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Low cost digester monitoring under realistic conditions: Rural use of biogas and digestate quality

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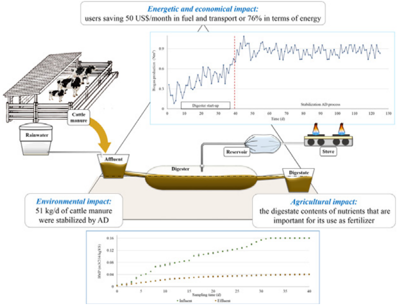
HIGHLIGHTS

- A rural tubular digester was installed and monitoring during under realistic conditions.
- Biogas production was enough to supply 76% of energetic requirements.
- A Colombian family from a rural area saved 50 US$/month by using biogas instead of propane.
- Biogas digestate has a good quality for agricultural systems.
- Digestate required a post-treatment for its final disposal.

GRAPHICAL ABSTRACT



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ABSTRACT

The purpose of this work was to assess the behaviour of anaerobic digestion of cattle manure in a rural digester under realistic conditions, and estimate the quality and properties of the digestate. The data obtained during monitoring indicated that the digester operation was stable without risk of inhibition. It produced an average of 0.85 Nm^3 biogas/d at 65.6% methane, providing an energy savings of 76%. In addition, the digestate contained high nutrient concentrations, which is an important feature of fertilizers. However, this method requires post-treatment due to the presence of pathogens.

1. Introduction

Modern energy services are crucial to human prosperity and national economic development. Currently, 1.2 billion people do not have access to electricity and more than 2.7 billion people rely on the traditional use of biomass for cooking (IEA, 2016). In developing countries, there is a link between energy, poverty, and the environment. The community poverty rate is indicated by the type of fuel used for cooking. In Colombia, 52% of rural areas are known as "non-interconnected", and are difficult to access due to tertiary roads (Escalante et al., 2016). In these zones, people use propane gas as an alternative fuel for cooking. Nonetheless, there are drawbacks to accessing this energy fuel, such as purchasing (USD $50/-month on average), transporting costs from urban to rural areas (USD $25/month on average), and risk in propane tank management. To mitigate these disadvantages, the anaerobic digestion (AD) process is a good candidate for improving the quality of life

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in the developing world. The tubular digester is widely used due to its simple design and construction from readily available materials (Kinyua et al., 2016a). Tubular digesters are mainly feed with cattle manure at an organic loading rate between 0.3–2 kg VS/m digester*d (Garfí et al., 2016). However, problems reported from field surveys indicate that users are not trained in proper tubular digester operation and biogas generation does not meet user expectations.

Research on low-tech tubular digesters has focused on design, construction, optimization in cold climates, odour control, water pollution from animal facilities, and diminution of pathogens (Garfí et al., 2016; Martí-Herrero et al., 2014). As example, low-cost tubular digesters have been adapted to cold climates by adding a greenhouse. This design acts as a solar heat collector, reducing heat losses to the ground. This configuration maintains the slurry 8.4 °C above the mean ambient temperature (Perrigault, 2012). Moreover, Kinyua et al. (2016a) reviewed small-scale tubular anaerobic digesters treating livestock waste in the developing world. They found that: (i) substrate characteristics, such as total ammonium nitrogen (TAN) and pH varied from 0.086 to 1.4 g NH_4-N/l and 6.5–8.8, respectively; (ii) operation parameters, such as Organic Load Rate (OLR) and temperatures ranged from 0.33 to 8.00 and 17 to 31 °C, respectively; and (iii) performance of tubular digesters yielded biogas at 0.012–0.50 Nm^3 biogas/kg VS_{added} and CH_4 contents from 21 to 76%. Subsequently, Kinyua et al. (2016b) investigated the performance of a tubular digester for treating livestock waste in through experimental studies and bioprocess modelling; they found reductions of >75% in volatile solids and biochemical oxygen demand (BOD_5). In contrast, studies of tubular reactors have emphasized the need to decrease pathogens content at the end of the digestion process. An anaerobic process removed 60% of *Cryptosporidium parvum* and 90% *Giardia lamblia,* which are common pathogens in swine (Kinyua et al., 2016c).

However, the majority of studies analyse biodigester performance with limited parameters. Generally, biogas production rate, specific biogas production, and methane percentage are the most studied variables. This represents a limited knowledge of operational conditions, biogas digestate, and microbiological behaviour under real conditions. Here this study investigated the operational dynamics and methanogenic activity in anaerobic transformation of cattle manure in digester at real scale. Consequently, the aims of this research were: (a) to assess the behaviour of anaerobic digestion of cattle manure in a rural tubular digester under realistic conditions, and (b) to estimate the quality and properties of the biogas digestate.

