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EFFECT OF NEARLY ONE HUNDRED PERCENT OF MUNICIPAL SOLID WASTE RECYCLING IN NAJAFABAD CITY ON IMPROVING OF ITS AIR QUALITY

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ABSTRACT:

Introduction: Now, 100% of solid waste in Najafabad is recycled. The main aim of this study is to evaluate the effect of 100% solid waste recycling on emissions of CO_2, CH_4 and more than 40 non-methane organic compounds from landfill to the atmosphere.

Materials and methods: To achieve this aim, it is assumed that if 100% solid waste recycling were not carried out in Najafabad, and if this city had a landfill with enough capacity to accept its solid waste for 20 years, a significant amount of the mentioned gases would have been emitted into the atmosphere. With this assumption, all necessary information about the amount of solid waste production in Najafabad was collected and the amount of gases released into the atmosphere was calculated by LandGEM software.

Results: The results show that for landfilling of Najafabad solid waste over 20 years, a landfill with capacity of 2.3 million m^3 is needed. Total generated CO_2 and CH_4 from this imaginary landfill during 20 years of fictional landfill operation are 107206 and 39074 tons, respectively. In addition, considerable amounts of CH_4 and CO_2 emission would continue for an estimated 120 years after landfill closure year. Calculations show that in 2015 alone, 93.79 tons of hazardous non-methane organic compounds could have been emitted into the atmosphere, most of them toxic and carcinogenic.

Conclusions: Today's 100% solid waste recycling in Najafabad has completely avoided these emissions. Consequently, it is recommended that nearly 100% solid waste recycling must become the final goal in all Iranian recycling organizations, to decrease landfill costs and to realize a healthier environment.

INTRODUCTION

Nowadays, air pollution has become one of the main problems of human society; therefore, extensive research has been conducted on emissions and control of pollutants [1, 2, 3]. Among the various air pollutants, greenhouse gases have attracted the most attention. Greenhouse gases include carbon dioxide, methane, nitrous oxide and

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chlorofluorocarbons [4]. Among the greenhouse gases, carbon dioxide and methane produce the greatest amount of pollutants released into the atmosphere. That is why these two gases have the greatest impact on global warming. There are different sources of carbon dioxide and methane released into the atmosphere, one of which is anaerobic biodegradation. Millions of tons of waste are generated in cities around the world, and significant portion are in landfills. Since a large portion of municipal waste is organic material and food waste, anaerobic microbial activity in landfills leads to the release of millions of tons of various gases, especially carbon dioxide and methane, into the atmosphere.

Among the gases produced in anaerobic decomposition of solid waste, methane is recognized as a gas from which energy recovery is possible [5]. Each cubic meter of biogas obtained from landfills can produce 5.22 kW of electrical energy. In developed countries, landfill design is based on the collection, treatment and energy recycling of produced biogas. Unfortunately, such a standard is yet not utilized in developing countries [6].

In addition to carbon dioxide and methane in biogas, dozens of other gases, such as volatile organic compounds (VOCs), are present. VOCs make up only 1% of biogas, but because of their high toxicity and carcinogenicity, are of utmost importance [7]. Lack of control of the biogas produced in landfills can lead to problems such as (1) the risk of fire and explosion at the landfill (2) health risks (3) destruction of plant life (4) groundwater pollution (5) impact on global climate change, and (6) odor emissions. One of the ways to reduce emissions of carbon dioxide and methane arising from biological decomposition of landfilled solid waste is to increase solid waste recycling. This will be more effective if organic parts of solid waste were almost completely recycled. The reduction of accessible biodegradable organic solid waste for anaerobic microorganisms can lead to lower emissions of carbon dioxide and methane. Isfahan, the large Iranian city (population 1.76 M) leading the way in solid waste management, celebrated the end of solid waste landfilling in 2012 [8]. Consequently, all solid waste produced in Isfahan is now completely recycled. After Isfahan celebrated this accomplishment, nearby communities followed suit, and began recycling 100% of their solid waste. One of the cities pioneering in solid waste management is Najafabad. This city, population 300000, daily produces 300 tons of solid waste. Few researchers have attempted to estimate the gases produced from solid waste landfills of Iranian cities. Therefore, only limited information exists about how much biogas is released into the atmosphere by Iranian landfills. The other researchers carried out such calculations for the landfill of the city of Shiraz, population 1.45 M. Their results showed that 1.5×10^6 m^3/year methane and 9.6×10^5 m^3/year carbon dioxide are emitted into atmosphere from this landfill [9]. It was reported that the municipal landfill of Rasht, an Iranian city with a population of 640,000, produced an estimated 538.8×10^7 m^3 of biogas and 3.21×10^7 tons/year of CO_2 during its 40-year operational life [10]. Another study carried out for the Mashhad (population 2.77 M) municipal landfill showed that an enormous amount of biogas was emitted into the atmosphere from this landfill [11]. The US Environmental Protection Agency (EPA) has determined that the combustion factor of emitted biogases from American landfills is equal to 0.24 ng l-TEQ/m^3 [12]. The main aim of this study is to evaluate the effect of 100% solid waste recycling on emissions of carbon dioxide, methane and more than 40 non-methane organic compounds from landfill into the atmosphere. Najafabad was selected as a representative city for this research. As the first step in this research, necessary information such as weight, density, etc., of Najafabad solid waste was collected through its municipal landfill. In the second step, it was assumed that if 100% solid waste recycling was not carried out in Najafabad, and if this city had a landfill with enough capacity to hold its solid waste for 20 years, how much carbon dioxide, methane and more than 40 non-methane organic compounds would have been emitted into the atmosphere. To estimate the above-mentioned gases' emissions, data were collected and analyzed by LandGEM software v. 3.02 (Landfill Gas Emissions Model, US Environmental Protection Agency, Washington, DC, USA). This software enables estimation of carbon dioxide, methane and more than 40 non-methane organic compounds that would have been emitted into the atmosphere if 100% of solid waste in Najafabad city were not recycled.

