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Estimation and Modeling of Biogas Production in Rural Small Landfills (Case Study: Chaharmahaal and Bakhtiari and Yazd Rural Areas)

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Abstract

One of the main factors contributing to greenhouse gas emissions in the environment is the production of pollutant gases in landfills. Collecting the landfill gases (LFG) effectively reduces the emission of gasses from the landfill site. A precise collection system for LFG can create the potential for energy generation in addition to emissions reduction. However, in Iran, the implementation of such systems remains undeveloped. During the design and construction of a gas collection system, it is necessary to correctly estimate the amount of emissions and type of gases produced at the landfill site. Using LandGEM model, in the span of 20-year (2016-2036), the amount of gases produced in the landfills of the rural areas of Chaharmahaal and Bakhtiari and Yazd provinces have been predicted. According to the results, the largest amount of landfill gas emission will be in 2037, one year after the last year of disposal of the waste to the landfill. The total amount of produced gas, methane, carbon dioxide and NMOCs will be 5435, 1452, 3983 and 62.4 tons per year in 2037 for Chaharmahaa and Bakhtiari and 1574, 4205, 1154 and 18.07 tons per year in 2037 for Yazd.

Keywords: Biogass, Rural Areas, Biofuel, Landfill Gas, Biomass

Introduction

More than 60% of the total methane emissions worldwide are due to human activities. In 2011, about 9% of the total emissions of greenhouse gases from human activities in the United States were methane. Landfills are one of the main sources of methane production from human activities (Janke et al., 2013; Lizik et al., 2013). Landfill sites are the third major source of human activity in methane emissions in the United States (Barlaz et al., 2004). According to the 2nd National Conference on Climate Change of the People's Republic of China, in 2004, municipal waste management and disposal activities were the third largest source of methane emissions in China (the Republic of China, 2010). Controlling and restriction of methane released from energy and agricultural activities are more difficult than methane produces at landfills. Methane collection not only reduces greenhouse gas emissions from landfills but also allows the use of accumulated gas as a new source of energy (Sun et al., 2015).

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Biogas production at landfills is due to biological activities in a waste mass (Kalantarifard et al., 2012; Couth et al., 2011). Methane and carbon dioxide, which are known as greenhouse gases, are the main components of this gas and can have adverse effects in the atmosphere (Abdoli et al., 2014; Chiriac et al., 2007). Although the waste disposal at a landfill site is typically carried out with a 10 to 15 cm coverage layer, gas-to-atmosphere spillage can be seen on these sites. The release of gases into the atmosphere is unavoidable.

The gas produced at the landfill site usually contains 45-60% methane (CH_4), 4- 60% Carbon dioxide (CO_2), and a small amount of Nitrogen (N_2), Oxygen (O_2), Ammonia (NH_3), Hydrogen sulfide (H_2S) Hydrogen (hydrogen), Sulfide (S_2), Carbon monoxide (CO), as well as nonmethane organic compounds (NMOCs) such as trichloroethylene, benzene and vinyl chloride (Aydi, 2012; Saral et al., 2009).

Due to the high thermal value of methane, it can be used as a fuel source as well as a source used in thermal power plants (Vahidi et al., 2018). Combining with air at a ratio of 5 to 15%, it can be blown up as an explosive material. Consequently, the improper collection at the landfill site is associated with the risk of explosion. Methane production usually starts from the second month after the start of landfilling and may continue for years (Kalantarifard et al., 2012).

In rural areas, due to the high cost of energy transfer to rural areas, the use of renewable and new energies can be considered as an alternative solution (Vahidi et al., 2016). The population distribution in rural areas is not uniform and depends largely on geography, topography, climate, soil type, water content, livelihoods and culture. Despite this uneven distribution of the population, one of the factors that are inseparable from the number of inhabitants of a region is waste production. The waste generated in rural areas is mainly due to four sources; garden and crop residues such as straw, grass, leaves, animal and chicken manure, agricultural waste, and, finally, human wastewater and municipal solid waste (Vahidi et al., 2017). Most solid wastes produced in rural areas are of the agricultural type and can be defined as putrescible waste (Tian et al., 2012). In developing countries, putrescible waste, which contains 50% of its total amount, can be recycled by composting or other biological methods (He, 2012). Also, in rural areas due to the high rate of putrescible materials, the potential for waste to energy is considered important.

