

1.1 LANDFILL AS WASTE DISPOSAL

Landfilling or land disposal is the most commonly employed method for waste disposal (Tchonobanoglous et al., 1993; Agamuthu, 2001). Landfills are sites of controlled burial of refuse, the surface areas ranging from tens to hundreds of hectares. Over the years, evolution in landfill design among developed countries has resulted in highly engineered modern facilities with systematic containment of solids, liquids, and gases (Bogner and Spokas, 1993). Waste is typically filled into landfill by a sectional approach. At completion of a given portion of a site, a final compacted soil cover (measuring 1 m–2 m thick) is placed on the surface. Topsoil is later seeded and revegetated.

A safe closure is required for a closed landfill. Daily cover applications of soil or synthetic alternatives are applied in an engineered landfill as well. Landfill is the least expensive and environmentally accepted waste disposal alternative. It has been selected as municipal solid waste final disposal worldwide. Increasingly, more controlled landfilling practices are evolving in developing countries such as Malaysia. Solid waste management has become the main challenge for the said country to address before 2020; Malaysia intends to become a fully developed nation by 2020 (Abdul Rahman et al., 2009).

After burial of solid waste, anaerobic condition is quickly established with the depletion of oxygen and aerobic microorganism (Bogner and Spokas, 1993; Tchonaboglous et al., 1993; Christensen, 1996; Petts and Edulgee, 1994; Hester and Harrison, 2002; Themelis and Ulluoa, 2006). Landfill gas will be generated in sites that receive biodegradable organic matter such as food, paper, wood, plastics, textiles, vegetation, and so on. Biochemical degradation of organic materials, especially cellulose and hemicellulose, by action of aerobic (presence of oxygen) and anaerobic (absence of oxygen) microorganisms in the landfill will produce landfill gas (Petts and Edulgee, 1994).

Landfill gas is a mixture of methane (CH_4), carbon dioxide (CO_2), and small quantities of other gases including nitrogen, hydrogen, and hydrogen sulphide. Production and accumulation of landfill gas within the landfill raises gas pressure in landfill above atmospheric pressure. Therefore, the pressure gradient will serve as a driving force that will cause the gas to diffuse out of the landfill into the surrounding soil strata or into the air. The least resistance paths where diffusion is likely to occur are through cracks, landfill cover, and the surrounding top soil (Farqugar and Rovers, 1973; Rees, 1980).

Generation of landfill gas will lead to safety concerns associated with the migration of a potentially explosive gas into surrounding areas, a detrimental effect on vegetation, odour generation, and contribution of gases to the greenhouse effect. Atmospheric concentrations of CH_4 are an active trace gas; these have increased steadily for several hundred years (Cicerone and Oremland, 1988). CH_4 and CO_2 are both greenhouse gases that contribute to global warming. CH_4 is an extremely potent greenhouse gas in which global warming potential (GWP) is 25 times more powerful than CO_2 (He et al., 1997; Foster et al., 2007). According to the Intergovernmental Panel on Climate Change or IPCC (2006), GWP of methane is 23 times stronger than CO_2 over a period of 100 years. On the other hand, Lashof and Ahuja (1990) estimated that GWP of methane is 63 times stronger than CO_2 for a time horizon of 20 years. In addition to impact on climate change, landfill operations raise concerns over public health. Populations exposed to landfill gas will face a number of health risks as accumulated CH_4 in enclosed spaces will cause significant property damage and loss of life (Drouin, 1995) when concentrations in air range from 5% to 15%. Such risks can occur during landfill gas migration through neighbouring soil or rock pores, infiltrating buildings or underground structures.

Solid waste generation is the common basis for estimating emissions from solid waste disposal. Solid waste generation rates and composition vary from country to country depending on the economic situation, industrial structure, waste management regulations, and lifestyle (IPCC, 2006). Solid waste is generated from households, offices, shops, markets, restaurants, public institutions, industrial installations, water works and sewage facilities, construction and demolition sites, and agricultural activities. Municipal solid waste (MSW) is generally defined as waste collected by municipalities or other local authorities. Typically, MSW includes household waste, garden waste, and commercial/institutional waste. Solid waste management practices include collection, recycling, solid waste disposal on land, biological treatment, incineration, and open burning (Kreith, 1994).

