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Effects of inoculum source and co-digestion strategies on anaerobic digestion of residues generated in the treatment of waste vegetable oils

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ABSTRACT

This work aims at selecting a suitable strategy to improve the performance of the anaerobic digestion of residues generated in the treatment of waste vegetable oils (WVO). Biochemical methane potential (BMP) assays were conducted at 35 °C to evaluate the effects of substrate mix ratio between a mixture of WVO residues (M) and pig manure (PM) co-digesting by using different inocula. Inoculum from an industrial digester fed with organic waste from hotels, restaurants and catering leftovers (HORECA) showed higher methanogenic activity (55.5 mLCH_4 gVS^{-1} d^{-1}) than municipal wastewater treatment plant (mWWTP) inoculum (42.6 mL CH_4 gVS^{-1} d^{-1}). Furthermore, the results showed that the resistance to WVO residues toxicity was higher for the HORECA sludge than for the mWWTP sludge. HORECA inoculum produced more biogas in all the assays. Moreover, the resulting biogas was of better quality, containing an average of 71.1% (SD = 1.6) methane compared to an average of 69.5% (SD = 1.2) methane for test with mWWTP sludge. The maximum degradation rate occurred at the higher PM mix ratio (M/PM:1/3), reaching 26.7 ± 4.3 mLCH_4 gVS^{-1} d^{-1} for mWWTP inoculum, versus 42.0 ± 1,5 mLCH_4 gVS^{-1} d^{-1} achieved for HORECA inoculum.

A high reduction of volatile solids (between 70% and 81%) was obtained with both inocula at all M/PM ratios assayed (1/0, 1/3, 1/1 and 3/1 v/v) but, bearing in mind the operation of a full-scale anaerobic plant, the optimal scenario assayed corresponds to the ratio M/PM: 1/3 v/v where shorter lag periods will make it possible to operate at lower hydraulic retention times.

1. Introduction

Biodiesel has been produced on an industrial scale in the European Union since 1992. However, the limited availability of traditional raw materials, such as animal fat or vegetable oils (both edible and non-edible) and their high cost limits the wider use of biodiesel (Math et al., 2010).

For biodiesel producers the cost of feedstock comprises between 75 and 90% of the operating cost of their plants (Mathiyazhagan and Ganapathi, 2011). Under these circumstances, waste vegetable oils (WVO) are becoming a promising alternative to the use of edible oils as feedstock as they are low in cost and easily available.

When WVO is collected, it goes through a treatment process to eliminate moisture, bulky particulate, free fatty acids and other undesirable compounds before sending it for biodiesel production. Nowadays, the increasing amount of wastes or residual subproducts generated by these WVO processing activities represents a new environmental concern.

According to various surveys carried out along recent years among WVO industrialists on the management of their wastes, and in light of the changes in the regulation, there is a willingness to reconsider the current recovering for some types of wastes/by-products, and anaerobic digestion is one possible solution (Torrijos et al., 2008). Furthermore, the WVO treatment and refining processes involve the use of steam and the related energy consumption is quite significant. In an international context of fossil fuels rising costs and greenhouse gases emissions reduction, manufacturers want to reduce the fossil fuels related energy consumption and biogas recovery can respond to this desire.

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However, it is well-known that anaerobic digestion (AD) of oil-rich wastes is not always easy and simple, since anaerobes are very sensitive to lipid-rich matters as well as to intermediate compounds of oily wastes degradation process (Hidalgo et al., 2012; Hong, 2011; Neves et al., 2009b). High lipids concentrations can destabilize anaerobic digesters due to inhibition of methanogenic bacteria by possible damage to cellular membrane (Göblös et al., 2008; Fernández et al., 2005). Nevertheless, lipids are attractive substrates for anaerobic digestion and co-digestion due to the higher methane yield obtained when compared to carbohydrates.

Different kinds of substrate give different methane production, which can be evaluated using the biochemical methane potential (BMP) assay. The BMP assay is a useful tool to determine the biodegradability and methane conversion yield of organic substrates (Angelidaki et al., 2009). Numerous studies have been carried out in which the BMP assay of different wastes were measured (Nieto et al., 2013; Ho and Sung, 2010; Labatut et al., 2011; Xie et al., 2011) and, in all of them, the source of inoculum played a vital role in the substrate degradation efficiency, especially for complex mix of substrates, due to the different makeup of the microbial consortia within.

