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Methodology for the determination of optimum power of a Thermal Power Plant (TPP) by biogas from sanitary landfill

Tiago Rodrigo Silva, Regina Mambeli Barros *, Geraldo Lúcio Tiago Filho, Ivan Felipe Silva dos Santos

Natural Resources Institute, Federal University of Itajubá, National Reference Center in Small Hydropower, (Instituto de Recursos Naturais da Universidade Federal de Itajubá, Centro Nacional de Referência em Pequenas Centrais Hidrelétricas), Av. BPS, 1303, Itajubá, MG CEP: 37500-903, Brazil

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ABSTRACT

This study aimed to determine theoretically, the electrical optimum power of LFG using the maximum net benefit (MNB) methodology, and taking into consideration the economic, demographic, and regional aspects of the Inter municipal Consortium of the Micro-region of the High Sapucaí for Sanitary Landfill (CIMASAS, as acronym in Portuguese), that is located in the southern part of the State of Minas Gerais, Brazil. To this end, the prognosis for a 20-year period of household solid waste generation in this region was estimated and quantified based on population data, in order to estimate the LFG production and the energy that can be generated. From this point, the optimum power for thermal power plant (TPP) by LFG was determined. The results indicated that the landfill in this region could produce more 66,293,282 m^3CH_4 (with maximum power of 997 kW in 2036) in twenty years and that there would be no economic viability to generate energy from LFG, because the Net Present Value (NPV) would not be positive. The smallest population to that can achieve a minimum attractiveness rate (MAR) of 15% should be 3,700,000 inhabitants under the conditions studied. Considering the Brazilian National Electric Energy Agency (ANEEL) Resolutions, it would be 339,000 inhabitants with an installed power of 440 kW. In addition, the outcome of the CIMASAS case-study demonstrated the applicability of MNB methodology for the determination of TPP optimum power.

1. Introduction

The generation and final disposal of municipal solid waste (MSW) is a severe environmental problems faced by cities in Brazil, as well as across the globe. Landfills have always been one of the most common ways to dispose the Municipal Solid Waste (MSW) (Zamorano et al., 2007; Fodor and Klemeš, 2012; Leme et al., 2014). According to the 2008 National Survey of Basic Sanitation (PNSB, as acronym in Portuguese), Brazil generated 259,547 tons of MSW and Household Solid Waste (RSD, as acronym in Portuguese) daily. According to the Brazilian Association of Cleaning Companies and Special Waste (ABRELPE, 2016) in 2015, the total amount of MSW generated was 79.9 million tons. From this total amount that was generated, 42.6 million tons were put into landfills i.e., 58.7% of the collected MSW, and almost 30 million tons of waste was disposed in open dumps or controlled landfills. In 2008, about 50.8% of the MSW were disposed to landfills (IBGE, 2010b). According to the Brazilian National Bureau of Information on Sanitation (SNIS, as acronym in Portuguese) in 2014, with 3765 participating municipalities and a total population of 147,496,108 inhabitants corresponding to 81.1% of the urban population, 52% of municipalities had their MSW disposed in landfills, 2.5% had theirs for sorting and 0.4% for composting plant, 13.1% for controlled landfilling and 12.4% for "open dumps" (Brazil, 2015). The landfills generate slurry and biogas as by-products of the predominantly anaerobic decomposition of the organic fraction of MSW mass/. Through draining and burning, the design of sanitary landfills must have systems for capturing and treatment of the liquid resulting from the mixture inside MSW mass (slurry), leachate, and biogas. In Brazil, these requirements are established according to the Brazilian Association of Technical Norms (ABNT, acronym in Portuguese), NBR 13896/1997 and 15899/2010 (ABNT, 1997; 2010), with or without energy use. However, there is a portion of LFG that is not drained and thereby escapes from the landfills surface. This refers to fugitive emissions, which can contribute to a significant fraction of the global anthropogenic methane emissions. Studies concerning the placement of a layer with waterproofing material, such as geosynthetic clay liners, geomembranes, compacted soil liners, compacted clay liners, high-density polyethylene (HDPE) geomembranes, nonwoven needle-punched geotextile, under the landfill coverage layer (Chen et al., 2011),

* Corresponding author.
E-mail address: remambeli@hotmail.com (R.M. Barros).