1.2 SOLID WASTE MANAGEMENT LEGISLATIONS

At present, Malaysia has no specific national legislation or policy on solid waste management. Policies, acts, regulations, and guidelines are developed by the Federal Government through the Ministry of Housing and Local Government. Subsequently, these are implemented by state governments and local authorities. The policies, acts, and regulations related to solid waste management include the Guidance Document on Health Impact Assessment (HIA) in Environmental Impact Assessment (EIA) – under the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987, Action Plan for a beautiful and Clean Malaysia (ABC) 1988, Policy for Integrated Solid Waste Management in Malaysia 2001, Guidelines on the Safe Closure and Rehabilitation of Landfill Sites in Malaysia 2004, National Strategic Plan for Solid Waste Management in Malaysia 2005, Master Plan on National Waste Minimization 2006, Solid Waste and Public Cleansing Act 2007 (Act 672), Solid Waste and Public Cleansing Corporation Act 2007 (Act 673), and Environmental Quality Act 1974 – Act 127: Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009.

As of 2010, 145 local authorities in Malaysia have implemented solid waste management as provided under the Local Government Act 1976 and Street, Drainage and Building Act 1974. In Penang Island Municipal Council, Public Cleansing and Safety (Penang Island Municipal Council) by Laws 1980 was implemented as well as enforcement on matters related to public cleanliness, including solid waste management (Goh, 2007).

1.3 VOLUME AND CHARACTERISTIC OF WASTE GENERATION

With a population of over 25 million, Malaysia is a humid tropic country with high temperature and rains throughout the year. Approximately 17,000 tonnes of solid waste are generated in Peninsular Malaysia daily; this is expected to increase to over 30,000 tones of solid waste by 2020 as a consequence of the growing population (UNDP, 2008). According to reports, 75% of waste was collected in 1998. In 2007, waste generation was approximated at 18,000 metric tonnes of domestic waste daily, one of the highest waste generators in the world (Ong, 2007). The collected waste is transported to landfill sites for disposal; the remaining waste is sent for treatment at incinerators, recycling, and reprocessing. Certain wastes are dumped illegally. Malaysia wastes composition is mainly organic/food waste, paper, textile, wood, plastic, rubber, glass, and metal. Table 1.1 shows Malaysian solid waste composition in 1995, 2001, and 2004.

Table 1.1 Malaysia waste composition in 1995, 2001, and 2004

Waste Composition	Percentage (%)		
	1995	2001	2004
Organic/food waste	32.0	29.5	35.72
Paper	29.5	26.8	16.61
Waste yard and wood	3.4	3.9	5.1
Textile/leather	7.0	13.6	13.85
Plastics	16.0	12.5	22.19
Rubber	2.0	1.9	0.89
Glass	4.5	2.7	3.2
Metals	4.3	1.9	2.44
Others	1.3	5.3	0.0
Total	100	100	100

Source: Ridhuan (1995); Dini *et al*. (2001); Syed (2004)

In 2004, 35% of organic waste was produced in the Malaysian waste stream. This organic fraction will contribute to a high production of landfill gas in Malaysian landfills. Wastes generated are disposed of at 230 disposal sites, sanitary and open dumps, in the country. At present, average per capita generation of solid waste in Malaysia varies from 0.5 to 0.8 kg/person/day, depending on the economic and geographical status of an area. In major cities, this figure rises to 1.7 kg/person/day (Kathirvale et al., 2003). In 2006, Penang Island generated an average of 808 tons of domestic solid waste per day, which is approximately 1.2 kg/person/day based on an estimated population of 700,000 (Goh, 2007). This amount excludes 400 tons of construction and demolition waste, garden, and bulky waste generated daily. Table 1.2 shows solid waste generation and recycling rate in Penang.

