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Determination of biogas generation potential as a renewable energy source from supermarket wastes

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ABSTRACT

Fruit, vegetable, flower waste (FVFW), dairy products waste (DPW), meat waste (MW) and sugar waste (SW) obtained from a supermarket chain were anaerobically digested, in order to recover methane as a source of renewable energy. Batch mesophilic anaerobic reactors were run at total solids (TS) ratios of 5%, 8% and 10%. The highest methane yield of 0.44 L CH_4/g VS_{added} was obtained from anaerobic digestion of wastes (FVFW + DPW + MW + SW) at 10% TS, with 66.4% of methane (CH_4) composition in biogas. Anaerobic digestion of mixed wastes at 5% and 8% TS provided slightly lower methane yields of 0.41 and 0.40 L CH_4/g VS_{added}, respectively. When the wastes were digested alone without co-substrate addition, the highest methane yield of 0.40 L CH_4/g VS_{added} was obtained from FVFW at 5% TS. Generally, although the volatile solids (VS) conversion percentages seemed low during the experiments, higher methane yields could be obtained from anaerobic digestion of supermarket wastes. A suitable carbon/nitrogen (C/N) ratio, proper adjustment of the buffering capacity and the addition of essential trace nutrients (such as Ni) could improve VS conversion and biogas production yields significantly.

1. Introduction

The retail sector is rapidly growing in Turkey, and the number of supermarkets has increased from 2135 in 1998 to 8252 in 2008 (Sogut et al., 2012). No information was encountered in literature reporting the amount or breakdown of waste generated from supermarkets in Turkey, but it is clear that the rapid development in this sector is likely to result in an increased amount of waste generation. The food waste generation from supermarkets was estimated to vary between 5–45 tons/month or 1–10 tons/week (Alkanok, 2012).

Anaerobic digestion of vegetable and fruit residues and leftovers from markets has already been evaluated in different studies (Ranade et al., 1987; Mata-Alvarez et al., 1992, 2000; Viswanath et al., 1992; Edelmann et al., 2000; Rajeshwari et al., 2001; Lastella et al., 2002; Bouallagui et al., 2003, 2004, 2005, 2009; Anhuradha et al., 2007; Garcia-Pena et al., 2011; Jiang et al., 2012; Zeshan et al., 2012). However, the information regarding anaerobic digestion of mixed supermarket wastes and residues in literature is scarce. Furthermore, the influence of essential trace metals such as nickel (Ni), zinc (Zn), molybdenum (Mo), selenium (Se), copper (Cu) and various commercial preservatives used in food industry on anaerobic digestion of supermarket wastes is also worth investigating.

Therefore, in this study, utilization of mixed market wastes, whose expiry dates were due, was evaluated for production of biogas as a source of renewable energy. Meat wastes, dairy products waste, fruit wastes, vegetable wastes, flower wastes and sugar containing waste products were obtained from a supermarket chain and batch anaerobic digestion tests were conducted to determine the potential of energy recovery from these materials. The digestate from anaerobic digestion process was also evaluated to determine whether the digestate was suitable for further utilization in agricultural activities.

2. Materials and methods

2.1. Substrates

Fruit, vegetable and flower waste (FVFW), meat waste (MW), sugar waste (SW), and dairy product waste (DPW) were used as substrates in this experimental study. The FVFW consisted of fruit, vegetable and flowers that were discarded as waste from supermarkets. The MW included poultry, fish and other meat products that were both packaged and delicatessen products. The DPW consisted of yoghurt, cheese, milk, milk puddings and other dairy products, while the SW included products such as chocolate, candy, chocolate wafers, and sugar. These substrates were obtained from the waste storage facility of one of the leading supermarket chain in Turkey. Initially, the wastes were shredded in order to enhance digestion. An inoculum from an industrial anaerobic waste-

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water treatment plant was also used in order to initiate biological activity in batch reactors. The substrates were stored at 4 °C prior to experiments. The characteristics of the substrates and the inoculum are given in Table 1.

2.2. Experimental design

During the experiments, the supermarket wastes were anaerobically digested for the determination of the biogas production potential. Two different sets of experiments (Set I and Set II) were conducted in the study and all of the reactors were operated in parallel ($n = 2$). Therefore, average results were reported. The control reactor only contained the seed sludge. The experiments lasted for about a month, when the biogas production curve reached a plateau. The experimental protocol of the whole study is given in Table 2. In Set I, batch reactors R1–R2, R3–R4 and R5–R6 contained FVFW, DPW, and Mix. W, respectively, while R7 contained only inoculum as the control reactor. All the reactors were operated at 5% TS in Set I. In Set II, batch reactors R1–R2, R3–R4, R5–R6, and R8–R9 contained SW, MW, Mix. W (8% TS), and Mix. W (10% TS), respectively, while R7 was run as the control reactor. The TS values of R1–R2 and R3–R4 were 5% in Set II. The values of pH, VS, alkalinity, VFA, TKN, ammonia (NH_3) and TP of reactor contents before and after digestion tests in Set I and Set II are given in Table 3. Borosilicate glass bottles with total volume of 1 L were used as batch digesters. In each set of experiments, the reactors were loaded with the selected wastes and inoculum. The substrate to inoculum ratio (S:I) was chosen as 9:1 by weight (w/w). The total solids (TS) concentration of these mixtures in reactors were adjusted to simulate wet anaerobic digestion conditions, where the TS value of the reactor contents is around or lower than 8–10% (Weiland, 2006). After loading, the pH of the reactors was adjusted to neutral range using 1 N potassium hydrogen carbonate ($KHCO_3$) solution in order to provide adequate buffering capacity to the system (Demirel and Scherer, 2009). The digesters were sealed with rubber stoppers to prevent leak and they were kept in a room with an average ambient temperature of around 35–37 °C to provide mesophilic conditions. The temperature of the room was regulated by an automatic heat controller. Daily gas production was measured by using water displacement method and corrected for standard temperature and pressure (STP). During the digestion period, the reactors were manually mixed each day prior to gas measurement to maintain intimate contact between the microorganisms and the substrate. Daily gas production was recorded and corrected for STP and the biogas composition was measured once a week.

