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➢ *ORAL PRESENTATION*

Effect of Temperature and Organic Loading Rate on the Methane Yield in Anaerobic Digestion of Municipal Sewage Sludge

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Abstract

Anaerobic digestion has been considered as the most suitable stabilization process for sewage sludge due to conversion to methane (energy) and useful biosolid as the end products. This study was conducted to evaluate the effect of different organic loading rates (OLR) and operational temperatures on the methane yield of the sewage sludge digestion in a municipal wastewater treatment plant (WWTP). The mesophilic temperatures of 35 and 38°C and three levels of OLR (0.72, 0.94 and 1.3 kg VS/m^3/d) were applied to a laboratory-scale semi-continuously fed anaerobic digester. The duration of the digestion was approximately 90 days for each level of OLR. The methane yield and volatile solids removal (VS_r) increased with increasing OLR and temperature. Methane yields at 0.72, 0.94 and 1.3 kg VS/m^3/day OLRs, respectively, were obtained as 0.32, 0.42 and 0.44 L/(gVS_{fed}.d) at 35°C and 0.42, 0.48 and 0.52 L/(gVS_{fed}.d) at 38°C. VS_r increased from 42 to 55% with increasing temperature and OLR. As the result, 38°C and 1.3 kg VS/m^3/day OLR proved to be beneficial for the anaerobic digestion of sewage sludge.

Keywords: anaerobic digestion, sewage sludge, methane, mesophilic, temperature.

INTRODUCTION

More focus has been placed on renewable and sustainable energy as an alternative to fossil fuels due to the continued growth of the global population and the steep rise in energy source demand. Future power sources that promise to be dominant include renewable energy (Zhou et al., 2012). Methane gas, a valuable and environmentally beneficial biofuel, is the major component of biogas, a promising renewable fuel produced by the anaerobic digestion (AD) of sewage sludge. Methane gas can be pumped into the natural gas distribution system or used directly to generate heat and electricity (Alqaralleh et al., 2015). Sludge and wastewater are the two main components that need to be handled in municipal wastewater treatment plants (WWTP). Stabilization and disposal of the sewage sludge generated during the treatment process is one of the most challenging and expensive issues in the field of environmental engineering. Primary sedimentation removes settleable materials that are easily thickened by gravity, producing primary sludge (PS) as a byproduct. Waste activated sludge (WAS) is biological sludge made up of particles that escape primary treatment and biological conversion products as bacterial cells and related polymers from soluble organic matter in the primary effluent (Arnaiz et al, 2006). The mixture of PS and WAS is thickened and stabilized in anaerobic digesters that produce methane which can recover up to 75% of the energy used by the entire WWTP (Erdirencelebi and Kucukhemek, 2015). Sludge management at municipal WWTPs is a persistent environmental issue. 25–65% of the total operating expenses may go toward the stabilization and disposal of the sludge (Liu, 2003). As the number and capacity of municipal WWTPs increases, the amount of sewage sludge produced will reach high volumes globally (Alqaralleh et al., 2016). Sewage sludge will induce a persistent waste issue that needs an appropriate solution since municipal wastewater treatment can be thought of as a continuous operation in the future (Riau, et al., 2010). Anaerobic digestion needs to be improved in performance as the oldest and most significant method for stabilizing sewage sludge. Its potential advantages over other stabilization processes include the production of energy as methane, a reduction of 30–50% in the volume of sludge requiring final disposal and the production of sludge residue that, when sufficiently digested, can be free from most pathogens and offensive odours (Nges and Liu, 2010).The rate of methane production and digestion performance can be improved varying process parameters, such as temperature, sludge retention time (SRT), and organic loading rate (OLR) (Ferrer et al., 2011). Together, they have an impact on the composition of microbial communities, biochemical conversion pathways, reaction kinetics and thermodynamic equilibrium, and stoichiometry of the products produced (Labatut et al., 2014). Anaerobic digestion can be conducted at psychrophilic (<25°C), mesophilic (25-40°C), and thermophilic (>45°C) temperatures. The most common temperature applied is 35°C due to lower energy consumption and higher stability compared to thermophilic range (Gavala et.al, 2003). In this study, the effect of OLR and and temperature increase was evaluated on the performance of anaerobic digestion as methane yield and volatile solid removal (VSr) of the mixed sewage sludge under mesophilic conditions.

