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Short communication

How to report biogas production when monitoring small-scale digesters in field

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A B S T R A C T

The aim of this research was to evaluate the error originated when biogas production from field monitoring digesters, influenced by the diurnal temperature cycle, was normalized to standard conditions for pressure and temperature (273.15 K and 100 kPa) from local conditions. The biogas production data is often reported without indicating if done under local conditions, whether these conditions have been standardized and, if they have actually been standardized, the standard temperature and pressure is not indicated. In this research ambient and biogas temperature, as well as biogas production were monitored with a 30 min frequency during three consecutive days, in three different tubular digesters. Normalization was realized using the high frequency data collected as reference values, and also using daily biogas production with mean daily biogas, ambient and nearby meteorological station temperatures. The outcome of this research shows that normalization of biogas production can be obtained using daily biogas production and the daily mean ambient temperature with an overestimation by no more than 1.5%, in comparison to the normalization achieved by using high frequency data from biogas temperature and production. Using mean daily ambient temperature or mean daily biogas temperature results in the same overestimation, while using mean daily ambient temperature from a nearby airport weather station pushes the overestimation up to 2.7%. So, if ambient temperature and altitude is identified, biogas production reported in local conditions can be normalized.

1. Introduction

Small scale digesters are being implemented in several countries as a renewable energy technology that also produces fertilizer and acts as an organic waste treatment system. In order to optimize the technology, considerable research has been completed regarding anaerobic digestion at laboratory scale, evaluating biogas production in relation to working temperature (e.g. Ref. [1]), different organic load rates (e.g. Ref. [2]), and also mono- and co-digestion of different substrates [3].

In order to compare results from diverse published studies, biogas production has to be presented in similar conditions of pressure and temperature, which is usually at local or standard conditions. There is not a unique definition for standard conditions. The International Union of Pure and Applied Chemistry (IUPAC) proposes 273.15 K and 100 kPa [4], the National Institute of Standards and Technology (NIST) proposes 293.15 K and 101.325 kPa [5], and the International Standard Metric Conditions (ISMC) for natural gas and similar fluids (ISO13443) is 288.15 K and 101.325 kPa [6].

In 2009 Walker et al. [7] remark on the existence of several published academic papers in the field of anaerobic digestion, that do not correct gas production from local conditions for pressure and temperature, and that “more often than not the standard conditions are not given”. Similar problems are found in real scale experiments. Research on the performance of different small scale reactor models, such as fixed dome, floating drum and tubular digesters, in real weather conditions was carried out in different climates and weather systems; warm [8,9], hilly [10,11], high altitude or cold climate [12,13], along with the study of different

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substrates of manures and co-digestion [14–17], as well as the monitoring of the real performance of household digesters operated by users comparing hilly and cold climate conditions [18].

In general, local conditions can vary widely in pressure (very low pressure at high altitude conditions) and temperature (from cold to warm climate). Consequently, the best practice is to specify the reference conditions (pressure and temperature) when biogas production is reported, as for example: biogas production per day [m^3 d^{-1}], methane production per day [m^3 d^{-1}], specific biogas production on dry volatile solids (VS) known as SBP [m^3 kg^{-1}], specific methane production on VS [m^3 kg^{-1}], biogas production rate on the working volume of the digester, known as BPR [m^3 m^{-3} d^{-1}], and methane production rate on the working volume of the digester [m^3 m^{-3} d^{-1}]).

The main challenge relates to monitoring field digesters, as they are influenced by an outdoor diurnal cycle of temperatures, in contrast to laboratory scale samples, were the biogas ambient temperature is usually controlled, identified, and used to standardize the biogas production results. In this context, Langsing et al. [8,14] reported the biogas production from different small scale field digesters, as well as other researchers from Peru reported biogas production from small scale field digesters that are fed with cow [11], pig [15], cow and co-digestion of cow–pig manure [16], without specifying the conditions of their study. However after requesting the information it turned out that biogas production was reported at local conditions for [8,14] and in NIST standard conditions (293.15 K, 101.325 kPa) for [11,15,16]. There are many other cases were authors forget to mention the conditions at which biogas is produced, as for example in Refs. [2,19,20]. In most of the cases the biogas production is reported as in 'normal conditions', which is defined as old IUPAC's definition (273.15 K, 101.325 kPa), a definition the IUPAC's itself recommends to abandon [21]. As for example reported in this old standard; field digesters fed with cow manure [13,18]; llama, sheep, co-digestion of both [17], or pig manure [9]. A further uncertainty is about the temperature of biogas used for the standardization in those researches.

