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Thermal Pretreatment of High Solid Digestion of Sewage Sludge

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Abstract

High solid anaerobic digestion (HSAD) for sewage sludge is a promising option to conventional AD since it minimizes treatment volumes, costs of transportation, and lower requirements energy; however, the long duration of the digestion is a major drawback. The purpose of this research was to study the effect of high solid anaerobic digestion of domestic WWTPs sludge on Methane yields and biochemical mechanisms. The effects of high-thermal pretreatment and solid content were examined in thebatch bioreactor for 22 days to determine the optimal thermal pretreatment temperature and the best solid content, the results show clearly that the TH improve the digestion of HSAD as the solid content ranged from 10 to 16 % with pretreatment at 180 ℃; the removal ratio was increased by 12.80% to 38%, 44% to 74% and 23% to 50% for COD, TS and VS respectively; also the gas production increased by 28 to 50% while methane yields were not significantly different, the solid content of 11% gives the high biogas production. Also, for sludge with a solids content of 11% at different temperatures the pretreatment at 180 ℃ gives high biogas production. and improved the performance as the COD, VS, and TS removal ratio increased from 49.28%, 30.91 %, and 36.45% to 71.68 %, 52.73%, and 63.5 % respectively, and the biogas production increased.

"Keywords: Thermal Pre-treatment, Anaerobic Digestion, High solids, Sewage Sludge

1. Introduction

WWTPs produced a large quantity of sludge during physical treatment, biological treatment, and chemical treatment and are mostly formed with dewatered biomass. Also, heavy metals, pathogens, and other dangerous materials are found in sludge [1]. Sludge from industrial and municipal WWTPs is residual biomass with major environmental consequences.

Methods of sludge treatment include thickening, anaerobic and aerobic stabilization, and sludge dewatering [2,3,4,5]. In Egypt, approximately two million tons of DS are produced yearly, and because of the density of population increasing and current low WWTPs capacity, an increase in the capacity and number of WWTPs is expected in the future; as a result, the sludge production is also expected to be increased [6]. The Nile River is the disposal of these vast amounts of sewage sludge, and cities located away from the banks of the Nile River dispose of the sewage sludge in the nearest available unoccupied area near WWTPs [7]. As a result, using sludge as a renewable energy source is significant from both an energy and an environmental standpoint. The process of converting organic materials in sludge to biogas is known as AD [8]. Although this procedure is often successful, it is limited in its applicability due to spatial and cost constraints. Because the sludge viscosity is high at higher TS hinders mixing and transferring mass, CAD generally treats sludge with a content of TS of 2-5 percent [9]. Traditional digesters require a large working volume because of the high content of water in SS; as a result, CAD is difficult to implement in small WWTPs and densely urbanized locations with limited space [10]. However, because of the special properties of the wastewater and treatment techniques, the content of organic in sludge solids is occasionally less than 50%. Poor organic content feedstocks usually cause low production of biogas during AD, which limits the benefit of AD.

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The content of total solids (TS) is an essential parameter affecting the performance of digestion. The mixing and pumping of the sewage sludge are difficult at higher content of TS, hence CAD of sewage sludge is done with content of TS between (2-6) % [11]. Anyway, the content of total solids can be enhanced up to 25% for (1) decreasing the area for storage within the wastewater treatment plant and (2) decreasing the transportation cost. Increased levels of TS lead to the increased capacity of the digester and less water in the feed sludge [12]. Furthermore, HSAD causes inhibitory metabolites accumulation like Hydrogen Sulfide (H_2S), LCFA, and FAN, which may slow down or damage the activity of methanogenic [13,14]. Also, the viscosity of dewatered sludge (DS) is high, which can make pumping and mixing activities difficult in AD.