MATERIALS AND METHODS

Wastewater sludges

The mixed sewage sludge used in this study were obtained by mixing of PS and WAS obtained from a full-scale municipal WWTP in Konya. PS and WAS were mixed in a fixed proportion of 60:40 (v:v) and used as the feed sludge. The raw sludge samples were kept in the refrigerator to be stored at 4^{o}C during the experimental periods. Mesophilic seed sludge was collected from an anaerobic digester's outlet at the same WWTP. The main characteristics of PS, WAS and inocula used in this study were presented in Table 1.

Table.1 Characterization of the raw sludge fractions

Sludge type	pH	TS (mg/L)	VS (mg/L)
Primary Sludge	6.5-7.2	30000-50000	20000-35000
Waste activated sludge	6.9-7.8	7000-11000	5000-8000

Semi-continuous reactor operation

The semi-continuous anaerobic digester (total volume 5 L) was a laboratory-scale "New Brunswick Scientific Bioflo IIc" batch/continuous fermenter operated at mesophilic (35 and 38 ^{o}C) temperature levels until achieving a steady state. The study was carried out at 3 different OLRs and 2 temperature levels applied consecutively as presented in the Table 2. The reactor was considered to be in a steady-state condition when the methane yield was constant in a lower change range of 10%. Mesophilic anaerobic digestion study was carried out for a continuous period of over 240 d for both temperatures.

Analytical methods

Analysis of total solids (TS), volatile solids (VS), were performed daily according to the Standard Methods (APHA, 2005), pH of the sludge samples was measured by Hach Lange HQ40d Multi parameter instrument. The process performance was daily monitored with parameters of methane yield (CH4) and VS removal (VSr) during the experimental study. Methane production was measured by liquid (% 3 NaOH) displacement method. Methane yield was calculated by dividing daily methane production (L.d) by the amount of VS_{fed} (g).

RESULTS and DISCUSSION

Methane Yield

The methane yield, daily methane production and VSr efficiencies obtained during the experimental study were presented in the Figures 1-3. For all temperature and OLR periods, the anaerobic digester reached steady-state condition after a certain acclimatization period. Methane yields were obtained as 0.32, 0.42 and 0.44 L/g VS_{fed}/d, respectively, at OLRs 0.72, 0.94 and 1.3 kg VS/m^3/d under steady-state conditions at 35^{o}C. When OLR was increased to 1.3 kg VS/m^3/d a similar degree of increase was not obtained in the methane yield despite higher methane production (Fig. 1-2). This indicated that the rate of hydrolysis was exceeded. This observation was supported by the VS accumulation as presented in the Figure 3. Although the hydrolysis reaction was rate limiting, OLR increase promoted acidogenic and methanogenic activities. Similar finding was observed at 38^{o}C. Likewise, after a certain acclimatization period, steady state conditions were reached. Under steady-state conditions, methane yields obtained were 0.42, 0.48 and 0.52 L/g VS_{fed}/d at OLR 0.72, 0.94 and 1.3 kg VS/m^3/d, respectively. Methane yield increase occurred at 14-31% at 38ºC. Higher VS concentration in the digester at OLR 1.3 kg VS/m^3/d showed an accumulation supporting limited hydrolysis rate, similarly to 35ºC. In summary, increase in temperature did not enhance hydrolysis rate but the rate of intermediate reactions and methanization. Another factor enabling higher methane yields and daily production values was evaluated as the low decreases in the HRT (SRT) values while implementing OLR changes.

Table 2. Anaerobic digester's operating programme

Temperature (°C)	OLR (kg VS/m^3.d)	HRT:SRT (d)
35	0.72	30
	0.94	25
	1.3	22
38	0.72	28
	0.94	24
	1.3	20

VS Removal

Change in VS concentration and VSr efficiencies were presented in the Figure 3. VSr was obtained as 42, 48 and 53% at OLR 0.72, 0.94 and 1.3 kg VS /m^3/d, respectively, at 35ºC. Parallel increase in VSr indicated a degree of augmented hydrolysis rate but not at an equal degree compared to OLR increase. VSr occurred at higher levels as 44, 48 and 55%, respectively, at the same OLR values at 38ºC. The positive effect was significant on the VSr efficiency by OLR and temperature. VS accumulation in the digester indicated that the hydrolysis rate was exceeded at the highest OLR and proved useful to evaluate the optimum operational conditions for both methane recovery and VS reduction.

