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Continuous biomethanization of agrifood industry waste: A case study in Spain

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ABSTRACT

The anaerobic digestion technology is a biological treatment widely used to reduce the pollution load of wet waste biomass. In this work we present the results obtained by performing extensive experiments of anaerobic digestion of slaughterhouse waste, tomato industry waste and olive oil industry waste in continuous mode, which were designed to demonstrate that anaerobic digestion is an effective technology from an environmental and economic point of view.Biogas yields obtained are between 35.22 and 5.45 Nm^3 biogas/m^3 olive oil industry waste and tomato industry waste respectively and the slaughterhouse wastes achieve intermediate production, 30.86 Nm^3 biogas/m^3 municipal slaughterhouse waste and 22.53 Nm^3 biogas/m^3 Iberian pig slaughterhouse waste. Moreover, it possible to degrade between 63.46 and 75.3% of the initial organic matter.If these results are analyzed, the environmental, energetic economic benefits of anaerobic digestion can be quantified. Biomethanation of all these wastes generated annually in Extremadura could prevent the emission of 134,772 t of equivalent carbon dioxide, generate an energy similar to that provided by 2826 toe and reach payback times from 3.29 to 3.75 years for anaerobic digestion plant designed to treat the wastes generated by a medium-sized industry. So, we have fulfilled all the planned aims.

1. Introduction

Extremadura is located in the southwest Spain and border Portugal. In this region agrifood industry plays a relevant role so the annual generation of significant quantities of high pollutant wastes is a serious environmental problem. It is estimated that the pollution generated by agroindustrial waste in this region is equivalent to the pollution generated by 1,100,000 inhabitants that is similar to the pollution caused by all inhabitants of Extremadura [1].

Although several steps are being taken to reduce the pollutant load of these wastes, in most cases, they are taken to Waste Water Treatment Plants (WWTP) to be treated. The dumping of these wastes into the sewerage system increase the chemical oxygen demand (COD) of the effluent, so sometimes lead the collapse of the WWTP and the direct discharge of agrifood industry waste to surface water flows. To reduce this environmental problem, agrifood industry waste should be treated and energy recovery in the industry that produces them. One of the techniques that can be used is anaerobic digestion (AD).

AD is a biological process in which the biodegradable organic matter, in absence of oxygen and as result of the action of a group of specific bacteria (hydrolytic, acidogenic, acetogenic and methanogenic), is decomposed into a gaseous product called biogas (CH_4, CO_2, H_2, H_2S, etc.) and a digested effluent, which is a mix of mineral products (N, P, K, Ca, etc.) and compounds of difficult degradation [2]. So, it is one of the most suitable process to reduce greenhouse gases emissions, to promote energy use of wet organic wastes, as well as to enhance the use of the processed products as fertilizers [3].

AD has demonstrated be effective to degrade a great variety of wastes from the agro-alimentary industry, like for instance those from swine wastewater [4], manure [5], onion waste [6], olive oil mill wastes [7], tomato processing waste [8] and slaughterhouse by-products [9].

Although the anaerobic biodegradation of agrifood industry wastes under study, Iberian pig slaughterhouse waste (IPSW), municipal slaughterhouse waste (MSW), tomato industry waste (TIW) and decanted olive mill wastewater (dOMW) had been carried out, few studies have been performed by using as substratum both solid and liquid wastes generated by each agrifood industry and using the same proportions in which wastes were produced. In addition, this work quantify the environmental benefits and the energetic potential of the AD of the most important wet waste biomass generated in Extremadura, as well as demonstrate the economic viability of industrial scale AD projects.

2. Materials and methods

2.1. Experimental setup

Fig. 1 shows a basic scheme of the anaerobic digester used to carry out the AD experiments. The reactor was a continuous flow stirred tank reactor (CSTR) with about 6 L operating volume. It was controlled by a control circuit which regulates the

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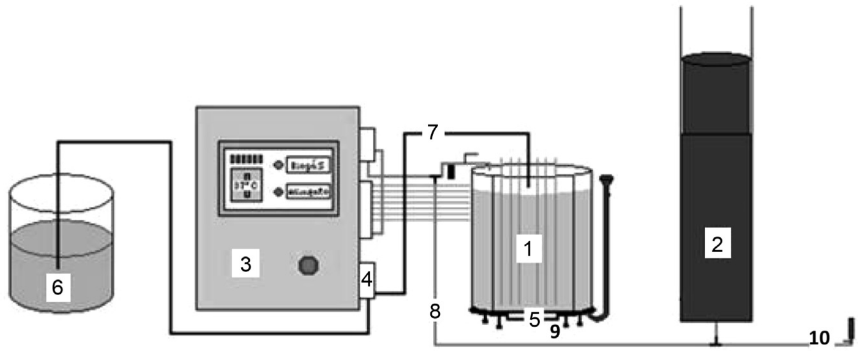

Fig. 1. Basic scheme of the continuous flow stirred tank reactor (CSTR).

substrate feeding, the operating temperature as well as the agitation stage inside the reactor; therefore, it operates like a real biomethanation plant. Experiments were conducted within the mesophilic range of temperature, particularly at 38 °C. The reactor content was agitated by the recirculation of part of the biogas produced. The biogas generated during the process was collected in a gasometer and the volume of biomass inside the digester was controlled by an overflow spillway, so that the digested effluent was collected via a cone separator. Finally, sampling in the digester was carried out by valves installed in its lower part.