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and a biological layer end (biolayers) for methane into biogas oxidation (Maanoja and Rintala, 2015; Broun and Sattler, 2016) were conducted. Methane laterally migrated or temporarily stored within the volume of landfill can be oxidized by metanotrophics archaeas; (Spokas et al. (2006) proposed values for recovery rate is 35% for an operating cell with an active LFG recovery system, 65% for a temporary covered cell with an active LFG recovery system, 85% for a cell with clay final cover and active LFG recovery, and 90% for a cell with a geomembrane final cover and active LFG recovery. Authors such as Barlaz et al. (2009), Phillips et al. (2014) and Broun and Sattler (2016) show that for each scenario of LFG collection and respective interval (period of time, in years), LFG collection efficiency of conventional landfill may vary between 55% (1–2 years) and 95% (26–100 years). Notwithstanding, it should be considered that usually, the post closure of the landfills is 30 years. The weighted average value for the temporally efficiency collection is estimated to be at 69% for the conventional landfill, resulting from the volume of collected biogas divided by the LFG volume generated over a period of100-years (Broun and Sattler, 2016), and the LFG collection efficiency of 75% was recommended by USEPA (2008).

Sevimoğlu (2015) and Delbin (2007) preconized some problems between engineering *versus* actual project. In the Bandeirantes sanitary landfill, São Paulo, Brazil (Delbin, 2007, 2009), installing surface cover on landfill for measurement was required in four areas due to fugitive gas emission problems. As a result, the author presented the average methane flow (CH_4) of these areas as 0.050 N $m^3/h/m^2$, with an initial estimate between 9400 and 23,929 N m^3/h (50% CH_4). According to Delbin (2007), when LFG curve was modeled in 2003, the model used was based on Van der Wiel's analyses, which were adapted to IPCC's first order decay model, using values of Lo equal to 0.055 tCH_4/t MSW and k to 0.105. Two wells presented about 22.000 N m^3/h with 50% of CH_4. At that time, a discharge of 13,000 N m^3/h was observed (50% CH_4). Therefore, the difference between the modeled and calculated for 9000 N m^3/h (50% CH_4) was verified. In addition, there was leachate in some extraction wells and landfill stress effects. Extraction wells break, thereby accumulating leachate, as a result of the landfill's vertical movements. This causes an LFG extraction double barrier. Implementation of practical solution such as buffer gas tank installation are required in order to minimize the fluctuation of LFG quality and to reduce leachate water level via pumping, in addition to drilling or installation of a PEAD surface cover (Delbin, 2007; Sevimoğlu, 2015). According to Delbin (2009), an installation of 10,000 m^2 PEAD cap in the Bandeirantes landfill plateau can provide gain of 1500 N m^3/h. Sevimoğlu (2015) studied the limiting parameters for Odayeri and Kömürcüoda Sanitary Landfills, Istanbul, Turkey. Several improvements were done aiming to overcome these limitations in LFG extraction. As a result, an increase in the recovery of LFG was observed. This is because in 2012 the recovery LFG rate to theoretical extractable LFG rate ratios were 60% and 75% for Kömürcüoda and Odayeri landfills, respectively.

