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Cow, sheep and llama manure at psychrophilic anaerobic co-digestion with low cost tubular digesters in cold climate and high altitude

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HIGHLIGHTS

- Low cost tubular digesters adapted to cold climate are monitored.
- Four digesters fed with llama, cow and codigestion of both with sheep manure.
- Cow–sheep co-digestion results in 100% more biogas production respect cow manure.
- The retention of solids is high and a bottom sludge outlet is strongly recommended.
- The increase of OLR leads to an increase in BPR but reduces bioslurry quality.

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ABSTRACT

The aim of this research is to evaluate the co-digestion of cow and llama manure combined with sheep manure, in psychrophilic conditions and real field low cost tubular digesters adapted to cold climate. Four digesters were monitored in cold climate conditions; one fed with cow manure, a second one with llama manure, the third one with co-digestion of cow–sheep manure and the fourth one was fed with llama–sheep manure. The slurry had a mean temperature of 16.6 °C, the organic load rate was 0.44 $kg_{vs}\ m^{-3}\ d^{-1}$ and the hydraulic retention time was 80 days. After one hundred days biogas production was stable, as was the methane content and the pH of the effluent. The co-digestion of cow–sheep manure results in a biogas production increase of 100% compared to the mono-digestion of cow manure, while co-digestion of llama–sheep manure results in a decrease of 50% in biogas production with respect to mono-digestion of llama manure.

1. Introduction

Anaerobic digestion has a long history in developing countries in order to take advantage of the biogas produced as fuel for cooking, the bioslurry as fertilizer and the decontamination process as a waste treatment system. At the household level, digesters are mostly fed with pig or cow manure (Bond and Templeton, 2011; Chen et al., 2012; Martí-Herrero et al., 2014a), which is related to the household technology implemented so far, mainly low cost tubular digesters that do not require active mixing or heating devices. Since no active heating is employed, these digesters were installed mainly in warm and hot climate regions, where the ambient temperature is high enough to permit the anaerobic digestion inside the digester in a range of mesophilic temperatures. In these hot climate regions the low cost digesters are buried in the ground and have a slurry temperature similar to that of the soil. This can vary from 26 °C to 30 °C (Lansing et al., 2008; Terradas-Ill et al., 2014). Small and medium farmers from these hot climatic regions have enough pigs or cows to collect fresh manure for their digesters. Mesophilic anaerobic digestion is well known and most of the 50 million household digesters installed worldwide function in this range (Bond and Templeton, 2011). However, less information and dissemination of low cost digesters has been done in hilly

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highlands or cold climate conditions. Kanwar and Guleri (1994) compared the slurry temperature in hilly conditions of a fixed dome digester and a plastic tubular digester. The slurry temperature of the fixed dome digester varied from 16 °C to 24 °C for eight months around the summer period (mean ambient temperature around 23 °C), and 13–15 °C for the other four months that correspond to the winter period (mean ambient temperature around 9 °C). While the plastic tubular digester reached 2–3 °C higher temperatures during summer periods, and 2–3 °C less during the winter period, in comparison to the fixed dome model. This particular plastic tubular digester installed at 1300 m above sea level (m.a.s.l.) did not carry any conditioning for cold climate, thus Kawar and Guleri concluded that this model "is not generally suitable for hilly areas". Almost ten years later, in 2003, a low cost plastic tubular digester adapted to cold climate was installed at 4005 m.a.s.l. in the surroundings of La Paz – Bolivia (Martí-Herrero, 2007). This particular digester led to the widespread application of this technology to hilly and cooler climatic regions, with more than 300 digesters installed in the highlands of Bolivia (Martí-Herrero et al., 2014a) and Peru (Garfí et al., 2012). Psychrophilic anaerobic digestion that corresponds to colder regions with no active heating devices is less reported in literature, even though there is a huge potential of implementation of this AD technology (Martí-Herrero et al., 2014a) in a great number of households.

The cold regions in the so called developing countries, usually converge at high altitudes as in the highlands of Bolivia, Peru, Ecuador, Chile, Colombia, Mexico, China, Pakistan, Nepal, etc., and are characterized by the lack of biomass to be used as cooking fuel, the nutrient poverty of the soil and the corresponding low crop productivity. Usually some cattle are owned by part of the rural population and dry manure is a common alternative used as fuel for cooking.

The AD technology provides energy (in the form of biogas), displacing the use of local biomass (deforestation), and the fertilizer (bioslurry) increases the crops productivity. Both products (biogas and bioslurry) are the outcome of the digestion of a local resource easily obtained (fresh manure). Though available manure to feed the digesters in cold regions comes from animals, about which literature is scarce. In the Andean highlands there are no pigs, and cattle are only found up to 4000 m.a.s.l. At higher altitudes and/or drier regions sheep and llamas take over the role of cattle as livestock, but no information has been reported so far about digesters working with these manure types and conditions, except at laboratory scale data (Alvarez et al., 2006; Alvarez and Lidén, 2008a,b, 2009).

