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Research paper

Analysis of a CHP plant in a municipal solid waste landfill in the South of Spain

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HIGHLIGHTS

- Analysis of biogas generation capacity in an existing landfill at South of Spain.
- Analysis of the integration of gas engine for cogeneration.
- CHP integration for increasing the leachates evaporation ratio and landfill capacity.
- Analysis of economic viability under old and new Spanish legislations for cogeneration.
- Alternative biogas uses integrated with CHP for increasing economic results.

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ABSTRACT

The most effective strategy to manage and treat solid urban residues, with the least environmental impact as well as lowest economic and energy costs, is a challenge for sustainability in current society, who actually pay for the final management of these residues. This manuscript analyzes the potential of biogas generation in an urban solid residue treatment plant, and the potential use for cogeneration *in situ* at the landfill. The objective is to identify the energy potential associated with the landfill and its potential use to accelerate the evaporation of leachate through the supply of heat, reducing the risks of exceeding the collection capacity of the leachate ponds. The change in legislation for generation within the special regime in Spain (2014) introduced a sudden change in the direction of energy policies, which affected significantly the profitability of these facilities. This manuscript analyzes the application of both legislations, previous (2007) and current (2014), for the case of a cogeneration system installed in this landfill. The results obtained indicate that even with a much more restrictive legislation in force, acceptable values are obtained for the evaluation of the investment – however, better results were obtained for the previous legislation that favored the special regime. The new regulation constrains the maximum and minimum annual operating hours for landfill cogeneration. It results in relevant periods with limited use of biogas for electricity generation. Biogas storage for delayed future consumption in the same installation and biogas selling for external use in boilers are proposed as options for this biogas in excess. They can reduce greenhouse gases emissions from the non-used biogas and can improve the economic results of the facility.

1. Introduction

Landfills are the most common destination for the disposal of solid waste generated in cities [1]. Landfills continue to be very attractive because they are the cheapest alternative for urban waste management commodities and end users [2]. Despite being an economic asset, this practice may cause different negative environmental impacts [3]. Carbon dioxide, methane and other greenhouse gases are generated during stabilization of the organic fraction of solid waste, and volatile components tend to be emitted into the atmosphere [4]. In this way, the main concerns related to landfills are the potential health hazards (including those related to animal pests), vegetation damage, unpleasant odors, landfill

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settlement, fires and explosions, ground water pollution, air pollution and global warming [5,6]. Different technologies for waste treatment and leachate or biogas management in a sanitary landfill have clear different environmental impacts [7].

Generation of heavily polluted leachates, presenting significant variations in both volumetric flow and chemical composition, constitutes a major drawback for landfills. Conventional landfill leachate treatment plants are in many cases under-dimensioned or do not allow to reach the specifications required by regulations [8]. One of the great challenges for landfills in South Europe is the rate of leachate elimination; the levels of leachate ponds must be monitored to avoid contamination of aquifers and soils due to overflow in rainy seasons.

Landfill gas (LFG, which is mostly constituted by methane) is produced by the decomposition of biomass (organic materials) in landfills, and is considered a valuable renewable energy source. IPCC (2007) [9] cited landfill methane (CH_4) recovery as one of the key mitigation technologies and practices currently commercially available in the waste management sector.

Regarding environmental impacts of landfills, Cherubini et al. [10] applied the life cycle assessment technique to the case of municipal solid waste management in Rome (Italy), with a special focus on energy and material balances, including global and local scale airborne emissions. The results of their analyses suggested as the worst waste management options: i) waste delivered to landfill without any further treatment (the real case of Rome and many other cities) and ii) part of the biogas naturally released by the landfill being collected, treated and burnt to produce electricity. They also found that a sorting plant coupled with electricity and biogas production was very likely to be the best option for waste management [10].

Additional energy can be recovered in the landfill via thermal treatments such as incineration [11] or gasification [12] which are applied to the non-organic, non-recyclable fraction [13] and depending on location and residues compositions different technologies have a better performance [14]. Depending on the origin of biogas, there are differences in the fuel composition and in the deposits. In engines operating with biogas from digesters, higher phosphorus, sulfur and calcium content are present in the deposits; when operating with landfill gas higher silicon levels are expected [15] as well as differences in the siloxanes generated [16]. The landfill biogas generation capacity and its composition are directly linked to the criteria for integration of different technologies from the technical and economic points of view [17]. In Ref. [18] the potential for electricity generation from municipal solid waste alternatives in Chile was assessed comparing landfill gas-to-energy and direct waste-to-energy as well as gas collection and upgrading to feed into the grid.

