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Biogas production in low-cost household digesters at the Peruvian Andes

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ABSTRACT

Low-cost tubular digesters originally developed in tropical regions have been adapted to the extreme weather conditions of the Andean Plateau (3000–4000 m.a.s.l.). The aim of this study was to characterise biogas production in household digesters located at high altitude, operating under psychrophilic conditions. To this end, two pilot digesters were monitored and field campaigns were carried out in two representative digesters of rural communities. Digesters' useful volume ranged between 2.4 and 7.5 m^3, and hydraulic residence time (HRT) between 60 and 90 days. The temperature inside the digester's greenhouse ranged between 20 and 25 °C. Treating cow manure, a specific biogas production around 0.35 $m^3\ kg_{VS}^{-1}$ was obtained, with some 65% CH_4 in biogas. In order to fulfil daily requirements for cooking and lighting, biogas production should be enhanced without increasing implementation costs as not to impede the expansion of this technology at household scale. In this sense, HRT below 60 days and OLR above 1 $kg_{VS}\ m^{-3}\ day^{-1}$ should be investigated to decrease digesters' volume (i.e. costs) and increase biogas production rate. The adaptation of conventional gas burners to biogas characteristics can also contribute in improving the efficiency of the system.

1. Introduction

Anaerobic digestion, also known as biomethanation, is an appropriate technology to improve the traditional energy use of biomass resources especially in rural areas of developing countries; bringing environmental, economical and social benefits [1]. At the same time, it promotes sustainable organic wastes management, transforming such wastes into resources for the generation of renewable energy (biogas) and an organic fertilizer (digestate). The potential methane production depends on the composition of the substrate, but also on operating parameters including temperature, pressure, organic loading rate (OLR) and hydraulic residence time (HRT), amongst others.

At household scale, this technology has been widely spread in countries such as China and India [2–4], and recently in Nepal [5]; typically in brick masonry reactors like the Chinese or Indian dome digesters. However, these designs are relatively complex

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and costly, impeding a widespread use of this technology in other contexts. On the other hand, tubular polyethylene digesters, which are easy to implement and inexpensive; may ease the expansion of this technology in rural areas [6]. The use of tubular PCV (geomembrane) digesters, which are more resistant, should expand the lifespan of the system, although at higher expenses [7].

Up to date, most experiences on the use of plastic tubular digesters are reported for tropical areas, for instance Costa Rica [8,9]. Recently, a lot of effort has been put on the adaptation of tubular digesters to extreme weather conditions of the Andean Plateau [10,11]. In rural mountain areas, additional barriers for the implementation of low-cost digesters are extremely low ambient temperatures (especially overnight) and, in some cases, the lack of water for dilution of cattle dung. In previous studies it has been shown that pig slurries may be a good substitute of water for substrate dilution [12].

Laboratory experiments on biogas production from manure at high altitude confirmed that temperature was the main parameter affecting biogas production, followed by HRT and manure concentration; while no significant effect of pressure was observed [13]. The assessment of cyclic temperature fluctuations (between 11 and 25, 15 and 28, and 19 and 32 °C) showed an immediate increase in biogas production with temperature, suggesting a well developed methanogenic population in spite of periodic temperature fluctuations [14]. In addition, methane production was improved by codigesting a mixture of llama, cow and sheep manure [15].

Since 2006 more than 30 digesters have been implemented in rural Andean communities of Peru by means of pilot research and development cooperation projects. Most of them are located at altitudes between 3000 and 4000 m.a.s.l., where average annual temperatures are around 10 °C and irradiation as high as 6.0–6.5 kWh m^{-2} day^{-1}. In such conditions, the use of greenhouses is aimed to increase process temperature (to around 20 °C) and reduce overnight temperature fluctuations [11]. Currently, biogas is used for cooking, leading to 50% substitution of traditional fuels (i.e. fire-wood or air-dried cattle dung) [11]. However, biogas production and methane content has not yet been quantified. This information is needed in order to evaluate the performance of the systems, improve gas production and reduce capital costs; which would help fulfilling the strong demand of low-cost digesters by families and farmers in the Andes.

This study aims to characterise biogas production and composition in low-cost tubular digesters located at high altitude, operating under psychrophilic conditions. To this end, two pilot plants were monitored and field campaigns were carried out in two representative household digesters of rural communities. Finally, biogas burners' efficiency was compared among alternative designs.

2. Materials and methods

2.1. *Context*

The Departments of Cajamarca and Cusco are located in the Northern and Southern regions of the Peruvian Andes, respectively. The Human Development Index (HDI) in these regions is 0.54, even lower in rural communities [16]. As a matter of fact, more than 50% of the population lives in rural areas [17], with an economy based on self-sufficient agriculture and farming. In most cases, there is still a lack of basic services such as potable water or electricity. Biomass consumption, including fire-wood and air-dried cattle dung, accounts for 65–75% of the total fuel consumption for cooking [17]. Improved cookstoves or smoke control systems are generally missing, generating indoor air pollution (IAP) (especially particulate matter) and unhealthy environments [18,19].

2.2. *System's description*

Low-cost household digesters are adapted from the Taiwanese-model [20]. In such plug-flow reactors, wastewater flows through a tubular polyethylene or PVC bag (the reactor) from the inlet to the outlet, while biogas is collected by means of a gas pipe connected to a reservoir (Fig. 1). There is neither heating nor mixing. Thus, in cold mountainous areas, the tubular plastic bag is buried in a trench and covered with a greenhouse, in order to increase process temperature and minimise overnight temperature fluctuations. Design criteria and dimensions for the digester, trench and greenhouse depend on each location; at high altitude long HRT of 60–90 days are generally used [21]. Feedstock dilution is aimed at reducing the total solids (TS) concentration below 9%, near the upper limit for wet anaerobic digestion. Biogas is stored in a reservoir, connected to the kitchen or cooking area. In this way it can be used as a heat source, substituting commercial fuels (i.e. LPG), and eliminating the need to burn wood [8].

The main characteristics of the 4 digesters studied are shown in Table 1. In general, digesters implemented in the region of Cusco have a gable roof greenhouse, a useful volume of 6 m^3 and an HRT of 100 days, according to Poggio et al. [11]. On the other hand, digesters in the region of Cajamarca have a shed roof greenhouse, a useful volume of 7.5 m^3 and 90 days HRT, as proposed by Martí [10,21]. The pilot digester of Cajamarca (D1) was designed and operated like household digesters, while the one in Cusco (D3) was operated at a reduced HRT (60 days) for the sake of comparison. Cow manure dilution was 1:4 and 1:2 in Cajamarca and Cusco; leading to TS concentrations around 3.5 and 9%, respectively.

Table 2 shows average cow manure composition in the studied systems. The composition of manure depends on the feedstock material of cattle and manure management techniques, which differ between locations according to their

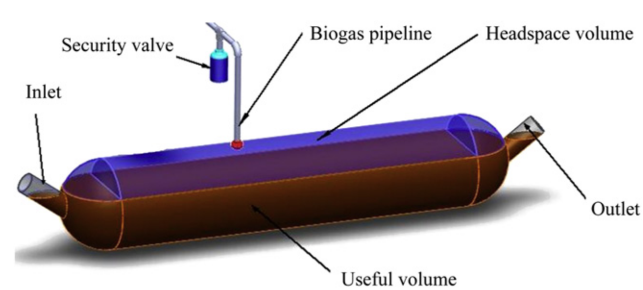

Fig. 1 – Schematic diagram of a low-cost plastic tubular digester.