Table 1.2 Solid waste generation and recycling rate in Penang

Year	Waste (ton/year)	Waste (ton/day)	Waste recycled (ton/year)	Total waste generated (ton/year)	Recycling rate (%)
	(A)	**(B)**	**(C)**	**(D) = (A+C)**	**(C/D)**
1992	184 812	505	-	-	-
1993	205 973	564	40.83	206 013.83	0.02
1994	232 625	637	91.89	232 716.89	0.04
1995	192 016	526	126.74	192 142.74	0.07
1996	187 921	515	300.41	188 221.41	0.16
1997	184 776	506	85.25	184 861.25	0.05
1998	174 686	479	74.60	174 760.60	0.04
1999	178 073	487	75.20	178 148.20	0.04
2000	199 185	545	57.54	199 242.54	0.03
2001	199 878	547	319.63	200 197.63	0.16
2002	237 983	652	3844.74	241 827.74	1.59
2003	252 215	691	22 669.29	274 884.29	8.25
2004	239 242	655	44 093.17	283 335.17	15.56

Source: MPPP (2005)

Waste generated increased throughout the period spanning 1994 to 2004. In 2004, total waste generated reached 283,335.17 tonnes. Penang state has promoted recycling to reduce the amount of waste to be sent to the landfill. Community participation is encouraged to raise the recycling rate in Penang. By 2004, the recycling rate in Penang state slowly increased to 15.56% compared to 2000 (0.03%) and 2003 (8.25%). Table 1.3 shows solid waste composition in Penang. Food waste is the major waste generated (53.24%). Waste generated is dominated by organic waste; once the waste is dumped into the landfill, biodegradation will occur and leachate and landfill gas will be emitted into the atmosphere.

Table 1.3 Solid waste composition in Penang

Material	**Total waste (%)**	**Municipal waste (%)**
Food	39.51	53.24
Paper	12.64	13.49
Greens	5.59	1.75
Wood	1.96	1.31
Plastics	10.73	10.54
Textiles	2.16	2.87
Rubber	0.04	0.04
Glass	1.77	2.35
Metals	5.79	4.79
Bulk	1.25	1.75
Aggregates (Construction & Demolition)	12.70	0.87
Water	5.86	6.99
Total	**100.00**	**99.99**

Source: MPPP (2005)

Figure 1 shows the percentage of solid waste generated in Nibong Tebal, Penang. The major waste generated is food waste (52%) and the least is textiles (1%).

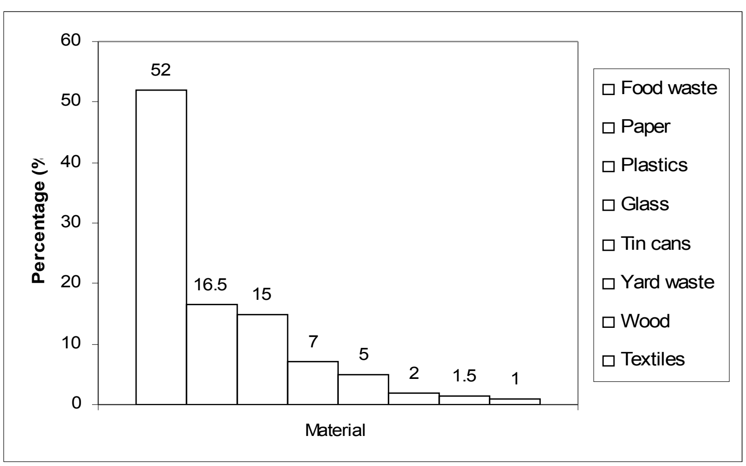

Figure 1.1 Solid waste compositions in Nibong Tebal, Penang
(Source: Hasnain et al., 2005)

The amount of solid waste generated in residential areas was observed to be 0.6 kg/capita per day (Hasnain et al., 2005). The amount is reasonable and appropriate for the Nibong Tebal population. This is because Nibong Tebal is a small developing town; thus, waste generation is expected to be low.

1.4 PROBLEM STATEMENT

The citizens of Nibong Tebal, especially those who live near the Pulau Burung Landfill Site (PBLS), are exposed to odour and pollution originating from the landfill. Those living in Kampung Changkat, 5 km from PBLS, complain that water pollution in their village has reached a severe stage. Polluted water has killed fish and plants near the Kuala Sungai Tengah where residents earn their income from fishing.

