Application of Anaerobic Bioreactor Landfilling as an Energy Production Alternative in Developing Countries

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ABSTRACT
Performance of a bioreactor reactor under anaerobic conditions as an alternative waste management strategy and gas production at laboratory scale was investigated. The reactor was made of a plastic container with dimensions of 0.5 x 0.5 x 1.0 m. The waste was placed into the reactor in layers and compacted to achieve a density of 550 kg/m^3. Twenty eight litres of leachate was recirculated daily for 157 days. The final COD of the leachate reduced from a maximum value of 64900 mg/L to a value of 5300 mg/L, showing a 92% reduction. The average methane concentration in generated gas was 58% and gas generation rate was 90 L/kg of waste on wet basis. The results show that anaerobic bioreactor technology with leachate recirculation performs very well in terms of decomposition of MSW, reduction of COD of the leachate and at the same time it has a considerable potential for gas (methane) production which could be used as a source of energy.

RÉSUMÉ
L'exécution d'un réacteur de bioreactor sous les conditions anaérobiques comme une stratégie de traitement des déchets alternatifs et la production de gaz à l'échelle de laboratoire ont été examinés. Le réacteur a été fait d'un récipient en plastique avec les dimensions de 0,5 x 0,5 x 1,0 m. Le gaspillage a été placé dans le réacteur dans les couches et a comprimé pour atteindre une densité de 550 kg/m^3. Vingt huit litres de leachate ont été quotidiennement recirculés pendant 157 jours. La COD finale du leachate a réduit d'une valeur maximum de 64900 mg/L à une valeur de 5300 mg/L, montrant une 92% réduction. La concentration moyenne de méthane dans le gaz produit était 58% et taux de génération de gaz était 90 L/kg de gaspillage sur la base mouillée. Les résultats montrent à cette technologie de bioreactor anaérobique avec leachate recirculation exécute très bien sur le plan de la décomposition de MSW, la réduction de COD du leachate et en même temps il a un potentiel considérable pour le gaz (le méthane) la production qui pourrait être utilisé comme une source d'énergie.

1 INTRODUCTION

Landfilling is the major method of MSW management worldwide. Despite increases in recycling, composting, and incineration in developed and industrial countries, a considerable fraction of MSW is disposed in landfills. For example, in the United States in 2007 approximately 54% by weight of the MSW generated was deposited in sanitary landfills (US EPA 2008). In developing countries the fraction of MSW going to landfills is much higher, more than 90% in most developing countries.

The most common problems associated with landfill operation are the generation of leachate and gases. Methane gas is a by-product of landfilling municipal solid wastes (MSW) and is the third most important greenhouse gas after water vapor and carbon dioxide. Landfills are estimated to account for about 35% of anthropogenic CH_4 emissions in the United States and 5–10% of global CH_4 emissions to the atmosphere (Stern et al. 2006). Some of the modern regulated landfills attempt to capture and utilize landfill biogas, a renewable energy source, to generate electricity or heat. The landfills that capture biogas in the US collect about 2.6 million tonnes of methane annually, 70% of which is used to generate heat and/or electricity. In contrast, when methane is allowed to escape to the atmosphere, it has a global warming potential that is estimated to be 23 times greater than that of the same volume of carbon dioxide.

Shortly after MSW is landfilled, the organic components start to undergo biochemical reactions. The principal bioreaction in landfills is anaerobic digestion that takes place with methane and carbon dioxide as its final products. According to Themelis and Ulloa (2007) complete anaerobic biodegradation of MSW theoretically generates about 200 m^3 of methane per dry tonne of contained biomass. However, the reported rate of generation of methane in industrial anaerobic digestion reactors ranges from 40 to 80 m^3 per tonne of organic wastes.

In most developing countries, relatively high percentages of organic waste and high moisture contents are the main characteristics of the MSW. Thus the potential for landfill gas production is significantly higher than MSW landfills in developed countries.

