A model based evaluation of anaerobic conversion kinetics on full-scale municipal sludge digesters

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INTRODUCTION

Plant-specific characterization of conversion kinetics is essential for design and operation of treatment processes. Process performance of sludge digesters can be assessed in lab-scale Specific Methanogenic Activity (SMA) tests where acetate is used as the main substrate. SMA test is a common methodology to determine the maximum biogas potential via measurement of the activity of acetoclastic methanogens (ASM) in comparison to observed biogas potential of the sludge in the anaerobic digester (Ince et al. 2001). Dynamic process simulation is a perfect tool to estimate true process kinetics and to evaluate the process performance (Insel et.al, 2020). In-depth analysis of full-scale municipal sludge digestors is therefore possible with the aid of modelling approach together with SMA and sludge biogas potential (SBP) batch tests. This study presents the results of performance analyses and modelling studies conducted for 3 full scale sludge digesters in advanced municipal wastewater treatment plants (AWWTP) located in Istanbul.

MATERIAL and METHODS

Laboratory scale batch anaerobic reactors were set up to characterize the mesophilic anaerobic digesters of three WWTPs (AD_1, AD_2 and AD_3) via SMA and SBP tests. SMA tests were carried out as described by Dubey and Hussain (2017) and Ince et al. (2001). SMA and SBP tests were conducted in 120 mL serum bottles and 4 L anaerobic reactors with addition of mineral nutrient medium and buffer solution. Sludges (S_1, S_2 and S_3) taken from three anaerobic digestors were used as inoculum in each test. SMA experiments were initiated by adding acetate solution with a final acetate concentration of 1874 mg/L. Control sets, in which acetic acid was not added, were run in parallel. SBP tests were fed with sludges of each plant (S_1, S_2 and S_3) to reflect actual digester operating conditions. All experiments were carried out under mesophilic conditions (35±2ºC). Biogas production was monitored by measuring pressure changes with the aid of a manometer, for about 20–25 days. Methane content of biogas was assumed to be 65% based on the data obtained from long term monitoring of full-scale ADs operation.

The SUMO® program was used for simulation of full-scale wastewater treatment plants. SUMO1 encrypted model was applied to calculate biogas production of anaerobic digesters. The steady state simulations of WWTPs were carried out using average values of annual pollution load and operating parameters. The dynamic simulation work was performed with daily flowrates, pollutant parameters, operation and sludge quantities. Model calibration with respect to biogas production was carried out in parallel with kinetic parameters obtained from the laboratory studies.

RESULTS and DISCUSSION

Cumulative biogas productions were monitored for SMA and SBP tests. The difference between the amount of biogas production obtained from the control reactor versus the biogas production in sets with acetate added is considered as net biogas production. SMA value is calculated through the conversion of this value into the amount of biogas produced per unit of time. In this way, the SMA values obtained for each facility are presented in Figure 1a. Obviously, the maximum SMA levels for all sludges were reached within 5 days. Accordingly, the maximum SMA values for AD_1, AD_2 and AD_3 were calculated as 75, 50 and 70 L CH_4/(kg VSS·day), respectively.

Based on the biogas potential tests, the amount of biogas formed per unit of VSS fed for S_1, S_2 and S_3 were calculated as 265, 193 and 350 L CH_4/kg VSS_{fed}, respectively (Figure 1b). Considering the data in the literature, cumulative total biogas formation was reported in the range of 365-470 L CH_4/kg VSS_{fed} (Kor, 2019; Hosseini and Eskicioglu et al., 2016, Cano et al., 2015; Bourgier et al., 2007). In this context, S_2 that feeds AD_2 has the lowest biogas generation potential although it has a readily biodegradable sludge characteristic. On the contrary, S_3 that feeds AD_3 has a high biogas formation capacity however it has slowly biodegradable characteristics. S_1 that feeds AD_1 has a moderate biogas production capacity, whereas the sludge has very rapidly biodegradable characteristics. Therefore, it can be concluded that low inlet biodegradable organic content and low anaerobic hydrolysis rate negatively influence the biogas production in the anaerobic digestors.

In parallel, annual performances of full-scale WWTPs were monitored and evaluated by means of dynamic model simulations. Figure 2 presents time course biogas production together with simulation results. The average biogas flow rates for ADs' were obtained as, 9160, 9115 and 13815 m^3/day, respectively. These findings were far below the guaranteed biogas production during design stages.

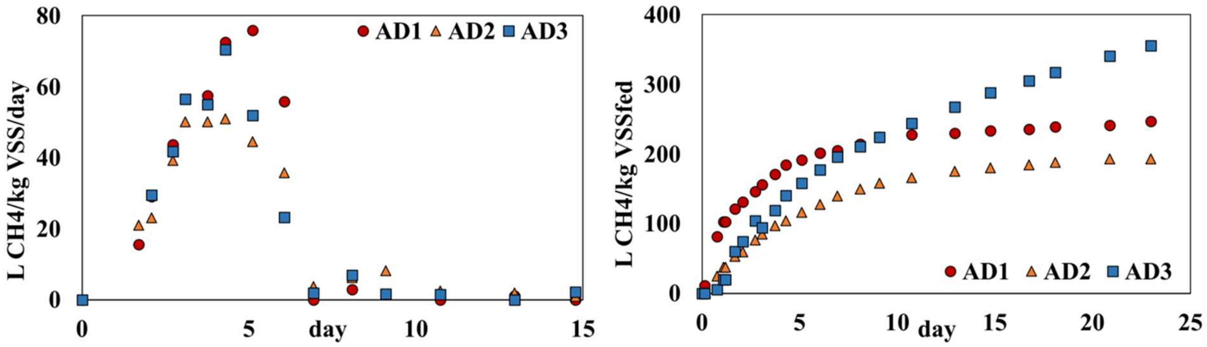

Figure 1. Batch (a) methanogenic activity tests and (b) anaerobic sludge digestion tests

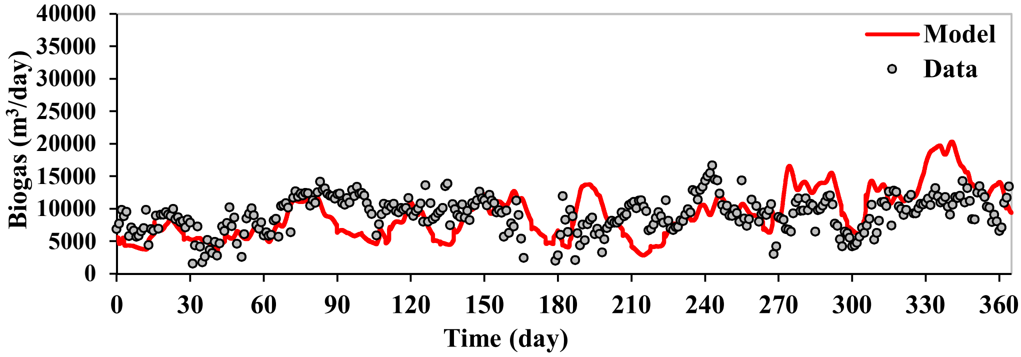

Figure 2. Daily biogas production and dynamic simulation for mesophilic anaerobic digester (AD1)

CONCLUSION

The low yields obtained in all three anaerobic sludge digestors are not related to the operation type, instead are related to the biodegradation characteristics of inlet organic matter and bio-sludge (biogas production capacity) that is formed in the treatment plants. Compared to the literature, the sludges exhibited closer activities with respect to SMA tests. On the other hand, low biogas production rates in anaerobic digester operations were attributed to reduced anaerobic hydrolysis rates possibly due to industrial contribution to the sewage system.

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