MATERIALS AND METHODS

In the first step of this research, the following data were gathered from Najafabad's municipal recycling organization: (1) the amount of solid waste collected daily, which would have been landfilled in the absence of recycling (2) the end of solid waste landfilling in July 2008, and the opening year for 100% solid waste recycling in Najafabad, and (3) the density of solid waste in Najafabad. Results revealed that 90 tons solid waste are collected daily and are recycled completely, roughly 33000 tons/year. According to the Najafabad's municipal recycling organization report, the density of produced solid waste was 400 kg/m^3 and it was assumed that this density will be fixed during the landfill operation. In this study, an annual population growth rate coefficient equal to 1.3% was used to predict future Najafabad city solid waste production.

For the second step, LandGEM 3.02 software was used to calculate the volume of produced landfill biogases. This software is an automatic apparatus for estimation of produced landfill gas volume, including CH_4, CO_2, non-methane organic compounds and special air pollutants (more than 40 types) [9]. July 2008 marked the beginning of Landfill Open Year. The Najafabad's landfill capacity was assumed to be 890000 tons. The software calculated automatically the Landfill Closure Year for roughly the next 20 years. This program requires 4 parameters to estimate the volume of produced landfill gases, including (1) methane generation rate (2) potential methane generation capacity (3) non-methane organic compounds (NMOC) concentration, and (4) methane content. In this study, these parameters were equal to software default values, according to these EPA recommendations: (1) methane production rate equal to 0.05 h^{-1} (2) methane production capacity equal to 170 m^3/ton (3) NMOC equal to 4000 ppmv as hexane, and (4) methane content of 60%. It should be noted that the LandGEM software uses the first order rate equation, Eq.(1), for calculation and estimation of landfill produced gases' annual emissions [9]:

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

where Q_{CH4} is annual methane generation in the year of the calculation (m^3/year); i is 1 year time increment; n is (year of the calculation) - (initial year of waste acceptance); j is 0.1 year time increment; k is methane generation rate ($year^{-1}$); L_0 is potential methane generation capacity (m^3/ton); M_i is mass of waste accepted in the i^{th} year (ton); t_{ij} is age of the j^{th} section of waste mass M_i accepted in the i^{th} year (in tenths of a year, e.g., 3.2 years).

The first order rate equation is the most comment way used to predict gas generation in landfills. It is reported that generally predictions of the first order rate equation is on average lower than actual gas generation [13]. Also, they reported that the uncertainty (coefficient of variation) in gas generation of the first order rate equation varied from ±11% to ±17% at initial years of landfills operation, ±9% to ±18% at the end of waste placement, and ±16% to ±203% for 50 years after landfill closure year. These information shows that accuracy of the first order rate equation for prediction of gas generation can be more accurate for landfill life duration compered after closure years.

In addition, the software was able to calculate the Landfill Closure Year. LandGEM calculates the closure year by summing the waste acceptance rates entered, subtracting this "waste-in-place" amount from the waste design capacity entered, then dividing by the final (or most recent) acceptance rate entered and summing with the current year. This method is shown in Eq. (2):

$$R_t = \frac{A - B}{C} + D \qquad (2)$$

where A is summation of the waste acceptance rates; B is total landfill capacity; C is the final (or most recent) acceptance rate of solid waste and D is year of final waste acceptance rate. All of Najafabad's imaginary landfill characteristics and the amount of assumed parameters for the model Eq. (1) are displayed in Table 1.

In this study, the amount of imaginary landfill capacity was calculated based on Eq. (3).

$$LC = \frac{TSW}{DSW} \quad (3)$$

where LC is landfill capacity (in m^3), TSW is total solid waste weight expected to be landfilled during the duration of the landfill's life (in tons), and DSW is density of solid waste (in $tons/m^3$). The necessary land area for the imaginary landfill was calculated by Eq. (4).

$$A = \frac{LC}{h} \quad (4)$$

where A is required land area (in m^2) and h is depth of landfilling (in m). In this study dispersion of pollutants in air were calculated by Screen View 3.5 which has been designed by EPA. All assumptions and parameters for using this software have been shown in Table 2. As Screen View software need length and width of area which emission is occurred, it was assumed that the landfill is rectangular with length and width of 500 and 260 m, respectively.

