CHAPTER 1

INTRODUCTION

1.1 Global Warming and Climate Change

Through the lens of climate change, global warming is termed as an increase in the average temperature of the Earth's surface including the atmosphere and oceans (IPCC, 2007, 2001). In the recently released Fifth Assessment Report (AR5) on Climate Change by the Intergovernmental Panel on Climate Change (IPCC), a small positive energy imbalance with an increase in the global heat content was observed through the Earth's radiative budget (IPCC, 2013). Adding on, observations on the temperature measurements over the oceans also exhibited an increase in the heat content of the oceans (Murphy *et al*., 2009; Trenberth *et al*., 2009; Hansen *et al*., 2011). These studies also uniformly demonstrated that the anthropogenic emissions of Greenhouse Gases (GHGs) are the main contributor to this phenomenon, particularly carbon dioxide (CO_2) from combustion of fossil fuel (Montzka *et al*., 2011).

1.2 Greenhouse gases and its sources

The concentration of GHGs in the atmosphere is a good indicator of human induced climate change. GHGs such as CO_2, methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), ozone depleting substances (ODSs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) contribute to global warming by absorbing infra-red radiation and trapping it within the atmosphere. These gases continue to affect the climate for years to millennia after being emitted (Montzka *et al*., 2011). Ever since the industrial era, the concentration of CO_2 in the atmosphere had increased by 35% (ISWA, 2009), while CH_4 surface mixing ratio has increased by 150% (IPCC, 2013). Besides consumption and burning of fossil fuels, deforestation, population growth and land use change have amplified the amount of GHGs in the atmosphere. **Figure 1.1** below shows the main drivers of climate change and the radiative balance between the incoming solar shortwave radiation (SWR) and the outgoing longwave radiation (LWR). Emission of greenhouse gases and other human activity absorbs, scatters and reflects the SWR and LWR thus changing the energy balance on the Earth's surface.

