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Technical, economic and environmental assessment of household biogas digesters for rural communities

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ABSTRACT

This study was carried out in response to the growing interest on household biogas digesters in Latin America, particularly in rural Andean communities. The aim was to compare the fixed dome and plastic tubular digester in terms of biogas production, cost and environmental impact, using the life cycle assessment methodology. Design and operational parameters, construction materials and implementation costs were based on our previous research and literature results for plastic tubular and fixed dome digesters, respectively. According to this analysis, the main advantage of the plastic tubular digester was its ease of implementation and handling, and lower investment cost compared to the fixed dome digester, which appeared to be more environmentally friendly.

1. Introduction

Household biogas plants have been used for several decades in rural areas of Asian countries like China and India [1–4]. The most widely used household systems are the Chinese fixed dome digester, the Indian floating drum digester and the Taiwanese plastic tubular digester [5–7]. The most appropriate design depends on weather conditions and socio-economic context [6,8].

In Latin America, household digesters have been spreading since the 1980s in rural areas of tropical countries like Colombia and Costa Rica [9–11] and hilly regions of Peru and Bolivia [12,13]. The first experiences on digesters implementation at the Peruvian Andes date back to the 1980s, when the Universidad Nacional de Cajamarca (UNC) together with the NGO INTITEC carried out a project on the implementation of Chinese fixed dome digesters [14–16]. In 1988 there were almost one hundred fixed dome digesters of 10–12 m^3 implemented in rural zones of the Department of Cajamarca [14,15]. Basic objectives of the biogas program were [15,17]: (i) to generate energy for cooking and lighting, satisfying household needs; (ii) to avoid deforestation and its effect on soil erosion; (iii) to reduce environmental pollution; and (iv) to improve household sanitation. When the program started there was a lot of interest in this novel technology, but after a few years people abandoned the digesters and the implementation of new household biogas plants turned off. A viability analysis pointed out that the program failure was mainly due to the high capital cost of fixed dome digesters; but also to social aspects, such as the lack of an appropriate management, family training and project monitoring [15].

During the last decade, there has been a growing interest in implementing plastic tubular digesters in rural Andean communities; because of its low-cost, and ease of implementation and handling [12]. In 2007 Peruvian and international NGOs started a project dealing with the implementation of plastic tubular digesters adapted to rural Andean communities in the Department of Cajamarca [18,19]. The main goal was to improve the living quality of rural families, by providing a clean fuel to replace traditional biomass. The project also aimed to: (i) preserve the environment by reducing greenhouse gas (GHG) emissions and deforestation; (ii) decrease families expenses for fuel and fertilizer; and (iii) reduce the workload and time spent by women and children for firewood collection [19]. A recent survey evaluated

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plastic tubular digesters technical, environmental and socio-economic impacts on rural communities of the Department of Cajamarca. The results showed how digesters improved household living conditions and economy, while reducing GHG emissions compared to traditional biomass [19]. However, the benefits were restricted by a poor performance of anaerobic digestion at high altitude. Indeed, under the harsh weather conditions of the Andean Plateau, digesters require proper insulation and longer hydraulic retention time (HRT) compared to analogous digesters implemented in the Tropics, where they were originally developed; which may increase the capital cost. From an environmental point of view, the eventual use of large amounts of plastic is a matter of concern. Optimizing the performance, economics and environmental sustainability of household digesters in rural Andes is currently considered a strong challenge [19].

The aim of this research was to compare the performance, cost and potential environmental impact of fixed dome and plastic tubular digesters implemented at high altitude.

2. Material and methods

2.1. Household digesters performance

The study considered two types of household digesters adapted to Andean conditions: 1) fixed dome – Chinese model and 2) plastic tubular – Taiwanese model (Fig. 1). Digesters performance comparison was based on a thorough literature review of case studies dealing with household digesters implementation at high altitude (Table 1).

Chinese fixed dome digesters (Fig. 1a) consist of a cylindrical chamber, a feedstock inlet and a digestate outlet, which also serves as a compensation tank [21]. Biogas is stored in the upper part of the chamber. When biogas production starts, the slurry is displaced into the compensation tank. The volume of the compensation tank is equal to the volume of biogas storage. Gas pressure increases with the volume of biogas stored and with the difference of slurry levels between the inside of the digester and the compensation tank. It is completely underground, and made with bricks and concrete [5,22].