HSAD may be a viable conventional AD alternative in order to improve AD applicability. The concentration of solids in high solid AD reactors improved up to 20%, and accordingly, less energy may be used for heating because of smaller digesters [15]. Furthermore, HSAD produces biogas volume extremely more than conventional digesters. Sludge with High-solid content may be easily acquired by DS dilution which contains a total solid content of about 20% or by sludge concentration with a lower TS than 2% by filtration or centrifugation. The consumption of high energy for the content's agitation of digester because of the high solids viscosity and limited digestion because of transferring of heat and blocking of mass are two downsides of HSAD. As a result, long times of digestion or low removal rates of organic characterize high solids AD as well as inefficient rates of hydrolysis [16]. The two unfavorable effects of HSAD somewhat cancel out the positive effects. Till now, there has been relatively little research on high-solids anaerobic mono-digestion of sludge, and all the studies that have been done have focused on enhancing agitation [10,16].

The dewaterability of sludge was first improved by thermal hydrolysis (TH) [17]. It permits the gel structure of sludge to degrade and linked water to be released. After pretreatment at 150℃ [18] or 180℃ [19], this enhances the dewaterability of sludge. in various research on TH for AD pretreatment [17,20,21], TH causes partial sludge solubilization, which improves AD. The majority of research suggests that the ideal temperature is between 160 and 180 degrees Celsius, with treatment duration ranging from 30 to 60 minutes. At this range of temperature, however, treatment duration has been demonstrated to have no effect [22]. Dohanyos suggested a 60-second heat treatment duration at 170 ℃ [23]. Thermal pretreatments include sanitation of sludge, sludge viscosity reduction with improved handling of sludge, and no additional energy requirements because energy needs can be met by excess production of biogas and the balance of energy is positive [24]. The initial sludge biodegradability has an impact on the production of methane, with bigger effects on hard sludge biodegradability [25] and better outcomes on waste-activated sludge (WAS) than on primary sludge (PS) [26]. While TH essentially decouples degradability from the age of sludge, a basic link still exists at long ages of sludge [27]. This study mainly aimed to investigate the effect of high solid anaerobic digestion of domestic WWTPs sludge on Methane yields and biochemical mechanisms. The BMP tests were used to study 1) the effect of the different concentrations of TS on HSAD performance to determine the optimum concentration at a certain pretreatment temperature, 2) the effect of different thermal pretreatment temperatures on the HSAD performance to determine the optimum pretreatment temperature.

2. Materials and Methods

2.1. Feed Sludge

The feed sludge utilized in the batch tests was the DS brought from El-Berka WWTP's drying beds in Cairo, Egypt. The capacity of El-Berka WWTP is 550,000 cubic meters per day and the population served is about 3 million persons. The biological treatment system used in this plant is the aeration tanks. The brought sludge was stored till used in the tests in 4℃. The distilled water was used to reach the required TS. The content of volatile solids is about 63.125% of total solids.

2.2. Seed Sludge

The used seed sludge is a mixture of fresh digested sludge from the anaerobic digesters of El-Gabal El-Asfar WWTP and dried sludge from the same plant, these two types of sludge were mixed till reaching the desired solid content. A closed container was used to collect the seed sludge for the lab. The sludge is stored in incubation treatment of 32℃ before use in biomethane tests in order to give a chance for the final digestion processes. Table 1 represents the properties of the used feed sludge and digested sludge.

Table 1. Characteristics of sewage sludge (SS) and the anaerobic inoculum.

Parameter	Unit	Value (average ± SD)		
		SS	Digested sludge (From digester)	Digested sludge (From Belt press filter)
Total COD	g/L	150 ± 4.1	----------	----------
TOC	g/L	60 ± 1.5	----------	----------
TS	g/L	160 ± 2.5	30 ± 0.5	210 ± 2.5
VS	g/L	101 ± 1.5	22 ± 0.5	109.2 ± 1.5
VS/TS	%	63.12	73.3	52
pH	−	6.12	8	6.5