2. Materials and methods

2.1. Site description

This study was carry out at a Colombian farm at an altitude of 959 m above sea level (m.a.s.l.) and a latitude of N 7°01′0.07″ W 73°08′13.3″ with an average precipitation of 692 mm/m^2. This farm has three cow heads (Normande breed), with an average weight of 210 kg. The cows are corralled 67% of the time. The farm is 9 km from an urban area and has "tertiary roads" that limit energy provision.

2.2. Sizing tubular digester and operational conditions

A low-cost digester was built with tubular polyethylene (caliber 8 and UV protection). Reactor dimensions were 1.3 m in diameter, 7.5 m in length, and 9.5 m^3 total volume. Operational volume was 7.1 m^3, corresponding to an average cattle manure production of 51 kg/d. The reactor was situated in a trapezoidal trench, upper width: 1 m; bottom width 0.8 m; long: 7.5 m; and depth: 1 m. The biogas produced was stored in a tubular polyvinyl reservoir, 5.1 m^3 in volume (Martí-Herrero and Cipriano, 2012). Commercial polyvinyl chloride used for water conduction was employed for accessories and inlet and outlet pipes. The reactor was operated with a continuous ORL of 0.7 kg VS/$m^3_{digester}$*d with a 1:3 cattle manure to rainwater mixture. A hydraulic retention time (HRT) of 35 d was calculated according to operational volume. The environmental temperature varied between 23 ± 5 °C.

2.3. Monitoring tubular digester

AD performance in a continuous tubular digester was monitored over four months (29 April to 29 August 2016), measuring biomethane potential ($BMP_{influent}$), residual methane potential ($BMP_{effluent}$), specific methanogenic activity ($SMA_{influent}$), residual methanogenic activity ($SMA_{effluent}$), organic matter content and consumption (in terms of VS), volatile fatty acids (VFA), biogas production, and methane concentration. The stability of the process was evaluated using the VFA/TA ratio and pH.

2.4. Energetic and economic consideration

In order to determinate the economic saving using biogas (*ESB*; S$), Eq. (1) was used to compare biogas with commercial gas (propane).

$$ESB = \eta_{biodigester} * PC \tag{1}$$

where *PC* is propane cost (US$). $\eta_{biodigester}$ is the digester energetic efficiency with respect to propane and is calculated as follows:

$$\eta_{biodigester} = \frac{LCP_{biogas} * B_{flow}}{LCP_{propane} * P_{flow}} * PC \tag{2}$$

where LCP_{biogas} is the biogas low calorific power (MJ/m^3), $LCP_{propane}$ is the propane low calorific power (MJ/m^3; Li et al., 2017), and B_{flow} and p_{flow} are the volumetric biogas flow (m^3/s) and volumetric propane flow (m^3/s), respectively. LCP_{biogas} was determined as:

$$LCP_{biogas} = LCP_{CH_4} * (\%CH_4)_{biogas} \tag{3}$$

where LCP_{CH_4} is the methane low calorific power (MJ/m^3) and $(\%CH_4)_{biogas}$ is methane percent in biogas.

2.5. Biogas digestate quality

In order to evaluate the digestate quality, two aspects were considered: (i) physicochemical characterization, including carbohydrates, lipids, proteins, K, Mg, Ca, Cl, Na, PO_4-P, NH_4-N and heavy metals and (ii) microbiological analysis, including fecal coliforms, helminth eggs and *salmonella* spp.

2.6. Analytical methods

Influent and effluent samples were collected every week over the four months. Samples were carried to the laboratory on ice and stored at 4 °C. BMP and residual methane potential tests were carried out at 37 ± 2 °C following the guidelines described by Angelidaki et al. (2009). $SMA_{influent}$ and $SMA_{effluent}$ test were determined in accordance with Astals et al. (2015). The inoculum to acetate ratio was 5.2 g $VS_{inoculum}$ g^{-1} Ac. Analyses of volatile solids (VS), proteins, and lipids were performed according to the standard methods for the examination of wastewater (APHA, 2005). Carbohydrates were estimated by subtracting the quantity of protein and lipids from volatile solids (Galí et al., 2009). Total alkalinity (TA) and VFA were measured by titration (Jobling et al., 2014). A pH meter (691, Metrohm) was used to determine pH. Biogas produc-