There are different methods to use the released gas from waste for energy production. Five technologies are widely used to convert municipal waste into energy: burning with energy recovery, pyrolysis or gasification, plasma arc furnace gasification, RDF production and biological methane production using anaerobic method (Greater London Authority, 2008; Sorenson, 2010; CHAMCO; Clark et al., 2010). In the process of biological methane production using anaerobic methods, predicting the amount of gases produced in the landfill is very important. Many studies have been conducted to estimate the amount of gases produced. In these studies, it is proved that predicting the amount of gases produced is feasible using laboratory methods or modeling. One of the most well-known models for estimating the amount and composition of gases produced in landfill is the LandGem Discharge Model, which is developed based on the first-order decay equation in order to determine the amount of greenhouse gas emissions from waste decomposition by the US Environmental Protection Agency (EPA) (Alexander et al., 2005).

The purpose of this paper is to determine the amount of greenhouse gas emissions such as methane during post-landfill maintenance years (waste disposal for the period of 20 years 2016-20) at landfills in rural areas of Chaharmahaal and Bakhtiari and Yazd provinces by estimating future waste production using LandGEM simulation model.

Materials and Methods

The study areas for this research were Chaharmahaal and Bakhtiari and Yazd provinces, Iran, ranging from 31° 4' to 42° 4' N and from 49° 39' to 51° 21' E, and from 29° 52' to 33° 27' N and from 52° 55' to 56° 37' E, respectively, located in the central plateau of Iran, with a total area of 145,617 km2. Using the latest census results, the population and growth rate are calculated (Population report, 2016). The climate of the studied provinces differs from each other. Yazd is located in the driest regions of Iran, and Chaharmahaal and Bakhtiari is located at the center of the Zagros Mountains experiencing a cold and freezing climate.

Figure 1 shows the area under study. Also, the per capita waste per person per day is 0.507 and 0.293 grams in Chaharmahaal and Bakhtiari and Yazd, respectively (Vahidi et al. 2017).

Fig. 1. Location of studied provinces in Iran

Table 1 shows the physical analysis of waste in rural areas of Chaharmahaal and Bakhtiari and Yazd provinces. About 39.3 and 41% of the total waste in the rural areas of the Chaharmahaal and Bakhtiari and Yaz province are of putrescible, respectively. Food waste is rapidly decomposed, but other municipal types of waste are not easily decomposed; a small amount of paper waste is also excluded.

Table 1. Physical analysis of waste in rural areas of the provinces

Province	season	Putrescible	Recyclable Materials												Others
			Paper	Cardboard	Plastic	Metals	Aluminum	Tin	Other non-metal[1]	Glass	PET	Textile	Wood	Rubber	
Charmahal and Bakhtiari	Autumn	33.6	6.3	2.8	11.8	12.1	0.6	4.2	0.7	10.1	4.9	3.5	3.0	2.2	4.2
	Winter	42.0	6.3	2.4	7.9	9.8	0.4	3.5	0.5	5.1	10.3	4.3	2.5	2.5	2.6
	Spring	38.1	6.1	2.8	9.3	8.1	0.7	3.8	0.6	4.9	8.8	4.6	2.8	2.3	6.1
	Summer	43.4	6.3	2.1	9.1	5.3	0.3	2.5	0.3	3.3	6.5	4.7	2.8	2.8	10.9
	Mean	39.3	6.3	2.5	9.5	8.8	0.5	3.5	0.5	5.8	7.6	4.3	2.8	2.4	5.9
Yazd	Autumn	41.5	7.0	3.5	10.1	7.7	0.7	2.6	0.2	7.0	3.9	3.7	2.8	2.7	6.8
	Winter	51.3	6.1	2.2	7.9	5.4	0.4	2.5	0.2	5.8	5.1	5.3	2.5	3.1	2.2
	Spring	37.6	7.4	3.1	11.5	9.1	0.7	2.5	0.1	10.2	3.3	4.8	2.4	2.7	4.6
	Summer	33.7	8.2	3.9	10.8	9.9	0.9	2.9	0.2	9.7	5.0	4.0	2.4	2.5	5.8
	Mean	41.0	7.2	3.2	10.1	8.0	0.7	2.6	0.2	8.2	4.3	4.5	2.5	2.8	4.9