RESULTS AND DISCUSSION

Solid waste components

In this study, all information about solid waste components was collected from the Najafabad municipal recycling organization. There was no sampling or analysis of Najafabad solid waste. All collected information about Najafabad solid waste is shown in Table 3.

Table 1. Najafabad imaginary landfill characteristics and assumed parameters for the model

Landfill characteristics	Landfill Open Year	2008
	Landfill Closure Year (with 80-year limit)	2027
	Actual Closure Year (without limit)	2027
	Does Model Calculate Closure Year?	Yes
	Waste Design Capacity	890000 tons
Model parameters	Methane Generation Rate, k	0.050
	Potential Methane Generation Capacity, L_o	170 m^3/ton
	NMOC Concentration	4,000 ppmv as hexane
	Methane Content	50% by volume

Table 2. Assumptions and parameter for using Screen View software

Parameters	CO_2	CH_4	NMOCs
Emission rate	0.046 g/s.m^3	0.000532 g/s.m^3	0.000298 g/s.m^3
In this study parameters of source release height is 0 m, source type is area, receptor height above area is 1 m, larger side of rectangular area is 500 m, smaller side of rectangular area is 260 m and dispersion coefficient is urban for CO_2, CH_4 and NMOCs.			

Table 3. Solid waste components

Composition	Percentage
Organic compounds	67.3
Branch and leaf	2.08
Paper and cardboard	5.33
Glass	1.12
Metal cans	1.17
Aluminum	0.28
Plastic	0.75
Polyethylene terephthalate (PET)	0.85
White plastic	0.92
Colored plastic	1.81
Plastic bags	3.45
Disposable containers	0.3
Styrofoam	0.28
Textiles	3.31
Bags and Shoes	0.58
Pampers	2.71
Electronic devices	0.13
Medicine	0.2
China plates	0.39
Soil	7.04
Hospital waste	0
Total	100

In the current study, it is assumed that if Najafabad had not achieved nearly 100% solid waste recycling, it would have needed a landfill. In the present study, this landfill is called the imaginary landfill. Based on 90 tons of collected solid waste in Najafabad each day, the imaginary landfill would need to have a capacity of 892000 tons for the next 20 years, so that 2.3 million m^3 space should be provided. If it is assumed that the depth of the imaginary landfill is 15 m, then an area of 130000 m^2 is needed. However, there will be no need for this area because of the city's nearly 100% recycling of solid waste, and money will be saved because no need will exist for discovering, purchasing, preparing and operating such a landfill. Additionally, the area benefits because the considerable volume of gases, such as CH_4, CO_2, H_2S and NH_3, which would be produced in the landfill, are never generated, and the air becomes healthier.

Based on comprehensive solid waste management act in Iran, municipal recycling organization do not have any responsibility for collecting and disposing of hospital waste. Therefore, hospital waste must be collected and disposed separately and generally they are not landfilled herewith municipal solid waste. Also, amount of hospital waste in Najafabad is very low compered total municipal solid waste in this city. Due to these reasons hospital solid waste has not considered in this article.

Analysis of total generated biogas emission

Generally, biogas is defined as a mixture of different gases produced by the biodegradation of organic compounds in an anaerobic condition. Biogas can be produced from biodegradation of raw materials such as agricultural and municipal solid waste. Because a large part of the biogas is methane, it is a renewable energy source. Landfilling municipal solid waste is one of the most critical sources of biogas emission into the atmosphere [4]. Fig.1 shows that the accumulated solid waste in the imaginary landfill of Najafabad increased from 2008 (landfill opening year) till 2027 (assumed landfill closure year), and its growth ended in 2027, because landfill capacity was fully utilized in this year. Furthermore, this figure shows that the total generated biogas emission, which began in 2008, grew rapidly until 2027, when the total generated biogas emission was reached its maximum. After landfill closure year, emissions decreased quickly, from 9101000 m^3 in 2027 to 22560 m^3 in 2148. It can be seen that considerable amounts of biogas emission existed for 121 years after landfill closure year (Fig. 1.). According to Fig. 1., nearly 100% waste recycling prevents the emission of 3.033×10^8 tons of biogases into atmosphere over a period of 140 years.