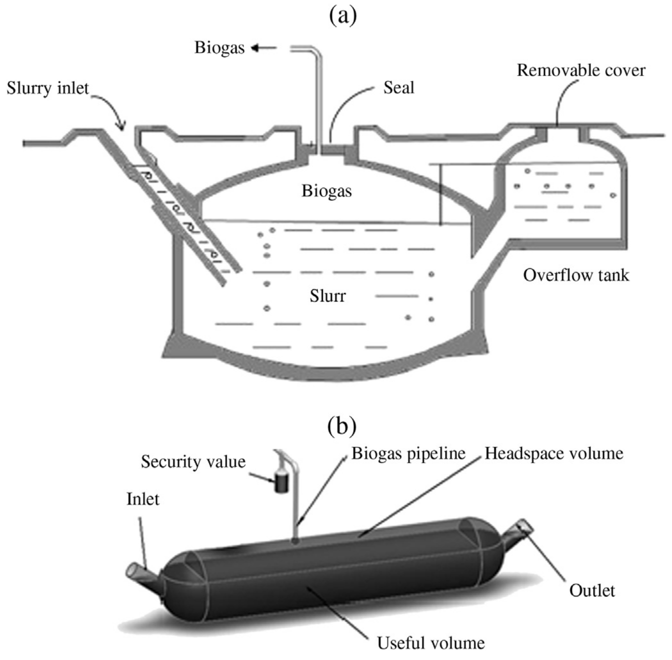

Fig. 1. Schematic diagram of the studied household digesters: (a) fixed dome – Chinese model [20] and (b) plastic tubular – Taiwanese model [12].

In plastic tubular digesters (Fig. 1b), 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. Because the system is unheated, in cold hilly regions the plastic bag is buried in a trench and covered by a greenhouse, aimed at increasing inner temperature and reducing temperature fluctuations. Design criteria for the digester, trench and greenhouse depend on each location; at high altitude long HRT of 60–90 days are generally used [12]. Biogas is stored in a reservoir, connected to the kitchen or cooking area.

2.2. Economic analysis

The economic analysis was based on the digesters capital cost, which accounts for the major cost of household biogas plants. Design parameters of digesters implemented in Peru were adopted for the Chinese fixed dome [15,23] and plastic tubular [12] digesters (Table 2). Operational parameters (Table 2) were also representative of household digesters implemented at high altitude [8,24]. Construction materials for each digester are summarised in Table 3. The considered lifespan was 20 years for all materials, except for plastic which was reduced to 5 years according to manufacturers' specifications and Nzila et al. [21].

2.3. Life cycle assessment

Life cycle assessment (LCA) is a methodological tool for the evaluation of environmental aspects and potential impacts through the whole life of a product, process or service; from raw materials extraction, to utilization and final disposal. In brief, LCA comprises mass and energy balances applied to the system, plus an assessment of the environmental impacts associated to the inputs and outputs. According to the ISO 14040 [25], there are four main stages in LCA: goal and scope definition, inventory analysis, impact assessment and interpretation of the results.

2.3.1. Goal and scope definition

The goal of this LCA model was to compare the environmental impact of both household digesters, 1) fixed dome – Chinese model and 2) plastic tubular – Taiwanese model, implemented at high altitude.

The main function of the system was to produce biogas for cooking; therefore the functional unit was defined as the production of 1 m^3 of biogas (under standard conditions).

The system analysis included raw materials for household biogas plants construction and maintenance. Bearing in mind that both of them operated under the same conditions, the same biogas production rate was assumed (0.12 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$) [24]. Biogas combustion for cooking and digestate reuse in agriculture were excluded from the system boundaries, since they were assumed to cause the same impacts in both scenarios.

2.3.2. Inventory analysis

Inventory data on digesters design and operation were the same as for the economic analysis, as the same construction materials and lifespan were considered (Tables 2 and 3); the same construction materials and lifespan were here considered. Household digesters were then described and quantified with reference to the functional unit (Table 4). Data concerning the embodied environmental aspects of materials were taken from Ecoinvent v2.2 database [26].