Bioreactor technology is becoming more widely accepted in landfill design and operation methodology. The concept of bioreactor was first introduced by Pohland in late 70's (IT&RC 2006). Solid Waste Association of North America (SWANA) defines bioreactor landfill as any landfill cell where liquid or air is injected in a controlled fashion into the waste mass in order to accelerate or enhance decomposition of waste. The most important and cost-effective method for enhancing biodegradation in bioreactor landfill is liquid addition, i.e. leachate recirculation. Leachate recirculation increases the moisture content in a controlled reactor system and provides the distribution of nutrients and enzymes between methanogens and solid/liquids (Sponza and Agdag 2004). Benefits of operating a landfill as a bioreactor include enhancement of the landfill gas (LFG) generation rates; reduction of environmental impacts, production of end product that does not need landfilling, overall reduction of landfilling cost, rapid settlement and increased landfill capacity; improved leachate quality; reduction of post-closure activities; and abatement of greenhouse gases (Warith 2002). However, if too much leachate is recirculated, problems such as saturation, ponding, and acidic conditions may occur. Limited data are available on the application of different leachate recirculation regimes to the waste matrix. For anaerobic bioreactors, it is recommended that leachate should be introduced slowly, since high flow rates may deplete buffering capacity and remove methanogens. As gas production is established, the flow rates and frequency of recirculation could be increased (San and Onay 2001).

Sanphoti et al. (2006) reported that anaerobic digestion with leachate recirculation and supplemental water addition showed the highest performance in terms of cumulative methane production and the stabilization period time required. It produced an accumulated methane production of 54.87 L/kg dry weight of MSW at an average rate of 0.58 L/kg dry weight/d and reached the stabilization phase on day 180. The leachate recirculation reactor provided 17.04 L/kg dry weight at a rate of 0.14 L/kg dry weight/d and reached the stabilization phase on day 290. The control reactor provided 9.02 L/kg dry weight at a rate of 0.10 L/kg dry weight/d, and reached the stabilization phase on day 270.

Most methods used by landfill operators to estimate landfill methane emissions are based on models. However, as mentioned by Scharff and Jacobs (2006) a considerable difference in results of modeling and field measurements could be observed, which raises doubts about the accuracy of the models and shows the importance of conducting experiments to measure methane gas generation and emissions from landfills. Considering the above information, the main objective of this study was to investigate the application of anaerobic bioreactors for methane production from MSW generated in developing countries.

2 MATERIALS AND METHODS

Figure 1 shows the laboratory set up used for the experiments. The reactor was a plastic container with a cross section area of 0.5 x 0.5 m, and a height of 1 m. As shown, the reactor was completely sealed and insulated to prevent the temperature loss and release of gases. Leachate was collected in a container at the bottom and pumped to another container at the top, from which leachate was recirculated back into the waste mass. The leachate in the top container was heated to maintain the temperature inside the reactor above 30 °C. A flexible tube was also provided at the top to collect the generated gases.

The output of the screen unit of Isfahan composting plant was used as waste material. The composition of the waste was modified by adding crushed glass and shredded paper, plastic and metal containers to obtain the same composition of the collected waste. Table 1 represents the composition of the modified waste used in the experiment. As presented, the organic content of the waste, like most developing countries, is very high. The maximum size of waste particles was 8-10 cm. The waste was placed into the reactor in layers and compacted to achieve a density of 550 kg/m^3. A 7.5 cm stone layer was placed at the bottom as a drainage layer. Another stone layer was placed at top in order to enhance uniform distribution of the leachate from the top.

Fresh leachate from leachate containers installed in waste collection vehicles was collected and transferred to the laboratory. The moisture content of the solid waste was brought to field capacity by adding leachate to the bioreactor cell, until the amount of leachate collected from the cell equaled the amount of leachate added. Twenty eight liters of leachate was recirculated daily for 157 days. COD and temperature of the leachate were measured on a continuous basis. Gas samples were also collected and analyzed by gas chromatography for CH_4, CO_2, and N_2.