When monitoring a small scale digester in the field, the frequency of gas production data collection is usually in the range from once a day, to three times per week [8,13,18]. The biogas production is easily measured using an analogical low pressure diaphragm gas meter. This measurement does not require software or electricity, it is low cost and it is readily available in most national market places [8,11,13–18]. The data obtained should be transformed to standard conditions and that "standard condition" outcome (any of the aforementioned standard definitions) should be explicitly specified, using the ideal gas law in order to report it. To transform the obtained data into standard conditions, gas temperature and pressure data are needed. Pressure data is easy to obtain since it can be identified from the barometric formula using the altitude above sea level of the digesters location. What follows is to obtain the biogas temperature. A precise temperature measure is obtained by installing a temperature gas sensor in the pipeline immediately after the gas meter. These sensors are expensive though; they require software and accessories, even an electricity connection. Consequently, when monitoring household digesters, only the value of biogas production per day is usually available (at best). Values of biogas and ambient temperatures are even harder to obtain. Therefore, taking all this circumstances into account, it is necessary to find a way for how to transform the biogas production into standard conditions.

The research presented in this paper answers this need, comparing different ways for the normalization of biogas production to 273.15 K and 101.325 kPa, using three digesters located in the same place, monitored during three different days, with different weather conditions and Organic Load Rates (OLR). The first and most accurate method to normalize is using biogas production and temperature data collected every 30 min as reference values. The other three methods make use of daily measurements of biogas production, mean daily temperature measurements taken from the biogas, ambient temperature and from data recorded at a nearby airport.

2. Experimental design

Three low cost tubular digesters were monitored for three days, measuring biogas production, ambient and gas temperature. The digesters were placed in the Cochabamba valley (Bolivia) at an altitude of 2572 m above sea level (m.a.s.l.) located at 17° 26′ 36.59″ S and 66° 10′ 8.71″ W. Each one of the digesters had 8.32 m^3 of liquid volume, and was connected to one another in series; the effluent from the first digester was gravity fed to the inlet of the second digester, and likewise the effluent from the second digester to the inlet of the third digester. These digesters were part of a wider research in anaerobic digestion of slaughterhouse wastewater, which soon will be published too. The digesters have been designed using the methodology reported in Refs. [21,22]. The reactor was built with tubular polyethylene, usually used for greenhouses but black color. As the polyethylene is a flexible material, it takes the shape of the ditch which defines the liquid volume, so the digesters were semi buried. The walls and floor of the ditch were insulated with 1 cm of expanded polystyrene. The inlet and outlet pipes used commercial polyvinyl chloride accessories for water conduction (Fig. 1). The design, materials, and volume of these digesters were comparable to hundreds of household low cost tubular digesters installed in Latin America [18,23], with the unique difference that the first digester from this research included Polyethylene Terephthalate (PET) rings from soda bottles inside, as recommended in Martí-Herrero et al. [13].

The first digester was loaded every day at 12:30 pm with 1 m^3 of wastewater from the slaughterhouse. The same amount of slurry was displaced from the first digester to the second one, and from the second digester to the third one. The retention time was 8.3 days for each digester, so the effluent from the first digester was obtained after 8.3 days, the effluent from the second digester was obtained after 16.6 days, and the total effluent from the third digester had a sum of 25 days of retention time. Operational parameters of the three digesters are presented in Table 1.

The biogas production was recorded every 30 min, every day, from 6:00 to 19:00, using a commercial analogical low pressure diaphragm gas meter (G2.5 Metrix). This gas meter has an accuracy of 1% and 0.1 L of resolution. Ambient luminosity and temperature were measured using a waterproof pendant data logger (HOBO 64 K – UA-002-64 [24]), with an accuracy and resolution bellow 0.5 K. The data logger was placed at 1.5 m above ground level inside a ventilated and shadowed structure near the digester. To obtain slurry temperature, a similar waterproof pendant data logger was introduced to a depth of about 1 m in each digester through the outlet pipe. To measure the biogas temperature, the waterproof pendant data logger was placed inside the biogas pipeline just after the gas meter, and subsequently shadowed.

The slurry temperature of each digester was measured from the beginning of the experiment. After 140 days from the first load to the system (more than 5 hydraulic retention times), the temperature sensors were moved from the slurry to the biogas pipe for a week. The sensors were placed immediately after the gas meter inside the biogas pipe, in order to measure the biogas temperature when gas flow was computed by the gas meter. During three consecutive days, light level, ambient, gas temperature and biogas production were monitored every 30 min.