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Boosting biogas production from sewage sludge by adding small amount of agro-industrial by-products and food waste residues

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ABSTRACT

In Greece, in many cities, wastewater treatment plants (WWTPs) operate their own anaerobic digestion (AD) facility in order to treat sewage sludge rather than achieve optimum biogas production. Nowadays, there is a growing interest regarding the addition of other co-substrates in these existing facilities in order to increase gas yield from the biomass. This practice may be possible by adding small amount of co-substrates which will not affect significantly in the designed hydraulic retention time. Nonetheless, the lack of experimental data regarding this option is a serious obstacle. In this study, the effect of co-digestion sewage sludge, with small amount of agro-industrial by-products and food wastes is examined in lab-scale experiments. Specifically, co-digestion of SS and food waste (FW), grape residues (GR), crude glycerol (CG), cheese whey (CW) and sheep manure (SM), in a small ratio of 5–10% (v/v) was investigated. The effect of agro-industrial by-products and food waste residues on biogas production was investigated using one 1 L and three 3 L lab-scale reactors under mesophilic conditions at a 24-day hydraulic retention time. The biogas production rate reached 223, 259, 406, 572, 682 and 1751 mlbiogas/lreactor/d for 100% SS, 5% SM & 95% SS, 10% CW & 90% SS, 5% FW & 95% SS, 5% FW & 5% CG & 90% SS and 5% CG & 95% SS respectively. Depending on the co-digestion material, the average removal of total chemical oxygen demand (TCOD) ranged between 20% (5% SM & 95% SS) and 76% (5% FW & 5% CG & 90% SS). Reduction in the volatile solids ranged between 26% (5% SM & 95% SS) and 62% (5% FW & 5% CG & 90% SS) for organic loading rates between 0.8 $kgVSm^{-3}\,d^{-1}$ and 2.0 $kgVSm^{-3}\,d^{-1}$. Moreover, co-digestion improved biogas production from 14% (5% SM & 95% SS) to 674% (5% CG & 95% SS). This work suggests that WWTPs in Greece can increase biogas production by adding other wastes to the sewage sludge without affecting the operation of existing digesters and without requiring additional facilities.

1. Introduction

Biogas is one of the most widely used types of renewable energy in the European Union countries, however Greece does not at present show corresponding progress. At the same time, in all major cities of Greece wastewater treatment plants (WWTPs) operate their own anaerobic digestion (AD) facility in order to treat sewage sludge rather than achieve optimum biogas production.

The plants already installed and in operation could, with the addition of other types of waste, dramatically increase biogas production, thus yielding significant amounts of electricity and heat. This would simultaneously achieve renewable energy production and waste processing, without requiring additional facilities.

Most urban and suburban areas of Greece produce the same products and therefore have to deal with the same waste. Particular mention should be made of the major agro units encountered in Greek rural areas, such as wineries, cheese factories and livestock units. These wastes, which have very high organic load, could be used for anaerobic reactors already established and operating in WWTPs which produce significant quantities of biogas. The existing wastewater treatment plants were designed mainly to reduce the amount of sewage sludge rather than achieve optimum biogas production.

The low organic load of the SS together with the non-used capacity of the wastewater treatment plants (WWTP) digesters, frequently as much as 30%, is the main driving force behind SS co-digestion (Montusiewicz and Lebiocka, 2011). SS is characterized by relatively low C/N ratio and high buffer capacity (Astals

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et al., 2013; Silvestre et al., 2011). Therefore, it is able to stand co-substrates with high amounts of easily biodegradable organic matter and with low alkalinity values. Full-scale SS co-digestion practices are not as reported as would be expected. This is mainly because of the low interest of the industrial sector to publish their results in the scientific literature (Mata-Alvarez et al., 2014).

In addition, anaerobic co-digestion of suitably selected waste has also been of great scientific interest in recent years. Different sources of organic load mixture allow synergistic effects on the metabolism of anaerobic bacteria, on energy efficiency and on the treatment of remaining solids, and contributes to cost reduction, as in most cases it increases the biogas yield (Fountoulakis et al., 2008; Hartmann and Ahring, 2005; Martinez-Garcia et al., 2007; Mshandete et al., 2004).

Co-digestion of organic wastes with municipal wastewater sludge can increase digester gas production and provide savings in the overall energy costs of plant operations. Methane recovery also helps to reduce the emission of greenhouse gases to the atmosphere. In this way, renewable energy production and waste processing are achieved simultaneously, without requiring additional facilities.