3. Biochemical Methane Potential (BMP) Batch:

The batch tests were two sets of BMP tests (Table 2). The first set of BMP tests was used to study the effect of the different concentrations of TS on the HSAD performance. The used concentrations are five different concentrations for total solids 10,11,12,14 and 16 % to determine the optimum concentration at a certain pretreatment temperature of 180℃ for 30 minutes. The second set of BMP tests was used to study the effect of different thermal pretreatment temperatures on the HSAD performance using the optimal TS concentration from the first set. The batch in this set was run with five different pretreatment temperatures 100,120,140,160 and 180℃ for 30 minutes to determine the optimum pretreatment temperature. Table 2 represents the experimental operating conditions for the two sets used in the batch test. The batch test for the two sets was done by using 1000 ml glass bottles with an effective volume of 500 ml. It consisted of 3 bottles (The first bottle is the digester and connected with the water displacement bottle by using a plastic tube and the displaced water will be collected in the third bottle) as shown in Fig. 1. All reactors are duplicated.

The distilled water was added to the sludge to get the required concentrations of TS. The BMP digesters were closed carefully with septa from rubber so that the gas does not leak. The first and second sets were studied at the mesophilic conditions at 35 ± 2℃ for 22 days for both sets. The inoculum sludge was added to the reactors with a ratio of 1:1 (volume-based) with sewage sludge for maximum production of biogas according to Lopes et. al. [28]…

Fig. 1. A photograph of the three batch cells in lab.

The production of biogas was simulated by the method of displacement of water for both sets. All reactors were carried out until no more production of biogas.

Table 2. Experimental operating conditions for BMP tests

	1st Set	2nd Set
Temperature	35± 2 ℃	35± 2 ℃
Ts	10,11,12,14 and 16 %	11%
Pre-treatment Temperature	180 ℃	100,120,140,160 and 180 ℃
Time of pre-treatment	30 min	30 min

4. Lab analysis

At the start and the end of the batch tests, TS, VS, and COD were measured. The digested sludge samples were measured using the traditional techniques (MEP, 2002). A pH meter was used to measure the pH values (pHep, HI 98107 pocket-sized pH Meter). The biogas production was measured during the experiment (the volume of water displaced due to the pressure of biogas was utilized to determine the volume of biogas produced).

5. Results

5.1. Stage I results

The effect of thermal pre-treatment on COD removal is shown in Fig. 2. The total COD removal ratio increased from (41-54) % for blank (BL) to (55-70) % for reactors R180 (treatment at 180 ℃) and the reactor with 12 % concentration had the higher COD removal ratio. The increase in COD removal ratio ranged from 12.80% to 38%, thus, the treatment allowed an increase in total COD removal efficiency. The COD removal ratio comply with the results of (Bougrier et al 2006) who found that the efficiency of COD removal in blank sludge reached (34-52) % while the COD reduction achieved in the model with a thermal treatment of 150 and 170 ℃ was 60, 70% removal, respectively.

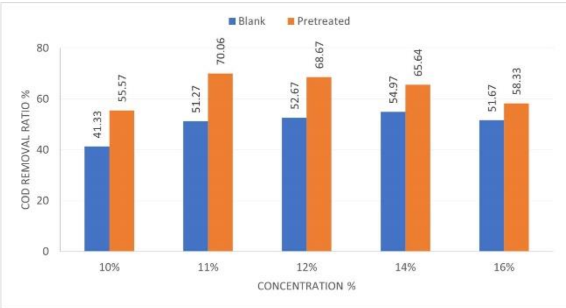

Fig. 2. COD removal ratio for the Batch (1st Set).

The effect of thermal treatment on VS and TS is shown in fig. 3 and fig. 4. TS removal ratio ranged between 45% and 51.43% for pre-treated sludge against 28.18 to 35.71% for high solid anaerobic digestion without pre-treatment while VS removal ratio was (47.52-58) % for pre-treated sludge against (35-40.6) % the untreated reactors. The increase in TS and VS removal ratio concerning sludge quantity reduction, and 180℃ pre-treatments allowed an improvement of suspended matter removal. The achieved volatile solids removal values are compiled with the values committed by several of the researchers who noted the best TP temperatures ranging between 160 and 180 ℃, with a duration of 30 and 60 min. The VS removal ratio due to these conditions is 40 to 60% [21,29]. It, also, compiles with the removal ratio of 41% obtained by Bougrier [30].