Alvarez et al. (2006) report the biogas production of llama and cow manure measuring the effects of altitude (pressure), low psychrophilic and mesophilic temperatures, Hydraulic Retention Time (HRT) and Organic Load Rate (OLR). Alvarez concludes that the main parameter for biogas production is temperature, followed by the HRT and OLR, however no significance was found for atmospheric pressure (altitude). The methane yield for cow manure at 11 °C AD had a value of 6.4–33.6 $lCH_4\ kg_{VS}^{-1}$ and at 35 °C of 49.6–131.3 $lCH_4\ kg_{VS}^{-1}$, while for llama manure the values at 11 °C were 3.3–19.31 $lCH_4 kg_{VS}^{-1}$ and at 35 °C of 35.6–84.1 $lCH_4 kg_{VS}^{-1}$. He also concluded that llama manure has a great potential for biogas production because of the high content of volatile solids (VS), which is greater than in other types of manures (44.31% of VS at wet weight).

The effects of daily temperature variation on anaerobic digestion is reported at the laboratory scale by Alvarez and Lidén (2008a) using a mixture of llama–cattle–sheep manure. In this study the daily temperature varies between 11–25 °C, 15–28 °C and 19–32 °C respectively, while other reactors have a fixed slurry temperature of 18 °C, 25 °C and 35 °C. Alvarez and Lidén found that during the periods of low temperature the digester almost stopped the biogas production, but during high temperature periods the biogas production turned "unexpectedly" high. Furthermore, biogas production of a constant slurry temperature digester is similar to that of biogas produced in a digester with a similar mean slurry temperature but with a daily temperature variation of ±6–7 °C around the mean value. Finally, in a daily temperature variation digester, biogas production during low temperature periods is much less than production in a digester with similar low, but constant, temperatures pointing out the adaptation of bacteria to cold thermal conditions.

The slurry temperature of low cost field digesters does not have this daily temperature variation (3 °C of daily slurry temperature amplitude, reported by Martí-Herrero et al., 2014b), but presents annual variations if the digester is not adapted to cold climate conditions. Kalia and Kanwar (1998) report in a long term thermal monitoring that fixed dome digesters in hilly conditions have a slurry temperature of 22–23 °C during summer (3 °C less than the mean ambient one), and 13–14 °C during the winter period (4 °C above the mean ambient temperature). Tubular digesters adapted to cold climate seem to fulfill a better thermal performance with less annual slurry temperature variation. Perrigault et al. (2012) report data of a tubular digester adapted to cold climate working at 3400 m.a.s.l, with a slurry temperature of 24.5 °C, (which is 8.4 °C higher than the mean ambient temperature). Also, Martí-Herrero et al. (2014b) report a slurry temperature of 16.4 °C for winter (10.3 °C above the mean ambient temperature) and 16.7 °C for summer (6.7 °C above the mean ambient temperature) for a tubular digester adapted to cold climate working at 3884 m.a.s.l.

To increase biogas production of low cost digesters in cold climate regions, some strategies were detected to optimize thermal performance (Perrigault et al., 2012); better design methodology for tubular digesters (Martí-Herrero, 2011; Martí-Herrero and Cipriano, 2012), higher rates of load (Ferrer et al., 2011) and the introduction of soda bottles inside the digesters as a biofilm carrier (Martí-Herrero et al., 2014b). Thus one of the actual issues in anaerobic digestion to get better biogas production is the co-digestion, although 50% of overall papers on this topic were published between 2012 and 2013 (Mata-Alvarez et al., 2014), and present no information for digesters in cold climate and high altitude regions.

Anaerobic co-digestion with animal manures, as with mono-digestion, is focused on pig and cow manure (Mata-alvarez et al., 2014), which is the typical livestock of hot and warm regions, but not for cold climate and high altitude regions. Garfí et al. (2011) report the results of a psychrophilic co-digestion of cow and pig manure in low cost tubular digesters at 2800 m.a.s.l, finding that the co-digestion of guinea pig and cow manure (0.08 $m^3\ m^{-3}\ d^{-1}$) produces more biogas than mono digestion of guinea pig manure (0.03 $m^3\ m^{-3}\ d^{-1}$), but less than the mono digestion of cow manure (0.12 $m^3\ m^{-3}\ d^{-1}$). At higher altitudes, sheep, llama and cow are the local livestock of the Andean region. The co-digestion of these three substrates were studied in laboratory scale by Alvarez and Lidén (2009), at 25 °C, HRT of 50 days and 1.2 $kg_{VS}\ m^{-3}\ d^{-1}$, obtaining 0.14 $m^3_{CH_4}\ kg_{VS}^{-1}$ for 50–50% (VS based) mix of llama and sheep manure, 0.10 $m^3_{CH_4}\ kg_{VS}^{-1}$ for 50–50% mix of cow and sheep manure, and 0.09 $m^3_{CH_4}\ kg_{VS}^{-1}$ for 50–50% mix of llama and cow manure. The biogas production at same conditions for mono-digestion from llama manure were 0.09 $m^3_{CH_4}\ kg_{VS}^{-1}$, for cow manure 0.10 $m^3_{CH_4}\ kg_{VS}^{-1}$ and 0.12 $m^3_{CH_4}\ kg_{VS}^{-1}$ for sheep manure.

In this study, co-digestion of llama-sheep and cow-sheep manure are evaluated in real cold climate and highland conditions, and are compared to mono-digestion of llama and cow manure in experimental low cost tubular digesters adapted to cold climate (Fig. 1). These experimental systems are similar to those hundreds of household systems already working in the Andean highlands