By dividing 3.033×10^8 tons by 140 years, the mean generated biogas amount would be estimated at about 2166428 tons/year. Other researchers performed similar calculations for the

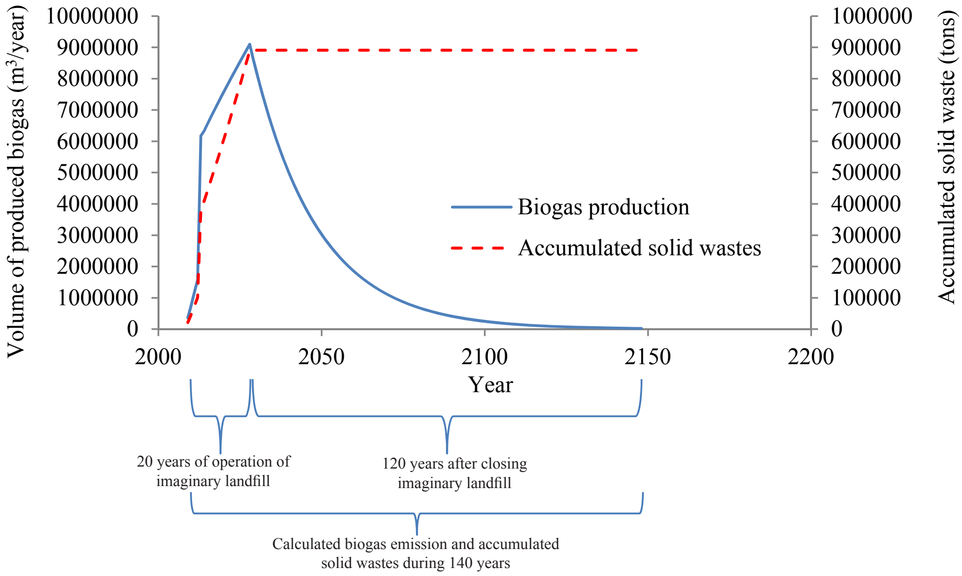

Fig. 1. Estimation of accumulated solid waste and produced biogas in the imaginary solid waste landfill of Najafabad over 140 years (2008–2148)

Shiraz landfill and showed that the generated biogas volume was about 2460000 per year for a population of 1200000 [5]. Comparison between the results for Shiraz and Najafabad yields approximate compatible landfill-generated biogas rates. The produced biogas in the imaginary landfill of Najafabad could be collected, treated and compressed in the form of compressed natural gas (CNG) to use as fuel for motor vehicles. Production of CNG is a profitable activity, which could return a part of solid waste landfilling cost. However, like most landfills in the cities around Najafabad, the gases might be released into the atmosphere without any usage due to a lack of collection and treatment facilities, resulting in air pollution. Therefore, nearly 100% recycling of solid waste in Najafabad can greatly reduce biogas emission into the atmosphere, which would improve the city's air quality.

Analysis of CO_2 and CH_4 emission

Results of this study show that a significant amount of CH_4 and CO_2 can be emitted into the atmosphere from the imaginary landfill of Najafabad. CH_4 and CO_2 play important roles in global warming. For unknown reasons, CH_4 concentrations increased until 1998, and stayed flat until 2007 ("nearly a decade"), when they began increasing again. However, these days CH_4 concentration is increasing again [14]. Many researchers are trying to understand why CH_4 is increasing and how it can be controlled. CH_4 gas can come from sources including wetlands, rice paddies, cow digestion, coal mines, termites and particularly solid waste landfills. Based on some reports, CH_4 concentration has raised nearly 150% since the pre-industrial period, which is a massive increase. On the other hand, CO_2 has increased nearly 30% in the same period. Although both CH_4 and CO_2 have contributed to global warming, the CH_4 molecule is regrettably much more effective at trapping heat in the atmosphere. The ratio of generated CH_4 to generated CO_2 was assumed to be 1:1 in this study, but given the difference between CO_2 and CH_4 molecular weights, the generated mass of CO_2 and CH_4 was not found to be equal. Fig.2 shows the production of CO_2 and CH_4 in tons/year. This figure shows that the generation of gases has been declining rapidly, but continues for 120 years after landfill closure year. The non-methane organic gases emission is shown in Fig.3, but even though it is slight, non-methane organic gases like benzene are very harmful even in a lawful amount of emission. Total generated CO_2 and CH_4 from the imaginary landfill between 2008 and 2027 (over 20 years of imaginary landfill operation) are 107206 and 39074 tons, respectively. Although after 2027 the imaginary landfill will not have any capacity for solid waste landfilling, LandGEM calculations demonstrate that considerable pollutant gases will be emitted into the atmosphere for 120 years after landfill closing. Total generated CO_2 and CH_4 from the landfill over those 120 years is 170396 and 62102 tons, respectively. Moreover, 2669 tons of non-methane organic gases are generated over this period (Fig.3). Although CH_4 and CO_2 are odorless and colorless gases, CH_4 is lighter and CO_2 is heavier than air. That is why CH_4 can move toward the ground while CO_2 can move toward underground water resources. Because CH_4 is extremely flammable, it can cause fire in concentration between 5 and 15% [4]. CO_2 dissolved in groundwater forms carbonic acid (H_2CO_3), which increases groundwater pH. Water with higher levels of pH can dissolve more calcium and magnesium ions, increasing groundwater hardness [4]. Human exposure to low concentrations of CH_4 is not harmful. Higher concentration of CH_4 can displace oxygen in the air. If less oxygen is available to breathe, symptoms such as rapid breathing, rapid heart rate, clumsiness, emotional upset and fatigue can result. However, emitted CH_4 from solid waste landfills is diluted in fresh air and may not be harmful to humans. Therefore, the main negative effect of CH_4 is its contribution in global warming. By achieving nearly 100% recycling of Najafabad solid waste, there is no possibility of firing and increasing of groundwater hardness level.

