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Assessment of energy generation potentials of MSW in Delhi under different technological options

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ABSTRACT

Municipal solid waste (MSW) is an important source of methane emission which is a greenhouse gas (GHG) and has high potential for its use as energy source. A study has been carried out to find out the energy generation potential of MSW being dumped in Delhi's three landfills viz. Ghazipur (GL), Bhalswa (BL) and Okhla (OL). Five technologies for waste to energy generation, namely biomethanation, incineration, gasification/pyrolysis, refused derived fuel (RDF) and plasma arc gasification have been evaluated for computation of possible energy (WTE) generation potential of MSW under ideal conditions using the MSW specific characteristic parameters. Bulk waste with and without pre-segregation of reusable high carbonaceous materials have been considered to develop range of energy generation potentials under two scenarios of with and without segregation of MSW. USEPA-LandGem model version 3.02 has been used to get LFG generation potential of Delhi's landfills. The potential of biomethanation process for producing energy has been found to be in the range of 3–10, 3–8 and 2–8 MW/day from the MSW deposited in GL, BL and OL respectively. The energy generation potentials of the MSW deposited in GL, BL and OL have been found to be in the range of 8–24, 7–22 and 7–19 MW/day for incineration process; 17–32, 16–29 and 11–25 MW/day from gasification/pyrolysis process; 9–19, 8–18 and 6–15 MW/day for RDF process; and 17–35, 16–32 and 11–28 MW/day for plasma arc gasification process respectively. The lower values in these ranges depict the energy generation potential for segregated waste while the higher values are for the bulk waste. These values are based on theoretical ideals and help in identifying the optimal WTE technique.

1. Introduction

The generation of municipal solid waste (MSW) increases with socio-economic development of urban population. In an emerging economy like India, rapid population growth has further added to the intensity of waste generation. The generated MSW in urban areas is predominantly managed by depositing it in the low lying areas, called landfills. As landfilling is a low cost management option, it is the most popular mode of waste management. However, unlike landfills in developed countries, only few properly managed landfills exist in India. The Indian Municipal Solid Wastes (Management and Handling) Rules, 2000 states that, "Landfilling shall be restricted to non-biodegradable, inert waste and other waste that are not suitable either for recycling or for biological processing." The deposition of MSW in the landfills results into generation of greenhouse gases (GHGs, mainly methane). Methane (CH_4) is a potential source of energy. Some efforts have already been initiated in India to harness the locked energy resource from the organic fraction of MSW. Adoption of environment-friendly waste-to-energy (WTE) technologies is one such effective way which could also help in reducing the GHG emissions into the atmosphere.

In India, mainly three technologies are being used for energy recovery, albeit on a small scale, from MSW viz. refused derived fuel (RDF), biomethanation and incineration. The RDF pellet is an efficient fuel with comparative advantages over the coal due to its high calorific value (0.145 kW/kg) [1]. It is a clean, energy efficient, eco friendly alternative fuel for coal based industries, including power generation. Biomethanation is an anaerobic process which produces landfill gas (LFG) containing 50–60% methane. It is estimated that 0.075 kW energy can be generated from a cubic meter of biogas in the biomethanation process in Indian MSW [2]. Incineration is the process of direct burning of waste in the presence of excess air (oxygen) at temperatures of $\geqslant$800 °C that liberates heat energy besides generating inert gases and ash. In practice, about 65–80% of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power via steam turbine generators [3].

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Saini et al. has estimated the total potential for energy generation from MSW in India as about 3000 MW in 2020 [4]. In India, 27 waste-to-energy plants have been installed in different cities by 2005 based on gasification/pyrolysis having the total installed capacity of 45.5 MW [5], RDF based plants at Vijaywada, Hyderabad, Chennai, Chandigarh, Jaipur, Mumbai, Pune, Bangalore, etc. and biomethanation plants at Chennai, Pune, Vijaywada, Guntur, Vishakapattanam, Kottayam, Tiruvanthapuram, Kochi, Allahabad, etc.[6–10].

The MSW to energy market in India is expected to grow at a compound annual growth rate (CAGR) of 9.7% by 2013, according to a report by market analysts Frost and Sullivan [11]. Hence there is a need to assess the appropriateness of different technologies for their use for Indian MSW. In this study, the energy generation potential of MSW reaching to Delhi's three landfills namely, Ghazipur (GL), Bhalswa (BL) and Okhla (OL) under different technological options available for WTE generation has been assessed. The Delhi's landfills have been earlier estimated to emit 10.2 Gg of CH_4 annually through field measurement studies [12] which could be significantly reduced by employing suitable WTE technologies.

2. Methodology

The energy generation potential of MSW reaching to Delhi's three landfills namely, Ghazipur (GL), Bhalswa (BL) and Okhla (OL) has been assessed in this paper. The detailed characteristics of three landfills have been given elsewhere [12]. The data related to MSW quantity reaching to these three landfills has been collected from the Municipal Corporation of Delhi (MCD) which was corrected for drainage silt addition as it was not incorporated in original records because of the different data management system followed by MCD. For the assessment of energy potential, the total MSW (i.e. bulk MSW) and segregated MSW (after removal of recyclable materials) have been considered.