The purpose of this work was to study the anaerobic digestion of the residues and by-products generated during the processing of WVO for biodiesel production, and more specifically, the influence of inoculum source on methane production, in order to evaluate the potential of anaerobic digestion as an alternative to the conventional management solutions for these streams while reducing the fossil-origin energy consumption on refinery sites.

2. Materials and methods

2.1. Waste streams

The processing of WVO generates a number of residues, as shown in Fig. 1. In this study, these wastes were supplied by a biodiesel company located in Madrid (Spain).

2.1.1. Residues from initial filtering (RIF)

Taken at the beginning of the treatment process, it is the solid residue that remains in the filtering mesh after pouring the WVO through it. It is basically a solid residue composed by food leftovers with a high organic load.

2.1.2. Drum sediment (DS)

The storage of WVO (before treatment) leads to the sedimentation of solid particles from the oil. These solids are called "drum sediments" and remain in the drums used to collect the WVO, after pouring their content in the reception hopper and the filtering mesh.

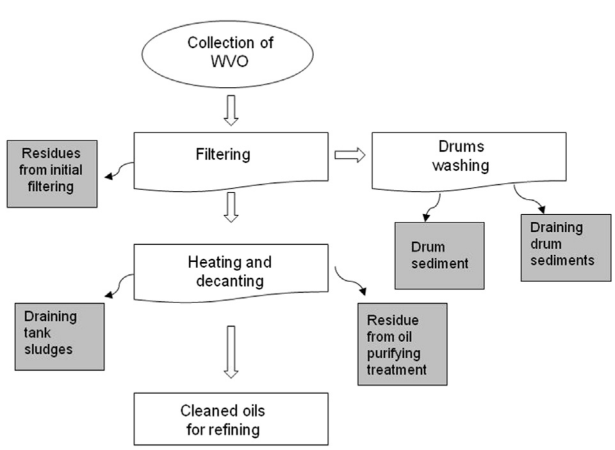

Fig. 1. Waste vegetable oil treatment steps.

2.1.3. Draining drum sediments (DDS)

Practically liquid residue resulting from the cleaning of the drums used to collect the WVO, once the drum sediments have been removed.

2.1.4. Draining tank sludge (DTS)

After heating the filtered oils, water and impurities are located at the bottom of the draining tanks, obtaining semi-solid sludge residues after the centrifugation of the decanted oil residues.

2.1.5. Residue from oil purifying treatment (OPT)

This residue is the wastewater proceeding from the draining tanks as a result of the previous heating and centrifugation treatment.

2.2. Research scheme

The experimental work has been carried out in three steps:

1) analyzing the anaerobic treatment of the individual waste streams;
2) simulating the joint digestion of these wastes (the waste mixture investigated (M) covered the main scenario of total waste generation in the WVO treatment industry) and
3) simulating the co-digestion of the mixture of residues from the treatment process of WVO (M) with pig manure (PM) at different M/PM rates (1/3, 1/1 and 3/1).

Table 1 shows the content of each waste in the selected mixtures. Results are presented on a volatile solids percentage basis.

2.3. Wastes analysis

Total and volatile solid concentration (TS, VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia nitrogen ($N{-}NH_4^+$), fat content, alkalinity, P and pH were determined following Standard Methods (APHA, 2005) recommendations. Protein content was measured with the Kjeldahl method using a conversion factor of 6.25. Fatty acids (FA) concentrations were determined using a gas chromatograph (HP-Agilent) equipped with a flame ionization detector (FID). C, N, H and S contents were determined by UNE-CEN/TS 15104 EX with a LECO Truspec CHN(S) elemental analyzer. Oxygen content was not measured directly but was estimated assuming that no other elements (apart from the measured C, H, N, S and P) were present in the wastes.

2.4. Biomethane potential (BMP) test

In order to study the biodegradability and biomethane potential of lipid-rich wastes and their mixtures and, at the same time, to

Table 1
Composition of the waste mixtures.

Mixture	Waste (%)					
	RIF	DS	DDS	DTS	OPT	PM
M	40	15	15	15	15	–
M/PM:1/3	10	3.75	3.75	3.75	3.75	75
M/PM:1/1	20	7.5	7.5	7.5	7.5	50
M/PM:3/1	30	11.25	11.25	11.25	11.25	25