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CASE STUDY

Assessment of electrical generation potential and viability of gas collection from fugitive emissions in a Tunisian landfill

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ABSTRACT

Three different models were used to estimate LFG generation and the collection efficiency of LFG collection systems at the landfill of Jebel Chakir, Tunisia. The feasibility of LFG-to-energy conversion was investigated based on the modelled results. Theoretical results were compared to the collected LFG from the whole site. Large differences were observed between theoretical and measured data, probably because of the models 'assumptions and subsequent inaccuracies. An analysis of the potential conversion of LFG to electric energy shows a total LFG-to-electricity energy of around 255 GWh with a heating value of 4475 kcal/m^3, based on a LFG collection efficiency of 58% (loss of 42%) and an energy efficiency of 33%. The analysis supported the economic feasibility for a 10 MW power plant at the Jebel Chakir landfill. Finally, the results of the investigation of LFG utilization are considered satisfactory in terms of electric energy generation and in terms of mitigation and reduction of greenhouse gas emissions.

1. Introduction

Municipal solid waste (MSW), when landfilled, causes several environmental problems such as leachate, the presence of vectors (e.g., insects, rodents, and birds), explosion and combustion, asphyxiation, vegetation damage, and greenhouse gas (GHG) emissions [1].

Landfill gas (LFG) is produced from the decomposition of the organic fraction of municipal solid waste and they include mainly methane (CH_4) and carbon dioxide (CO_2) but also ammonia (NH_3), carbon monoxide (CO), hydrogen (H_2) and oxygen (O_2) [2]. Non-methane organic compounds (NMOCs) usually make up less than 1% of LFG [3]. Additionally, methane is regarded as one of the most important GHG because its global warming potential that can exceed 25 times that of carbon dioxide; it may initiate explosion when its air concentration exceeds 5–15% [3]. Because of this, LFG is considered a major source of bad odour, as well as health and safety hazards if controlling measures are not taken. To avoid these hazards, many landfilling sites have installed LFG recovery systems (or landfill gas-to-energy systems) to use LFG for energy production and to minimize fugitive emissions.

Landfill gas production depends on several parameters such as the age and composition of landfilled material, its moisture content, geology of the landfilling site, leachate level, temperature distribution within the landfill, the presence of oxygen, and the effectiveness of the cap and the site [4]. LFG, and specifically methane, can be (1) recovered by the collection system for subsequent treatment, (2) emitted into the atmosphere through the cover layer, (3) oxidized by microorganisms that exist in the methanotrophic layer of the soil cover or (4) accumulated or stored inside the landfill creating pockets, especially in the absence of a drainage system or efficient gas extraction [5]. Environmentalists and decision makers are implementing waste management policies that will help reduce gas emissions from landfills and decrease GHG concentrations in the atmosphere. To minimize environmental pollution and a global energy shortage, energy recovered from LFG can be used to generate electricity. This electricity can be used in internal combustion generators, turbines, microturbines, fuel cells and other power producing facilities [6]. Over the years a large number of models have been proposed to estimate LFG generation (such as the GasSim, the IPCC method, the EPER, the LandGEM model, and the Mexico LFG Model, among others) based on zero, first and

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second-order approaches [1,7—10]. However, second-order models are not commonly used because the required parameters in each model are often so uncertain that they negatively affect the accuracy of the model out comes [11]. The main problems of modelling LFG generation are not only forecasting the amount of LFG which will be produced, but also the rate and the duration of the production [12]. Therefore, several different emission models were used in this study to (1) estimate the gas production from landfills and (2) investigate the feasibility of LFG electricity generation potential from LFG fugitive emissions at Jebel Chakir. The feasibility study also considered economic benefit from electricity generation.

2. Materials and methods

2.1. Site description

The landfill of the Jebel Chakir is located 10 km southwest of Tunis City (36°44′16″N/10°04′30″E) (Fig. 1). The climate in Tunis City is Mediterranean with a precipitation average of 450 mm/year. The summer (from June to August) is the dry season, while winter (from December to February) is the wet season. The annual average temperature is 19 °C (minimum in January with 12 °C and maximum in August with 27 °C), and the average evaporation rate is 129 mm/month. The predominant wind blows northward with an average speed of 5 m/s.

The landfill of Jebel Chakir covers an overall area of about 124 ha and receives the municipal solid waste (MSW) produced by private sectors and the municipalities of Tunis, Ariana, Ben Arous and Manouba areas, totalling approximately 1800 t/day of MSW.