Table 1
The characterization of the substrates and the inoculum used in the experiments.

Parameter	Unit	FVFW	DPW	SW	MW	Inoculum
TS	%	31.58	42.25	35.20	41.00	7.20
VS	% of TS	85.00	63.10	93.38	48.61	57.40
Carbon	%	47.02	78.92	39.06	63.71	41.16
Nitrogen	%	2.46	3.86	1.50	7.50	2.31
Hydrogen	%	5.37	9.13	8.60	7.34	4.44
C/N	–	19	21	26	9	18
Sodium (Na)	g/kg	0.05	15.00	4.15	9.58	0.40
Calcium (Ca)	g/kg	12.35	22.50	0.24	5.75	2.50
Magnesium (Mg)	g/kg	0.97	1.23	2.50	0.78	0.08
Cadmium (Cd)	g/kg	ND	ND	ND	ND	0.01
Nickel (Ni)	g/kg	ND	ND	ND	ND	0.02
Zinc (Zn)	g/kg	0.03	0.04	0.02	0.04	0.03
Chromium (Cr)	g/kg	ND	ND	ND	ND	0.02
Lead (Pb)	g/kg	ND	ND	ND	ND	ND
Copper (Cu)	g/kg	0.01	0.01	ND	0.01	ND

FVFW: fruit, vegetable, flower waste; DPW: dairy product waste; SW: sugar waste; MW: meat waste.
ND: none detected.

2.3. Analytical methods

The measurements of total solids (TS), volatile solids (VS), total Kjeldhal nitrogen (TKN), ammonia nitrogen (NH_3), total phosphorus (TP) and alkalinity for characterization of supermarket wastes and inoculum were conducted according to the procedures outlined in Standard Methods (APHA, 1998). Analyzes of carbon (C), nitrogen (N) and hydrogen (H) for supermarket wastes were carried out using a Costech Elemental Analyzer. Calcium (Ca), sodium (Na), magnesium (Mg), cadmium (Cd), nickel (Ni), zinc (Zn), chromium (Cr), lead (Pb), and copper (Cu) concentrations in supermarket wastes and inoculum were measured using a Perkin Elmer AAS. The supermarket wastes were digested according to Standard Methods prior to TKN, TP and heavy metal analyzes. TS, VS, C, N, and H results were reported in percentage (%), while the results for TKN, TP, alkali and heavy metals were reported as g/kg. The measurement of pH was conducted using a WTW pH-meter. The composition of biogas, namely methane (CH_4) and carbon dioxide (CO_2), was measured using a HP 6850 Gas Chromatograph with a thermal conductivity detector (TCD). The volatile fatty acid (VFA) measurements were performed using a Perkin Elmer 600 Gas Chromatograph with a flame ionization detector (FID). The VFA content of the supernatant was measured after the digestion test was accomplished.

3. Results and discussion

3.1. Biogas production potential of supermarket wastes

The cumulative biogas and methane production values of each reactor in Set I are shown in Fig. 1a and b. The highest average cumulative biogas production was observed to be 6175 mL in R1–R2 (FVFW), while the average cumulative biogas production for R3–R4 (DPW) and R5–R6 (Mix. W) were 4710 and 6038 mL, respectively. However, the highest average cumulative methane production was observed in R3–R4 (DPW) as 432 mL, while in R5–R6 (Mix. W), it was 386 mL. The highest methane composition of biogas was measured to be 57.3% in R3–R4 (DPW). The highest average VS removal of 50% in Set I was obtained in R1–R2 (FVFW), while for R3–R4 (DPW), and R5–R6 (Mix. W), VS removals were 45% and 47%, respectively (Table 3). Even though fruit and vegetable wastes could be defined by their high moisture and organic contents and they were readily biodegradable (Jiang et al., 2012), only 50% of VS conversion for FVFW observed in this study seemed low, when compared with values of 95% (Bouallagui et al., 2005) and 81.3% (Jiang et al., 2012). In addition, lack of trace elements such as Fe, Ni, Co, Mo and Mn in FVFW could also have reduced the conversion of VS and biogas production potential as well (Lane, 1984), since no trace metal solution was used in this work. In FVFW, no Ni was detected, while Cu and Zn were available (Table 1).

DPW contained lactose, which was readily biodegradable, however, the other components of DPW, such as fats, might have decreased the biogas yield, since the intermediates of fat degradation, glycerol and long chain fatty acids (LCFAs) were reported to inhibit the anaerobic digestion process (Chen et al., 2008). Cho et al. (2013) also stated that the accumulation of unsaturated LCFAs in batch anaerobic digestion systems might also affect the methanogenic activity when dealing with food wastes. For R5–R6 (Mix. W, 5% TS), even though lower cumulative biogas and methane production values were observed than those of R1–R2 (FVFW) and R3–R4 (DPW), the final pH (a very slight change