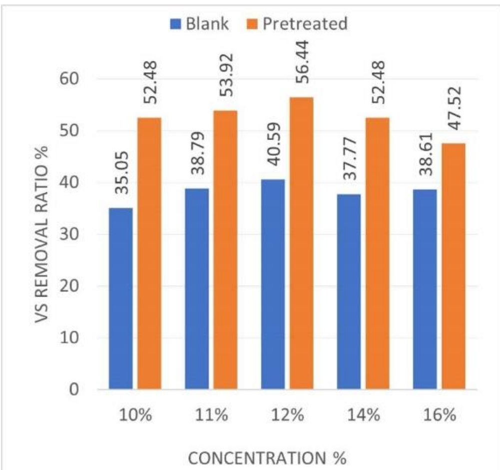

Fig. 3. VS removal ratio for the Batch (1st Set).

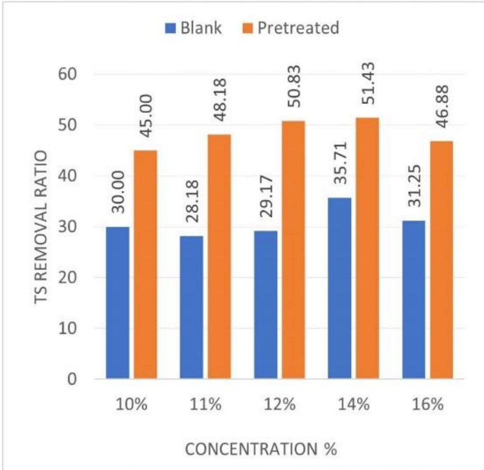

Fig. 4. TS removal ratio for the Batch (1st Set).

Fig. 5 shows the gas production for the different concentrations used in the first run. The total gas flow of the blank for 10, 11, 12, 14, and 16% were 2300, 2475, 2220, 1575, and 1065 (mL), respectively. the gas production for the thermal pre-treatment was higher than the production in the blank as it was 3285, 3850, 3150, 2025, and 1370 (mL), respectively.

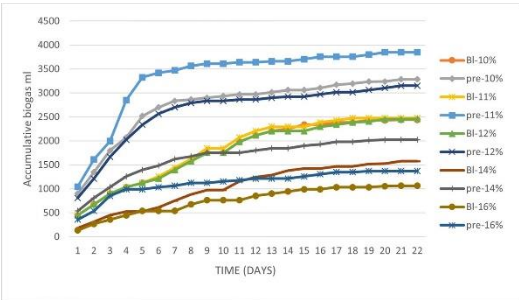

Fig. 5. Accumulative biogas production of 1st Set.

It was noted that the gas production for the concentration 11% was the best and biogas production increased due to thermal treatment by (28-55 %). The achieved results are within the ranges achieved in the AD of sludge which was (30 to 50) % [31]. Also, it is close to the improvement achieved by Bougrier [30] which was 25% at pre-treatment temperatures of 135 to 190°C for sludge AD. This difference in the increasing ratio may be due to using manual mixing. Wang, N [32] stated that thermal hydrolysis is an effective pre-treatment method by which to accelerate high-solids anaerobic digestion, and in this study thermal pretreatment accelerated biogas production as shown in figure 4 where the most amount of biogas achieve in the first few days. Thermal treatment allowed to improve removal yields; thus, biogas production should be improved too. The maximum cumulative biogas yields achieved in the batch at a solid concentration of 11% for 22 days were 367 mLbiogas/gVS$_{removed}$ and 187 mLbiogas/gCOD$_{removed}$ for untreated sludge while for pretreated sludge reached 394 mLbiogas/gVS$_{removed}$ and 213 mLbiogas/gCOD$_{removed}$. The reactors' methane yields were not significantly different, and this matched with Wang et al. [32], who reported that the production of biogas was 415 mLbiogas/gVS$_{removed}$ in mesophilic conditions. This could indicate that the reactors were functioning properly. The higher the temperature, the better the results have been in every case. The improvement in biogas production achieved in this research was matched with Bougrier [30] who reported that TP at 190 ºC was more efficient than treatment at 135 ºC in terms of removal of total chemical oxygen demand, carbohydrates, lipids, and protein, and production of methane.