Kampung Ladang Byram residents, located only 1 km from PBLS, complained of odour, dust, and hazardous gas emitted by the landfill site as well as spillage of waste and waste water from collection and transfer of waste by waste collection trucks on the roadside. The spill is not only odorous but may cause accidents as well among passing motorcyclists. A memorandum has been released by the people of Kampung Changkat and Kampung Ladang Byram, and sent to the Penang State Government, Seberang Perai Municipal Council, and PBLS contractor in the hope of solving problems that have been in existence for nine years (Mohamad Saad, 2010). In addition to odour and water pollution, other hazardous gases produced from landfill will be harmful to human beings as well as other nearby habitats.

Various research have been conducted on issues related to PBLS. Majority of works have focused on leachate production and quality from the landfill (Ghafari et al., 2005; Aziz et al., 2007; Bashir et al., 2009, 2010; Daud et al., 2009; Mohajeri et al., 2010). To date, no research has addressed surface emission of landfill gas and its effects on human beings in nearby population centres, especially concerning the perception of odour. When landfills were introduced as venues for final waste disposal, the method employed for dealing with landfill gas involved covering the landfill with a permeable cover to allow gas to vent freely. However, environmental problems associated with the uncontrolled dispersion of landfill gas have led to risk to human health and damage to properties (Bogner and Spokas, 1993). Organics in waste decompose and produce CH_4 and CO_2, as well as trace amount of toxic substances and hydrogen sulphide (H_2S) and ammonia (NH_3), which is an odorous gas. CH_4 and CO_2 are both greenhouse gases that contribute to global warming. CH_4 emissions from solid waste dumping sites are the largest source of greenhouse emissions in the waste sector (IPCC, 2006).

In Malaysia, total methane emissions from the waste sectors is approximately 1.3 million metric tonnes (mT) per year compared to total methane emission in Malaysia of 2.2 million mT estimated in 1994 (MEWC, 2004). The most significant methane (CH_4) emission sources are landfill gas from municipal solid waste (53%), followed by biogas from Palm Oil Mill Effluent or POME (38%). Less significant sources include swine manure (6%) and industrial effluent (3%). Total carbon dioxide (CO_2) emissions are estimated to be roughly 27 million mT, approximately 19% of the total greenhouse gas emission in Malaysia in 1994. Waste and wastewater treatment and discharge will produce non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), and carbon monoxide (CO) as well.

CH_4 produced at the solid waste disposal sites contributes approximately 3% to 4% of annual global anthropogenic greenhouse gas emissions (IPCC, 2006). Emissions of landfill gas varies with the composition of waste (depending on the biodegradable fraction of waste), presence of microorganisms and suitable aerobic and anaerobic conditions, and climate. Waste streams are country-specific. In developing countries, recovery of valuable material at collection, during transportation, and at dumping sites has been common. However, Malaysia continues to use landfill as the major final disposal of solid waste. In 1993, Malaysia's urban population generated approximately 5.2 million tonnes of waste. Average waste generation increased from 0.70 kg/person in the 1990s to 1.7 kg/person in 2003 (Kathirvale et al., 2003). The accumulated amount of CH_4, estimated for the years 2005–2010 is presented in Table 1.4.

Table 1.4 Accumulated greenhouse gas emissions from anaerobic landfills

Year	2005	2006	2007	2008	2009	2010	Total (mT/yr)
CH_4	90 085	104 763	142 812	78 534	80 104	78 909	578 207

Source: MEWC (2004)

Waste generation in Malaysia is closely related to the activities performed in respective communities and economic status. Degradation of waste will occur in the landfill. As a result, greenhouse gases will be released into the environment, increasing the amount of harmful gases in the air. In the process, this harms humans as well as habitats. The principal greenhouse gases, CH_4 and CO_2, stay in the atmosphere long enough to mix uniformly over the entire globe (Rabl et al., 2008). When pollutants are emitted into the air, they will affect human beings as well as habitats. The pollutant will transfer to animals and humans through two means, inhalation and ingestion. Inhalation occurs when air from the external environment moves into the lungs through the airways. Landfill gas movements into the atmosphere occur because the gases seep out from the permeable cover of the landfill. These gases will stay in the air and disperse initially to the nearest habitat.