2.1. Estimation of methane generation from Delhi's landfills

The annual methane emission from Delhi's three landfills has been estimated using the USEPA LandGEM model. The LandGEM (landfill Gas Emissions Model, Version 3.02, USEPA) is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste. The model is based on the Eq. (i) for estimating methane emissions. It also provides estimation of CO_2 emissions and total landfill gas emissions based on default values from US landfills. However, field test data can also be used in place of model defaults when available. This model is useful where conventional type of landfill practice occur viz. leachate circulation or any liquid addition, aerobic decomposition practice etc. are not practiced. The value of methane generation potential (L_0) of MSW has been derived using the Eqs. (ii) and (iii) of the IPCC 2006 methodology [13] based on site specific characteristics for use in LandGEM model. In addition, the mass of degradable organic carbon (DOC) values for the different types of waste have been taken from IPCC 2006 [13].

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

where Q_{CH4} is the annual methane generation in the year of the calculation (Gg/y), i is the 1-year time increment, j is the 0.1-year time increment, n is the (year of the calculation) − (initial year of waste acceptance), k is the methane generation constant (y^{-1}), L_0 is the potential methane generation capacity (m^3/Mg), M_i is the mass of waste accepted in the ith year (Mg), t_{ij} is the age of the jth section of waste mass M_i accepted in the ith year (*decimal years*, e.g., 3.2 years).

$$L_0 = \text{DDOCm} \cdot F \cdot 16/12 \quad \text{(ii)}$$

$$\text{DDOCm} = \sum_{i,j,k...} \text{DOC}_{i,j,k...} \cdot W_{i,j,k...} \cdot \text{DOC}_f \cdot \text{MCF} \quad \text{(iii)}$$

where L_0 is the CH_4 generation potential (Gg CH_4), DDOCm is the mass of decomposable $\sum_{i,j,k...}\text{DOC}_{i,j,k...}$ deposited (Gg), F is the fraction of CH_4 in generated landfill gas (volume fraction), 16/12 is the molecular weight ratio CH_4/C (ratio), $\text{DOC}_{i,j,k...}$ is the mass of degradable organic carbon in waste types $i,j,k...$ (Gg C/Gg waste), $W_{i,j,k...}$ is the fraction of waste types $i,j,k...$ by waste category, DOC_f is the fraction of DOC that can decompose anaerobically (fraction), MCF is the CH_4 correction factor for aerobic decomposition in the year of deposition (fraction).

2.2. MSW composition analysis

Compositional analysis was carried out on samples collected on random basis on two different days in each of the three landfills of Delhi during the period of November 2011–March 2012. During each sampling event, total truckloads of MSW, reaching to the landfill sites during 10 AM to 4 PM on that day was accounted. All of the MSW during the sampling events were segregated into different constituents like cloths, jute bags, types of polythene, plastic materials, glass items, foam, other packaging materials, cardboard, metals, and wooden materials, etc. which were then weighted to get the fraction of the different constituents of MSW. The monthly values of total waste dumped into each of the three landfills have been obtained from MCD.

2.3. Calorific value estimations bulk and segregated MSW

The calorific values of MSW have been estimated using the bomb calorimeter. The bulk and segregated MSW samples were collected from the three landfills of Delhi on random basis. Twelve samples each of both bulk and segregated MSW have been collected and brought back to laboratory. These samples were sun dried and grinded using a soil pulveriser. The powdered samples were converted in to pellets and subjected to bomb calorimeter studies. The calorific values were determined by the following equation:

$$\text{CV}_s = W \cdot t - (\text{CV}_t - \text{CV}_w)/M \quad \text{(iv)}$$

where W is the water equivalent (2711.6 in benzoic acid), T is the rise of temperature, CV_t is the calorific value of thread, CV_w is the calorific value of wire, M is the mass of the sample.

2.4. Heat to energy generation potential calculation by thermo-chemical conversion of solid phase of MSW

The thermal de-composition of organic matter to produce heat energy is useful for MSW containing high percentage of organic non-biodegradable matter and low moisture content. An assessment of the potential of recovered energy from MSW through different treatment methods can be made from knowledge of its calorific value and organic fraction. The energy recovery potential and power generation potential can be calculated using the following Eqs. (v) and (vi) while the net power generation potential can be calculated by the Eq. (vii). The conversion efficiency in these calculations has been taken as 25%.

$$\text{Energy recovery potential(kW h)} = \text{NCV} \times \text{W} \times 1000 \quad \text{(v)}$$

$$\text{Power generation potential(kW)} = 41.67 \times \text{NCV} \times \text{W} \quad \text{(vi)}$$

$$\text{Conversion efficiency} = 25\%$$