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Improving biogas production from anaerobic co-digestion of sewage sludge with a thermal dried mixture of food waste, cheese whey and olive mill wastewater

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ABSTRACT

Anaerobic co-digestion of sewage sludge and other organic wastes at a wastewater treatment plant (WWTP) is a promising method for both energy and material recovery. However, transportation and storage of wastes to WWTP may be the bottleneck for the successful implementation of this technology. In case of wet wastes and wastewater it is possible to reduce their volume and as a result the transportation and storage cost by using a drying process. During this study, the optimization of biogas production from sewage sludge (SS) was attempted by co-digesting with a dried mixture of food waste, cheese whey and olive mill wastewater (FCO). A series of laboratory experiments were performed in continuously-operating reactors at 37 °C, fed with thermal dried mixtures of FCO at concentrations of 3%, 5% and 7%. The overall process was designed with a hydraulic retention time (HRT) of 24 days. FCO addition can boost biogas yields if the mixture exceeds 3% (v/v) concentration in the feed. Any further increase of 5% FCO causes a small increase in biogas production. The reactor treating the sewage sludge produced 287 ml $CH_4/L_{reactor}$/d before the addition of FCO and 815 ml $CH_4/L_{reactor}$/d (5% v/v in the feed). The extra FCO-COD added (7% FCO v/v) to the feed did not have a negative effect on reactor performance, but seemed to have the same results. In all cases, the estimated biodegradability of mixtures was over 80%, while the VS removal was 22% for the maximum biomethane production (5% v/v). Moreover, co-digestion improved biogas production by 1.2–2.7 times.

1. Introduction

In a typical wastewater treatment plant (WWTP), a significant amount of solid material is collected from the settling (primary treatment) and activated sludge (secondary treatment) processes. These are collectively called sewage sludge and must be treated prior to disposal for environmental protection. Sludge management can account for up to 60% of the total cost associated with municipal wastewater treatment (Ramakrishna and Viraraghavan, 2005). As a result, significant efforts have been devoted toward minimizing sludge generation (Semblante et al., 2014) and optimizing sludge treatment (Brisolara and Qi, 2011). Among several options currently available for sewage sludge treatment, anaerobic digestion is probably the most widely used technology.

In addition, growing concerns about energy security, environmental impacts and increasing energy cost for wastewater treatment have reinstated the anaerobic digestion process as a major renewable energy production technology to the center of the scientific spotlight (Iacovidou et al., 2012; Karthikeyan and Visvanathan, 2013). In particular, using anaerobic digestion to co-digest sewage sludge with other organic waste materials to enhance both biogas production and the quality of the treated bio-solids has been proposed and implemented at several WWTPs around the world (Cabbai et al., 2013; Fountoulakis et al., 2010; Nielfa et al., 2015; Pitk et al., 2013; Wang et al., 2013). This can be achieved by using existing anaerobic digestion infrastructure at WWTPs without any significant capital investment.

Some agro-industries such as olive oil mills and cheese factories represent a considerable share of the Mediterranean countries' economy. The by-products of olive oil production such as olive mill wastewaters (OMW) pose a serious environmental risk. The organic load measured as COD is 40–220 g/L and includes organic compounds such as sugars, tannins, polyphenols, polyalcohols,

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pectins and lipids (Aktas et al., 2001; Azbar et al., 2004; Hamdi, 1993; Vlyssides et al., 2004). OMW has been the subject of many waste treatment studies involving chemical and physical treatment (coagulation/flocculation and chemical oxidation), biochemical treatment (fermentation, aerobic process, composting) and combined processes/techniques (El-Gohary et al., 2009; Roig et al., 2006; Sarika et al., 2005). However, no satisfactory solution has yet been found for safe OMW disposal, mainly due to technical and financial limitations (Morillo et al., 2009). One of the more effective ways to dispose of these wastes is using the anaerobic digestion process (Boari et al., 1984; Borja et al., 1993). However, conventional anaerobic digestion of OMW exhibits well-known problems related to OMW characteristics that have limited its application such as: low alkalinity and pH, lack of ammonium nitrogen and high content of both organic and phenolic compounds. To overcome these limitations, several processes have been reported for upgrading OMW anaerobic digestion. The most cost-effective process with energy recovery employs the technique of co-digestion of OMW with other substrates. Previous studies showed that OMW could be treated successfully without high dilution and without adding chemical substances if it was co-digested with substrates containing a high level of ammonium nitrogen and alkalinity to compensate for their lack of OMW (Angelidaki and Ahring, 1997; Angelidaki et al., 2002; Fezzani and Ben Cheikh, 2007).