Surface emissions begin to occur from 5–7 cm from the landfill surface. Rabl et al. (2008) indicated that ingestion may arise from seafood, fresh water fish, milk, and meat that have been exposed to the pollutant's emission pathways. Movement of pollutants is subtle and may not manifest its impact until years later. Human beings will be threatened with a health risk and habitats will be endangered.

1.5 RESEARCH QUESTIONS

This research aims to study the patterns of gas emissions at the PBLS landfill through the age of waste layer and ambient temperature. CH_4 and CO_2 will be emitted into the air during the methanogenesis phase, and these will increase with the ground temperature. The study will investigate the landfill gas emission pattern and peak in gas emission during the day. Dispersion of landfill gases into the atmosphere will be estimated using a dispersion model. Gases will be measured at the nearest residential area to assess their movement from the landfill. Gases will travel to the nearby dwelling and environmental effects are expected to occur there.

A survey will be conducted to establish the impacts of landfill gas movements on the daily lives of nearby residents. Responses from landfill employees and residents from nearby residential areas will be used to investigate perception of the suitability of landfill for the final disposal of solid waste as well as the environmental effects of landfill. The study will investigate the existing situation on solid waste in their area and major concerns regarding environmental problems caused by the landfill. The opinion of respondents on new technologies and their willingness to pay for these new technologies will help create a deeper understanding of the actual problems at the site. Employees will be asked on environmental issues associated with the workplace condition. Data obtained from the responses will help to understand the problems faced by the people more directly exposed to landfill sites.

1.6 RESEARCH OBJECTIVES

This research has four objectives, which are as follows:

1. To identify the pattern of landfill gas (CH_4, CO_2, CO, and H_2S) emission with age of waste (different sites)

2. To investigate the relationship between landfill gas emissions and age of waste

3. To investigate the perception of odour as a nuisance amongst people near a landfill

4. To determine the environmental concerns associated with landfill employees and the effects on the environment, health, and economy experienced by residents of nearby dwellings

1.7 DATA COLLECTION

Landfill gas data is collected using handheld equipment GA2000 Infrared Gas Analyzer, Keison International Ltd. Gases to be monitored were methane (CH_4) and carbon dioxide (CO_2). GA2000 measures CH_4 and CO_2 via infrared absorption, as well as oxygen (O_2), hydrogen sulphide (H_2S), and carbon monoxide (CO) via internal electrochemical cells. CH_4 was measured using the dual beam infrared absorption method. Analysers were calibrated using certified methane mixture. Calibration of the equipment was performed between gas monitoring sessions. The accuracy of the equipment for CH_4 for 0%–5% volume was ±0.5% and accuracy for CO_2 measurement for 0%–5% volume was ±0.5%. Temperature was measured using the temperature probe, which could measure temperature between -10 ºC to 75 ºC with ±0.2 ºC accuracy. Meanwhile, odorous gases are measured using photo ionisation detector meter. The range of the equipment for total volatile organic compounds (TVOC) are from 0.02 to 20.00ppm (user selectable units: ppb or ppm) and operating range is zero to 90 %RH and 0 °C to 40 °C. Range for H_2S is 0.1 to 80.00 ppm.

Wind movement was assessed from data on wind speed and direction collected at the site. VOCs, CO_2, CO, and H_2S were measured at selected points within the study area at the same time that landfill gas and wind data were collected to present a set of comparable data. Air quality data at the dwelling were collected extensively for 28 days. Questionnaire surveys on environmental effects from landfill on human beings were carried out as well. Two questionnaires were employed. The first was developed to investigate major concerns regarding environmental effects on landfill employees. The second consisted of a set of questions developed to investigate effects on the environment, health, and economy as perceived by people living near the landfill.