Compared to the previous studies carried out in the anaerobic digestion of sewage sludge (Table 3), the methane yield and VSr obtained for the mixed sludge digestion at 35ºC were mostly higher. Davidson et al. (2008) obtaind the lowest methane yield as 0.271 L/g VS_{fed}/d in the continuous reactor operated under extreme conditions at 35°C, HBS:13 d and OLR 2 kg VS/m^3/d. This indicated that high OLR and low HRT were not favorable for sewage sludge digestion resulting in considerably low methane yield. Malekzada (2019) obtained the methane yield at the highest level as 0.665 L/g VS_{fed}/d at 38°C and a similar OLR using an intermittent mixing mode. The general summary was that optimization of OLR was effective to reach the maximizable methane yield for any sewage sludge where extremely high OLRs and low HRTs would not be practicable in anaerobic digestion as the hydrolysis stage is slow and rate-limiting due to the slow biodegradability of the complex organic content for which chemical and physical pre-treatment methods are currently applied for fastened or up-graded anaerobic digestion process at real-scale.

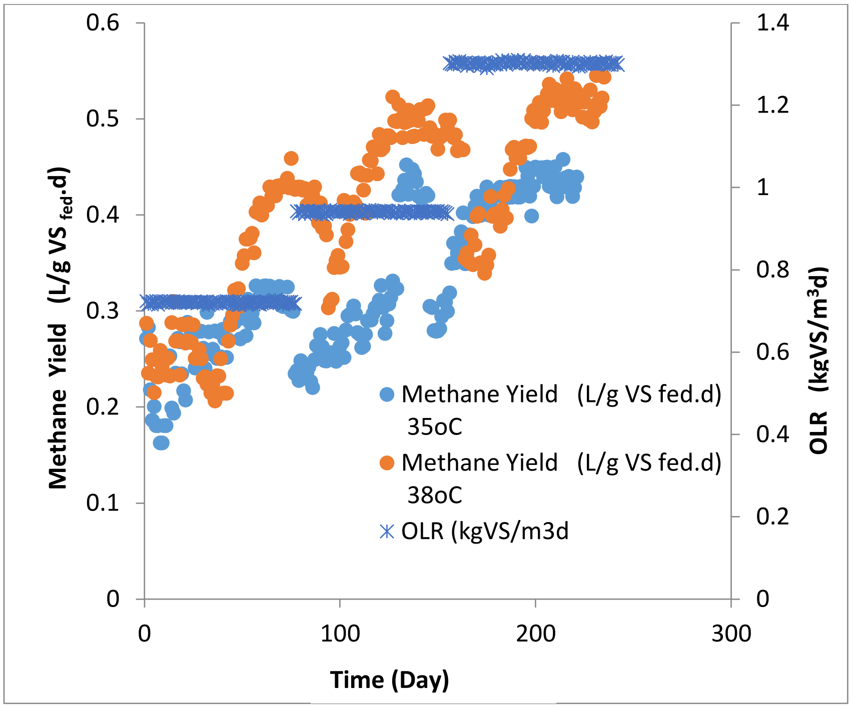

Figure 1. Methane yield values obtained at 35 and 38°C during the study at varied OLR