Landfill cells have been built and operated sequentially, cell by cell, and have an expected active life of 12 years, reaching a final waste height of 15 m. Four cells are in operation, their areas totalling 31.32 ha. The first cell (cell 1 = 8 ha) opened in May 1999 and closed in September 2001; it received 1.17 million tons of solid waste. The second cell (Cell 2 = 8 ha) was in operation from October 2001 to September 2003, receiving approximately 1.23 million tons of solid waste during that time. The third cell (Cell 3 = 7 ha) opened in October 2003. Its operational lifetime was extended to June 2006, with a final quantity of 1.73 million tons of landfilled waste. The fourth cell (Cell 4) covered 8.32 ha and began operating after the closure of Cell 3 in June 2006. During the subsequent life of the landfill (i.e., 2006—2010), cell 4 received approximately 3.15 million tons of MSW. From 1999 to 2010, a total mass of 7.28×10^6 tons of MSW was landfilled in the Jebel Chakir landfilling site (Fig. 2).

The dumping methodology was undertaken as following: after 2 m of waste, a layer of 30 cm sand was introduced; approximately 1.8 m thick soil layer was used as final cover. The slope inclination of the cell base was 30°. The composition of MSW received in the Jebel Chakir landfill shows that the organic fraction (composed mainly of food waste) is the largest in the waste received (65%), followed by paper and cardboard (12%), fines (8%), plastics, leather and rubber (7%), metals (4%), textiles (3%), and glass and ceramic (1%) [13]. The average moisture content of the landfilled MSW was around 70% [13]; the carbon content was estimated to be 30% by weight [14]. High organic matter content, exceeding 77% by dry weight was recorded in Tunis City [13]. The landfill of Jebel Chakir was selected for this project since it is the first and largest MSW landfill in Tunisia. It receives about 40% of the total MSW generated in the country. The total amount of waste present at this landfill site indicates its potential for biogas generation. Electricity generation through biogas utilization is therefore a very attractive option for this landfill. The LFG collection system at the landfill of Jebel Chakir was installed in 2008 as part of a large project funded by the National Waste Management Agency of Tunisia (ANGed). The LFG collection system in Jebel Chakir consists of 89 wells spaced at 35 m centres. A blower pulls the gas from the collection wells to a main collection header that carries the gas to the two flares with a combustion capacity of 3000 Nm^3/h used to burn the collected LFG.

At the landfill of Jebel Chakir, a monthly physico-chemical analysis of leachate generation was monitored from 1999 to 2010. The landfill leachate (LFL) composition is shown in Table 1.

It was clearly observed that pH values of LFL showed a linear trend from 6.05 to 8.37, similarly to those found by Tatsi and Zouboulis [15] in leachate from old site (an average pH of 7.9 with a variation from 7.3 to 8.8). The electric conductivity ranged from 25.1 to 52.39 mS/cm, exceeding that of typical domestic wastewater and those reported in literature (15 mS/cm) [16]. This parameter can be considered an indicator of a high mineral content of the leachate. All leachates were characterized with high COD values. However, the youngest leachate (less than 3 years old) presents the highest COD (>31 g/l) from 1999 to 2001. This value substantially decreased with the age of leachate to reach 7 g/l in 2010. Considerable variation in the quality of leachate produced from different landfills was reported in the literature [17—20]. The COD value of 31 g/l is much higher than the domestic wastewater and it is higher than the Tunisian Norm (NT) for waste water discharge into public sewers (NT 106,002: COD = 1000 mg/L and

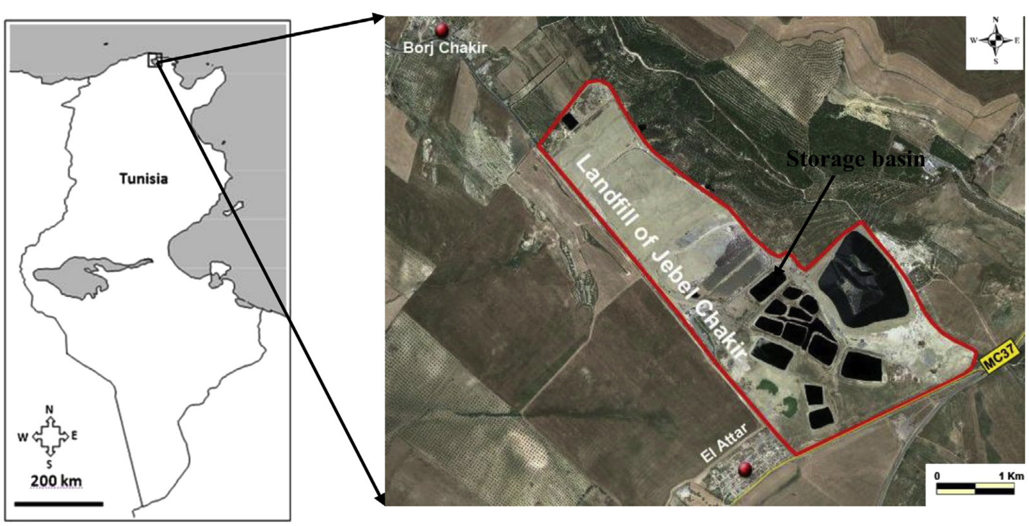

Fig. 1. Landfill Jebel Chakir map.