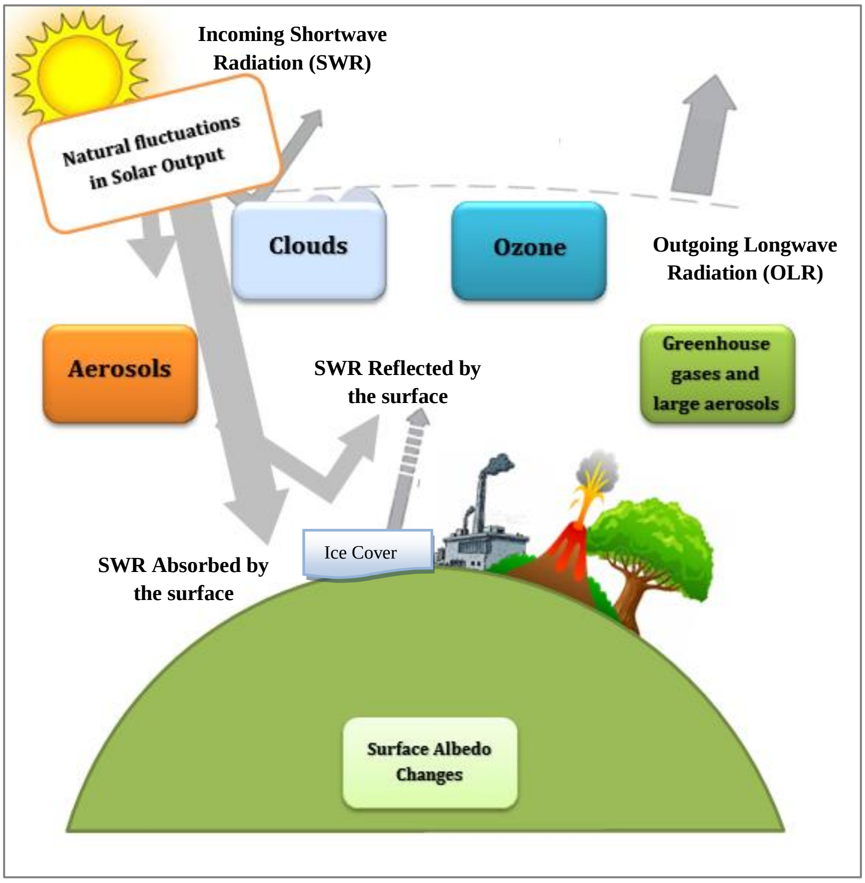

Figure 1.1: Main drivers of climate change

1.3 Methane as a potent GHG

It is certain to our knowledge that CO_2 is the highest contributor to global warming. However, CH_4 is also equally important as it is 25 times more potent than CO_2 in trapping heat in the atmosphere for over a 100 year time period (IPCC, 2007). Dlugokencky *et al*., (2009), showed a stabilized trend of CH_4 from 1999 to 2006 but thereafter an increasing CH_4 concentration from 2007 through 2011. The current climate forcing of CH_4 is 17 ± 2 % of the total radiative forcing by all long-lived GHG (Foster *et al.*, 2007; IPCC, 2013). Radiative forcing is a scale of energy balance used to assess and compare the natural and anthropogenic drivers of climate change. **Figure 1.2** shows the percentage of estimated global anthropogenic CH_4 by source. Global CH_4 budget from year 2000 to 2009 for agriculture and waste is 187 to 224 Tg (CH_4) y^{-1} and the anthropogenic emissions are from paddy agriculture, ruminant livestock, landfills, man-made lakes and wetlands, and waste treatment (IPCC, 2013).

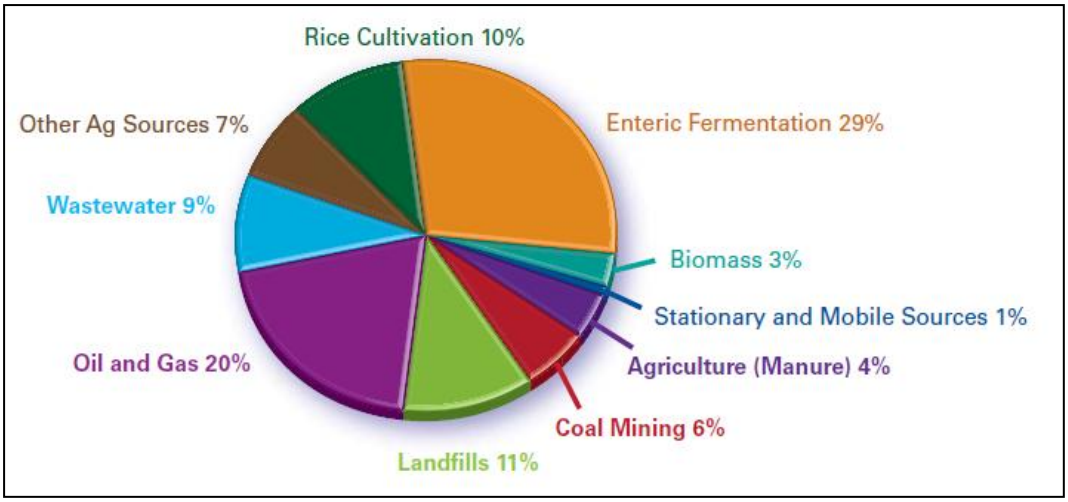

Figure 1.2: Estimated global anthropogenic methane emissions by source *(Global Methane Initiative, 2010)*

1.4 Methane from the waste sector

The most important GHG emissions from the waste sector are landfills CH_4 and followed by, wastewater CH_4 and N_2O (Bogner *et al*., 2007). In 2005, less than 5% of the total GHG global emissions or approximately 1300 $MtCO_2$-eq were recorded from the waste sector (IPCC, 2007). CH_4 from landfills alone constitutes to about 12% of the global anthropogenic CH_4 (World Bank, 2012). Although the percentage is amicably low, there has been an increase in CH_4 concentration over the years. **Figure 1.3** shows the global trend in CH_4 emission from 1990 to 2010.