To support the findings, this study used sources such as data from landfill management of gas emissions, landfill operational activity, and a physical study of the landfill; extracts from reports, journals, government documents, proceedings, and Web sites on surface emissions of landfill gas at the national and international level; and data on the environmental effects of solid waste disposal on human habitat and infrastructure provided by the government to control the disposal means for solid waste in Malaysia.

1.8 ANALYSIS OF DATA

Data analysis will focus on landfill gas emission using SPSS software (Version 11.5) and MINITAB (Version 14). Data gained via questionnaire will be analysed as well using SPSS software (Version 11.5). Wind rose will be plotted using Lakes software.

1.9 RESEARCH SCOPE

The scope of research is as follows:

1. The selected landfill in this study is Pulau Burung Landfill Site (PBLS), which is situated in Nibong Tebal, Seberang Perai Selatan, Pulau Pinang. PBLS is a semi-aerobic landfill. The landfill area spans 66 hectares, with an operational area of 33 hectares. This landfill accepts domestic non-hazardous waste and individual waste. Waste from both Penang Island and Seberang Perai are sent to this landfill. Landfill gas data will be collected at the site using handheld equipment.

2. The survey on household responses covers issues on environmental effects from the landfill. Distance is determined by the nearest town, Nibong Tebal, situated within the radius. Majority of human activities in this town are concentrated in

the residential area, school, government offices, private offices, shops, and market. The household survey will be conducted with sets of questionnaire while the gas survey will be conducted using handheld gas instrument.

3. Odour monitoring is performed within an 8 km radius from PBLS. Movement of emission from PBLS into the atmosphere will change perception of odour as nuisance.

1.10 ORGANISATION OF THE THESIS

Chapter 1 is the introduction to the thesis, including basic information on solid waste disposal and its management in Malaysia as well as a brief overview on landfill gas generation at the landfill and gas emission into the atmosphere. The research problem statement, research objectives, research questions, and research scope are outlined in Chapter 1 as well.

Chapter 2 is the literature review that will elaborate on landfill gas arising from the degradation process occurring in the landfill as well as the surface emissions at the landfill. In this chapter, behaviour of a semi-aerobic landfill that undergoes several phases of degradation will be discussed. The environmental effects towards human habitat will be discussed in this chapter as well.

Chapter 3 is the research methodology that presents details of the procedures employed in this study. Descriptions of landfill gas data and questionnaire data as well as other data generation techniques used in the research will be elaborated.

Chapter 4 is the analysis of data where results and their interpretations will be presented.

Chapter 5 is the discussion of findings and conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLID WASTE: GENERATION AND MANAGEMENT

In Malaysia, the Environmental Protection Act (EPA) 1990 defines waste as any substance that constitutes scrap materials, an effluent, or other unwanted surplus substances arising from the application of a process. It can be any substance or article that requires being disposed of; it may be broken, worn out, contaminated, or otherwise spoiled (Omran, 2008). Waste also is likewise defined as any object or substance that the holder discards or intends to discard. Regardless of its origin, waste represents the imperfect utilisation of raw materials, fuel, water, and a financial loss for somebody (Read, 1999). Other researchers define waste as arising from human and animal activities; it is discarded as useless or unwanted (Tchobanoglous et al., 1993). Solid wastes arise from unusable residues in raw materials, leftovers, rejects, and scraps from process operations (Read et al., 1998). Solid waste implies a negative economic value, suggesting it is cheaper to discard than use (Pitchtel, 2005).

All definitions imply that solid waste consists of the solid type of refuse, such as garbage, old newspapers, packaging materials, yard waste, and other materials usually disposed from a household. Other components of solid waste are bulky appliances, old furniture, dead trees, junked automobiles, street sweepings, construction and demolition rubble, and debris. Commercial and industrial refuse materials such as waste paper, damaged products, food processing residues, and scrap metals are considered as solid waste as well (Lund, 2001). Therefore, it can be summarised that solid waste basically consists of non-liquid and non-effluent components discarded from household, industrial, or commercial activities (Omran, 2008).