Cheese whey (CW) is a by-product during cheese manufacturing (Ferchichi et al., 2005; Kisaalita et al., 1987). CW is the most important waste stream produced with a high organic content (up to 70 g COD/L), which is highly biodegradable, and low alkalinity (50 meq/L) (Mawson, 1994). The main contributors to the organic load of these wastes are carbohydrates, proteins and fats. Whey has a pH of 5.9–6.6 while the manufacture of mineral–acid precipitated casein yields acidic whey, with a pH of 4.3–4.6 (Bylund, 1995). Whey management has attracted more attention due to stricter legislation (Farizoglu et al., 2004) and for financial reasons (Yang et al., 2007). From a wastewater treatment point of view, anaerobic digestion of cheese whey offers an excellent approach. Previous studies have shown that co-digestion with dairy manure provides the necessary nutrients and buffer capacity. As a result, they obtained, in a two-stage system, an overall COD reduction of over 46% (Lo and Liao, 1989). According to Desai et al. (1994), the combination of whey and poultry manure was found to be capable of maintaining the proper C/N ratio in the reactor. It has been shown that the digestion of the mixture of these wastes was more efficient in producing methane than that of each material individually.

Some studies pointed out that the digestion of food waste (FW) alone may lead to the accumulation of abundant volatile fatty acids (VFA), especially at high organic loading rate (OLR), which could inhibit the methanogenesis and even destabilize the anaerobic process (El-Mashad et al., 2008). These findings led to the investigation of its co-digestion with sewage sludge (SS) as an alternative. Moreover, co-digestion of SS and FW could be a strategic and cross-sectorial solution to deliver beneficial synergies for the water industry and FW management authorities (Iacovidou et al., 2012).

The anaerobic co-treatment of organic wastes, known as co-digestion, is not often found in SS treatment facilities even though is a common practice with agro-industrial wastes (Long et al., 2012; Mata-Alvarez et al., 2014). The objective of improved gas yield is based on an improved composition of the influent, since the co-substrates are usually complementary to the major waste in most cases, or due to an increased organic loading rate without changing the retention time. It is a well-recorded fact that biogas productivity in an anaerobic digestion unit is significantly increased when a mixture of wastes is used, compared to a single source influent (Aichinger et al., 2015, Xie et al., 2017, Khoufi et al., 2015, Liu et al., 2016). What this means is that, even though the single feed/substrate might be at its optimum for the whole range of characteristics, productivity increases when a mixture of substrates is used, and this increase is far greater than that which the stoichiometric decomposition should deliver (Astals et al., 2014, Xie et al., 2016). This is due to the co-digestion phenomenon, well recorded in all biological decomposition process (Fountoulakis et al., 2010, Zheng et al., 2015).

In many cases, co-digestion projects involve high costs to transport feedstock which renders logistics optimization crucial for determining project viability (Mayerle and De Figueiredo, 2016). For this reason, biomass densification was examined in the past in order to solve the extra high cost of logistic issues (Wang et al., 2016). In addition, CW and OMW are produced seasonally, so there is a need for storage facilities during design of the project. Similar design problems would arise for FW in holiday resorts, where the population also can increase by an order of magnitude. The drying of these materials would have as a result a significant reduction of volume of feedstock reducing significantly transportation and storage cost. However, is still unknown the effect of drying on down-stream processes, particularly the biogas production from anaerobic digestion.

This article focuses on a thermal dried mixture of food waste and two seasonally produced agro-industrial wastes representative of Greece: olive mill waste water and cheese whey. The goal of the present work was to investigate, on the lab scale, how a mesophilic digestion system will react when this dried mixture is added in different concentrations of 3–7% (v/v) to the sewage sludge in the co-digestion process. To our knowledge this is the first time examined the co-digestion of sewage sludge with this kind of dried waste and wastewater.

2. Methodology – materials and methods

2.1. Feedstock

Sewage sludge (SS) was the primary sludge originating from the Municipal Sewage Treatment Plant (MSTP) of the city of Heraklion (population 175,000), Crete. The sludge was stored frozen at 4 °C until use. Food waste (FW) used in the present study was collected from the students' restaurant at the Technological Educational Institute of Crete, Heraklion. The FW composition was 80% raw-fresh food (vegetables), 10% fruits and 10% salads (on a wet-weight basis). FW was homogenized using a mechanical mixer (approximately 4.0 mm). The cheese whey (CW) was obtained from a local cheese-producing factory located in the same region, which uses traditional cheese manufacture technologies. Wastes were characterized and immediately frozen to avoid biological activity. All Feedstock was stored at −20 °C, during the whole experimentation period in order to maintain its physicochemical characteristics. The mean composition of raw SS, FW, CW and OMW is summarized in Table 1.

2.2. Pre-treatment of feedstock

The FW in this study was homogenized using a mechanical mixer, (approximately 4.0 mm). In order to create a 1:1:1 (v/v) mixture of FW, CW and OMW (FCO), 1 L of FW (1.040 g), 1 L of CW (1.020 g) and 1 L of OMW (1.000 g) were mixed and dried at a temperature of 105 °C to reduce the initial volume of the mixture to 1/3. The 1:1:1 (v/v) FCO mixture was placed in a beaker in a lab oven. The reduction of volume lasted for approximately 1 week. After the treatment, the feed was cooled down to room temperature and three different SS and FCO mixtures were prepared on a

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