In addition, the issuance of the biogas collection and maybe energy use, consists of the fact that LFG can be a threat to the environment by generating unpleasant odors and presenting risk of explosion at high concentrations. According to Zhu et al. (2013), urban communities in the vicinity of the landfill are directly exposed to these LFG emissions. Biogas is composed primarily of methane, CH_4 (35–65%), carbon dioxide, CO_2 (15–50%), Nitrogen (5–40%), hydrogen (0–3%), oxygen (0–5%), and it also contains hydrogen sulfide, H_2S (0–100 ppm) and other sulfur compounds. In some places where biogas is produced, it can also contain compounds such as siloxanes and aromatic hydrocarbons, halogenated chlorofluorocarbons and other volatile organic compounds (VOCs) and ammonia, NH_3 (approximately 5 ppm) (Rasi et al., 2011; Persson and Baxter, 2015; Barros, 2012; Petersson and Wellinger, 2009), which may vary depending on the degree of MSW degradation into the sanitary landfill (Farquhar and Rovers, 1973; Zamorano et al., 2007; Mambeli Barros et al., 2014; The World Bank/ESMAP, undated). Authors opine that the biogas has lower heating value (LHV) on the average of 4475 kcal/m^3 (Aydi et al., 2015), 4.4 kW h/Nm^3 (Petersson and Wellinger, 2009) or 4.8591 kW h/Nm^3 (Chacartegui et al., 2015). There may be a variable LFG production and composition, depending on the MSW composition and factors that affect the predominantly anaerobic digestion into a sanitary landfill (Aguilar-Virgen et al., 2014). On average the average it is 0.350 N m^3/kg of MSW (Zamorano et al. (2007), or 80 kW h/t_{RSU} (Fodor and Klemeš, 2012). The methane and carbon dioxide are greenhouse gases (GHG); however, methane has a global warming potential 21 times higher than carbon dioxide (Johari et al., 2012; Lombardi et al., 2006).

According to the Intergovernmental Panel on Climate Change (IPCC), the concentration of methane in the atmosphere has increased to 1060 ppb (parts per billion) since 1750 (the first industrial revolution) (IPCC, 2006), and the limit of 400 ppm was exceeded in 2014 (IPCC, 2014). This number represents an increase of 151% in the total methane emissions of the world; however, it is estimated that more than half of this issue is from anthropogenic origin. Landfills produce 5–20% (IPCC, 2006) or 17% (UNFCCC, 2015; Gonzalez-Valencia, 2016) of the total methane.

The total value of anthropogenic GHG emissions have increased continually from 1970 to 2010, with greater increases between 2000 and 2010, even if there are a growing number of mitigation of climate change policies (UNFCCC, 2012, 2015). The anthropogenic GHG emissions in 2010 extended to 49 ± 4.5 Gt of $_{CO2\text{-}eq}$/3-years. The CO_2 emissions from the fossil fuels burning and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution to the observed increment during the period of 2000–2010 (IPCC, 2014).

Due to the increased GHG release by anthropic activities, increase would occur with an average temperature of the overall area in 2100 base-line scenarios (those without mitigation) in an additional range of 3.7 °C to 4.8 °C above the average of 1850–1900. These range values can vary from 2.5 °C to 7.8 °C if the uncertainty of the climate is included (IPCC, 2014). However, stabilizing the temperature rise below 2 °C above pre-industrial levels will require an urgent and fundamental departure from business as usual (IPCC, 2014) and involve the primary objective of COP 21-Paris2015, which proposes to maintain the increase in global mean temperature below 2 °C beyond pre-industrial levels toward 1.5 °C by the year 2100 (United Nations, 2015). Consequently, there was a search for renewable energy aiming to release smaller GHG amounts into the atmosphere, taking into account that the current forms of energy production based on fossil fuels always have negative impact on the environment. Brazil has a National Policy on Climate Change (PNMC, as acronym in Portuguese) established in 2009 by Law n°. 12,187 (Brazil, 2009), and regulated by Decree n°. 7,390/2010 (Brazil, 2009). According to this decree, the baseline of GHG emissions for 2020 was estimated at 3.236 $GtCO_{2eq}$. Thus, the absolute reduction agreement was established between 1.168 GtCO2 eq and 1.259 $GtCO_{2eq}$ as 36.1% and 38.9% reduction of GHG emissions respectively. For the sector of "Industrial Processes and Waste Treatment", the emissions projected 2020 to be 234,031 $GtCO_{2e}$ by the regulator decree of the PNMC.

Waste management systems are not a negligible source of GHG. According to this context, the collection of the LFG with its subsequent burning or combustion with energy recovery to reciprocate is an attractive option for the reduction of GHG emissions, being one of the conventional possibilities for GHG emissions reduction (Phillips et al., 2014). In addition, methane has large energy