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Anaerobic co-digestion of wine/fruit-juice production waste with landfill leachate diluted municipal sludge cake under semi-continuous flow operation

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ABSTRACT

Anaerobic co-digestion of four organic waste streams; a thickened waste activated sludge (TWAS) and screen cake (SC) from a fruit-juice/winery wastewater treatment plant along with municipal sludge cake (MC) and landfill leachate (LL) was evaluated. A total of eight semi-continuously-fed single and co-digesters were operated side-by-side at sludge retention times (SRT) of 20 and 10 days. Co-digestion of industrial waste streams (TWAS and SC) with MC and LL resulted in increased operational stability compared to the single digestion of industrial TWAS at the higher organic loading (10 d SRT). Although digester operational temperature had no statistically significant effect on organics removal and biogas production, mesophilic digesters had consistently higher total coliform densities (8838–37,959 most probable number or MPN/g-dry weight) compared to the thermophilic digesters (41–6723 MPN/g-dry weight) at both SRTs. Coliform analysis results also proved that most of the thermophilic digestates could be classified as Class A biosolids according to regulations. Furthermore, addition of industrial TWAS to co-digesters enhanced the dewaterability of the digested streams. A cost-benefit analysis confirmed the benefits and indicated that a full-scale co-digester utilizing all four waste streams can decrease the total capital and operational cost by 22% ($10.52 million).

1. Introduction

Fruit harvesting and juice industries are rapidly expanding in Southwestern Canada with a relatively recent shift in focus to vineyards and wine. These industries typically produce significant amount of wastewater which needs to be treated prior to discharge to the environment or to a municipal wastewater treatment plant (WWTP) for further purification (Amor et al., 2012). The juice industry wastewater is mainly characterized by low pH and high macronutrient and organic content (Devesa-Rey et al., 2011; El-Kamah et al., 2010) containing enzymes, cellulose, lignin, acids, raw juice and high concentration of solids (Ribeiro et al., 2010). In addition to wastewater generated during fruit processing, as a result of fruit-juice wastewater treatment, different organic wastes such as screen cake, primary sedimentation sludge and biological activated sludge are also generated with similar safe treatment and disposal requirements.

Composting is one of the most commonly used waste disposal methods for organic residues of fruit-juice/wine production. Although composted materials can be used as soil amendment if they meet fecal coliform, heavy metal and nutrient requirements, it has several disadvantages, such as occupation of large land areas, high energy and moisture requirement, uncontrolled release of biogas as a result of organics decomposition, carbon and nutrient losses via compost leachate and risk of groundwater pollution with organometallic compounds presents in the compost leachate (Tiquia et al., 2002).

Anaerobic digestion is known as an effective waste management technique for bioconversion of different high-strength biowaste, such as municipal primary and secondary sludge, organic portion of kitchen waste, pulp and paper sludge, agricultural off-farm and on-farm residues including animal manure into methane-rich biogas (Eskicioglu et al., 2007; Eskicioglu and Ghorbani, 2011; Sanscartier et al., 2012; Lin et al., 2012; Riaño et al., 2011; Lin et al., 2011). The biogas can be also converted into reusable energy either for heating or electricity generation. Previous studies showed that the digester remaining content (digestate) will be less odorous (Moody et al., 2009) having lower density of pathogens and enriched nutrients compared to raw waste, which make it particularly desirable as soil amendment.

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While conventional anaerobic digesters have been used to recover energy from organic waste since 1930s, in recent years, adoption of co-digestion is increasing. Anaerobic co-digestion is a technology whereby different types of organic waste are digested simultaneously within one bioreactor. Enhanced organics biodegradation as well as biogas production is one of the main advantages of this technology, with few facilities approaching "net zero-energy" operation. In addition to benefits on energy recovery, previous studies reported that co-digestion has the potential to generate higher buffering capacity (Capela et al., 2008) which can protect the process from the inhibitory effect of volatile fatty acids (VFAs) accumulation (Cuetos et al., 2011). Digestion of organics, such as fat and protein which are difficult to degrade, will be possible through co-digesting them with other, more degradable compounds (Alatriste-Mondragon et al., 2006). Moreover, positive synergistic effects of co-digesting different substrates were also reported in the literature due to the supply of missing nutrients (Ozbas et al., 2006). Batch co-digestion of pulp and paper sludge and food waste was conducted at different waste mixture ratios. The authors reported higher methane yield and organics removal efficiency and more buffering capacity for the co-digestion scenario compared to the single-substrate digestion (Lin et al., 2012). Another study reported 10% increase in volatile suspended solids degradation efficiency when households organic waste was co-digested with municipal sludge (Zupančič et al., 2008). Biogas production enhancement was observed by adding silage as co-substrate to the anaerobic reactors digesting Kimchi factory waste (Kafle et al., 2012). The hydrolysis specific rate constant was increased from 0.78 d^{-1} and 0.65 d^{-1} during separate starch and bovine serum albumin (BSA) digestions, respectively, to 1.06 d^{-1} when 80% starch was co-digested with 20% BSA (Elbeshbishy and Nakhla, 2012).

