ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 51, No.3 July. 2022, pp 98-104
Journal Homepage: http://erj.bu.edu.eg

Effect of Thermal Pre-treatment and Anaerobic Co-Digestion of Sludge and Waste on Physical Characteristics and Total Organic Carbon Removal

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Abstract

A biogas potential test was used to study the physical characteristics and Total Organic Carbon (TOC) removal ratio caused by the anaerobic co-digestion (AcoD) of thermally pre-treated waste and sludge. Waste was mixed with sludge by a ratio of 1:2 (VS based) and the total solids was 11.20%. A fresh inoculum was mixed with the waste and sludge mixture by a ratio of 1:1 (based on volume). The waste and sludge were heated at 100, 120, 140, 160, and 180°C. Several mixing conditions were used 1) pretreated waste with untreated sludge, 2) untreated waste with pretreated sludge, 3) pretreated waste with pretreated sludge. These cases are replicated for all temperatures and compared with the blank reactor. The results indicated that the viscosity of the mixture was reduced with pretreatment and the optimal removal ratio was obtained in the second case at 140°C. The TOC removal ratio was 53.902% higher than the blank reactor which was 34.91%.

Keywords : Digestion; Anaerobic Co-digestion; Sludge, Waste, Total Organic Carbon.

1. Introduction

Food waste (FW) production has expanded dramatically as the world's population and civilization have grown [1]. The global demand for energy in 2030 is expected to increase from 472 quadrillions Btu to 678 quadrillions Btu. As a result of this massive need, different significant technologies of power like biomass, wind, and solar are urgently needed to replace fossil energies [2]. Biomass is one of the most widely used renewable energy sources, with the potential to significantly reduce carbon emissions. AD is one of the available options for converting natural biomass into fuel outcomes like biogas [3]. The Biogas produced from AD is a mixture of many gases like methane (CH_4) (60–70%), CO_2 (30–40%), and fraction quantities of H, H_2S, and NH_3[4]. Electricity and heat can be generated by using the biogas as well as to replace nonrenewable fossil energies with a biofuel. FW, animal waste, farming waste, and other biodegradable wastes can all be used to produce biogas [5]. When compared to landfills, and composting, AD is offered as an inexpensive and environmentally harmless solution for generating renewable energy [4], [6]. To solve the issues associated with mono-digestion of FW, AcoD of FW with different substrates like sludge has been suggested.

Waste management in Egypt is a great challenge. It has a high C/N ratio. Most of the industry utilizes AcoD to avoid the limited buffer capacity and high C/N ratio issues related to FW mono-digestion [7]. sludge has a high content of nitrogen and fraction elements but insufficient biodegradable organic content, thus limited biomethane resulting from mono-digestion [8]. Sludge has a large number of active bacteria, so it is a good co-substrate for microorganism production. Furthermore, the sludge's low ratio of C/N of 6–10 necessitates co-digesting with substrates with larger C/N ratios, like FW, to compensate for the absence of organic molecules and avoid process inhibition. The ideal C/N ratio for AD is considered to be between 20 and 30 [9]. The ideal hydraulic retention time for the mesophilic digestion is in between 10–40 days [10].

Different FW to SS mixing ratios may influence the AD performance because it signifies the balance of nutrient content in the mix [9].It was shown that FW added to the SS and mixed with a ratio of 1:2 (based on the volatile solids content). The maximum volume of biogas was generated after 21 days [11]. The best mixing ratio for AcoD depends on many factors as the characteristics and components of FW and SS. Due to the different customs and traditions of countries, the components of FW differ from place to place, which affects the AcoD.pH value is a critical parameter that has a great effect on the production of methane [12], [13]. Liu et al. showed that the maximum production of methane was occurred when the pH values was in between 6.50 to 7.50 [12]. pH reduction might be due Maillard reaction. pH was reduced because of acid production and the creation of cyclic nitrogen compounds from amines during the Maillard reaction, so these differences might be compensated to some extent by carbon dioxide loss [14].

In the current study, the total organic carbon and physical characteristics of waste and sludge after thermal pretreatment and AcoD were studied. The entity of this analysis was to acquire a more satisfactory knowledge of the performance of TP on the physical and chemical properties of BMWs. The total organic carbon and physical characteristics of the waste and sludge incorporate viscosity and dewaterability. The impacts of TP on the removal of TS, VS, and COD and biogas production were focused on the previous paper [15].

2. MATERIALS

The materials used in this research are sewage sludge, waste and Inoculum. The characteristics and sources of these materials are expressed in the following.