2.2. Preparation of substratum and setup of the anaerobic digestion process

Each agrifood industry waste was periodically collected from one medium-size industry located in Extremadura (Spain), in this way, slaughterhouse waste were taken from the municipal slaughterhouse in Badajoz and an Iberian pig slaughterhouse called Jamón y Salud, S.L., TIW were collected from the Agrifood Technology Centre of Extremadura (CTAEX) and dOMW was taken from a two phase olive mill wastewater (TPOMW) processing industry, Troil Vegas Altas, S.C. Once in the laboratory, all waste samples were stored at −4 °C to prevent their natural degradation. The procedure for the preparation of each substrate under study is explained in detail below.

All wastes, except dOMW (pretreatment is not required because it has high moisture content and small particle size), were firstly forced to undergo a mechanical treatment to reduce particle size, provided that this feature is reported in the scientific literature as one of the most relevant parameters in the AD process [10]. The lower the particle size is, the higher the efficiency of the process is, given the fact that a decrease in particle size implies an increase of the surface on which bacteria might act.

The actual ratios of waste generation in real operating conditions at a standard industrial plant were taken into account, so that the final results might be used for future real-scaled projects. Slaughtering activities generate a waste consisted of 6% solid waste, 93% sewage and 1% blood. The ratio waste from tomato industry is reported as 2.5 kg peels and seeds per kilogram sludge, this substrate to be treated was prepared, taking into account this ratio, by adding treated water from the tomato processing plant in order to the moisture content of this waste was suitable for the AD process, i.e. 90% water and 10% solids (of which 7.14% corresponded to peels and seeds and the remaining 2.86% to sludge).

Agrifood industry wastes lack of suitable microorganisms to activate a biodigestion process, for which an acclimated inoculum ought to be necessary. The sludge used as inoculum to activate biodigestion was collected from an anaerobic reactor located at the Wastewater Treatment Plant (WWTP) in Badajoz (Spain). The inoculum once was collected at the WWTP was transported to the laboratory and was introduced into the anaerobic reactor as soon as possible. The reactor was completely filled with inoculum, and it was begun to feed the flow of substrate to be treated the next day. The same flow of substrate is fed for a time equal to 2 times period twice the hydraulic residence time (HRT), the first HRT stands for the acclimatization period. After this time the reaction has reached stability, i.e. the organic matter content is reduced down to a constant value and methane production reaches a maximum. This way, we can obtain reliable data of degradation and methane production for the tested flows. This work only presents the results obtained by treating the optimum flow rate for each waste under study, which achieves the highest waste degradation and methane production.

2.3. Analytical methods

Samples were periodically taken from the digester in order to appropriately monitor the following parameters: COD, volatile fatty acids (VFA), alkalinity, pH, volatile solids in suspension (VSS) and volatile dissolved solids (VDS).

VFA, alkalinity, pH, VSS, VDS were determined according to the standard methods [11], whereas COD was analyzed using Nanocolor® (Macherey-Nagel) kits and a PF-12 portable spectrophotometer (Macherey-Nagel).

2.4. Estimate of environmental benefits

The estimated volumes of methane and carbon dioxide that would be released to the atmosphere if all the wastes under study were naturally decomposed or dumped to landfills for putrefaction, has been estimated taking into account the amount of such wastes generated in a typical year in Extremadura and the biogas and methane yields obtained in laboratory experiments; because AD is only an acceleration, under controlled conditions, of the natural putrefaction process of organic matter.

Furthermore, the equivalent carbon dioxide emissions avoided, has been calculated taking into account that methane is 23 times more effective than carbon dioxide to absorb longwave radiation reradiated from the Earth and the difference between the emission of carbon dioxide that would be generated if all the wastes were dumped in a landfill and emissions from combustion of biogas obtained by anaerobic digestion of theses wastes. The calculation procedure is described below:

- Equivalent carbon dioxide emissions derived of natural degradation (END):

$$\text{END (t/year)} = \text{ECDE} + \text{CDE} \tag{1}$$

$$\begin{aligned}&\text{Methane emissions (ME) (t/year)}\\&\quad = \text{wastes generated (m}^3\text{/year)} \times \text{methane production by AD (Nm}^3\text{/m}^3\text{ substrate)}\\&\quad \times \text{density of methane (t/m}^3\text{)}\end{aligned} \tag{2}$$

$$\text{Equivalent carbon dioxide emissions (ECDE) (t/year)} = \text{methane emissions} \times 23 \tag{3}$$

$$\begin{aligned}&\text{Carbon dioxide emissions (CDE) (t/year)}\\&\quad = \text{wastes generated (m}^3\text{/year)}\\&\quad \times \text{carbon dioxide production by AD (Nm}^3\text{/m}^3\text{substrate)}\\&\quad \times \text{density of carbon dioxide (t/m}^3\text{)}\end{aligned} \tag{4}$$

- Equivalent carbon dioxide emissions derived of anaerobic digestion (EAD):

$$\text{EAD (t/year)} = \text{CDEC} + \text{CDEAD} \tag{5}$$

$$\begin{aligned}&\text{Carbon dioxide emissions by combustion of methane (CDEC) (t/year)}\\&= \frac{\text{mole of methane generated by AD/year} \times \text{molecular weight of carbon dioxide}}{10^6}\end{aligned} \tag{6}$$

Note: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + heat (the combustion of 1 mole of methane generates 1 mole of carbon dioxide)

$$\begin{aligned}&\text{Carbon dioxide emissions by anaerobic digestion (CDEAD) (t/year)}\\&\quad = \text{wastes generated (m}^3\text{/year)}\\&\quad \times \text{carbon dioxide production by AD (Nm}^3\text{/m}^3\text{ substrate)}\\&\quad \times \text{density of carbon dioxide (t/m}^3\text{)}\end{aligned} \tag{7}$$