Given the census results for the 20-year period and the effect of growth rates, with the assumption that per capita waste production remains constant over time, the amount of waste generated per year can be achieved. Table 2 and 3 shows the population and waste production in the period 2017-2036 in the provinces.

Table 2. The population and amount of waste generated in the period 2016-2036 Chaharmahaal and Bakhtiari

Year	Population	Waste generation (Mg)	Putrescible waste (Mg)	Year	Population	Waste generation (Mg)	Putrescible waste (Mg)
2017	339667	62857	24703	2027	282097	52204	20516
2018	333417	61700	24248	2028	276906	51243	20138
2019	327282	60565	23802	2029	271811	50301	19768
2020	321260	59450	23364	2030	266810	49375	19404
2021	315349	58357	22934	2031	261900	48466	19047
2022	309547	57283	22512	2032	257082	47574	18697
2023	303851	56229	22098	2033	252351	46699	18353
2024	298260	55195	21691	2034	247708	45840	18015
2025	292772	54179	21292	2035	243150	44996	17684
2026	287385	53182	20901	2036	238677	44168	17358

Table 3. The population and amount of waste generated in the period 2016-2036 Yazd

Year	Population	Waste generation (Mg)	Putrescible waste (Mg)	Year	Population	Waste generation (Mg)	Putrescible waste (Mg)
2017	166724	17830	7310	2027	135670	14593	5949
2018	163323	17467	7161	2028	132903	14213	5427
2019	159991	17110	7015	2029	130192	13923	5709
2020	156727	16761	6872	2030	127536	13639	5592
2021	153530	16419	6732	2031	124934	13361	5478
2022	150398	16084	6595	2032	122385	13089	5366
2023	147329	15756	6460	2033	119889	12822	5257
2024	144324	15435	6328	2034	117443	12560	5150
2025	141380	15120	6199	2035	115047	12304	5045
2026	138496	14811	6073	2036	112700	12053	4942

LandGEM is a Microsoft Excel tool that is used to estimate gasses generated at landfills including methane, carbon dioxide, nonmetallic organic compounds, and pollutants. LandGEM can either use real-time information from landfill sites or use the default information provided for such sites. This default information is divided into two categories: 1) Default CAA information and 2) Full list default information. The CAA's default data has been adapted from the US federal law on municipal waste disposal, and the software can determine if there is a need to install air pollution control systems in landfills or not.

LandGEM is developed based on the first-order solid state decay rate equation. The software has provided a simple method for estimating waste disposal. The model used in this software is based on the empirical model of landfills in the United States. LandGEM is a screening tool that provides a better estimation of input data. Typically, the limitation in information on the quantity, composition and, process of landfill can be effective in determining the accuracy of produced gases. Changing the landfill condition, such as increasing the humidity of the landfill by returning the produced leachate, can lead to an increase in the amount of gases produced. Equation (1) is the first-order decay equation.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_i}{10} \right) e^{-kt_{ij}} \quad (1)$$

The first-order decay equation is as follows:

Where Q_{CH4} predicts annual methane production, i is the increase in the studied years, n is difference between the predicted and first year of waste disposal, j is 0.1 (increase within the studied years), k is methane production rate (year-1), L_0 is methane production potential (m^3/Mg), M_i is waste mass in the ith year (Mg or ton), and tij is the jth section's age of M_i waste mass in the *ith* year (decimal year, for example, 2.3 years).