2.1 Feed Sludge

The sludge was brought from drying beds. It was kept at 4℃ inside the incubator. The laboratory analyzes of the sludge were performed as total solids (16%), volatile solids (10.10%),total organic carbon (60000 mg/l), and pH (7.50).

2.2 Waste

In this research, MSW is used as a substrate. The waste was mainly consisted of the kitchen waste. Non-biodegradable components like bones were eliminated. The substrate was prepared for co-digestion process by grinding it using grinding machine. The laboratory analyzes of the waste were done as total solids (13%), volatile solids (10.20%), total organic carbon (82000 mg/l), and pH (4.70).

2.3 Inoculum Source

Inoculum is a digested sludge. The inoculum used in this research was brought from El Gabal El Asfar WWTP in a prepared container. It was two types 1) dried digested sludge, and 2) fresh digested sludge preserved at 32°C until it reached the laboratory. The laboratory analyzes of the digested sludge were done as total solids (21% for dried and 3% for fresh), volatile solids (10.92% for dried and 2.20% for fresh), total organic carbon (70000 mg/l for dried and 60000 mg/l for fresh), and pH (7.90 for dried and 7.80 for fresh).

3. METHODOLOGY

The main purpose of this research is to study the effect of the anaerobic co-digestion of thermally pretreated waste and sludge mixture on the TOC removal. AcoD depends on the mixing ratio between the co-substrates (waste and sludge). The used waste to sludge ratio was based on the volatile solids and it was 1:2. This ratio generated the maximum biogas in biogas potential test at mesophilic condition after 21 days according to [8], [16]. The inoculum was mixed with the substrates based on the volume by 1:1 [17].

3.1 Batch Test

1. Prepare the substrates (waste and sludge) by diluting with distilled water to get the required volatile solids concentration.
2. Pre-treat each substrate alone in a glass beaker for five temperature (100, 120, 140, 160, and 180℃) for 30 minutes and cover the beaker to prevent the evaporation of water.
3. Prepare the inoculum sludge to the required concentration (TS of 11.20%) for AD by mixing the two types of the digested sludge.
4. After cooling the samples using the water path, mix the substrates in the reactors of 1 liter with 0.50 liter working volume (Fig 1) to get final TS of 11.20% as the following cases according to the mixing ratios:
    a. Blank case: mix untreated waste with untreated sludge and inoculum.
    b. Case 1: mix treated waste with untreated sludge and inoculum.
    c. Case 2: mix untreated waste with treated sludge and inoculum.
    d. Case 3: mix treated waste with treated sludge and inoculum.
5. Close all reactors carefully to prevent biogas leakage. The digestion process was done in a mesophilic prepared room (temperature 35±1℃).
6. Due to the digestion process, the biogas will be produced and transferred to the second bottle and measure the volume of displace water and it will be equal to the gas volume.
7. Duplicate all reactors for all pre-treatment temperatures.
8. At the end of the batch, measure the physical properties and total organic carbon and other parameters.

Fig 1. Glass bottle reactors

4. RESULTS AND DISCUSSION

The main purpose of this research is to study the effect of the anaerobic co-digestion of thermally pretreated waste and sludge in different physical properties like viscosity mixing and total organic carbon (TOC) removal. Using waste as a co-substrate with sludge improve the co-digestion process in terms of VS, TS, and COD removal and biogas production [8], [18], [19]. In this section, we will discuss the effect of thermal pretreatment on AcoD in physical characteristics and total organic carbon removal.

4.1 Effect of Thermal Pre-treatment on Physical Properties

It is noticed that the physical properties like viscosity and dewaterability were affected by TP. The viscosity of the sludge and waste was improvednoticeably, which led to the improvement of the mixing and sedimentation process. One of the main challenges facinghigh solid AcoD of the waste and sludge - in this research the total solids was 11.2% - is the mixing process but the thermal pretreatment might help to improve the mixing process because TP reduce the viscosity and this lead to use low energy and not specialized mixers. The viscosity is considered as a key factor in sedimentation. As the viscosity decreased, the sedimentation process improved. It is complied with Bougrier et al. [20] who stated that TP had great effects on the viscosity of sewage sludge. Sewage sludge without pretreatment was fake plastic liquid. As TP increased upto 150℃, it deceased the sludge apparent viscosity and there is no change in viscosity if TP exceeded 150 ℃. So, TP improved the settleability of sewage sludge because of the structure of sewage sludge modification [20]. Also, it was complied with Liu et al. who stated that after TP at 175 °C/1 hour, the viscosity reduced. The decrease in viscosity existed and enhances the performance of dewatering of municipal biomass wastes because of the demolition of extracellular polymers during TP. The decrease in viscosity of the AD indicated the digester could be fed with a higher WAS concentration and a more increased organic loading rate and production of biogas could be acquired. Also, as one of the major power consumers in an anaerobic technique, viscosity has been demonstrated to have a positive relationship with agitation power. Accordingly, the TP usage improves the chance of net energy decrease of the anaerobic system. [21].

