Energy for Sustainable Development 27 (2015) 73–83

Contents lists available at ScienceDirect

Energy for Sustainable Development

The influence of users' behavior on biogas production from low cost tubular digesters: A technical and socio-cultural field analysis

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ARTICLE INFO

Article history:
Received 15 April 2014
Revised 5 February 2015
Accepted 5 May 2015
Available online 15 May 2015

Keywords:
Biogas production
Bioslurry
Cold climate
Household low cost tubular digester
Socio-cultural technical analysis

ABSTRACT

The aim of this paper is to understand the influence of the user behavior on tubular digesters performance, through a technical and a social approach in the Bolivian context. Fifteen domestic digesters were evaluated, from which 6 were installed in the Altiplano and other 6 in the Andean Valleys. Data about slurry temperature, feedstock and biogas quality were collected from these 12 digesters, while daily biogas production and feeding pattern were also monitored from further three digesters in the valleys. Because of changes in user behavior along the monitoring period and particular characteristics of the digesters monitored, 5 complete patterns of biogas production and digester management were established. Furthermore, the results of a socio-cultural study with Andean families about the perception of poverty, their needs and the role played by digesters in their expectations in improving life quality, are correlated to the obtained technical data. The technical evaluation shows how the digester management seems to have a seasonal performance throughout the year according to the agricultural calendar. This means that families are more interested in using bioslurry in crops and agricultural improvements than in the use of biogas. The Bolivian government subsidy on liquefied gas seems to be one of the key issues to understand these results. Finally, data also reveals how the thermal behavior of tubular digesters adapted to cold climate that use a passive solar design, is similar to the thermal behavior of valley digesters, and therefore intends to add the same passive heating techniques for warm and tropical climates, to increase slurry temperatures and achieve a higher biogas production.

Introduction

According to a special report by the *International Energy Agency* in, 2012 more than 1.3 billion people live without access to electricity and more than 2.6 billion use wood, charcoal or animal dung for their daily cooking. As modern energy is seen as a key element to reduce poverty and enable human development, various international programs now focus on the distribution of access to appropriate modern ways of energy worldwide. One of these promising technologies is the household digester to provide biogas for cooking from the anaerobic digestion of fresh manure. In recent years many National Biogas Programs (NBP) were developed in South Asia, India and Africa and more than 45 million systems were installed (Bond and Templeton, 2011; Chen et al., 2012; Ghimire, 2013). This massification strategy is now being transferred to Nicaragua as well.

Since 1992, when the first NBP started in Nepal, all the upcoming programs mainly focused on biogas production, in order to replace wood as a cooking fuel, improving family health through a smoke free indoor environment, reducing deforestation and water contamination (Bond and Templeton, 2011; Chen et al., 2012; Ghimire, 2013; Mwirigi et al., 2009; Walekhwa et al., 2009). Just as recent as the Ghanaian NBP (Arthur et al., 2011) the digestate (which is also known as bioslurry, especially when referring to the fertilizer or when the potential wants to be highlighted) is appreciated as the main product of anaerobic digestion. In the last years, African and South American experiences have also highlighted the importance of bioslurry as a fertilizer which improves crop productivity (Garfí et al., 2011a), as well as protection and recovery from frost damage (Martí-Herrero et al., 2014a). In 2013 the FAO published a review about bioslurry and the opportunity to use it with the suggestive title of "Bioslurry = brown gold?" (de Groot and Bogdanski, 2013), similar to other recent review publications like "Bioslurry: a supreme fertilizer" (Warnars and Oppenoorth, 2014)

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http://dx.doi.org/10.1016/j.esd.2015.05.003

and that from Bonten et al. (2014). Therefore, digesters in comparison with other most popular renewable energy technologies, benefit the economic development and the mitigation of climate change in rural areas, by producing energy, increasing local food production and acting as an efficient waste and water treatment system.

There are plenty socio-economic and technical analyses published about household digesters, focused on the fixed dome and floating drum model users, which are the most widespread models in the world, but less attention has been given to the tubular digesters users, which are mainly implemented in Latin America. Most of these investigations have an *etic* point of view, where the "*etic* approach" is focused from the researcher observations, categories, explanations, and interpretations, instead of being focused from the point of view of the target people from the study (Kottak, 2006). For example, Walekhwa et al. (2009) analyzes factors affecting the adoption of biogas energy in Uganda, according to age and gender, household income and size, and number of cattle owned. Walekhwa et al. conclude some policy recommendations, but no information is given outside of these parameters about the opinion of the potential biogas users. Mwirigi et al. (2009) do a similar exercise for Kenya, coming up with the statement "while a farmer's socio-economic status significantly influenced the decision to adopt the technology, it did not influence the sustainability of the constructed plants", when analyzing the answers from the users of different digester models about biogas production, repairs, and appropriation. Van Groenendaal and Gehua (2010) realized a standard economic feasibility analysis, without considering the users' point of view. They explain how the impacts of bio-digesters on the farm economy "are often small if not non-existent", but "contribute considerably to a more convenient lifestyle and an improved indoor environment". Furthermore, Yiridoe et al. (2009) extended the standard economic feasibility analysis by including key nonmarket co-benefits from biogas energy production, trying to consider other no measurable parameters. These benefits, among others, include the reduction on manure odor, toxicity and pathogen spreading, weed seed germination and expansion, water contamination and greenhouse gases emission, but again the opinion and other possible co-benefits that users may identify, are not considered in the study. Garfí et al. (2012)) reported technical, environmental and socio-economic impacts of low cost tubular digesters in rural communities of the Peruvian Andes. The survey that was realized with 12 families, who were biogas users, was structured as a close questionnaire that did not permit gathering the free opinion of the users, it only considered the parameters important for researchers. Later on, Garfí et al. (2014) compare the fixed dome and plastic tubular digester in terms of biogas production, costs and environmental impact, using the life cycle assessment methodology. Nzila et al. (2012) also present a multi-criteria analysis considering technical, economic and environmental sustainability dimensions for different digester models. Arthur et al. (2011) show the actual biogas technology utilization, and the potential benefits, prospects and challenges in Ghana. Ghimire (2013) reports the results from different NBPs in Asia and Africa, providing the number of digesters installed through the multi-actor program methodology, recommendations and lessons learned. Similar studies were conducted by Martí-Herrero et al. (2014a) in Bolivia, Chen et al. (2012) in China or Bond and Templeton (2011) for the general developing world. However, the end user's opinions (also known as *emic* approach, which is opposed to the *etic* one, and consists in a description of behavior or a belief of a group of people in terms of internal elements and their functioning rather than in terms of any existing external scheme) about poverty, energy poverty and the role of digesters in their lives is hardly considered in these studies.

