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Co-digestion of municipal sludge and external organic wastes for enhanced biogas production under realistic plant constraints

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A B S T R A C T

A bench-scale investigation was conducted to select external organic wastes and mixing ratios for co-digestion with municipal sludge at the F. Wayne Hill Water Resources Center (FWHWRC), Gwinnett County, GA, USA to support a combined heat and power (CHP) project. External wastes were chosen and used subject to two constraints: a) digester retention time no lower than 15 d; and b) total biogas (methane) production not to exceed a specific target level based on air permit constraints on CO_2 emissions. Primary sludge (PS), thickened waste activated sludge (TWAS) and digested sludge collected at the FWHWRC, industrial liquid waste obtained from a chewing gum manufacturing plant (GW) and dewatered fat-oil-grease (FOG) were used. All sludge and waste samples were characterized and their ultimate digestibility was assessed at 35 °C. The ultimate COD to methane conversion of PS, TWAS, municipal sludge (PS + TWAS; 40:60 w/w TS basis), GW and FOG was 49.2, 35.2, 40.3, 72.7, and 81.1%, respectively. Co-digestion of municipal sludge with GW, FOG or both, was evaluated using four bench-scale, mesophilic (35 °C) digesters. Biogas production increased significantly and additional degradation of the municipal sludge between 1.1 and 30.7% was observed. Biogas and methane production was very close to the target levels necessary to close the energy deficit at the FWHWRC. Co-digestion resulted in an effluent quality similar to that of the control digester fed only with the municipal sludge, indicating that co-digestion had no adverse effects. Study results prove that high methane production is achievable with the addition of concentrated external organic wastes to municipal digesters, at acceptable higher digester organic loadings and lower retention times, allowing the effective implementation of CHP programs at municipal wastewater treatment plants, with significant cost savings.

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1. Introduction

Anaerobic co-digestion of municipal sludge has been widely tested with various high strength food, agricultural, animal, and industrial wastes (Zitomer et al., 2008; Mata-Alvarez et al., 2011; Tezel et al., 2011; Long et al., 2012; Jensen et al., 2014; Astals et al., 2014; Mata-Alvarez et al., 2014; Tchobanoglous et al., 2014). Co-substrate selection depends on its properties, such as digestibility, complementary nutrient richness, and toxicity, along with co-substrate handling and storing considerations. In addition, cost, availability, as well as transportation factors determine the economic feasibility of municipal sludge co-digestion. The objectives of co-digestion are enhanced biogas production and solids destruction, resulting in biosolids with better dewaterability, ease of handling and disposal. High strength wastes, such as fat-oil-grease (FOG) and food processing wastes, are suitable co-substrates for municipal sludge co-digestion. Anaerobic digestion of organic wastes alone requires careful digester design and operational strategies, such as longer retention time and controlled organic loading rates. However, when digested with municipal sludge, digestion of high strength wastes becomes simpler, and more importantly, contributes to enhanced degradation of the co-substrates resulting in higher biogas production and solids destruction (Kabouris et al., 2008, 2009a; Feng et al., 2009).

Co-digestion studies have been carried out in laboratory- and full-scale mesophilic and thermophilic anaerobic digesters (Cecchi et al., 1988; Agdad and Sponza, 2007; Zitomer et al., 2008; Kabouris et al., 2008, 2009a, 2009b; Mata-Alvarez et al., 2011; Jensen et al., 2014; Astals et al., 2014; Mata-Alvarez et al., 2014). Kabouris et al. (2009a) reported a three-fold higher methane yield when municipal sludge was co-digested with FOG mixed at a ratio of 52:48 on a volatile solids (VS) basis. Likewise, Davidsson et al. (2008) reported a 9–27% increase in methane yield when FOG was co-digested with mixed sewage sludge at a ratio of 10–30% on a VS basis. A recent review summarized FOG generation and results of recent studies on the co-digestion of municipal sludge with FOG (Long et al., 2012).

In addition to high ultimate digestibility and relatively fast biodegradation kinetics, wastes with relatively high COD (and solids) content lead to high organic loading rates (OLR) at relatively low volumetric loadings and are thus ideal for co-digestion with municipal sludge, as they allow digester operation at slightly reduced hydraulic retention time (HRT) values. Thus, the selection criteria for a suitable external organic waste are high COD and solids concentration, high ultimate digestibility, fast degradation kinetics, lack of toxicity, as well as ease of handling and storing. OLR used in anaerobic processes depend primarily on the type of the process and waste, as well as temperature, and are in the range of 1–50 kg COD/m^3-d (Tchobanoglous et al., 2014). Typical OLR values are between 5 and 10 kg COD/m^3-d (Rittmann and McCarty, 2001), though values close to 4 kg COD/m^3-d are typical for completely mixed, single-stage suspended-growth digesters treating semi-solids wastes with HRT values between 15 and 30 d, which apply to municipal sludge digestion (Tchobanoglous et al., 2014). The technical, economic, and environmental drivers for the co-digestion of high-strength, external organic wastes with municipal sludge were summarized in a recent report (WEF, 2010).

In spite the fact that many co-digestion studies have been conducted, limited information is available relative to co-digestion of municipal sludge with external organic wastes to address the energy balance of a specific municipal wastewater treatment plant. The research reported here was conducted to address this limitation. In order to benefit from waste to energy production using combined heat and power (CHP) at the F. Wayne Hill Water Resources Center (FWHWRC), Gwinnett County, GA, USA, a 2.1 megawatt (MW) biogas engine generator was installed, for which the biogas produced from the anaerobic digestion of the municipal sludge was about 70% of the engine generator biogas demand. Thus, co-digestion of municipal sludge and external organic wastes was deemed necessary to increase biogas production and match the engine generator biogas demand. Based on plant-wide solids and energy balance calculations at the FWHWRC, the increased biogas production was subject to two constraints: a) the digesters retention time should not fall below a certain minimum value; and b) based on air permit constraints on CO_2 emissions, the total biogas production should not exceed a certain upper value. The present study was designed to support the co-digestion and CHP project at the FWHWRC.

The overall goal of this study was to assess the feasibility of co-digestion of municipal sludge and external organic wastes in laboratory-scale, mesophilic anaerobic digesters at different combinations and organic loading rates in order to produce sufficient biogas (methane) needed to achieve a specific target level of waste to energy production at the FWHWRC. The specific objectives of the study were to assess the effect of co-digestion on: 1) the enhancement of biogas production; 2) the possible enhancement of the degradation of the municipal sludge; and 3) sludge dewatering and filtrate quality.

2. Materials and methods

2.1. Plant description

The FWHWRC is a medium size municipal wastewater treatment plant with a peak treatment capacity of approximately 190,000 m^3/d, using advanced, secondary treatment based on the activated sludge process, achieving biological nutrient (i.e., N and P) removal. The plant uses five egg-shaped mesophilic (36 °C) anaerobic digesters, fed with a 40:60 mixture (w/w, total solids basis) of primary sludge (PS) and thickened waste activated sludge (TWAS) at a retention time of 20 days, resulting in total biogas production at standard temperature and pressure (STP; 0 °C and 1 atm) of approximately 14,800 m^3/day or 0.783 m^3/m^3 digester-day. In support of the above-mentioned CHP project, co-digestion of municipal sludge and external organic wastes was considered in order to match the engine generator biogas demand. The increased biogas production was subject to two constraints, both pertaining to the FWHWRC plant: a) the digesters retention time should not fall below 15 d; and b) the targeted total biogas production at