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Co-digestion performance of organic fraction of municipal solid waste with leachate: Preliminary studies

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ABSTRACT

The main aim of the study was to evaluate the co-digestion performance of OFMSW with different wastes. Leachate, reverse osmosis (RO) concentrate collected from a leachate treatment facility and dewatered sewage sludge taken from a wastewater treatment plant (WWTP) were used for co-digestion in this paper. An extra effort was made to observe the effect of leachate inclusion in the co-digestion. In the study, the mono-digestion of OFMSW, leachate, RO concentrate and sewage sludge as well as digestion of 7 different waste mixtures were carried out for this objective. The experiments were carried out for approximately 50 days under mesophilic conditions. The highest methane yield was 785 L CH_4/kg VS_{added} in the reactor, which had only OFMSW. While the methane yield derived from OFMSW was found higher than previous studies, methane yield of leachate was found to be 110 L CH_4/kg VS_{added}, which was lower than findings in the literature. The mono-substrate of OFMSW was followed by the reactor of having waste mixture of leachate + sewage sludge + OFMSW + water (C7) with 391 L CH_4/kg VS_{added}, which was the only combination included water. In order to understand the effect of leachate and water inclusions on co-digestion, two separate waste combinations; leachate + sewage sludge + OFMSW + water (C7) and leachate + sewage sludge + OFMSW (C1) were prepared that had different amounts of leachate but same amounts of other wastes. The methane yield of leachate + sewage sludge + OFMSW + water (C7) indicated that addition of some water instead of leachate could stimulate biogas production. Methane yield of this reactor was found to be 71% higher than the waste combination of leachate + sewage sludge + OFMSW (C1). It could be thought that the high amount of non-biodegradable matters in leachate could be responsible for lower methane yield in leachate + sewage sludge + OFMSW (C1) reactor. Methane yields of the reactors showed that co-digestion of OFMSW and leachate could be a solution not only for treatment of leachate and but also increasing the biogas potential of leachate. Leachate addition could also adjust optimum total solids (TS) content in anaerobic digestion. It was also understood that RO concentrate did not affect the methane yield in a negative way. The similar characterization of leachate and RO concentrate in this study could offer the utilization of RO concentrate instead of leachate. The findings showed that volatile solids (VS) removals were changed from 32% to 61% in the reactors. While the reactor of leachate + RO concentrate + OFMSW (C6) had the highest VS removal, the reactor of the sole substrate leachate had the lowest VS removal.

1. Introduction

Municipal solid waste (MSW) management is hard to achieve especially in developing countries due to increase in waste generation, lack of financing and insufficient waste management facilities (Guerrero et al., 2013). New holistic approaches should be suggested to find solutions subjected to MSW management. The solutions should help to protect public health and supply resource recovery as much as possible (Henry et al., 2006).

Organic fraction of municipal solid waste (OFMSW) is mainly composed of food waste, garden waste, wood, paper and other organic residues (Hoornweg and Bhada-Tata, 2012; Hartmann and Ahring, 2006). The ratio of OFMSW changes between countries. The ratio of the OFMSW is 62% in the Eastern Asia and Pacific countries while the OECD countries have 27% of OFMSW in total MSW. Although the OECD countries have lower ratios, they have the highest OFMSW production all around the world (Hoornweg and Bhada-Tata, 2012). EU Landfill Directive (1999/31/EC)

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obligates biodegradable waste reduction going to landfills. According to the directive, the total amount of biodegradable waste accepted to landfills in 2006, 2009 and 2016 should respectively be 75%, 50% and 35% of the total biodegradable waste generation in 1995 by weight. Biodegradable waste is defined as any waste that can be degraded under aerobic or anaerobic conditions (Luning et al., 2003). OFMSW is categorized under biodegradable waste meaning biological processes can be used for management of OFMSW.

Due to the restraints in landfilling enforced by directives, composting and anaerobic digestion technologies are implemented in a widespread manner for management of OFMSW (Gómez et al., 2006). Incineration is not suitable for disposal of OFMSW because of its very high moisture content (Zupančič et al., 2008). In terms of energy recovery, anaerobic digestion is more favorable compared to composting. Anaerobic digestion is a net energy producing process that produces 100–150 kWh/ton treated waste. On the other hand, composting is an energy consuming process and requires approximately 30–35 kWh/ton treated waste (Hartmann and Ahring, 2006). Not only energy recovery, but also resource recovery is an important issue in OFMSW treatment. Valuable substances such as carbon, nitrogen, phosphorus can be recovered by various processes and can be reused for different purposes (Mata-Alvarez, 2001). Digestate is produced during anaerobic digestion and it is a valuable product in terms of nutrients. Application of digestate especially in soils that have a lack of organic substance is an appropriate option to support plant growth (Gebrezgabher et al., 2010). It should be noted that digestate should be dewatered to eliminate excess water and hygienized to remove pathogens (Mata-Alvarez et al., 2000).