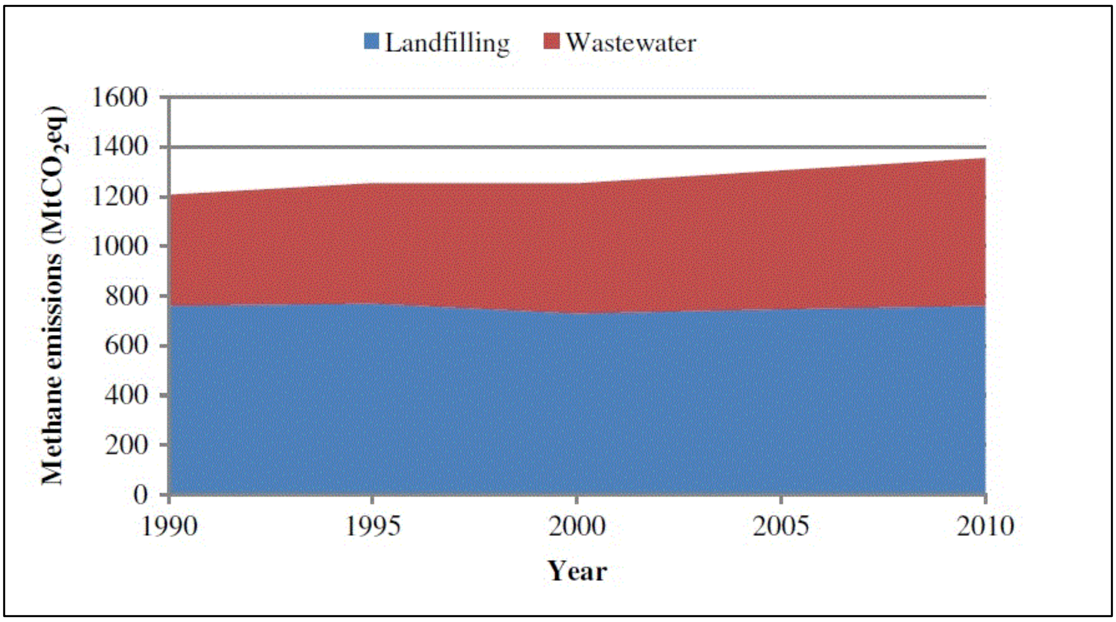

Figure 1.3: Global trend of methane emissions from landfilling and wastewater *(Yusuf et al., 2012)*

Globally landfill CH_4 emissions are estimated to be between 500 and 800 $MtCO_2$-eq per year (USEPA 2006; Monni *et al*., 2006; Bogner and Matthews, 2003). With the implementation of Clean Development Mechanism (CDM) and Joint Implementation

(JI) under the Kyoto Protocol, worldwide rates of landfill CH_4 is estimated to be reduced by 70% by the year 2030 with proper economic mitigation potentials (Bogner *et al.,* 2007). Although many measures and mechanisms have been implemented, the root cause of existing waste generation should be tackled foremost to reduce the global emissions of GHG.

1.5 Waste generation

The growth in population, urbanization, economic development and affluence are often linked to the rapid increase in waste generation. At present, it is estimated almost 1.3 billion tonnes of municipal solid waste (MSW) or 1.2kg/capita/day of waste is being generated globally every year (World Bank, 2012). The richer society produce higher rate of waste generation per capita, while the less affluent societies generate less waste and practice informal recycling and re-use initiatives that reduce the waste per capita to be collected at municipal level.

In Malaysia, the per capita generation of waste is 1.3 kg per day with an increase of 66.6% in the daily generation of MSW within 7 years (Agamuthu *et al.,* 2009), The daily generation of MSW was recorded at 18,000 tonnes in 2004 while in 2011 the figure accelerated to 31,000 tonnes (Agamuthu *et al*., 2011). Therefore this situation has caused for the need of proper waste management to minimize the impacts to the environment and people.

In accordance to this, a good waste management practice with strategic planning, legislation and policies should be incorporated. In developed countries, the waste management system is continuously improved with well-established policies and regulations. However, it is in the contrast for the developing countries where inefficient policy implementation, weak enforcement and lack of technology characterise the waste management system (Bogner *et al.*, 2007).

