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Optimization of energy generation using landfill biogas

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ABSTRACT

Municipal solid waste landfills (MSWL) generate large quantities of landfill gas (LFG) that can be converted to renewable energy. But, the economics of such operation are not adequately attractive and in most of the MSWL, worldwide, the LFG is flared to the atmosphere unused, contributing to the global warming. In this study, a Linear Programming (LP) Model was developed and used to evaluate the economic return of LFG power generation from a landfill – HAGAL MSWL, aiming to improve the economic viability and the ways to maximize the economic benefits resulting from the conversion of LFG to electricity. The analysis indicated that as compared to a continuous power generation, the adoption of an intermittent power generation regime, in which the LFG is stored to limit the operation of the energy center to the hours of the day when the power demand reach its peak, the economic return is significantly higher by 20%. Due to a price incentive offered to electricity producers through a form of Time Load Tariff (TLT), in which the sale price of power fluctuates during the day of the week and season, it was demonstrated that the return on investment (ROI) justified the additional cost incurred for the storage of the LFG. The LP optimization model was found to be a useful tool for the evaluation and maximization of the ROI of power generation from a largely un-tapped renewable source which is readily available and abundant.

1. Introduction

1.1. Landfill gas

Landfill gas (LFG) is created during the anaerobic decomposition of organic substances found in municipal solid waste (MSW) dumped in a landfill. The MSW produced a biogas which contains gas methane, a powerful greenhouse gas, causing global warming if it is allowed to escape to the atmosphere [1]. However, the number of landfill gas projects which collect and utilize this valuable renewable energy is minimal. The LFG is not widely used although MSW landfills are a major source of greenhouse gas (GHG) emission, particularly in the developing world. In Malesia of the 296 landfills and 14 sanitary landfills only 4 installations are equipped with LFG utilization systems, all the rest flare the produced LFG to the atmosphere contributing approximately 40% of the country's methane generation and the resulting environmental consequences and a waste of a valuable resource [2]. In the United States, out of the 2300 active landfills, only 382 (16.6%) are energy producers, while there are many more landfills with potential to utilize the generated biogas, [3]. Thus, LFG emission standards are becoming more and more stringent, aiming to prevent its release to the atmosphere and its utilization as a renewable fuel source [4] converting the vast LFG into a viable renewable energy source for electricity generation in a carbon constrained world.

Energy recovery from LFG is a waste-to-energy (WTE) process in which non-recyclable solid waste materials are converted into useable electricity, heat, or fuel by combustion, gasification and anaerobic digestion processes. In the process, methane gas may be collected, treated and used for generation of electricity or upgraded to power homes, buildings, and vehicles. Harnessing the LFG is a renewable energy activity which contribute to effective management of the MSWL, while minimizing the associated environmental impacts [4].

1.2. Landfill gas composition and calorific value

LFG composition and production rates are primarily affected by the type of waste that has been deposited in the landfill, the landfill

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storage height, the density and the maturity of the waste and compaction, moisture, air temperature, atmospheric pressure and precipitation [5]. Generally, MSW contains 150–250 kg of organic carbon per ton which is converted by anaerobic micro-organisms to LFG. Of which methane (CH_4) production amounts to 45–60% and the remaining is composed of carbon dioxide, nitrogen and oxygen [6]. On average LFG contains 50% methane (CH_4) – 50%, carbon dioxide (CO_2) – 45% and nitrogen (N_2) and other gases including trace amounts of non- methane organic compounds – 5% [3]. For the global 1.5 billion ton of MSW that is deposited in landfills annually, the corresponding rate of methane generation is 75 billion Nm^3 [7]. The generated gas can be either flared or utilized for energy recovery. For every 1 ton of MSW: ~0.78 MW of electricity could be generated producing 6500–10,000 MWh of electricity per year, corresponding to the power demand of 1500–2200 EU households [8].

1.3. Optimization of the energy generation

To turn waste to energy, the biogas is pumped from vertical wells (perforated piping in bulk of waste) and transmitted by primary horizontal pipes that connect each well the station. In the station, the biogas is passed through appropriate equipment of dehumidification and elaboration and supplied in the generator unit for combustion and electric power production. A combustion engine and a turbine could be used or alternatively, direct combustion of the MSW to produce steam to run a turbine and the electric generator. The costs of installing and maintaining the energy generation system and the revenues from the sale of the electricity are the main factors being considered if power is to be generated, evaluating the cost benefit ratio and the return on investment that would be required to make the project economically viable.