The methane generation rate (k) represents the production of methane. Increasing rates, decomposition occurs at a shorter time. The production rate of biofuels depends on four parameters: waste moisture, the ability of microorganisms to decompose waste to methane and carbon dioxide, pH of waste and temperature of the waste. Due to the dry and semi-arid climate of the study area, the CAA and LandGEM (version 3.02) usually make the landfill gas amount equal to 0.20. Methane production potential (L_0) depends only on the type and composition of landfill waste, for example, increasing the amount of cellulose, the methane production rate increases. Depending on the climate and according to the CAA, suggested values for arid and semi-arid areas, the production potential Methane is equal to 170 cubic meters per ton. Given the default values of software for arid regions, L_0, is considered to be 170.

Results

According to the United Nations, the generation of waste around the world in developing countries is 500 to 900 grams per capita per day, while in Iran is an average of 850 grams per capita per day (Rezaee, 2014). According to the studies of Vahidi et al., Per capita waste from rural areas in Yazd, Chahar Mahal and Bakhtiari and Isfahan provinces is 507, 293 and 497 grams per capita per day. Also, according to Vahidi et al., 39.3 and 41% of waste generated in rural areas of Chaharmahaal and Bakhtiari and Yazd provinces belong to the putrescible waste (Vahidi et al., 2017). According to the results of the census released by the Iranian Statistical Center in 2016, the rate of population growth in Chahar Mahal and Bakhtiari and Yazd provinces estimated to be -1.84 and -2.04%, respectively.

The amount of municipal putrescible waste in the landfill site is considered as an input to the LandGEM model. Methane is produced during the primary process of fermentation and decomposition. In fact, methane and carbon dioxide are the main gases, but the amount of hydrogen can also be important. Landfill gases include 60 percent of methane, the remaining amount being essentially carbon dioxide. According to the model results, the maximum amount of landfill gas release will be in 2037, a year after the last year of waste disposal to the landfill. The total amount of gas production, methane gas, carbon dioxide and NMOCs will be 5435, 1452, 3983 and 62.4 tons per year in 2037 for Chaharmahaa and Bakhtiari and 1574, 4205, 1154 and 18.07 tons per year in 2037 for Yazd.

Figure 2 and 3 shows the amount of methane, carbon monoxide and NMOC produced at landfills regarding each year in Chaharmahaal and Bakhtiari and Yazd, respectively.

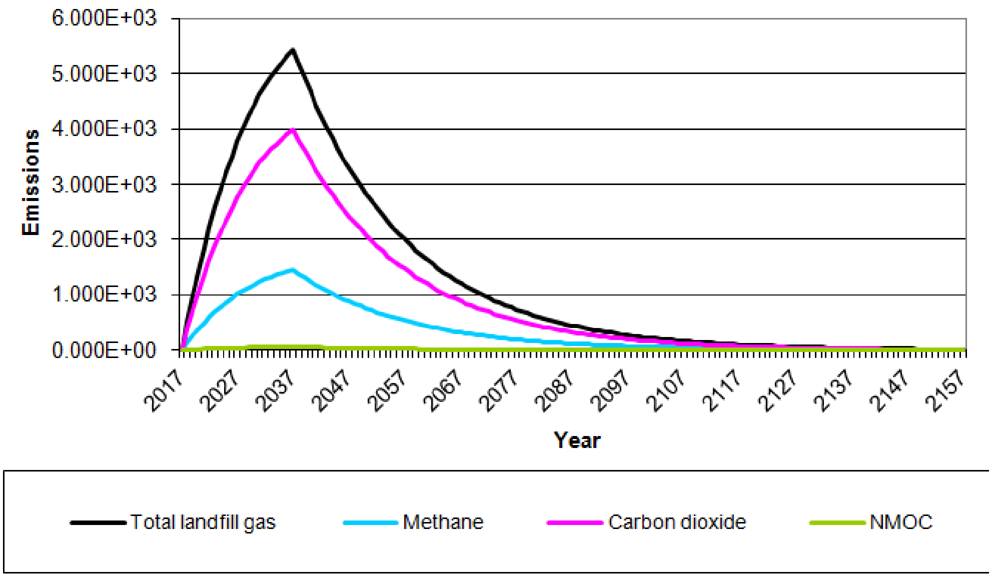

Fig 2. The amount of generated gas, methane, and carbon dioxide and NMOC, Chaharmahaal and Bakhtiari