Analysis of non-methane organic (NMO) gases emission

The term non-methane organic gases (NMOGs) means "the sum of non-oxygenated and oxygenated hydrocarbons contained in a gas sample, including, at a minimum, all oxygenated organic

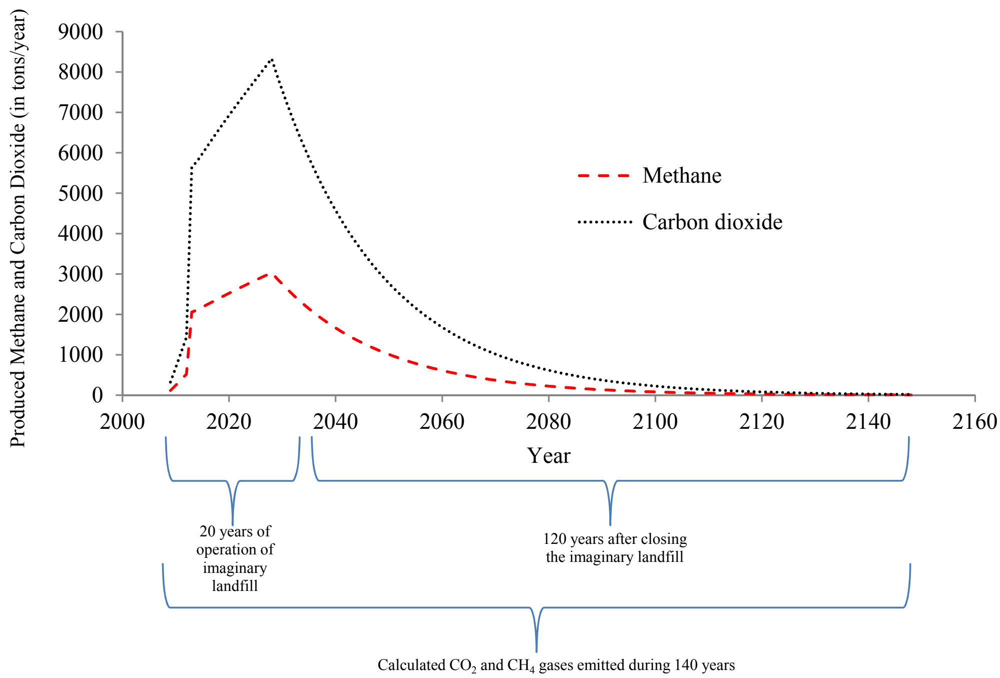

Fig. 2. Amount of CO_2 and CH_4 emission from the imaginary landfill of Najafabad over 140 years

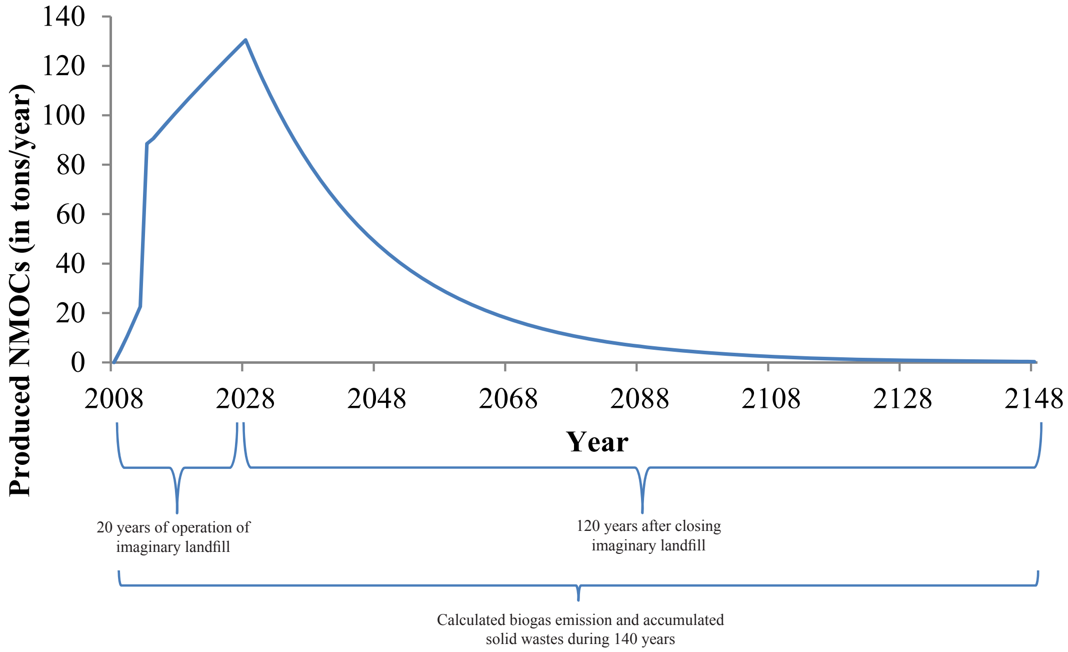

Fig. 3. Amount of non-methane organic compounds emission from imaginary landfill of Najafabad over 140 years