Previous LFG studies were motivated by the GHG emission and the need to efficiently generate and utilize LFG as a renewable source of energy. The studies were related to the type of the renewable energy to be produced e.g. power, heat or a combination of both, the equipment to be used and the projected quantities and qualities, the treatment and the appropriate technology to be used, and how to maximize the profit and to minimize the environmental footprint [9]. Also, the potential renewable energy generating capacity, the return on investment, and the economic feasibility were studies including the material balance of LFG in the system, the pressure difference (input–output) in all sections of pipelines, the gas flow rate, phase composition, and flow were evaluated [10,11] as well as the annual energy generated, carbon dioxide emissions and environmental and economic benefits [12]. The adequate electric power for grid connection and the reduction of sequential greenhouse gases emissions as well, an experimental procedure in a municipal solid waste site was implemented in order to foresee a possible electric power production [13].

In a similar study, a Linear Programing approach for LFG utilization for renewable energy production was applied to Seelong landfill in Johor, Malaysia, to select the most promising utilization technology from a number of options such as: gas engine, gas turbine and steam turbine for electricity or combined heat and power production, as well as steam boiler; direct LFG distribution to residences/industries as a substitute to natural gas [14].

In this study, an LP model was developed and used to assess the ways to increase the profitability of such operation adding a storage element of the generated LFG allowing intermitted power generation to the commensurate with power peak demand, avoiding power generation during off-peak hours. The aim is to maximize the net income from the sale of the electricity. The model follows previous studies in which optimization models for energy pricing in power plants were developed [8,15,16] and where correct power factors in optimal operation of industrial, power plants and desalination plants were determined [17,18].

To illustrate the effectiveness of the LP model, a case study, the operation of the electricity generating facility at “HAGAL” Landfill was studied, evaluating the operational and economic variables that influence the energy production and the total revenue. The existing generation modalities were evaluated against a new strategy in which additional capital investment and higher revenues would ignite the utilization of a largely wasted renewable source of energy.

2. Methodology

2.1. The case study – hagal landfill electricity generation facility

The selected Municipal Solid Waste Landfill (MSWL) “HAGAL” was established in 1999 in the north of Israel, 20 km south to the Sea of Galilee. The MSWL, extending on an area of 34 ha, was built under a BOT (Built Operate Transfer) contract by SITAHAL, a consortium of SITA and TAHAL Group to handle 1000 ton of municipal solid waste (MSL) per day. During the first years of operation, the generated land fill gas (LFG) was flared using a basic open flaring system. In 2006, the flaring system was replaced with a power generation system which produce electricity that is delivered to the national utility grid. The plant producer license is for power installation of 2.2 MW. Due to a limited gas production and generation capacity, the average power sale is only 1.4 MWh.

2.1.1. Description of the power generation system

2.1.1.1. Landfill gas collection system. The LFG is collected from the landfill through adequately spaced extraction vertical and horizontal wells Connected to perforated tubes that penetrate the landfill body and interconnected by a pipework system. Blowers are used to pull the gas from the gas collecting wells through a network of pipes, leading to the collection header and further down the line to the treatment unit. The main collection header is connected to the leachate collection system to properly discharge the condensate forming in the pipes.

2.1.1.2. Landfill gas treatment. Landfill gas is treated to remove impurities, condensate, and particulates which may damage the generating equipment. Before the landfill gas is fed into the gas engines, it is dried and compressed, ensuring that severe contaminants are removed if exceeding a certain level.

2.1.1.3. Electricity generation. After treatment, the LFG is introduced into a gas generator set specifically designed for operation using LFG. The engine parts are hardened against corrosive elements to resist the impurities that usually appear in this type of fuel, the low heating value and fluctuating gas quality and pressure. Two internal combustion engines, Caterpillar and GE-Jenbacher generators reciprocating engine (engine/generator system) with an electrical generation capacity of approximately 1.0 MW each. The specific biogas consumption for electricity generation is nearly 550–600 m^3/MWh.

2.1.1.4. Monitoring system. Maintenance/monitoring/balancing is conducted through a Supervisory Control and Data Acquisition System (SCADA). The SCADA controls the engine/generator system shut down, managing the basic and heavy duty maintenance of the engines, as well as monitoring and reporting as required by the regulator. A switchgear with a Programmable Logic Controller (PLC) is installed to control the export of the renewable power, at a premium price, to the electric grid.