Dewaterability is greatly affected by thermal pretreatment and the time of the treatment. However, the TH reaction changes the physical properties of the mixed substrates to those of a slurry, the dewaterability will be increased. Increased dewaterability indicates that the solid material has been altered into a slurry, implying that the TH reaction changes the particulate material to a soluble material. While the temperature of the TP increases, the time of reaction of CST and TTF is decreased due to the destruction of the sewage sludge cell walls and alters the intent of sludge water -which causes dewatering difficulty- to release water. The outcomes obviously mean that the sludge's physical structure was changed by TP [22]. Multiple particles in the waste are anticipated to flock together to form larger particles in the used mixture, therefore these flocs are possible to be broken down and transformed into smaller particles in the sludge during TP [23].

4.2 Effect of Anaerobic Co-Digestion on pH

Thermal Pre-treatment of waste and sludge has an effect on the pH values of the mixture. FIGURE 2 shows the effect of AcoD of thermally pretreated waste and sludge and blank mixture on pH values in the different three cases. The figure shows that the pH of the blank reactor is high. As the pre-treatment temperature increase from 100°C to 160°C, the pH value decrease and then increase again with increasing the temperature to 180°C. pH reduced might be due Maillard reaction. pH was reduced because of acid production and the creation of cyclic nitrogen compounds from amines during the Maillard reaction, so these differences might be compensated to some extent by carbon dioxide loss [14]. pH is a critical parameter that has a great effect on the production of methane [12], [13]. The pH values of the batch tests are located between the optimal ranges achieved by several studies. This study complies with Liu et al. who show that the maximum production of methane was occurred when the pH values was in between 6.50 to 7.50 [12].

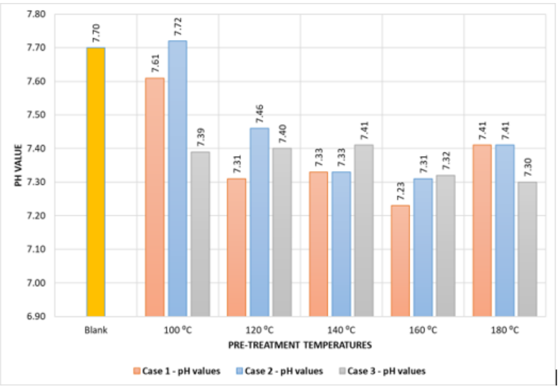

Fig 2. pH Values after the batch tests

4.3 Effect of Anaerobic Co-Digestion on TOC Removal

Microorganisms oxidize total organic carbon rich compounds to produce carbon dioxide and protons as end products [24], [25]. When growth conditions such as temperature and source of organic carbon are kept roughly consistent, it is anticipated that microorganisms' growth will be stable [25]. The Content of TOC removed, and TOC removal ratio are studied at the end of batch test. The batch had been ended after the biogas produced is less than 5ml/day and batch time was 23 days. As shown in FIGURE 3 and FIGURE 4, the thermal pretreatment has an effect on the TOC removal. The TOC removed thus TOC removal ratio increase as the TP increase till the treatment temperature of 140°C and the still approximately the same as the temperature of TP increase till 180°C. The removed TOC content and TOC removal ratio changed by changing the three cases. The best case in removing the TOC was case 2 (untreated waste + treated sludge) at temperature 140°C.

The value of TOC removed and removal ratio at blank reactor was 20087.9 mg/li (34.91%). For case 1 (treated waste + untreated sludge) at 100, 120, 140, 160, and 180°C were 21084.9 (36.64%), 24007.9 (41.72%), 27253.9 (47.36%), 29243.9 (50.81%), and 28990.9 (50.38%) mg/li respectively. For case 2 (untreated waste + treated sludge) at 100, 120, 140, 160, and 180°C were 25178.9 (43.75%), 28094.9 (48.82%), 31029.9 (53.92%), 28291.9 (49.16%), and 30320.9 (52.69%) mg/li respectively. For case 3 (treated waste + treated sludge) at 100, 120, 140, 160, and 180°C were 23776.9 (41.32%), 26421.9 (45.91%), 29290.9 (50.90%), 28869.9 (50.16%), and 27991.9 (48.64%) mg/li respectively. From these values, it is shown that the optimal case for removing TOC is the reactor containing the mixture of the untreated waste and the treated sludge at 140°C.