gases containing 5 or fewer carbon atoms (i.e., aldehydes, ketones, alcohols, ethers, etc.), and all known alkanes, alkenes, alkynes, and aromatics containing 12 or fewer carbon atoms [8]. In addition, NMOs include some compounds such as VOCs and hazardous air pollutants (HAPs), of which 48 types are listed in Table 4. Amounts of these 48 gases have been estimated by LandGEM for 2015 (Table 4). Some of these compounds, such as benzene and vinyl chloride, are carcinogenic, so controlling their emissions in the atmosphere is vital [15]. The calculation in this study shows that without 100% waste recycling, 93.79 tons of NMOCs would be emitted into the atmosphere in 2015. In Table 4., the superscripted 1s mean the chemicals are VOCs, and 2s means the chemicals are HAPs. Several reports, including EPA reports, revealed that anaerobic biodegradation of solid waste can be extremely active only or within a few years after closure year of a landfill [8]. However, the emission of pollutant gases will not be completely finished after 10 years. EPA reported that even after 140 years, different emissions of pollutants can be detected around a closed landfill. Our results show that after 120 years from Najafabad's landfill closure year, significant amounts of CO_2 and CH_4 will still be emitted into the atmosphere. However, the emission of many pollutants including some NMOCs will cease after 120 years. This is shown in Fig.3.

According to Table 3, in the absence of nearly 100% waste recycling, the H_2S emission is 132.6 kg in 2015, which causes human injury and caustic, unpleasant smells. Vinyl chloride and benzene emission in 2015 are 124 and 274 kg, respectively. Ethanol has a synergistic effect on benzene toxicity in humans [10]; as can be seen

Table 4. Amount of 46 gas pollutants emission produced in imaginary landfill of Najafabad in 2015 (estimated by LandGEM)

Gas/Pollutants	Production in tons	Gas/Pollutants	Production in tons
Total landfill gas	8169	Dichlorobenzene [1, 2]	0.008
Methane	2182	Dichlorodifluoromethane	0.526
Carbon dioxide	5987	Dichlorofluoromethane [1]	0.073
NMOCs	93.79	Dichloromethane (methylene chloride) [2]	0.324
1,1,1-Trichloroethane (methyl chloroform)[1]	0.017	Dimethyl sulfide (methyl sulfide) [1]	0.132
1,1,2,2-Tetrachloroethane[1, 2]	0.050	Ethane	7.281
1,1-Dichloroethane (ethylidene dichloride)[1, 2]	0.065	Ethanol [1]	0.339
1,1-Dichloroethene (vinylidene chloride) [1, 2]	0.005	Ethyl mercaptan (ethanethiol) [1]	0.039
1,2-Dichloroethane (ethylene dichloride) [1, 2]	0.011	Ethylbenzene [1, 2]	0.133
1,2-Dichloropropane (propylene dichloride) [1, 2]	0.006	Ethylene dibromide [1, 2]	0.000
2-Propanol (isopropyl alcohol) [1]	0.818	Fluorotrichloromethane	0.028
Acetone	0.111	Hexane [1]	0.155
Acrylonitrile [1, 2]	0.091	Hydrogen sulfide [1, 2]	0.334
Benzene - No or Unknown Co-disposal [1, 2]	0.040	Mercury (total) [2]	0.000
Benzene - Co-disposal [1, 2]	0.234	Methyl ethyl ketone [1, 2]	0.139
Bromodichloromethane [1]	0.138	Methyl isobutyl ketone [1, 2]	0.052
Butane [1]	0.079	Methyl mercaptan [1]	0.033
Carbon disulfide [1, 2]	0.012	Pentane [1]	0.065
Carbon monoxide	1.067	Perchloroethylene (tetrachloroethylene) [2]	0.167
Carbon tetrachloride [1, 2]	0.000	Propane [1]	0.132
Carbonyl sulfide [1, 2]	0.008	t-1,2-Dichloroethene [1]	0.074
Chlorobenzene [1, 2]	0.008	Toluene - No or Unknown Co-disposal [1, 2]	0.978
Chlorodifluoromethane	0.031	Toluene - Co-disposal [1, 2]	4.261
Chloroethane (ethyl chloride) [1, 2]	0.023	Trichloroethylene (trichloroethene) [1, 2]	0.100
Chloroform [1, 2]	0.001	Vinyl chloride [1, 2]	0.124
Chloromethane [1]	0.016	Xylenes [1, 2]	0.347

[1] Member of VOCs

[2] Member of HAPs

in the results, 339 kg ethanol is emitted into the atmosphere from the imaginary landfill in 2015 along with benzene (Table 4). However, with nearly 100% waste recycling and no landfilling of solid waste, the generation of NMOCs (Table 4) would not occur, which has positive direct effects on the health of Najafabad inhabitants and their environment.