1.6 Landfills

From a global perspective landfilling still represents the main disposal practice for solid waste especially in developing countries giving consideration to high costs for alternative strategies. In Malaysia, CH_4 emission from landfills accounts for 47% of the total CH_4 emission and 24% of the total GHG emission of the country (NC2-Malaysia, 2010). Increased waste generation by rapid urbanization and population growth are the two main reasons contributing to high levels of CH_4 in Malaysian landfills.

Disposal of waste by landfilling has become more difficult as the existing landfills are quickly filled up and constructing new landfills have become a challenge due to lack of space and increasing land price. In total there are about 165 operating MSW disposal sites in Malaysia in 2012 which includes 8 operating sanitary landfills (KPKT, 2012). Landfill or open dumps in Malaysia are mostly non-sanitary which pose serious threat to the environment.

In a study by Giusti (2009), he opined that improper waste disposal not only pollutes the environment but also leads to health issues. He provided evidence of high risk of gastrointestinal problems associated with pathogens from sewage treatment plants, non-Hodgkin's lymphomas and sarcomas form dioxins from incinerators and congenital malformations were associated with landfills.

1.7 Landfill gas production and quantification

The major outputs of landfills are landfill gas (LFG) and leachate. LFG is generated from the physical, biological and chemical processes through the anaerobic decomposition that occurs when waste is buried in a landfill. The principal component of LFG are CH_4 (50-60%) and CO_2 (40-50%) (Amini *et al.*, 2012, Chakraborty *et al.*, 2011). According to Agamuthu (2001) the major drivers of LFG production are the composition of the waste, age of the waste and age of landfills, moisture content, temperature conditions in the landfill, quantity and quality of nutrients, organic content of refuse, pH and alkalinity of liquids in the landfill and presence of toxic or hazardous materials.

Since landfill CH_4 is a key GHG, there has been considerable interest in quantifying emission of CH_4 from landfills. As the emissions continue over several decades after waste disposal, hence the estimation of emission trends requires models that include temporal analysis and trends (Bogner *et al.*, 2007). Consequently, mathematical models are used to determine the amount of CH_4 generated in landfills so that a feasible gas collection can be planned or developed for the landfills.

On the other hand, LFG collection for smaller and older landfills with low CH_4 generation rates is not economically beneficial. For these types of landfills, a secondary control measure and a low-cost approach by indigenous methanotrophic microorganism are used to increase CH_4 oxidation in cover soil (Bogner *et al.*, 2007). CH_4 oxidation in conventional soils covers has been reported to be effective in reducing the amount of CH_4 emitted (Scheutz *et al.,* 2009; Bogner *et al.*, 1997). Soil covers such as compost from organic material are widely used in increasing microbial activity within the soil to enhance CH_4 oxidation.

1.8 Methane Oxidation

Methanotropic bacteria (or methanotrophs) are bacteria unique in their ability to utilize CH_4 as a carbon and energy source (Scheutz *et al*., 2009). A comprehensive review on the properties of methanotrophic bacteria by Hanson & Hanson (1996) summarizes the functional effect in landfill cover soils. Aerobic methanotrophs enable CH_4 oxidation with the help of methane mono-oxygenase (MNO) enzyme. Previous studies show that methanotrophic bacteria consume about 10-20% of the CH_4 passing through landfill cover and in laboratory conditions about 60% of CH_4 is oxidized (Kightley *et al*., 1995). The CH_4 oxidation in the cover soil is according to the following overall reaction (Scheutz *et al*., 2009):

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat\ (\Delta = -780\ kJ\ mol^{-l} CH_4)$$

In addition, CH_4 oxidation is also controlled by external environmental factors like soil texture, temperature, soil moisture content, CH_4 and O_2 supply, and nutrients within the soil. From literature it is also found that in simulated landfill cover soils CH_4 oxidation potential is the greatest around 20cm below the surface, in zones where vertical profiles of CH_4 and O_2 overlap (Kightley *et al.*, 1995). Therefore the thickness of the cover material is also crucial in influencing the CH_4 oxidation rate.