In Greece, there are currently seven (7) anaerobic digestion units for power production with agro-livestock residues and eleven (11) WWTPs treating sewage sludge for biogas production. In most cases the exploitation of biogas covers unit heating requirements. Nevertheless, according to Hellenic Transmission System Operator S.A, the installed capacity of electricity generation from biogas is 45.4 MW and the electricity amounts to 155.9 GW h. Most of the energy produced in Athens from biogas units operating in the Psitalia WWTP is from treated wastewater (11.4 MW). WWTPs with biogas production in Greece are shown in Fig. 1.

The anaerobic co-treatment of organic wastes, known as co-digestion, is not often found in SS treatment facilities even though it is a common practice for 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.

This article focuses on food waste and also on four representative, seasonally produced agro-industrial waste with high organic content found in Greece and other Mediterranean countries: grape residues, cheese whey, crude glycerol and sheep manure. The goal of the present work was to investigate, on the lab scale, how a mesophilic digestion system reacts when adding other wastes in a small ratio of 5–10% (v/v) to the sewage sludge in the co-digestion process. Findings will help engineers in existing digesters at Greek wastewater treatment plants as well as all over the world, in order to boost biogas production during the anaerobic treatment of sewage sludge without affecting the operation of existing digesters and without requiring additional facilities.

2. Methodology – materials and methods

2.1. Agro-industrial by-products, food waste residues and feedstock

Sewage sludge (SS) was 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 50% cooked food (10% meat, 15% potatoes, 20% rice and 5% other), 20% raw-fresh food (vegetables), 10% fruits, 10% salads, 8% bread and 2% dessert (on a wet-weight basis). FW was homogenized using a mechanical mixer, (approximately size 4.0 mm) and diluted with tap water to approximately 3% TS to reduce viscosity for pumping and stirring in the lab-scale experimental equipment. Grape residues (GR) were obtained from a local winery (Alexakis SA) in Heraklion, Crete. Thermal pretreatment was used for GR, at 60 °C, 30 min and 1:4 dilution with water. The cheese whey (CW) was obtained from a local cheese factory using traditional technologies for cheese manufacture. Crude glycerol (CG) was obtained from a biodiesel production pilot scale unit of the Technological Educational Institute of Crete, producing biodiesel mainly from fried olive oil. In general, this waste contained glycerol, water, methanol and soaps. Fresh sheep manure (SM) was obtained from a small farm located in the same region. All waste was stored at −20 °C during the whole experimentation period, in order to maintain its physicochemical characteristics. The mean composition of raw SS, FW, GR, CW, CG and SM is summarized in Table 1. The characteristics of the feedstock are summarized in Table 2.

2.2. Lab-scale anaerobic digester

The continuous experiments were carried out in three 3 L and one 1 L lab-scale continuous stirred-tank reactors (CSTR) constructed of stainless steel, with a double wall. The reactor operated under mesophilic conditions (35 °C) via water bath through water jackets surrounding the reactors. Agitation was ensured by a motor drive unit installed on the top of the reactor. The mixed liquid from the reactor was stirred periodically for 15 min, twice an hour. Biogas was collected by displacement of water. The schematic diagram of the digester is presented in Fig. 2.

2.3. Experimental procedure

Eight types of influent feedstock were utilized: 100% sewage sludge (SS), 5% (v/v) food waste, grape residue, crude glycerol, sheep manure, cheese whey and 95% sewage sludge, a mixture of 5% (v/v) food waste and 5% (v/v) glycerol, and a mixture of 5% sheep manure and 5% glycerol and 90% sewage sludge, in order to investigate the biogas production of the food waste - sludge and agro-industrial by-products - sludge co-digestion. The continuous experiments on crude glycerol and cheese whey were carried out in a 1 L digester and the rest of the experiments were carried out in a 3 L digester. The feedstock was stored in a tank placed in a refrigerator at a constant temperature of 4 °C. Feedstock was added four times daily (every 6 h) with a total feeding volume of 40 ml and 125 ml daily for a 1 L and 3 L digester respectively and hydraulic retention time of 24 days. New influent was prepared every week and stored in 2 L glass vessels, which were stirred for 2 min before feeding.

2.4. Analytical methods

The pH was measured by an electrode (Crison, GLP 21), while total (TS) and volatile (VS) solids, total and dissolved chemical oxygen demand (TCOD and DCOD), total nitrogen (TN) and total phosphorus (TP) were determined according to standard methods (Apha, 1995). Gas samples were collected in gas-tight syringes and transferred to the gas chromatograph by sealing the needle with a butyl rubber stopper. Twenty microliters were injected into a gas chromatograph (Agilent 6890N GC System) for methane and carbon dioxide analyses. A thermal conductivity detector (TCD) and a capillary column (GS Carbonplot, 30 m × 0.32 mm, 3 lm) were used. The column was operated isothermally at 80 °C and the detector port was operated at 150 °C. Helium was used as the carrier gas at a flow rate of 15 ml/min.

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