3 RESULTS AND DISCUSSION

Variation of COD of the leachate is presented in Figure 2. Since the putrescible fraction of MSW generated in developing countries is high (40-85%), the organic matter concentration of the produced leachate is high. The initial COD of the leachate was about 40000 mg/L, which reached above 60000 mg/L after 3 days and a maximum

Table 1: Composition of the waste used in the experiment (in percent)

Organic Matter	Plastic	Paper & Cardboard	textile	glass	metal
78	10	5	3	2	2

Figure 1. Experimental setup of anaerobic reactor

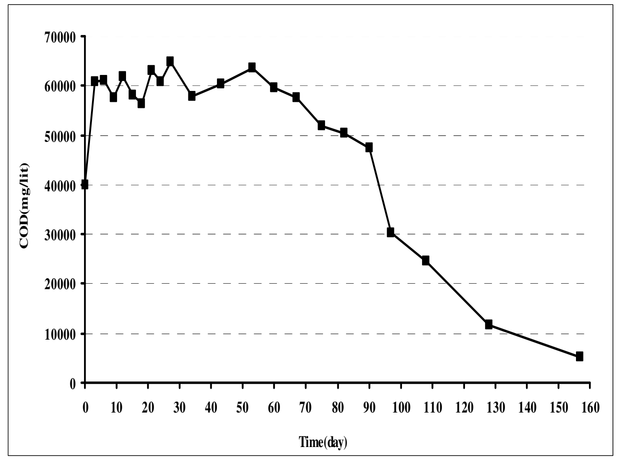

Figure 2. Variation of the leachate COD with time

value of 64900 mg/L on day 27. COD of the leachate remained above 60000 mg/L for 60 days during which the microorganism's community was developing and adapting to the environment. After 60 days and acclimatization and establishment of microorganisms, rapid biodegradation of organic matter started and as a result COD started to decline. The final COD of the leachate at the end of the experiment (157 days) reduced to a value of 5300 mg/L. This means a 92% reduction of COD.

Temperature variation within the reactor is shown in Figure 3. In order to maintain anaerobic biodegradation it is recommended to keep the temperature within the range of 30-40 °C. As mentioned before, the recirculated leachate was heated before entering the reactor to prevent a drop in temperature. As seen in Figure 3, the temperature within the reactor was above 30 °C after the initial stage.

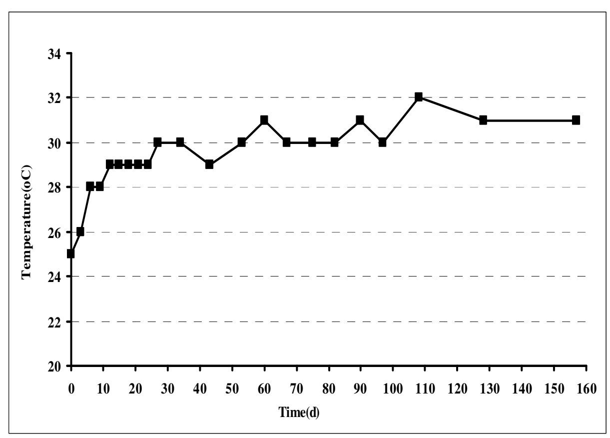

Figure 3. Variation of temperature within the reactor

Three gas samples were collected on days 87, 97, and 116 and analyzed by gas chromatography. The results are presented in Figure 4. The average methane concentration was 58%. This is in agreement with the data reported in Table 2 (Bove and Lunghi 2006). The

Table 2: Typical composition of landfill gas in USA (Bove and Lunghi, 2006)

Component	Typical US landfill	Anoka landfill	Malagrotta landfill
Methane	40–55%	52.2%	58%
Carbon dioxide	35–50%	38.1%	41.38%
Water	1–10%	Saturated	0.41%
Nitrogen	0–20%	9.1%	0.48%
Oxygen	NA	0.5 – 1	0.13%
Condensible hydrocarbons (ROGs)	250–3000 ppm as hexane	138 ppm	NA
Chlorine compounds	30–300 mg/m^3	38 μg/l (8.4 ppm)	0.26 mg/m^3 (as HCl)
Hydrogen sulfide	Till 200 ppm	53 ppm	110 mg/m^3