The core of this research is to analyze the household digesters' performance as they are used by families, and highlight the influence of the users' mindset and behavior in relation to the performance of the system. So this study combines the *emic* and the *etic* approach. In this case we evaluate 15 digesters, 6 installed in the Bolivian Altiplano (at 3800 meters above sea level, masl) and 9 in the Bolivian Andean valleys (around 2600 masl). Some of them were monitored in depth for a long period on user behavior, resulting in 5 different patterns of digester management and biogas production. At the same time, a social analysis from the users' point of view, about poverty and the role of digesters to overcome the poverty situation, will be presented. The social analysis conducted among users and non-users of digesters was carried out with Aymara indigenous families from the Bolivian highlands. Finally, how the different patterns of digesters use evolve according to the influence of government energy policy is discussed. In Bolivia, liquefied petroleum gas (LPG) has been subsided and therefore became more accessible to the rural population in the last years.

Low cost tubular digesters

Household low cost tubular digesters (Fig. 1) are the cheaper evolution of the Taiwanese 'red mud' model (Pound et al., 1981), developed by Preston and co-workers (Botero and Preston, 1987; Bui Xuan et al., 1994) at the end of the 80s. These models were adapted to the cold climate of the Andean region in Bolivia and Peru, despite only making use of a passive solar heating design (Martí-Herrero, 2007; Poggio et al., 2009). These digesters have a tubular reactor made with a double tubular polyethylene plastic layer (Lansing et al., 2008; Martí-Herrero, 2011), although, in some countries polyethylene is replaced by PVC or polyethylene geomembrane as in Mexico, Colombia, Ecuador, Costa Rica and Peru. The dimension of the reactor can vary from 3 to 8 m of circumference (Martí-Herrero, 2011). A detailed design methodology can be found in Martí-Herrero and Cipriano (2012). These digesters are semi-buried in a trench, leaving the biogas bell visible from outside. The household digester in Bolivia has been designed to be fed every day with 20 kg of fresh manure and 60 l of water (1:3 manure:water ratio), producing 0.7 to 0.8 m^3 of biogas per day and 80 l of bioslurry, independently of the climatic region, as for each climate (cold-altiplano, warm-valleys and tropical-tropics) a specific design is developed to achieve the same results (Martí-Herrero, 2008). The Organic Load Rate (OLR), Specific Biogas Production (SBP), Biogas Production Rate (BPR) and the Hydraulic Retention Time (HRT) values obtained from the monitoring of low cost tubular digesters fed with cow manure, adapted to normal conditions from Martí-Herrero et al. (2014b), are: 0.34 kg_{SV}/m^3/day, 0.335 m^3/kg_{SV}, 0.11 m^3/m^3/day and 90 days (Garfí et al., 2011b) and also 0.22 kg_{SV}/m^3/day, 0.30 m^3/kg_{SV}, 0.065 m^3/m^3/day and 90 days (Ferrer et al., 2011) at valley conditions. While for cold climate conditions the values are 0.26 kg_{SV}/m^3/day, 0.23 m^3/kg_{SV}, 0.06 m^3/m^3/day and 124 days (Martí-Herrero et al., 2014b). In cold climates, such as in the highlands of the Altiplano, the tubular digester is insulated from the ground and integrated into a greenhouse, composed by thermally massive adobe walls covered with a transparent plastic sheet.

Digester characterization methodology

Four parameters are considered the most relevant to characterize a digester, two of them are related to the operation and the other two parameters to the performance of the system. The Organic Load Rate (OLR) [kg_{sv}/m^3/day], which is related to the amount of organic matter (kilograms of volatile solids, VS) charged every day to the digester per m^3 of useful volume of digester, and the Hydraulic Retention Time (HRT) [day], that is calculated dividing the liquid or useful volume of the digester by the mean volume loaded every day, are both operational parameters. When a digester is designed, the operational parameters (OLR and HRT) are fixed for a specific feeding pattern, but when the user changes this pattern, the real OLR and HRT values of the system change as well.

The digesters fed with cow manure considered in this survey were designed for cold climate regions with a reference OLR of 0.37 kg_{sv}/m^3/day, an HRT of 81 days, and with a liquid digester volume of 6.47 m^3; for valleys with an OLR of 0.66 kg_{sv}/m^3/day, an HRT of 46 days and 3.65 m^3 of liquid volume. In the case of digesters fed with pig manure in the valleys the reference OLR is 0.58 kg_{sv}/m^3/day, the HRT of 65 days and the liquid volume is 6.47 m^3, similar to the highland