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Biogas from anaerobic co-digestion of food waste and primary sludge for cogeneration of power and heat

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Abstract

The anaerobic digestion (AD) process is being increasingly recognised as a technology for clean energy generation. However, in Ecuador, there is a little application of this technology due to lack of adequate research, economic incentives and the current relatively low price of electricity. This study examined the feasibility of biogas production using anaerobic co-digestion of food waste (FW) and primary sludge (PS) under thermophilic (55 ºC) and mesophilic (35 ºC) conditions. The biogas is then used for power and heat generation. Using case study approach, data were collected from Riobamba vegetable market and Penipe waste treatment plant in Ecuador. Three different mixing ratios of FW: PS were used (1:2, 1:1 and 2:1) with volatile solids (VS) content of 84.53%, 86.99%, and 89.6% respectively. Furthermore, the organic loading rates (OLR) used were 2.08, 2.49 and 3.34 g_{VS} l^{-1} day^{-1} for the above mixing ratios with a hydraulic retention time (HRT) of 21 days.

Computational models of biogas production and a combined heat and power (CHP) system were developed using Aspen Plus software. Results indicated that a mixing ratio of 1:2 and mass flow of 132.42 tonnes/day, the maximum specific methane production obtained was 270 and 205 ml CH_4/ g_{VS} at thermophilic and mesophilic conditions respectively. The power production with the aforementioned values were 188.42 and 137.79 kW for both thermal conditions. Finally, an economic analysis for both scenarios was carried out using Ecuadorian renewable energy tariffs. A positive NPV values of £147,580 and £186,307 with a discounted payback period of 20.97 and 17.33 years were obtained for both scenarios respectively, assuming that the interest rate was 4.89% and a lifetime of 25 years.

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Keywords: Anaerobic co-digestion, CHP simulation system, biogas simulation;

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1. Introduction

The increasing threat of global warming, price instability and energy security have necessitated decoupling of global economy from fossil fuel which still accounts for over 67% of the world total energy consumption in 2015 [1]. Ecuador an upper middle-income country is a fossil fuel energy-based economy [2] but with public policies that encourage the use of renewable energy. In 2014, Ecuador reached an energy access index of 97.04% of which, the electricity generation was 51% from thermoelectric, 47% from hydro and only 2% from non-conventional renewable energy including the wind, solar and biomass source [3]. Although the Ecuadorian government is encouraging the use of renewable resources, the use of wastes to produce energy can be considered negligible compared to other renewable energy sources.

Furthermore, in the country, the final waste disposal is handled by the local municipalities and it represents a serious environmental and social issue. According to the Department of Statistics and Censuses, 39% of the solid waste collected is disposed of in landfills, 26% in controlled dumps, 23% in open dumps and 12% in emergent cells [4]. Similarly, about 88% of wastewater is disposed of in rivers and only 12% is treated before its final disposal [5]. This has, in the past, led to serious environmental and social concerns. Biosolid composting and anaerobic digestion (AD) are the frequently used matured mechanisms to recover useful energy from bio-waste. However, the implementation of AD technology in Ecuador has been limited to pilot or empirical projects [6]. Hence, there is a need for further studies on how this technology can be technically and profitably utilised to solve challenges of the Ecuadorian waste management as well as the generation of useful energy.

Anaerobic Digestion Model No. 1 (ADM1) is being more frequently used because of its complexity and its kinetic values related with temperature and pH influence in all the steps of AD process. Nevertheless, ADM1 does not include all the mechanisms in AD, but the results obtained have a satisfactory accuracy [7]. Based on ADM1, some authors have developed software simulations which are able to forecast real scenarios of AD system with accurate results at low resources compared to experiments carried out in labs [8-10]. However, these studies mainly focused on biogas generation and do not include power generation and heat recovery. Thus, the main objective of this study was to investigate the feasibility of producing power and heat from anaerobic co-digestion of food waste (FW) and primary sludge (PS) under thermophilic and mesophilic conditions, in one assembled model simulation for biogas production and a combined heat and power (CHP) system using Aspen Plus. Furthermore, an economic analysis is also included.

2. Materials and methods

2.1. Case Study

Food waste was collected from the biggest local market in Riobamba where vegetables, fruits, and other food products are mainly sold directly by farmers. Riobamba is the capital city of Chimborazo province (1°40′27.65″S 78°38′53.86″W). Its population at 2010 was 225,741; land mass 59.05 km^2 and elevation 2,754 m above the sea. The temperatures averaging between 23 °C and 14 °C. Moreover, the primary sludge required in the process was collected from Penipe treatment plant located 30 km north-east far from the market.

2.2. Characterization of wastes and energy consumption of the market.

The average daily waste production of 6,598 kg/day is assumed constant all the year. This is because there is a constant influx of fruits and vegetables amongst the regions which experience seasonal variations at different times of the year. The daily production of PS in the treatment plant is 4,854 kg/day. More PS would be required to meet the set VS of the AD process. This is expected to be collected from small wastewater treatment plants around the city. The proximate analysis of FW and PS were evaluated separately with the standardised ISO methods. Subsequently, characterization of the mixtures is determined following references [11-13] and presented in Table 1.

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