Today, enhancing anaerobic digestion performance by addition of fats, oil and grease (FOG) has become a common practice with many full-scale applications. However, addition of other types of organic waste material, ranging from food scraps to the by-products of food processing facilities (e.g. chicken blood) and agricultural production (e.g. winery, fruit and fruit-juice production wastes) is less common. So far, very small (serum bottle) scale biochemical methane potential (BMP) assays have been conducted as a preliminary assessment for co-digestion of fruit-juice/winery waste and municipal waste sludge (Hosseini Koupaie et al., 2014). The BMP assays revealed positive initial performance in terms of biogas potential and degradation efficiency with no sign of acute or chronic inhibition or unfavorable environment for the inoculum (Hosseini Koupaie et al., 2014). However, the findings of BMP assays are not representative of a typical full-scale application mainly due to different flow regime. Therefore, they do not have the accuracy to perform a reliable process performance or cost-benefit analysis for a full-scale digester or co-digester.

Recognizing full-scale potential of such co-digestion operation for Southwestern Canada, the Okanagan Valley in particular, the main objective of present research was to evaluate bench-scale performance of anaerobic single and co-digestion of fruit-juice/winery waste (e.g. TWAS, SC) with municipal waste streams (e.g. MC, LL) under semi-continuous flow conditions. Upon side-by-side process comparison, a preliminary cost/benefit analysis was conducted based on experimental results and historical waste production data obtained from treatment facilities.

2. Materials and methods

2.1. Sampling and characterization of waste streams

The municipal sludge cake (MC) was taken from a municipal WWTP in City of Kelowna (British Columbia or BC, Canada). The treatment facility bases its treatment on preliminary, primary and biological processes which target inorganic and organic fractions of municipal wastewater and also accepts on-site pre-treated industrial and agricultural streams collected from the Okanagan Valley (BC, Canada). The main industries discharging to Kelowna WWTP upon pre-treatment are wineries, breweries, fruit-processing and juice-making facilities. It is also important to emphasize that Kelowna has sanitary sewer/storm drain regulation bylaw that prohibits discharge of any pesticide, insecticides, herbicide, benzene, gasoline, oil, solvents, acetone, alcohol or radioactive materials. Furthermore, the bylaw restricts the organic loading, oil and grease and heavy metals in incoming wastewater to protect biological treatment processes and to minimize heavy metals in the stabilized biosolids sold as commercial soil amendment. The bioreactor operated at Kelowna WWTP is a modified Bardenpho® (barnard denitrification phosphate) system consisted of an anaerobic fermentation zone followed by two stages of anoxic and aerobic complete-mix activated sludge. The hydraulic retention time of the system is 9.3 h. Sludge retention times are 6 and 13 d during summer and winter months, respectively. The fermented primary and thickened secondary sludge streams are mixed at a volumetric ratio of 40:60 and then dewatered to a final total solids (TS) concentration of 17.5 ± 1% (by wt.) by a centrifuge. In this study, the centrifuged MC was used as one of the two municipal waste streams. However it was diluted to 4.5 ± 0.5% TS (by wt.) before included in the feed mixture.

The second municipal stream was taken from a landfill. Glenmore Landfill (15 km away from Kelowna WWTP) is an old but operational landfill for disposal of solid waste. The purpose of using landfill leachate as co-substrate was to evaluate whether landfill leachate could be co-digested (as a dilution liquid) with the other highly concentrated municipal (e.g. MC) and industrial wastes (e.g. SC). If feasible, the co-digester can be built on the landfill site and methane recovered from the co-digester can be connected and utilized as part of the existing landfill biogas system for electricity generation and cost savings. On the other hand, a concern in using landfill leachate is the presence of heavy metals which could inhibit the acid and methane formers in the digester, which was also assessed as part of this study.

The industrial streams including screen cake (SC) and thickened waste activated sludge (TWAS) were taken from the Brandt's Creek Tradewaste Treatment Plant (BCTTP). BCTTP receives two different wastewater streams produced at Calona Vineyards, a winery industry and Sun-Rype Beverage Ltd., western Canada's largest fruit-based food and beverage manufacturer. The combined industrial wastewater streams entering BCTTP is pumped to an 85 μm Salsnes screen (where the SC was sampled for this research) which collects large solids such as apple seeds and skins. The screening is followed by an equalization tank, an anaerobic selector adding nitrogen and phosphorus nutrients to the wastewater and an activated sludge unit with an aeration basin and two secondary clarifiers. Hydraulic and SRT of the activated sludge tank are 3 and 25 d at peak winter/summer loadings, respectively. The excess waste activated sludge collected at the bottom of the secondary clarifiers enters a dissolved air flotation (DAF) unit to increase its concentration to 3–5% TS (by wt.). The thickened sludge, or TWAS, scraped from the surface of the DAF was used as the second industrial substrate.

The initial characteristics of the sludge streams and landfill leachate used as digester co-substrates are listed in Table 1. Among all the substrates characterized, landfill leachate had the highest alkalinity, a neutral pH and lower ammonia concentration. Considering the preliminary characteristics, the leachate presented itself as a suitable co-substrate for diluting industrial and municipal cakes. Its high alkalinity concentration would also increase the buffering capacity of the co-digester mediating any potential adverse effects of high VFA accumulation (Demirel and Scherer, 2008).