The energy from biogas can be recovered in many different technologies. Landfill biogas use is proposed for: boilers for residential heating [19], direct thermal applications [19,20] (kilns, sludge dryers, etc.), leachate evaporation [21,22], electricity generation with internal combustion gas engines (ICE) [23,24], micro gas turbines [24], steam turbines [25], combined cycles [26], hybrid systems integrating ICE-ORC [27], hybrid systems ICE-fuel cells [28,29], cooking [30], fuel for vehicles [31] or using oxy-fuel combustion conditions [32].

The evaluation of landfill biogas production capacity [33] allows to evaluate the investment requirements and economic returns [34]. The dispersion of landfill regional characteristics and residues is presented in works from Brazil [35], Spain [36] or Mexico [37]. For the development of cleaner and more efficient landfills is required an adequate planning and management [38]. It is directly linked to a good understanding on potential technologies, investments risks [39] and regulations including analyses of the technologies, environmental and economic impacts. In Ref. [40] different pathways for recovering energy from municipal waste were analyzed and utilization of landfill gas for electricity production and landfill gas flaring showed the greatest economic benefit.

The use of landfill gas requires in most of the previous technologies aforementioned high investment costs, and landfill management deals with several uncertainty sources: availability of waste, price of waste processing, energy costs and regulations. The determination of the suitable capacity and sizing of an appropriate system, according to adopted heat utilization strategy represent crucial decisions.

This manuscript addresses the exploitation of landfill gas in an existing landfill at the South of Spain through the installation of a cogeneration system for the production of electricity and heat, with use of cogenerated heat for dehydration of leachate. With this purpose, the LFG generation capacity was modeled from waste composition data full details of biogas capacity evaluation are given. Based on this estimation a cogeneration system based on a biogas internal combustion engine and a forced evaporation system installation is proposed. A techno economic analysis of the proposed installation is presented analyzing the effect of recent regulation changes in Spanish cogeneration legislation (June 2014) on the viability of the facility and alternative uses are proposed for the biogas in excess for the cogeneration use.

2. Cogeneration facility

The facility under study is located in the province of Seville, South Spain. The installations located within the environmental facility are: controlled deposit (landfill for non-dangerous residues, mixed solid municipal residues – organic and inorganic), collection and treatment of residues, plant for aspiration and combustion of landfill gas, system for extraction of leachate, leachate ponds, and offices. The facility was built with characteristics that made it efficient at the time of launching, however in recent years there have been increasing demands to better make use of residues, which in many cases can be transformed into benefits. The energy process diagram of the facility under study is presented in Fig. 1. The decomposition of the organic matter accumulated in the landfill generates both landfill gas (LFG) and leachate. LFG can be burned directly in a gas flare to avoid emission of methane and odor, or as proposed in this study it can be used to generate electricity in reciprocating gas engines (spark-ignition engines specifically adapted for biogas operation) in order to supply the internal demand of electricity at the plant, and if possible, export the surplus electricity to the grid.

The singular features of the fuel and the simultaneous production of heat and power pose two main challenges to these installations: (i) to be qualified as high efficiency co-generators in order to have access to the beneficial electricity sale conditions [41,42], and (ii) to eliminate certain impurities that are inevitably found in the LFG yield, which could compromise the mechanical integrity of the system (engines and others equipment). Volatile sulfur compounds (VSC) and siloxanes are some of the compounds whose concentrations must be controlled [43,44], as they can seriously damage engines and heat exchangers even in very small amounts [43,45]. Different technologies for the abatement of VSCs and siloxanes exist [43,46]. The three main commercial technologies available to remove siloxanes today are adsorption, absorption and deep chilling [47]. In the context herein considered, treatment with ferric chloride ensures that the concentration of hydrogen sulfur in the clean biogas remains under 20 ppm. O&M costs including biogas cleaning have been included in the economic analyses presented in Section 5.