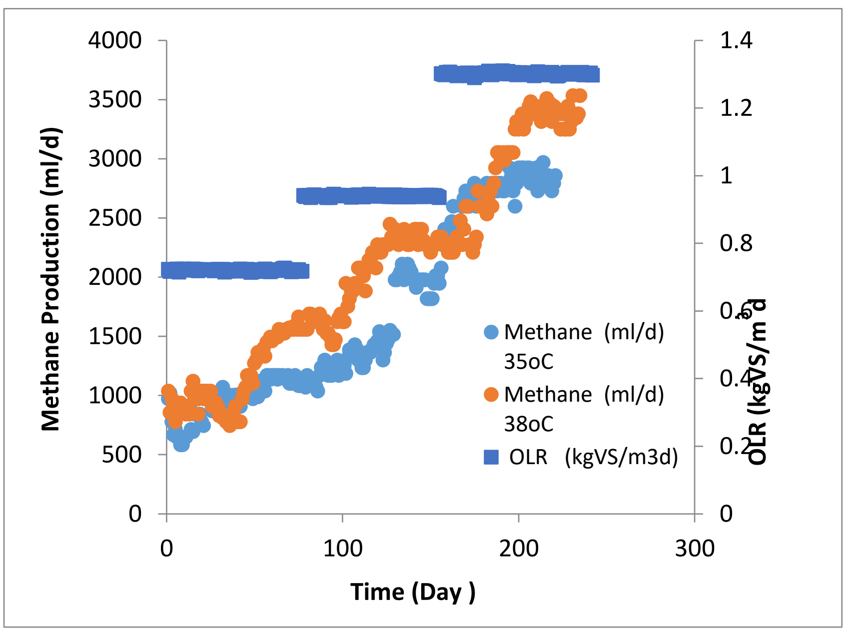

Figure 2. Methane production at 35 and 38°C during the study at varied OLR

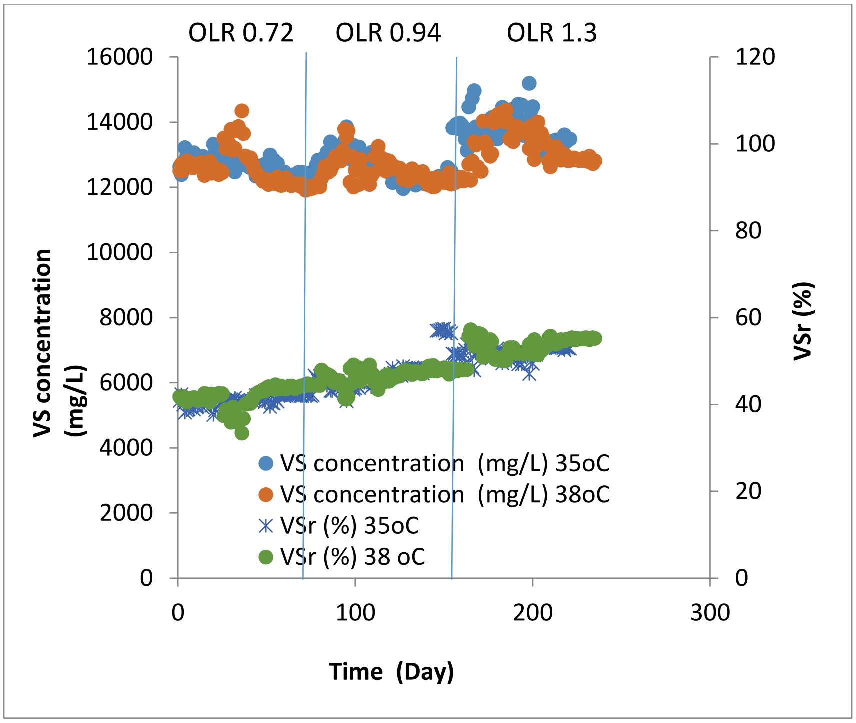

Figure 3.% UKM removal and VS concentration against OYH change in effluent sludge

Table 3. Summary with the previous sewage sludge digestion studies

Reference	Methane yield (L/g VS_{fed}.d)	VSr (%)	OLR (kgVS/m^3/d)	HRT (day)	Temperature (°C)
Davidsson et al. (2008)	0.271	45	2.5	13	35
Kabouris et al. (2009)	0.159	25	2.45		35
Malekzada (2019)	0.665	50	0.9	20	38
Yu et sl. (2014)	0.322-0.391		3		
Dai et al. (2017)	0.245	-	1.13		35
Kymäläinen et al. (2012)	0.245	72-75	0.9		35-37
Present Study	0.32-0.44	42-53	0.72-1.3	22-30	35
Present Study	0.42-0.52	44-55	0.72-1.3	20-28	38

CONCLUSIONS

The highest methane yield and VSr for this study was obtained at 38°C and OLR 1.3 kg VS/m^3/d. Increase in the methane yield, production and VSr efficiency was enhanced as the OLR and temperature increased. Increase in temperature to 38°C did not enhance hydrolysis rate significantly but the rate of intermediate reactions and methanization augmented. The hydrolysis rate was exceeded at 1.3 kg VS/m^3/d and resulted in VS accumulation at some degree despite increase in the digestion performance. Optimization of the anaerobic digestion of sewage sludge through operational parameters is simple and crucial and can reveal potential benefits in sludge line management in the municipal WWTPs.

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