5.2. Stage II result

Fig. 6 shows the COD removal ratio for HSAD used in the batch. The removal ratio of the untreated HSAD reached 49.28%, while for the pretreated sludge it reaches 69.70 % and 71.68 % at pretreatment temperature 160 ℃ and 180℃, respectively. The COD removal ratio complies with the results of Dwyer et al. and Liu et al. [33,34] who found that the Temperature between 160°C and 180°C is recommended as the optimal one for the TH process because, at the higher temperature, the sludge biodegradability drastically decreases.

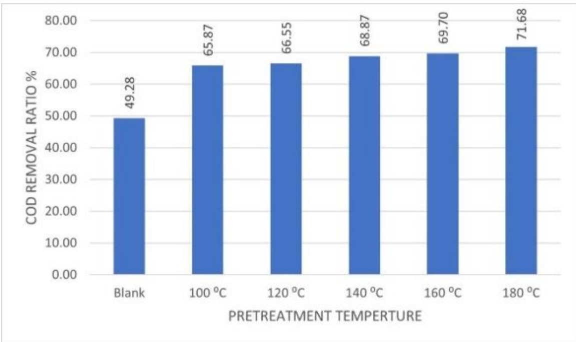

Fig. 6. COD removal ratio for the Batch (2nd Set)

It is caused by the increasing production of refractory compounds. It was noted that thermal pretreatment at a temperature in the range of 160–180℃increases carbohydrates and protein solubility, particle size reduction, a decrease of apparent viscosity, and improvement of downstream sludge anaerobic digestibility.

The effect of thermal treatment on VS and TS is shown in fig. 7 and fig. 8. TS removal rate was about 52.73% against 30.91 % for high solid anaerobic digestion without pre-treatment and VS removal rate was about (63.5) % against about (36.45) % for raw sludge samples. Thus, concerning sludge quantity reduction, 180ºC pre-treatment allowed an improvement of matter removal. The achieved volatile solids removal values are compiled with the values committed by several of the researchers who noted the best TP temperatures ranging between 160 and 180 ℃, with a duration of 30 and 60 min. The VS removal ratio due to these conditions is 40 to 60% [21,29]. It, also, compiles with the removal ratio of 41% obtained by Bougrier [30].

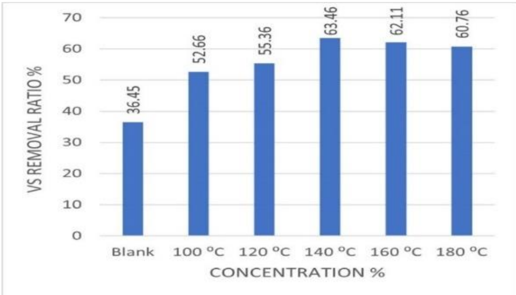

Fig. 7. VS removal ratio for the Batch (2nd Set)

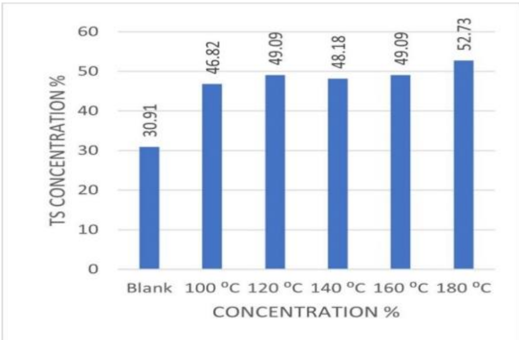

Fig. 8. TS removal ratio for the Batch (2nd Set)