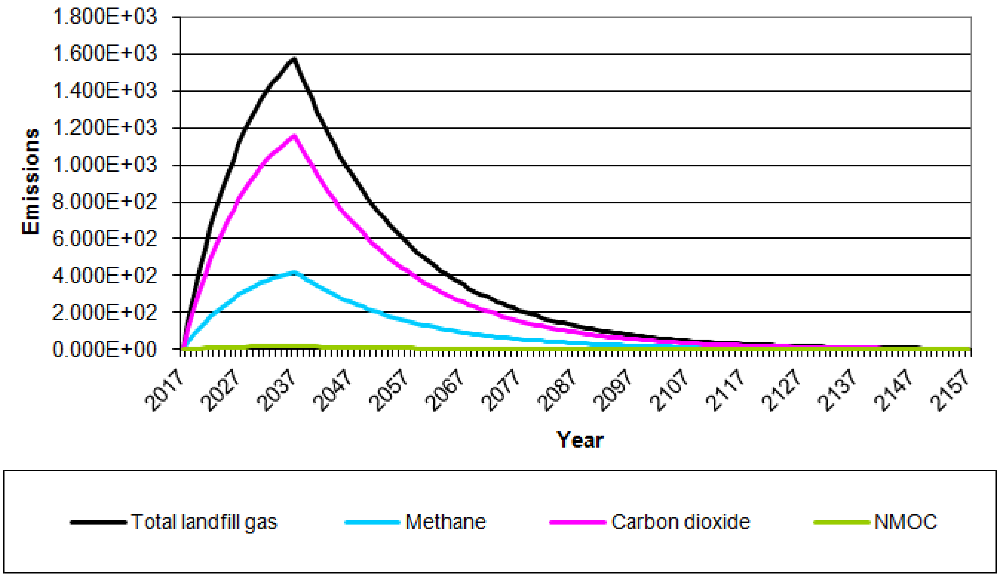

Fig 3. The amount of generated gas, methane, and carbon dioxide and NMOC, Yazd

Table 4 and 5 shows the amount of gases and pollutants produced in 2037 in Chaharmahaal and Bakhtiari and Yazd, respectively.

As the value of k increases, methane production also increases. The US EPA proposed gas production capacity is 170 cubic meters per tonne as mentioned in the literature. As this amount increases, the methane production rate increases, which depends on the composition of the input waste. This amount varies with increasing amount of putrescible materials and also changing the rainfall and temperature of the environment. The potential of gas production has been estimated and reported in a number of other studies, which is estimated at 100 cubic meters per tonne (Chalvatzaki et al., 2010; Tchobanoglous et al., 1993).

Table 4. The amount of gases and pollutants produced in the province's landfills in 2037, Chaharmahaal and Bakhtiari