Wastes can be designated by generator type. Major classes of waste include municipal solid waste (MSW), hazardous waste, industrial waste, medical waste, universal waste, construction and demolition waste, radioactive waste, mining waste, and agricultural waste (Pictel, 2005). MSW, likewise known as domestic waste, is generated within a community from several sources, both individual consumers and households. MSW originates from residential, commercial, institutional, industrial, and municipal sources. MSW are highly heterogeneous; these include durable and non-durable items, packaging and containers, food waste, yard waste, and miscellaneous inorganic waste (Pictel, 2005).

Table 2.1 shows region-specific default data on per capita MSW generation and management practices. These data are based on wet waste and may be assumed to be applicable for the year 2000.

Table 2.1 MSW generation and treatment data - regional defaults

Region	MSW Generation Rate (tones/cap/yr)	Fraction of MSW disposed to solid waste disposal site (SWDS)	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management unspecified
Asia					
Eastern Asia	0.37	0.55	0.26	0.01	0.18
South-central Asia	0.21	0.74	-	0.05	0.21
South-east Asia	0.27	0.59	0.09	0.05	0.27
Africa	0.29	0.69	-	-	0.31
Europe					
Eastern Europe	0.38	0.90	0.04	0.01	0.02
Northern Europe	0.64	0.47	0.24	0.08	0.20
Southern Europe	0.52	0.85	0.05	0.05	0.05
Western Europe	0.56	0.47	0.22	0.15	0.15
America					
Caribbean	0.49	0.83	0.02	-	0.15
Central America	0.21	0.50	-	-	0.50
South America	0.26	0.54	0.01	0.003	0.46
North America	0.65	0.58	0.06	0.06	0.29
Oceania	0.69	0.85	-	-	0.15

[1]Data are based on weight of wet waste.
[2]To obtain the total waste generation in the country, the per-capita values should be multiplied with the population whose waste
is collected. In many countries, especially developing countries this encompasses only urban population.
[3]The data are default data for the year 2000.
[4]Other, unspecified, includes data on recycling for some countries.
[5]Regional average is given for the whole Africa as data are not available for more detailed regions with Africa.
[6]Data for Oceania are based only on data from Australia and New Zealand.

Source: IPCC (2006a)

Based on Table 1.1, it can be concluded that most countries opt for landfill for final disposal. The Southeast Asian region, in which Malaysia is located, with 0.27 tonnes/cap/yr waste generation rate, prefers landfill for final disposal, followed by incineration. Approximately 70% of waste is collected and disposed, while the remaining 30% is either disposed illegally or recycled. Waste produced in the world has been growing considerably for many decades, especially in affluent countries, as shown by the link between national gross domestic product (GDP) and waste generation per capita (World Bank, 1992). Although data on waste arising is often incomplete and in certain cases unreliable, recent estimates suggest that MSW alone generated globally exceeded two billion tonnes per year at the turn of the millennium.

Solid waste generation that results from human activities varies with type of dwelling, socio-economic group, standard of living, occupation, and habits of the contributing population. Climate, dietary habit, geographic location, and season affect the generation of solid waste as well, both in physical and chemical composition (Tchobanoglous et al., 1994). Although humans have produced solid waste since the beginning of civilisation, rapid industrialisation of many developing countries in the recent years has increased solid waste generation. Industries have become more modern and sophisticated and so is the waste being produced, a number of which require specialised techniques for treatment and disposal (Agamuthu, 2001).

Solid waste management involves all activities related to waste generation, storage, collection, transfer and transportation, processing, disposal, reuse, or recycling (Agamuthu, 2001; Tchobanoglous, 1994). Solid waste management considers various aspects with the best principles of public health, economics, engineering, conservation, aesthetics, and environmental considerations. It includes all administrative, financial, legal, planning, and engineering functions. Waste management systems include setting up the elements, planning and evaluating municipal solid waste management (MSWM) activities, conducting waste characterisation studies, physical waste handling for recoverable material, marketing recovered materials, establishing training programs for MSWM workers, promoting public information and education programmes, identifying financial and cost recovery mechanisms, and managing public sector administration and operation.