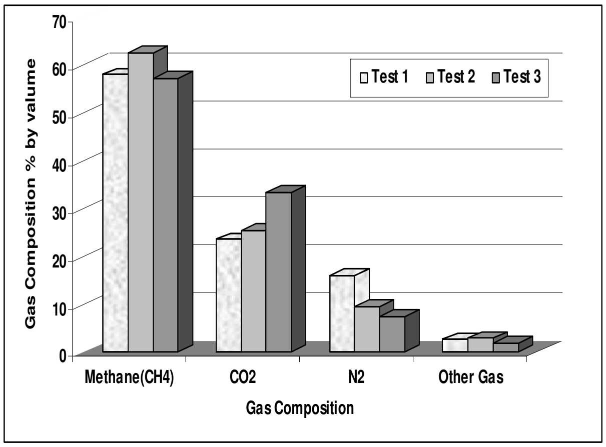

Figure 4. Gas composition of the anaerobic reactor

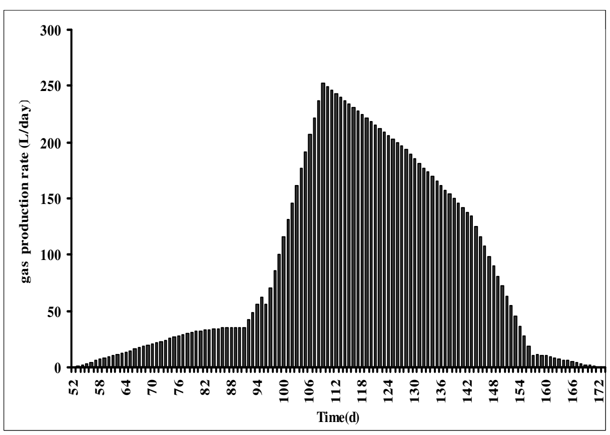

Figure 5. The amount of generated gas over time

amount of generated gas was measured as well. Figures 5 and 6 show the generated gas flow rates and accumulative gas volume over time. Comparison of Figures 2 and 5 shows that the gas generation started to increase as the COD of the leachate started to decrease. The total amount of gas collected was about 10800 liters. Since 120 kg of waste was initially put inside the reactor, this is equal to a gas generation of 90 L/kg of waste on

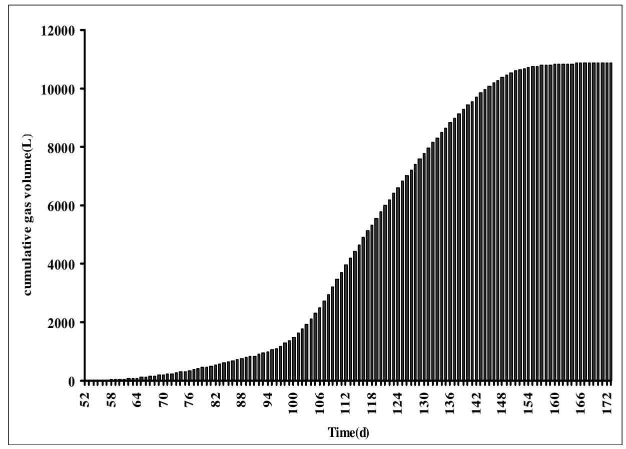

Figure 6. The amount of cumulative gas generation

wet basis, which is much higher than the values reported in the literature for the wastes generated in developed and industrial countries.

Figure 7 shows the burning of the collected gas confirming the presence of high percentage of methane within the generated gas.

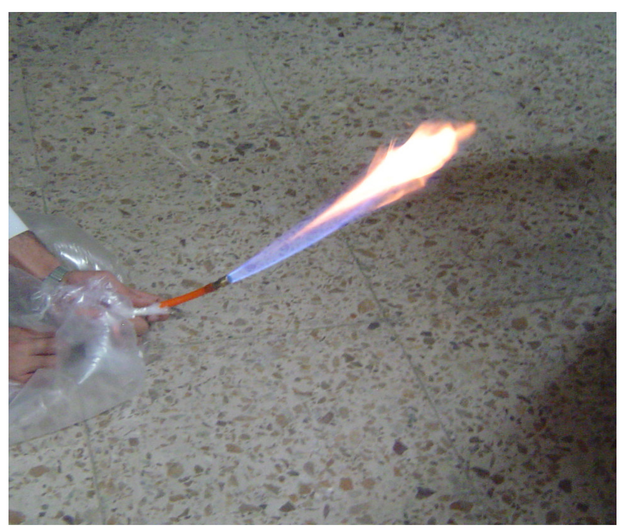

Figure 7. Burning of the collected gas

4 CONCLUSIONS

The results obtained show that anaerobic bioreactor technology with accompanying leachate recirculation performs very well in terms of decomposition of MSW, reduction of COD of the leachate and at the same time it has a considerable potential for gas (methane) production which could be used as a source of energy.

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