Performance of Anaerobic Digestion with Hydrothermally Pretreated Municipal Sludge

X. Liu[1], Y. Tang[2], S. G. Pavlostathis[1]

[1]School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia, 30332-0512, USA

[2]School of Earth & Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332-0340, USA

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Presenting author email: spyros.pavlostathis@ce.gatech.edu

The current study aimed to systematically investigate the effect of hydrothermal treatment (HT) on mixed sewage sludge (i.e., primary and waste activated sludge) solubilization, ultimate digestibility and semi-continuous anaerobic digestion. The sludge used in this study was a mixture of the primary sludge (PS) and waste activated sludge (WAS) at a total solids (TS) ratio of 63:37, obtained from a local municipal wastewater treatment plant. HT was performed at three target temperatures: 90, 125 and 155 °C. The effective HT duration for each target temperature was 1 h (3 h of pre-heating to reach the target temperature plus a holding time of 1 h at the target temperatures, total heating duration 4 h).

The ultimate digestibility was evaluated through biochemical methane potential (BMP) tests with pre-reduced medium and pre-incubated anaerobic inoculum. The initial seed and substrate concentrations were both 3 g COD/L. Anaerobic digestion tests were conducted using four semi-continuous digesters (R1, R2, R3 and R4), set up and operated at 35 ºC. All four digesters were inoculated with predigested anaerobic sludge. The feed for R1, R2, R3 and R4 was raw sludge mixture, and pretreated sludge mixture at 90, 125, and 155 ºC, respectively. The target solids retention time (SRT) and organic loading rate (OLR) in all the digesters for phase I and II were 20 d and 3.5 g COD/L-d, and 10 d and 7 g COD/L-d, respectively. The digesters were fed every three and two days during phase I and II, respectively. pH, total solids (TS) and volatile solids (VS) were determined according to the Standard Methods (APHA, 2012).TCOD, SCOD, ammonia, phosphate, TN and TP were measured with HACH vial test kits. Biogas composition (i.e., carbon dioxide and methane) were measured using a gas chromatography (GC) unit (Agilent Technologies, Model 6890N; Agilent Technologies, Inc., Palo Alto, CA) equipped with two columns and two thermal conductivity detectors (Tugtas and Pavlostathis, 2007). VFAs were determined by gas chromatography/flame ionization detection as previously reported (Misiti et al., 2013).

HT significantly increased the SCOD concentration of sludge mixture and increased linearly with temperature. HT at 90 and 125 ºC greatly enhanced sludge solubilization but did not enhance acidification, while HT at 155 ºC enhanced both solubilization and acidification. At 155ºC, although acidification was greatly enhanced, the predominant volatile fatty acid (VFA) was propionate (54%), which may be inhibitory to anaerobic digestion. In addition, HT significantly enhanced nitrogen release, as evidenced by increased soluble nitrogen concentration.

For phase I, the ultimate substrate biodegradability for the raw sludge mixture, and the sludge mixture after HT at 90, 125, and 155 °C was 0.583, 0.581, 0.608, and 0.655 mg $COD_{Methane}$/mg COD, respectively. The pseudo-first-order rate constant (k_f) for methane production for raw sludge mixture, and the sludge mixture after HT at 90, 125, and 155 °C was 0.169, 0.173, 0.194, and 0.191 d^{-1}. For phase II, the ultimate substrate biodegradability for the raw sludge mixture, and the sludge mixture after HT at 90, 125, and 155 °C was 0.569, 0.608, 0.639, and 0.577 mg $COD_{Methane}$/mg COD. The pseudo-first-order rate constant (k_f) for methane production for raw sludge mixture, and the sludge mixture after HT at 90, 125, and 155 °C was 0.171, 0.171, 0.180, and 0.204 d^{-1}.

Performance summary data of the four semi-continuous digesters during phase I and II are shown in Table 1 and 2, respectively. During phase I, in all four digesters, the COD_{VFA} was quite low (<161 mg/L), with acetate as the dominant VFA. The acetate fraction ranged from 68% to 100% for R1, 64% to 100% for R2, and 79% to 98% for R3, and 35 to 73% for R4, respectively. During phase II, the VFA concentrations as mg COD/L of R1-R3 were less than 61 mg COD/L, whereas the VFA concentration in R4 ranged from 3444 to 4170 mg COD/L. For R1-R3, acetate was the dominant VFA. The acetate fraction ranged from 95% to 100% for R1, 61% to 100% for R2, and 27% to 100% for R3, respectively. Propionate was the dominant VFA in R4 and ranged from 77% to 83%.

Table 1. Performance summary of four semi-continuous digesters – Phase I (20 d SRT)

Parameter	R1	R2	R3	R4
pH	7.67±0.02	7.71±0.05	7.70±0.04	7.65±0.05
VS destruction (%)	39.2	41.8	49.0	48.4
TS destruction (%)	28.1	33.1	35.5	34.3
Total COD destruction (%)	44.3	49.4	53.9	53.5
Crude protein removed (%)	29.4	38.5	35.4	46.7
Effluent ammonia (mg N/L)	1257±70	1565±92	1562±78	1733±41
Effluent phosphate (mg P/L)	1.7±0.7	2.0±1.5	1.9±0.8	2.5±0.5
COD balance (%)	0.2	0	0.9	-1.0
Biogas production (mL/L-d at STP)	748±23	826±4	888±10	943±21
Methane production (mL/L-d at STP)	535±21	602±11	646±14	661±12
Methane (%)	71.5	72.9	72.7	70.1

Table 2. Performance summary of four semi-continuous digesters – Phase II (10 d SRT)

Parameter	R1	R2	R3	R4
pH	7.32±0.06	7.33±0.03	7.34±0.06	6.98±0.01
VS destruction (%)	41.7	45.0	43.2	48.4
TS destruction (%)	33.3	36.3	34.1	38.7
Total COD destruction (%)	49.9	48.3	44.4	37.5
Crude protein removed (%)	26.4	26.2	21.6	30.3
Effluent ammonia (mg N/L)	864±46	917±33	866±38	1143±68
Effluent phosphate (mg P/L)	32±3	26±5	29±4	118±8
COD balance (%)	5.2	3.0	-4.0	-2.6
Biogas production (mL/L-d at STP)	1706±18	1655±20	1754±11	1564±18
Methane production (mL/L-d at STP)	1202±19	1118±8	1210±15	1013±6
Methane (%)	70.5	67.6	69.0	64.8

The main results of the semi-continuous digestion tests are as follows:

1. For phase I, at 20 d SRT, HT enhanced TCOD, VS, and TS destruction in a decreasing order of 155 ^{o}C ≈ 125 ^{o}C > 90 ^{o}C > Raw sludge;
2. For phase II, at 10 d SRT, HT at 90^{o}C and 125^{o}C enhanced TCOD destruction whereas HT at 155^{o}C negatively impacted TCOD destruction, possibly due to accumulation of propionate in R4 (1833-2238 mg COD/L);
3. Both HT and anaerobic digestion led to crude protein destruction;
4. Due to substrate hydrolysis and fermentation, an increase in the produced ammonia was observed for all four digesters in both phases. The ratio of net ammonia produced to protein removed ranged from 14.0 to 22.8%; and
5. Soluble phosphate decreased significantly in digester effluents. Good TCOD, TN and TP balances for both anaerobic digestion phases were achieved (<8.4%).

Additional data, such as detailed N and P balances, the effect of HT and combined HT/anaerobic digestion on sludge dewaterability, as well as the microbial community structure as a function of combined HT/anaerobic digestion and SRT will be presented.

References

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