At this point, it is recommended that all of the municipalities operate nearly 100% solid waste recycling programs in their cities. Najafabad and other cities in Isfahan Province could provide the appropriate design. If there is no way to accomplish nearly 100% recycling of solid waste, it is recommended that the amount of gases emitted from local landfills must be reduced by using a gas collection system in the landfill and utilizing methane energy.

Dispersion of pollutants in air

Based on Table 4 amount of emitted CO_2, CH_4 and NMOCs are equal of 5987, 2182 and 94 ton/year, respectively in 2015. By dividing them in 130000 m^2 (area of imaginary landfill) and converting them from ton/m^2.year to g/m^2.s emission rate of CO_2, CH_4 and NMOCs from imaginary landfill were calculated equal of 0.0014, 0.000532 and 0.000021 g/m^2.s, respectively. As can be seen in Figs.4, 5 and 6, CO_2, CH_4 and NMOCs are able to disperse in a wide area. It should be noted that direction of dispersion strongly depends on wind direction. Therefore, it is assumed that Figs.4, 5 and 6 are shown pollutants dispersion in wind direction. Based on these Figures even in 5000 meters far from imaginary landfill significant amount of produced pollutants can be detected. 100 m far from imaginary landfill, the concentration of CO_2, CH_4 and NMOCs are 0.054, 0.032 and 0.0011 g/m^3, respectively. Pollutants concentration is decreased by increasing of distance from imaginary landfill so that in 5000 meters the concentration of CO_2, CH_4 and NMOCs are decreased to 0.00135, 0.0004 and 0.000027 g/m^3, respectively (Fig.7). Average concentration of CO_2 in air is equal of 0.000756 g/m^3 [16]. Therefore, 5000 meters far from landfill, concentration of CO_2 in air can be increased from 0.000756 to 0.002106 g/m^3. As the negative effects of CO_2 on human health is appeared in concentration of greater than 0.0096 g/m^3, residences health out of the radius of 5000 m of imaginary landfill are not threated by CO_2 emission. However, for residences who live or work within the radius of 1000 meters of imaginary landfill, average of CO_2 concentration is 0.06368 g/m^3 which is upper than dangerous level (Fig.4). Knowing negative effects of other emitted pollutants such as NMOCs from this landfill needs to more studies. These results show that closing of landfill in najafabad city by nearly 100% recycling of solid waste can reduce concentration of many pollutants such as CO_2 in air of this city.

CONCLUSIONS

To decrease the great quantity of CO_2 and CH_4 emission from anaerobic destruction of municipal organic solid waste, landfilling must be decreased. In Najafabad, the landfilling of municipal solid waste has ended, and nearly 100% solid waste recycling is underway. Therefore, CO_2 and CH_4 emissions from landfilling have declined