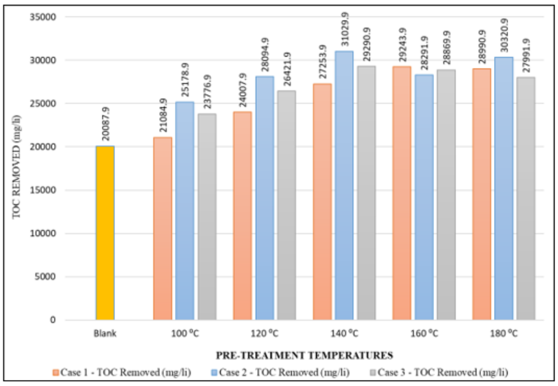

Fig 3. TOC Removed After Anaerobic Digestion

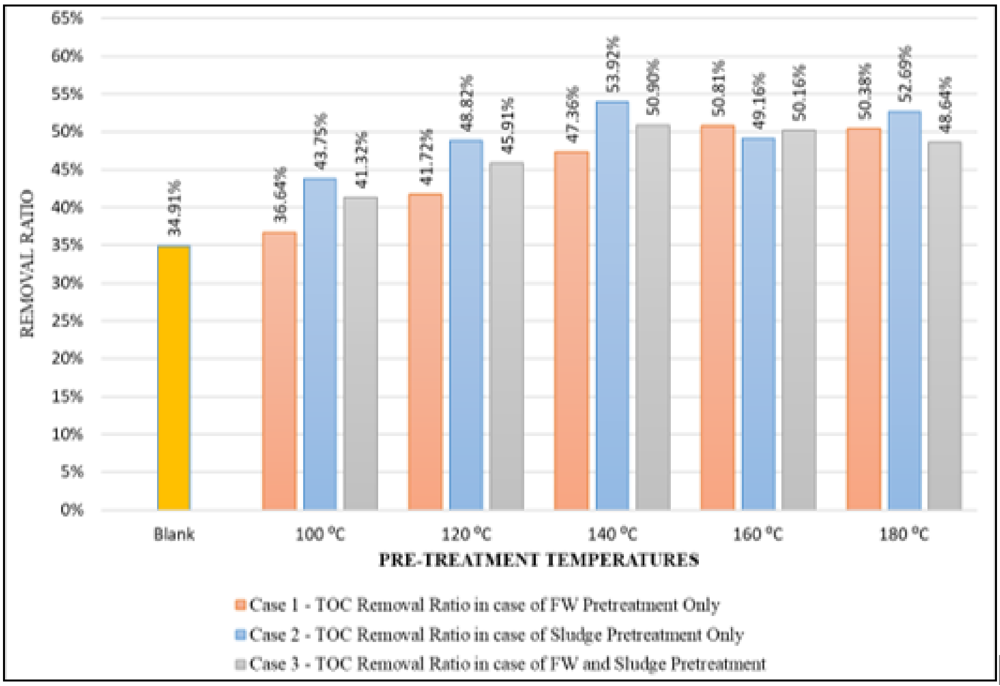

Fig 2. TOC Removal Ratio

The biogas production at this case was 5685ml more than the biogas produced in the blank reactor (4385 ml) by 29.65%. Fig 3 shows the biogas yield of the batch tests in terms of the removed COD, removed VS, and removed TOC. As the removed value increases, the biogas yield in terms of TOC removed decreases.