Anaerobic digestion is conducted under anaerobic conditions and organic materials in the waste are transformed into another form biologically. The final products of this process are biogas (mainly methane and carbon dioxide) and other organic residues called digestate. Different sequential reactions named hydrolysis, acidogenesis, acetogenesis and methanogenesis take place during anaerobic digestion (Khalid et al., 2011). Waste characterization and biodegradability test are important steps to design anaerobic processes. After these steps, operational conditions can be determined for the process. There are different aspects to classify anaerobic digestion processes in respect to operating temperature, solid content and reactor numbers (Hartmann and Ahring, 2006).

Co-digestion is an anaerobic digestion method with at least two different wastes that are mixed and digested together. Co-digestion has many advantages compared to digestion of wastes alone. The most significant ones (Khalid et al., 2011; Mata-Alvarez, 2001):

- Improving the process stability
- Increase in organic loading rates
- Increase in biogas and methane yield
- Dilution of toxic compounds
- Balance of solid content
- Balance of nutrients
- Utilizing of synergistic effect of microorganisms
- Allowing treatment of different wastes in one facility

The most common co-digestion process is treatment of sewage sludge and OFMSW. Many researchers have studied different co-digestion processes of sewage sludge and OFMSW in the last decades (Hamzawi et al., 1998). Sewage sludge is characterized with having relatively low C/N ratio in the range of 6:1–13:1. In contrast, the C/N ratio of OFMSW is generally high due to presence of paper materials and other carbon rich substances. For example, paper and newspaper could have a C/N ratio greater than 1000:1. The ratios for both sewage sludge and OFMSW make the mono-digestion of these substrates inefficient. Appropriate mixing ratios of sewage sludge and OFMSW can provide an optimum C/N ratio for anaerobic digestion which changes between 20:1 and 30:1 (Zhang et al., 2008). Sludge is also rich in terms of other macro and micronutrients which stimulate anaerobic digestion (Silvestre et al., 2015). Co-digestion also helps to adjust solid content in the digester by mixing two or more different substrates. Organic wastes having high water contents like manure can be used to reduce TS content (Mata-Alvarez, 2001). If both substrates have high TS content, water should be used to reduce TS content of wet systems.

Although co-digestion of OFMSW and sewage sludge is the most studied co-digestion process in the literature, there are also some researches made on co-digestion of OFMSW and landfill leachate. It was mentioned that using landfill leachate enhances biogas production in co-digestion of landfill leachate and sewage sludge compared to mono-digestion of sewage sludge (Montusiewicz and Lebiocka, 2011). Nair and his colleagues (2014) had a laboratory study for monitoring co-digestion performance of OFMSW and leachate. The findings showed that leachate added reactors had higher methane yield compared to the reactor, which had the sole substrate of OFMSW. In the same study, the authors observed the effect of the leachate age on methane yield as well. Mixture of young and old leachate promoted the methane yield at most. Leachate can also be used as inoculum solely or with sludge in anaerobic digestion (Abdelhay et al., 2016). Apart from OFMSW and sludge, other substrates such as food waste, used oils were tested to monitor the co-digestion performance of leachate and these substrates (Kawai et al., 2012; Pastor et al., 2013; Xiaofeng et al., 2014). In addition to additional methane yield and energy recovery purposes, co-digestion could be suggested as an encouraging option for leachate treatment. Due to changes in meteorological conditions and waste characteristics over time, leachate treatment could be very complex (Renou et al., 2008) and co-digestion of leachate with different wastes could be an option for leachate management.

It was proven that the co-digestion of sewage sludge and OFMSW yielded more biogas in comparisons with mono-digestion of sewage sludge in many cases (Abudi et al., 2016; Koch et al., 2015). Nielfa et al. (2015) had a study about co-digestion performance of OFMSW and sewage sludge in different mixing ratios. The results showed that maximum methane yield was observed for the mixture, which had 80% of OFMSW and 20% of sewage sludge on weight basis. 221 L CH_4/kg VS of methane yield was attained which was higher 10% and 35% than the sole substrates of OFMSW and sewage sludge, respectively. Heo et al. (2004) implemented different sludge blending ratios in co-digestion of waste activated sludge and food waste. The authors of the paper concluded that the methane yields improved gradually as the food waste ratio increased.

Nutrient availability is another important factor for anaerobic biomass to sustain the metabolic activities (Kim et al., 2002). Not only macronutrients such as C, H, O, N, but also micronutrients like light metal ions and heavy metals are required for microorganisms (Zhang et al., 2014). The requirement for trace metals is very low, however their limitations can suppress biological growth. It was reported that methanogens are the most sensitive anaerobic consortia to trace metal deficiency (Thanh et al., 2016). On the other hand, these metals can be inhibitory in high concentrations (Paulo et al., 2003). Determination of amount of heavy metal content is very important to find out whether the level of metals are inhibitory for biological activity. High amounts of heavy metal can also limit utilization of excess sludge produced in anaerobic digestion (Lema et al., 1988). Leachate can contain significant amount of heavy metals (Wiszniowski et al., 2006) and the heavy metal content of the leachate should be