1.9 Biocover

The two main IPCC recommendations as potential strategies for mitigation of GHG from waste sector are (1) the enhancement of landfill CH_4 recovery and utilization, and (2) the optimization of methanotrophic CH_4 oxidation in landfill cover soils and biofilters (IPCC, 2007, Humer *et al*., 2011). Therefore it is agreed that an appropriate landfill cover or biocover which enhances microbial activity for CH_4 oxidation into CO_2 is necessary to mitigate landfill emissions.

Biocover materials with high CH_4 oxidation level are observed to be porous, course and rich in organic matter (Kightley *et al*., 1995). Raw or composted waste materials such as sewage sludge and garden waste are often used as cover materials. In studies done by Navarani (2009), Sitiaishah (2011) and Jayanthi (2013), compost used as biocover had 100% CH_4 oxidation capacity within four days of exposure to CH_4 and the black soil took seven to eight days to achieve 100% CH_4 oxidation.

Biocover acts as a filter material that supports the growth of methanotrophs, when it is placed above a gas distribution layer (Scheutz *et al*., 2009, Hilger and Humer, 2003). Clay is normally used as landfill cover in most of the Malaysian landfills to reduce rain water intrusion and hence minimizing landfill leachate. Design of the final cover is an important aspect as it will determine the performance of landfill. The co-benefits of CH_4 oxidation in cover soils is the secondary oxidation of many non-CH_4 organic compounds (Bogner *et al*., 2007; Scheutz *et al*., 2003).

1.10 Problem Statement

The MSW management is a major challenge to municipalities in Malaysia. It's daily MSW generation of 33,000 tonnes (Agamuthu & Tanaka, 2014) is proportional to its population growth and rapid urbanization. The current method for waste disposal in Malaysia is by landfilling. However, a well-constructed emission inventory for landfills is still lacking behind. The amount of LFG generated in landfills has large uncertainties due to inadequate data availability on MSW management and emission. This is because when analyzing the cradle to grave process of MSW, it goes through various stages such as recovery, recycling and composting. Therefore, the amount and type of waste reaching the landfills ultimately varies and the LFG is not properly estimated.

Thus for this purpose, a mathematical model such as the IPCC Waste Model which takes into account the amount of waste in-situ, landfill and climatic condition and composition of waste reaching the landfill was used to evaluate the LFG generated, especially CH_4. The CH_4 generated was later compared with the surface emission of CH_4 from the landfill. Besides that, few studies have been done in Malaysia to determine the influence of meteorological factors that affect the transport processes of CH_4 leading to gas emission or migration. Parameters such as barometric pressure, rainfall, temperature and relative humidity are expected to contribute to the emission rate of CH_4 in the tropical landfills. Therefore in this study, the temporal effects of meteorological parameters on CH_4 emission were examined.

Oxidation of CH_4 from landfill using biocover is a low cost approach to mitigate GHG emissions from the waste sector. CH_4, a potent GHG that currently contributes about 18% of the Earth's radiative forcing induces climate change (IPCC, 2013). Biocover technology using organic waste will be applied in this study for the reduction of CH_4 emission in landfill by converting CH_4 to CO_2 under tropical conditions.

1.11 RESEARCH OBJECTIVES:

1. To quantify CH_4 generation in Jeram Sanitary Landfill (JSL) using the IPCC Waste Model.
2. To quantify CH_4 surface emission using flux chamber technique at JSL.
3. To determine the influence of meteorological parameters on CH_4 emission at JSL.
4. To design a biocover material from organic waste to enhance CH_4 oxidation at JSL.
5. To determine the best thickness or height of biocover material used for CH_4 oxidation at JSL.

In general, this research work has been divided into chapters in order to enhance easy and proper concept of the study conducted. In Chapter 1, a formal introduction has been given to explain the current situation and problems faced while itemizing the research objectives of this study. In Chapter 2, a literature review on the relevant issues and topic were done. Chapter 3 shows the materials and methodologies used in this study. Next in Chapter 4, the results are discussed in depth. Finally, Chapter 5 concludes the research findings.