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Influence of heavy metals in the biomethanation of slaughterhouse waste

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ABSTRACT

The results of two sets of experiments concerning the anaerobic digestion of Iberian pig slaughterhouse wastes are reported in the present work. In the first series experiments were carried out according to the actual proportions in which wastes were produced. In the second series of experiments, lung material was removed during the setup of the substrate, while the original proportions were maintained. The results highlight the influence of nickel on the biogas yield, Chemical Oxygen Demand (COD) degradation and economic viability of the process. Most notably, the use of substrate with lung waste led to a 21% decrease in biogas production rates. In addition, the lung waste substrate was found to increase the payback period for the construction of an anaerobic digestion plant of by 1 year when electrical energy generated by the anaerobic digestion plant is consumed in the slaughterhouse. However, no significant difference was found regarding the degree of substrate degradation.

1. Introduction

The Iberian pig is a highly valued indigenous breed from the Southwest of the Iberian Peninsula, extensively raised in its natural environment, known in Spain as *dehesa*. The raising of Iberian pigs for the manufacture of meat products is a key economic activity in the Spanish Autonomous Community of Extremadura. A total of 522,088 pigs were slaughtered in the region in 2010 (MAGRAMA, 2010). However, the meat industry generates a vast quantity of solid (stomachs, intestines, fats, entrails, etc.) and liquid wastes (blood and sewage), which carry a high pollution charge.

The present work reports on the contamination generated by an Iberian pig slaughterhouse owned by the company "Jamón y Salud S.L.", located in Badajoz, Spain. 36,093 Iberian pigs were slaughtered in this factory in 2011, producing some 11,165 m^3 of solid and liquid wastes.

From the Biological Oxygen Demand (BOD_5) values of the generated wastes, it is possible to quantify the contamination produced by this activity in terms of Equivalent Inhabitants (EI). An EI is defined as the biodegradable organic load with a BOD_5 of 60 g/day (Directive 91/271/CEE. DOUE L 135 May, 30th 1995). The contamination generated in 2011 by Iberian pig slaughterhouse under analysis presents a BOD_5 of 37.36 g/L, which would, according to the aforementioned formula, be approximately equivalent to that of a 19,000-inhabitants town.

Due to the contaminant potential of these wastes, it is necessary to apply some form of decontamination technique before they are dumped into the environment. For this type of waste, anaerobic digestion (AD) is regarded as the most appropriate technique, due to the high moisture content of the waste.

AD is a biological process in which the biodegradable organic matter is decomposed in the absence of oxygen, as result of the action of a group of specific bacteria (hydrolytic, acidogenic, acetogenic and methanogenic). This yields a gaseous product called biogas (CH_4, CO_2, H_2, H_2S, etc.) and a digested effluent, a mix of mineral products (N, P, K, Ca, etc.) and compounds of difficult degradation. The biogas has a high percentage of methane, CH_4 (between 50% and 80% depending on the substrate), which makes it suitable for energy exploitation by combustion in engines, turbines or boilers, either alone or mixed with another fuel. Moreover, the solid portion of the digested effluent can be used as a soil amendment, while the liquid component is suitable for crop irrigation (Bermudez et al., 1998).

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Nomenclature

BOD_5	Biological Oxygen Demand
EI	Equivalent Inhabitants
AD	Anaerobic Digestion
WWTP	Wastewater Treatment Plant
HRT	Hydraulic Residence Time
COD	Chemical Oxygen Demand
VFA	Volatile Fatty Acids
VSS	Volatile Solids in Suspension
VDS	Volatile Dissolved Solids
PBP	Payback period
NPV	Net Present Value
IRR	Internal Rate of Return

AD techniques have been widely used to degrade an extensive variety of wastes from the agrifood industry, such as dairy industry wastewater (Passeggi et al., 2012), olive oil mill wastes (Borja et al., 2002), and food waste (Kastner et al., 2012). In addition, they have also served to carry out numerous co-digestion experiments, such as those involving slaughterhouse solid wastes with manure and vegetable residues (Álvarez and Lidén, 2008), or biosolids and organic fraction of municipal solid waste (Zhang et al., 2008). The anaerobic biodegradation of slaughterhouse by-products has been extensively reported in the scientific literature, (Hejnflet and Angelidaki, 2009; Marcos et al., 2012). However, few studies have been carried out using both solid and liquid slaughterhouse wastes as substrate (Cuadros et al., 2011; González-González et al., 2013).