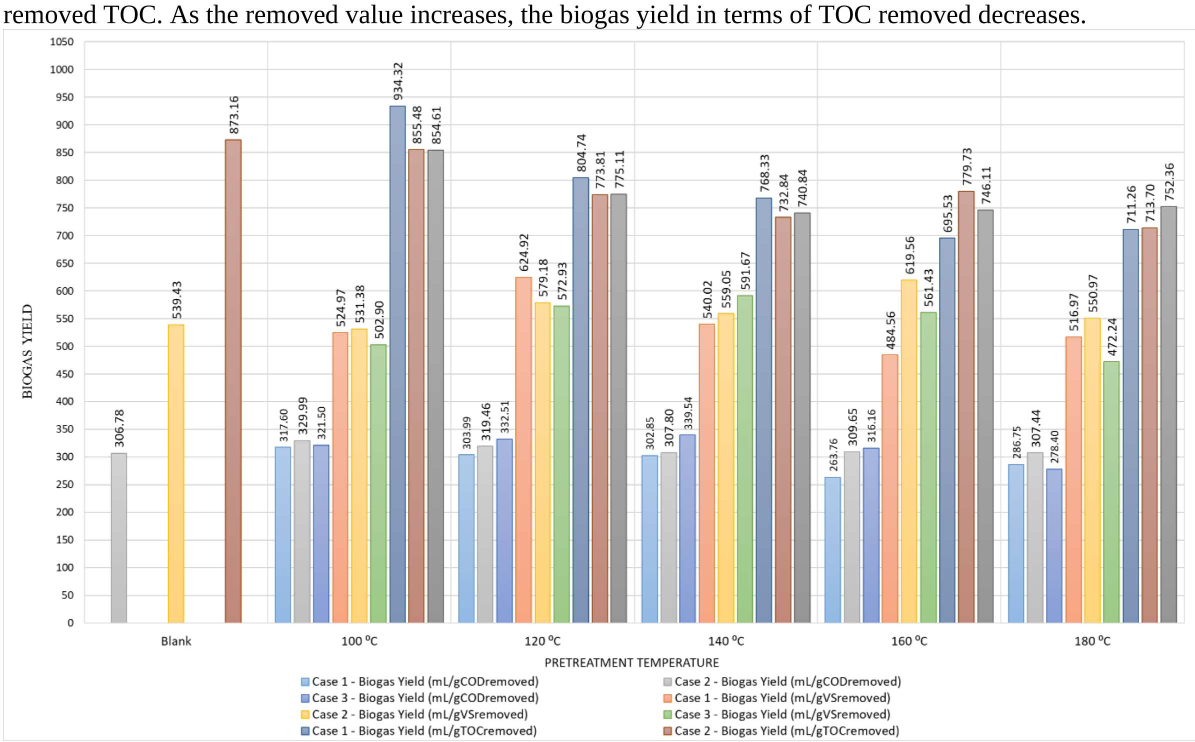

Fig 3. Biogas Yield for the batch tests

The biogas yield at the case 2 was 732.84 ml/gTOCremoved. COD removal was improved to be 51.09% more than the blank reactor which was 39.54%. Also, the TS and VS removal ratio obtained at this case was 33.18% and 58.90% that compiles with many studies as [20], [26], [27].

5. CONCLUSIONS

Waste using as a substrate with sludge has great benefits as improving the carbon to nitrogen ratio to be within the optimum range for anaerobic digestion. A biogas potential test was used to study the TOC removal ratio caused by the anaerobic co-digestion (AcoD) of thermally pre-treated waste and sludge. waste was mixed with sludge by a ratio of 1:2 (VS based) and the total solids was 11.20%. A fresh inoculum was mixed with the waste and sludge mixture by a ratio of 1:1 (based on volume). The waste and sludge were heated at 100, 120, 140, 160, and 180℃. Several mixing cases were used 1) pretreated waste with untreated sludge, 2) untreated waste with pretreated sludge, 3) pretreated waste with pretreated sludge. These cases are repeated for all temperatures and compared with the blank reactor. The results indicated that the optimal removal ratio was obtained in the second case at 140℃. The TOC removal ratio was 53.902% higher than the removal ratio obtained at the blank reactor which was 34.91%. As the removed value increases, the biogas yield in terms of TOC removed decreases. The biogas yield at the case 2 was 732.84 ml/gTOC$_{removed}$. The biogas production at this case was 5685ml more than the biogas produced in the blank reactor (4385 ml) by 29.65%. COD, TS and VS removal was improved more than the blank reactor. So, it is recommended to use the AcoD of untreated waste and pretreated sludge at 140℃ for improving TOC removal and highest biogas production

6. ABBREVIATIONS

WWTP	Wastewater Treatment Plant
VS	Volatile Solids
MSW	Municipal Solid Waste
C/N	Carbon To Nitrogen
TOC	Total Organic Carbon
AcoD	Anaerobic Co-Digestion
COD	Chemical Oxygen Demand
TS	Total Solids
TP	Thermal Pre-Treatment
NH_3	Ammonia
H_2S	Hydrogen Sulfide
CO_2	Carbon Dioxide
H	Hydrogen
TH	Thermal Hydrolysis
TTF	Time To Filter
CST	Capillary Suction Time
AD	Anaerobic Digestion

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