Various factors affect the success of solid waste management in a developing country. There is a shortage of funds for waste treatment and disposal. This is due to the low priority given to this aspect compared to infrastructure and industrialisation. Lack of disposal sites in a number of developing countries will result in more environmental problems associated with MSWM. MSW is produced by people, and it has to be managed following legislative, technical, and social rules. People do not necessarily follow the rules and translate into action. Although many individuals state they are in favour of recycling, they do not necessarily translate this belief into action due to situational (Corraliza and Berenguer, 2000; Borgstede and Biel, 2002), attitudinal (Costarelli and Colloca, 2004), and institutional (White et al., 2005) barriers. Other factors such as insufficient space to store recyclables both inside and outside the home as well as inadequate local facilities (Williams and Kelly, 2003; Darby and Obara, 2005; Martin et al., 2006; Perry and Williams, 2007; Alexander et al., 2009; Hage et al., 2009; Timlett and Williams, 2009), lack of time (McKenzie-Mohr, 2000; Grodzin´ska-Jurczak et al., 2003; Martin et al., 2006) and delay in bag delivery or poor collection service (Grodzin´ska-Jurczak et al., 2003) discourage people from recycling for waste management.

Other reasons for not recycling include the dearth of incentives to recycle (Robinson and Read, 2005; Timlett and Williams, 2008), households' attitudes towards recycling and perceptions of the barriers to recycling (Tonglet et al., 2004), thinking "we do not produce enough waste" (Grodzin ´ ska-Jurczak et al., 2003), apathy (Robinson and

Read, 2005), lack of awareness on recycling provision (Robinson and Read, 2005; Shaw et al., 2007), lack of motivation and stimulus (Tonglet et al., 2004; Shaw et al., 2007), negative nearest neighbour effects (Shaw, 2008), and parental influences on young people (Williams and Gunton, 2007).

2.2 LANDFILL AS FINAL WASTE DISPOSAL

Every country will implement a different type of treatment and disposal depending on the type of waste, composition, infrastructure, land availability, labour, economic aspects, recycling strategy, public awareness, calorific value of waste, energy availability and demand, as well as environmental impacts. The methods employed should not expose workers or the public to health hazards. From an economic perspective, it should be economically less demanding and recycling options should be considered prior to final disposal. An ideal disposal method is an environment-friendly one. Landfilling is one of the main methods for the final disposal of solid waste. It is defined as a method of refuse disposal of significant volumes of waste into a hole, which is then systematically covered by layers of earth (Agamuthu, 2001).

Landfilling or land disposal is the most commonly used method for waste disposal. Modern landfills are classified into four types (Hester and Harrison, 2002). Landfill with total containment prevents all water movement through landfills. This type of landfill is most suitable for hazardous waste. Landfill with containment and collection of leachate is one where all water leakage from the landfill is controlled using a low-permeability liner beneath the waste. Meanwhile, landfill with control containment release has a base made of natural, often local, materials. Therefore, leachate levels will rise within the waste. This type of landfill is not suitable for all locations. The fourth type, unrestricted contaminant release landfill, has no control over water infiltration or leachate escape. Majority of modern landfills are classified according to the type of waste material deposited in them. Modern landfills require a minimum of one landfill liner that consists of a layer of compacted clay with minimum required thickness and maximum allowable hydraulic conductivity. Finally, various final cover systems such as clay or topsoil, depending on the type of wastes, are needed (Kreith, 1994).

Similar to most developing countries, Malaysia has two types of landfill: open dumping and controlled dumping sites. However, proper sanitary landfill concepts are not fully implemented due to financial and technological constraints (Chong et al., 2005). Approximately 117 landfill sites are in operation in the country. Table 2.2 presents a list of existing landfill sites in Malaysia as prepared by Ministry of Housing and Local Government (MHLG).

The classification of landfills in Malaysia is based on the decomposition processes that occur within them. There are five classes of landfill, namely, anaerobic landfill, anaerobic sanitary landfill with daily cover, improved anaerobic sanitary landfill with buried leachate collection pipes, semi-aerobic landfill with natural ventilation and leachate collection pipe, and aerobic landfill with forced aeration.