Emission Rate Assessment in Landfill and Energy Generation Technologies (Case Study: Aradkooh Landfill)

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Abstract
A landfill is a location designed for systematic long-term storage of waste under the conditions that it will prevent contamination of air and water. Landfill gas is produced by bacterial decomposition, which occurs when organic waste is broken down by the bacteria naturally present in the waste and in the soil used to cover the landfill. Landfill gas is composed of a mixture of hundreds of different gases. By volume, in general the landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. This study has estimated total produced gas, carbon dioxide and methane, by the basic first-order decay model for Aradkooh Landfill till the next 30 years after the landfill is closed. Gas production has decreasing trend in time, as the maximum gas production for methane and carbon dioxide is in order of 6 and it will be 16 million kg in the year 2015.The minimum contribution will also be in order of 0.3 and 0.8 million kg in 2044. The total produced gas in the 30 years is 213 million m^3 which 27% of its mass belongs to methane and 73% is carbon dioxide gas. In addition, the amount of methane, carbon dioxide and sulfur dioxide contributed from energy generation technology is calculated for 30 years and compared. The results show that the emission rate of controlled carbon dioxide gas is 1.85 times in uncontrolled state and the emission of controlled methane gas is 0.15 in uncontrolled state. In addition, using energy generation technology leads to sulfur dioxide contribution. The estimation for total amount of this gas in 30 years is predicted about 361 kg. Finally, the gases emissions predicted from this model are validated using the mass balance method according to other studies. Comparison of results shows good agreement with other studies.

Introduction
Industrialization, along with economic growth, results in an increase in production of municipal solid waste (MSW). Landfills are managed by a simple landfill method, and it creates secondary pollution such as water pollution by leachate, leakage of gases, and bad odors. LFG consists of 50–60 vol% CH_4 and 30–40 vol% CO_2 with numerous chemical compounds such as aromatics, chlorinated organic compounds, and sulfur compounds.

CH_4 and CO_2, both greenhouse gases (GHGs), contribute to global warming. CH_4, in particular, is a very potent greenhouse gas which is almost 21- 25 times more powerful than CO_2. However, it is a green fuel which can be used for electricity generation. The most common disposal method for municipal solid wastes (MSW) is burial in landfills since the usage of intermediate treatments such as incineration, pyrolysis, and recycles are not actively practiced to effectively remove the wastes (in Korea). According to various studies, a total of 40–60 Mtonnes of CH_4 is emitted from landfills and old waste deposits worldwide, accounting for approximately 11–12% of the global anthropogenic CH_4 emissions. This ranks landfills third after rice paddies (60 Mtonnes/year) and ruminant livestock (85 Mtonnes/year). Shin and his colleagues (2005) assess different gas-to-energy technology with landfill gas and analyze and compare emission rates of each technology using LEAP model. Jaramillo and Mathews (2005) presented formulas for calculating emission rates of CH_4, CO_2, SO_2 based on landfill gas emission rates and compared emission of controlling landfill gas technologies such as flares, IC engines, gas turbine and steam turbine. In this study, emission rates of different gases such as CO_2 and CH_4 in MSW landfill located in south of Tehran will be calculated in different elapsed time from burial of waste using equations and formulas. The influence of using LFG controlling technologies on emission reduction will also be discussed.

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Material and Methods

When a landfill-gas-to-energy project is designed, one of the most important factors to be considered is the amount of gas available to generate the electricity. Landfill gas starts being generated shortly after the landfill begins accepting waste and it can last for up to 30 years after the landfill closure. The production of landfill gas generated in year T given previous disposal of waste at time x (in millions of cubic meter per year) can be estimated from a basic first-order decay model:

$$LFG_{T,x}=2KR_xL_0e^{-K(T-x)}$$

Where, 2 is the ratio of landfill gas to methane; K is the rate of methane generation (1/yr); Rx is the amount of waste disposed in year x (kg); L_0 is the total methane generation potential of the waste and x is the year of waste input (m^3/kg) .The total landfill gas generated (LFG_T) in a year by all the waste in the landfill is the sum of $LFG_{T,x}$ across all values of R_x. k depends on the climate of the area where the landfill is located. EPA recommended value for wet climate is 0.225/yr. For medium moisture and dry climates, EPA recommends values of K are 0.1/yr and 0.06/yr. Municipal landfills have the potential to emit large quantities of methane and carbon dioxide, as well as some non-methane organic compounds. Under the 1996 New Performance Standards for Municipal Landfills, large landfills have to control these emissions. Flaring has been traditionally used as the control method. Methane emission control can also be achieved by using electricity-generating equipment. It is important to note that both flaring and electricity-generating equipment create emissions of criteria pollutants such as NOx, CO, SO_2, and particulate matter (PM). To perform a more socially relevant analysis, valuation of emissions (greenhouse gases and criteria pollutants) was included for this project. Equations were used to calculate these emissions and were developed by use of the AP-42 emission factors for municipal solid waste landfills. For any given landfill, the costs of net emissions from a landfill gas-to-energy project were compared with the current net emission costs at the landfill. For a landfill where a collection/flaring system is not present, current emissions are uncontrolled (U) methane and CO2 emissions, as calculated by:

$$U_{CO2}=(0.5)(1.794)(LFG_T)$$

Where, 0.5 is the assumed percentage of landfill gas that is CO_2. 1.794 is the amount of CO_2 (kg/m^3_{LFG}), and LFG_T is the total amount of landfill gas generated in year T (m^3)

$$UCH_4=(0.5)(0.6567)(LFG_T)$$

Where, 0.5 is the assumed percentage of landfill gas that is CH4, and 0.6567 is the amount of CH4 (kilogram per cubic meter of landfill gas). The results obtained from this model are validated using the mass balance approach. Due to this method, the maximum amount of LFG generated in the anaerobic decomposition can be estimated by the following simplified reaction:

$$C_6H_{10}O_{4(waste)} + 1.4H_2O \rightarrow 3.25CH_4 + 2.75CO_2$$

In landfills where a collection and flaring system is in place, emissions are those from a flaring system. In this case, the uncontrolled methane is converted into emissions of CO_2 (combustion efficiency was assumed to be 100%) and criteria pollutants. Equations are used to calculate controlled (C) emissions of CO_2, CH_4. Collection efficiency (η_{col}) is assumed to be 85%.

$$C_{CH_4} = (1-\eta_{Col})(U_{CH_4})$$

$$C_{CO_2} = U_{CO_2} + (\eta_{Col})(U_{CH_4})(2.75)$$

Where, 2.75 is the ratio of the molecular weight of CO_2 to the molecular weight of CH_4. The equations are also valid for CH_4, CO_2, and SO_2 emissions from internal combustion engines, gas turbines, and steam turbines, where methane combustion is also assumed to be 100% efficient.

Results and Discussion

It is predicted that according to capacity of the landfill and daily volume of burial waste, Aradkooh landfill will be closed in 2015 to emit gas. The emission of uncontrolled CH_4 and CO_2 were calculated in 30 years. According to the calculation, the maximum volume of landfill gas emission will be 18 Mm^3 in 2015. And minimum volume of LFG emission will be approximately 0.9 Mm^3 after 30 years. The maximum and minimum mass of uncontrolled CH_4 will be approximately 6 Mkg in 2015 and 0.3 Mkg in 2044, respectively. Deceasing rate of CH_4emission is slower in comparison with landfill gas emission. Emission rate of contaminant gases like CH_4 and CO_2 in presence of landfill gas-to-energy technologies such as IC engine, gas turbine and steam turbine in next 30 years were calculated. It is predicted that maximum volume of controlled CH_4 will be 0.85 Mkg in 2015.After 30 years this mass will be decreased approximately up to 0.3 Mkg. Incomplete combustion in each of CH_4 molecules after combusting in gas-to-energy facilities will be altered to 1 CO_2 molecule and 2 H_2O molecules. So the emission of CO_2 in state of using gas controlling technology will become more than emission of uncontrolled CO_2. Emission rate of uncontrolled CH_4 is approximately 6 times more than emission rate of CH_4 in presence of landfill gas-to-energy facilities. The emission rate of CO_2 in state of using landfill gas-to-energy facilities are 1.85 times more than emission rate of uncontrolled CO_2. This increase is the result of altering CH_4 into CO_2 in state of using landfill gas-to-energy facilities. Controlled CH_4 emission rate is 0.15 of uncontrolled CH_4 emission rate. Considering that CH_4 global warming effects is approximately 25% more than CO_2, it can be concluded that using landfill gas-to-energy has a significant impact on reducing global warming.

Conclusion

It is predicted and estimated that maximum methane and carbon dioxide emitted from Aradkooh landfill will be approximately 6 and 16 Mkg in 2015 and minimum mass of methane and carbon dioxide emission will be 0.3 and 0.8Mkg after 30 years in 2044.Total gas emission in 30 years will be 213 Mm^3. %27 of total mass of landfill gas is methane and %73 of total emitted gas from landfill is carbon dioxide. Using landfill gas-to-energy technologies causes SO_2 emission. The amount of SO_2 emitted from Aradkooh landfill will be approximately 361 kg in 30 years.

Keywords: biogas, energy, greenhouse gas, waste.