The AD is characterized by the existence of four consecutive stages in the substrate degradation process (hydrolytic, acidogenic, acetogenic and methanogenic) and the action of five main populations of microorganisms. It is therefore a very complex process that can be altered by the interference of many inhibitory substances.

In the ambit of AD, the presence of heavy metals in the substrate has elsewhere been proven to negatively affect the acidogenic and —above all- methanogenic stages (Chen et al., 2008). When the entire AD process is accounted for, the toxic potential of four heavy metals has been reported, following the sequence Cr > Ni > Cu > Zn (Wong and Cheung, 1995). According to the bibliography consulted (Altas, 2009), among the aforementioned elements, nickel is regarded as showing the highest concentration in pig slaughterhouse wastes, even exceeding the recommended limit for the performance of AD experiments (inhibitory concentration reported as 35 mg/L).

Many methods have been tested for the removal of heavy metal from some substrates, such as the utilization of lignite for the removal of metal ions (Pehlivan and Arslan, 2007) and heavy metal removal via chlorination and thermal treatments (Nowak et al., 2010). However, the greatest concentration of nickel in mammals is found in the lungs and liver. Indeed, nickel has been shown to enter the human body in greater quantities through the stomach and intestines when consumed via drinking water than via solid foods, even when the food contains the same amount of nickel (Department of Health and Human Services, 2005).

The slaughterhouse under study usually sells the livers for use in manufacturing other products, so that lungs are the only remaining organ containing nickel. As a consequence, the simple removal of lung material from the substrate to prior to digestion should result in a drastic reduction in nickel concentration.

In this work we present the results obtained in several anaerobic digestion experiments of pig slaughterhouse wastes. Experimental materials were selected as follows: a sample group of residues taken directly as they were generated by the plant, and a sample group of residues in the same proportions, but which had previously undergone a process to remove lung waste.

Experiments were designed according to the following two main objectives: (i) determination of the optimum flow of substrate to be digested —regarded as the feeding substrate flow into the biodigester- which allows maximum biogas production and maximum decontamination of wastes-; (ii) quantification of the influence of nickel on the environmental, energy and economic performance of the biomethanation process as performed on of Iberian pig slaughterhouse wastes.

2. Material and methods

2.1. Anaerobic digester

Fig. 1 shows a basic scheme of the experimental setup used to carry out the AD experiments. The reactor was a continuous-flow stirred-tank reactor (CSTR) with about 6 L operating volume, with a control circuit to regulate the substrate feeding, operating temperature, and agitation stage inside the reactor. Experiments were conducted within the mesophilic range of temperature, most particularly at 38 °C. The reactor content was agitated by the recirculation of part of the biogas produced and the biogas generated during the process was collected in a gasometer and measured daily at ambient temperature (23 ± 1 °C) and atmospheric pressure (1017 ± 5 hPa). The biomass level inside the digester was controlled by a spillway attached to a settling tank which stores the digested effluent. Finally, sampling in the digester was carried out by valves installed in its lower part.

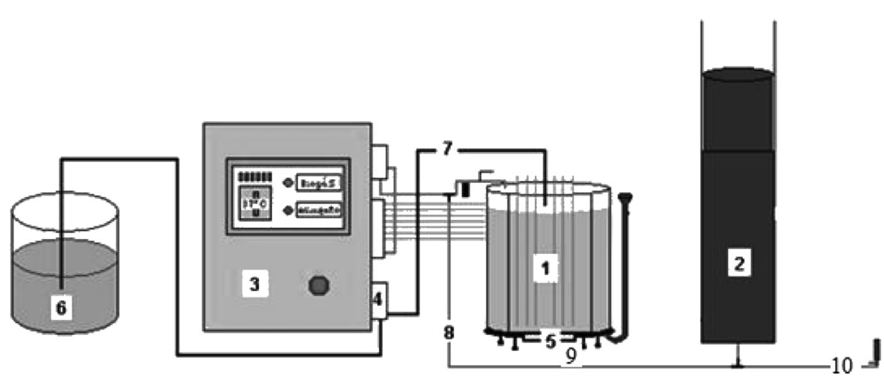

Fig. 1. Basic scheme of the Continuous Flow Stirred Tank Reactor (CSTR). (1) Digester; (2) Gasometer; (3) Control system; (4) Feeding valve; (5) Heating plates; (6) Substrate tank; (7) Substrate flow; (8) Biogas recirculation flow; (9) Sampling points; (10) Gas flares.