Gas / Pollutant	Emission Rate	
	(Mg/year)	*(m^3/year)*
Total landfill gas	5.435E+03	4.352E+06
Methane	1.452E+03	2.176E+06
Carbon dioxide	3.983E+03	2.176E+06
NMOC	6.240E+01	1.741E+04
1,1,1-Trichloroethane (methyl chloroform) - HAP	1.159E-02	2.089E+00
1,1,2,2-Tetrachloroethane - HAP/VOC	3.342E-02	4.787E+00
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	4.300E-02	1.044E+01
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	3.509E-03	8.704E-01
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	7.344E-03	1.784E+00
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	3.681E-03	7.834E-01
2-Propanol (isopropyl alcohol) - VOC	5.440E-01	2.176E+02
Acetone	7.359E-02	3.046E+01
Acrylonitrile - HAP/VOC	6.051E-02	2.742E+01
Benzene - No or Unknown Co-disposal - HAP/VOC	2.686E-02	8.269E+00
Benzene - Co-disposal - HAP/VOC	1.555E-01	4.787E+01
Bromodichloromethane - VOC	9.193E-02	1.349E+01
Butane - VOC	5.260E-02	2.176E+01
Carbon disulfide - HAP/VOC	7.993E-03	2.524E+00
Carbon monoxide	7.098E-01	6.093E+02
Carbon tetrachloride - HAP/VOC	1.114E-04	1.741E-02
Carbonyl sulfide - HAP/VOC	5.328E-03	2.132E+00
Chlorobenzene - HAP/VOC	5.094E-03	1.088E+00
Chlorodifluoromethane	2.035E-02	5.658E+00
Chloroethane (ethyl chloride) - HAP/VOC	1.518E-02	5.658E+00
Chloroform - HAP/VOC	6.483E-04	1.306E-01
Chloromethane - VOC	1.097E-02	5.222E+00
Dichlorobenzene - (HAP for para isomer/VOC)	5.588E-03	9.139E-01
Dichlorodifluoromethane	3.502E-01	6.963E+01
Dichlorofluoromethane - VOC	4.844E-02	1.132E+01
Dichloromethane (methylene chloride) - HAP	2.153E-01	6.093E+01
Dimethyl sulfide (methyl sulfide) - VOC	8.772E-02	3.395E+01
Ethane	4.844E+00	3.873E+03
Ethanol - VOC	2.252E-01	1.175E+02
Ethyl mercaptan (ethanethiol) - VOC	2.587E-02	1.001E+01
Ethylbenzene - HAP/VOC	8.839E-02	2.002E+01
Ethylene dibromide - HAP/VOC	3.401E-05	4.352E-03
Fluorotrichloromethane - VOC	1.890E-02	3.307E+00
Hexane - HAP/VOC	1.030E-01	2.872E+01
Hydrogen sulfide	2.221E-01	1.567E+02
Mercury (total) - HAP	1.053E-05	1.262E-03
Methyl ethyl ketone - HAP/VOC	9.267E-02	3.090E+01
Methyl isobutyl ketone - HAP/VOC	3.445E-02	8.269E+00
Methyl mercaptan - VOC	2.177E-02	1.088E+01
Pentane - VOC	4.310E-02	1.436E+01
Perchloroethylene (tetrachloroethylene) - HAP	1.111E-01	1.610E+01
Propane - VOC	8.779E-02	4.787E+01
t-1,2-Dichloroethene - VOC	4.913E-02	1.219E+01
Toluene - No or Unknown Co-disposal - HAP/VOC	6.504E-01	1.697E+02
Toluene - Co-disposal - HAP/VOC	2.835E+00	7.398E+02
Trichloroethylene (trichloroethene) - HAP/VOC	6.660E-02	1.219E+01
Vinyl chloride - HAP/VOC	8.259E-02	3.177E+01
Xylenes - HAP/VOC	2.306E-01	5.222E+01

Table 5. The amount of gases and pollutants produced in the province's landfills in 2037, Yazd