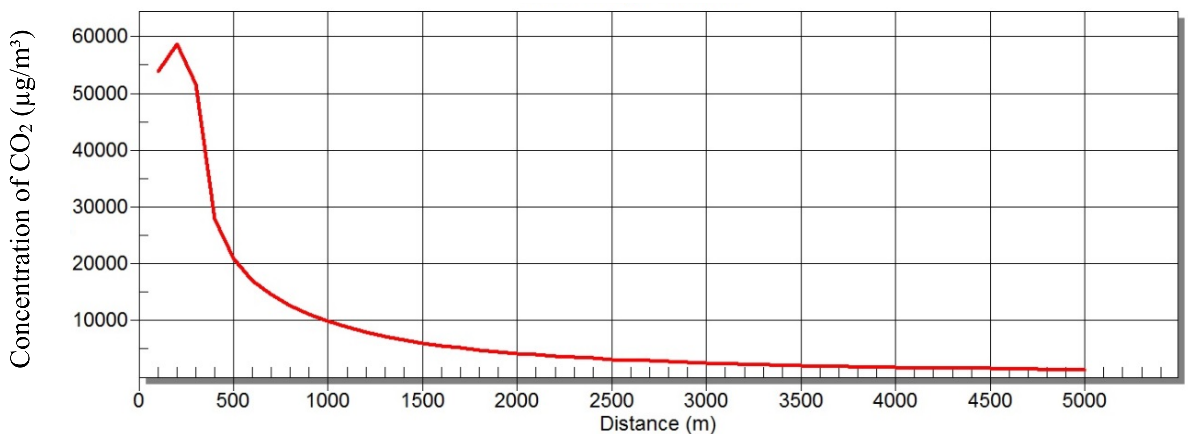

Fig. 4. Concentration of CO_2 in air versus distance in 2015

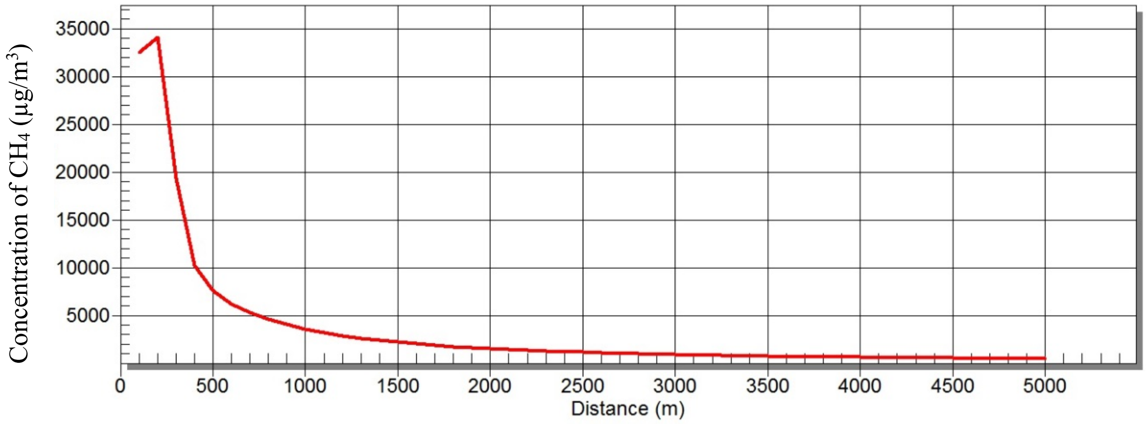

Fig. 5. Concentration of CH_4 in air versus distance in 2015

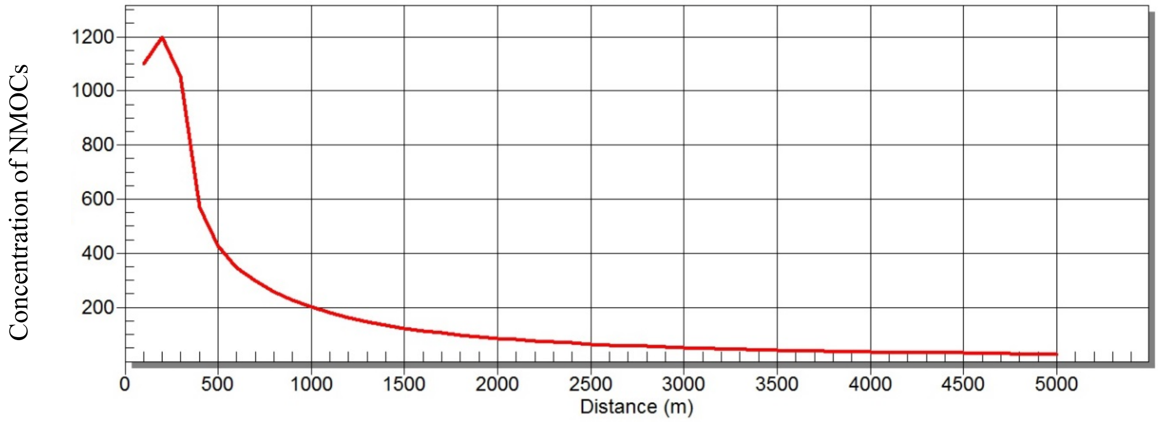

Fig. 6. Concentration of NMOCs in air versus distance in 2015

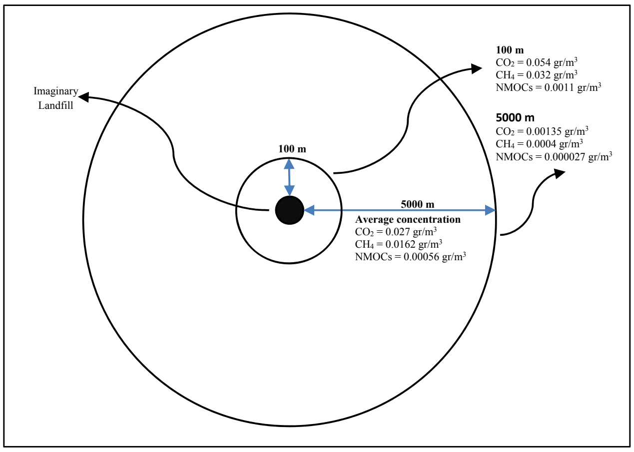

Fig. 7. Concentration of CO_2, CH_4 and NMOCs in air at distance of 100 and 5000 m in 2015

to zero. In this study, CO_2, CH_4 and more than 40 non-methane organic compounds' emissions were calculated in the absence of solid waste recycling. The results show considerable volume of biogases generated during 20 years of landfilling, and that this emission continues until 121 years after landfill closure year. The generated biogases volume from landfill open year to 140 years later is 3.033×10^8 tons. It was revealed that 93.79 tons of non-methane organic compounds generated in 2015 alone, can be interrupted today by 100% solid waste recycling. Also, emitted pollutants are able to travel for kilometers so that 5000 meters far from the landfill the concentration of CO_2, CH_4 and NMOCs are equal of 2, 0.9 and 0.045 g/m^3, respectively. Consequently, it is recommended that nearly 100% solid waste recycling must become the final goal in all Iranian recycling organizations, to decrease landfill costs and to realize a healthier environment.

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COMPETING INTERESTS

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

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ETHICAL CONSIDERATIONS

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

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