Gas / Pollutant	Emission Rate	
	(Mg/year)	(m^3/year)
Total landfill gas	1.574E+03	1.261E+06
Methane	4.205E+02	6.303E+05
Carbon dioxide	1.154E+03	6.303E+05
NMOC	1.807E+01	5.043E+03
1,1,1-Trichloroethane (methyl chloroform) - HAP	3.358E-03	6.051E-01
1,1,2,2-Tetrachloroethane - HAP/VOC	9.681E-03	1.387E+00
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	1.245E-02	3.026E+00
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	1.017E-03	2.521E-01
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	2.127E-03	5.169E-01
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	1.066E-03	2.269E-01
2-Propanol (isopropyl alcohol) - VOC	1.576E-01	6.303E+01
Acetone	2.132E-02	8.824E+00
Acrylonitrile - HAP/VOC	1.753E-02	7.942E+00
Benzene - No or Unknown Co-disposal - HAP/VOC	7.782E-03	2.395E+00
Benzene - Co-disposal - HAP/VOC	4.505E-02	1.387E+01
Bromodichloromethane - VOC	2.663E-02	3.908E+00
Butane - VOC	1.524E-02	6.303E+00
Carbon disulfide - HAP/VOC	2.315E-03	7.312E-01
Carbon monoxide	2.056E-01	1.765E+02
Carbon tetrachloride - HAP/VOC	3.227E-05	5.043E-03
Carbonyl sulfide - HAP/VOC	1.543E-03	6.177E-01
Chlorobenzene - HAP/VOC	1.475E-03	3.152E-01
Chlorodifluoromethane	5.894E-03	1.639E+00
Chloroethane (ethyl chloride) - HAP/VOC	4.398E-03	1.639E+00
Chloroform - HAP/VOC	1.878E-04	3.782E-02
Chloromethane - VOC	3.177E-03	1.513E+00
Dichlorobenzene - (HAP for para isomer/VOC)	1.619E-03	2.647E-01
Dichlorodifluoromethane	1.014E-01	2.017E+01
Dichlorofluoromethane - VOC	1.403E-02	3.278E+00
Dichloromethane (methylene chloride) - HAP	6.235E-02	1.765E+01
Dimethyl sulfide (methyl sulfide) - VOC	2.541E-02	9.833E+00
Ethane	1.403E+00	1.122E+03
Ethanol - VOC	6.524E-02	3.404E+01
Ethyl mercaptan (ethanethiol) - VOC	7.493E-03	2.899E+00
Ethylbenzene - HAP/VOC	2.561E-02	5.799E+00
Ethylene dibromide - HAP/VOC	9.851E-06	1.261E-03
Fluorotrichloromethane - VOC	5.474E-03	9.581E-01
Hexane - HAP/VOC	2.982E-02	8.320E+00
Hydrogen sulfide	6.433E-02	4.538E+01
Mercury (total) - HAP	3.050E-06	3.656E-04
Methyl ethyl ketone - HAP/VOC	2.684E-02	8.950E+00
Methyl isobutyl ketone - HAP/VOC	9.978E-03	2.395E+00
Methyl mercaptan - VOC	6.306E-03	3.152E+00
Pentane - VOC	1.248E-02	4.160E+00
Perchloroethylene (tetrachloroethylene) - HAP	3.217E-02	4.664E+00
Propane - VOC	2.543E-02	1.387E+01
t-1,2-Dichloroethene - VOC	1.423E-02	3.530E+00
Toluene - No or Unknown Co-disposal - HAP/VOC	1.884E-01	4.916E+01
Toluene - Co-disposal - HAP/VOC	8.212E-01	2.143E+02
Trichloroethylene (trichloroethene) - HAP/VOC	1.929E-02	3.530E+00
Vinyl chloride - HAP/VOC	2.392E-02	9.203E+00
Xylenes - HAP/VOC	6.680E-02	1.513E+01

. It should be noted that the amounts considered for these parameters are estimated for local conditions and type of waste produced in the United States of America. Therefore, in order to accurately assess the required parameters (k and L_0), for calculating the amount of gas produced in landfills, other methods such as studies and estimations conducted by World Bank should be used.

Conclusion

The main reason for the formation of gases released from waste is biological activity. CO_2 and CH_4 are the main gases produced in the landfill, both of which are among greenhouse gases. In addition, due to the presence of methane the risk of explosion at landfills is high. Methane's high thermal value can mark methane as a new energy source. Therefore, it is very important to predict the amount of gases in the landfill. The LandGem model, developed on the basis of first-order decay equations, is used to measure the rate of gas release rate from the municipal landfill. In this paper, the amount of gases from landfilled waste is calculated according to the rate of decomposition, as well as the amount of putrescible waste for rural areas of Chaharmahaal and Bakhtiari and Yazd province. According to the results, the maximum amount of landfill gas release will be 2037, a year after the last year of waste landfilling. The total amount of gas production, methane gas, carbon dioxide and NMOCs will be 5435, 1452, 3983 and 62.4 tons per year in 2037 for Chaharmahaa and Bakhtiari and 1574, 4205, 1154 and 18.07 tons per year in 2037 for Yazd. Accordingly, with the development of existing infrastructure for the gas and other pollutants released in landfills, it is possible to provide sources of energy for these areas using released landfill gas instead of transferring energy resources to rural areas. Also, the results are obtained assuming a constant waste generation rate over the years studied. Consequently, changing these parameters can lead to different results. It is suggested to calculate the potential of electricity generation based on the current energy conversion technology to compare costs of the prevalent electricity transferring systems and energy conversion technologies.

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