Fig. 9 shows the gas production for the different treatment temperatures used in the second run. The total gas production of the blank was 2270 mL. Thermal pretreatments at 100, 120, 140, 160, and 180 ℃ led to an increase in biogas production by 20.7, 30.2, 45.4, 50.7, and 60.6 %, respectively.

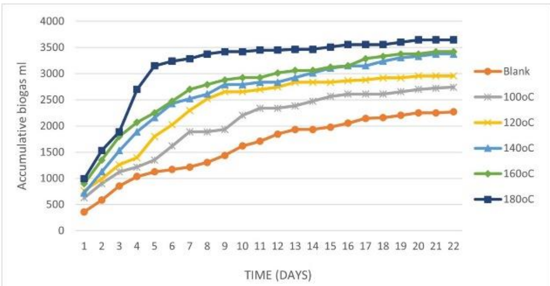

Fig. 9. Cumulative biogas production of 2nd Set

It was noted that after five days the amount of gas production at 180 °C reached 86.4% of total production which indicated that thermal hydrolysis is an effective pre-treatment method by which to accelerate high-solids AD. The achieved results are within the ranges achieved in the AD of sludge which was (30 to 50) % [31]. Also, it is close to the improvement achieved by Bougrier [30] which was 25% at pretreatment temperatures of 135 to 190°C for sludge AD. TP allowed to enhance removal yields, thus the production of biogas may be enhanced too as shown in table 3. The reactors' methane yields were not significantly different, and this matched with Wang et al. [32], who reported that the production of biogas was 415 mLbiogas/g$VS_{removed}$ in mesophilic conditions. This could indicate that the reactors were functioning properly. The higher the temperature, the better the results have been in every case. The improvement in biogas production achieved in this research was matched with Bougrier [30] who reported that TP at 190 ◦C was more efficient than treatment at 135 ◦C in terms of removal of total chemical oxygen demand, carbohydrates, lipids, and protein, and production of methane.

Table 3. Impact of thermal pre-treatments on high solid anaerobic digestion of sewage sludge (Gas production rate)

	Gas Production	Improvement in gas production	Biogas Yield (mLbiogas/g $COD_{removed}$)	Biogas Yield (mLbiogas/ g$VS_{removed}$)
Blank	2270	-	178.65	336.30
100 °C	2740	20.70%	161.35	281.03
120 °C	2955	30.18%	172.23	288.29
140 °C	3375	48.68%	190.08	287.23
160 °C	3420	50.66%	190.32	297.39
180 °C	3645	60.57%	197.24	324.00

6. Conclusions

TP at High temperatures is an adequate pre-treatment method by which HSAD of sludge is accelerated. After high-temperature TP, a considerable quantity of organic in solids of sludge is dissolved, and the flowability of sludge is improved significantly.

This study investigates the effect of high solid anaerobic digestion of domestic WWTPs sludge on Methane yields and biochemical mechanisms. The effects of high-thermal pretreatment and solid content were examined in the batch bioreactor for 22 days to determine the optimal thermal pretreatment temperature and the best solid content, the results show clearly that the TH improve the digestion of HSAD as the solid content ranged from 10 to 16 % with pre-treatment at 180 ^{0}C; the removal ratio was increased by 12.80% to 38%, 44% to 74% and 23% to 50% for COD, TS and VS respectively; also the gas production increased by 28 to 50% while methane yields were not significantly different, the solid content of 11% gives the high biogas production.

Pretreatment of sludge with solid content 11% at different temperatures also improved the performance as the COD, VS, and TS removal ratio increased from 49.28%, 30.91 %, and 36.45% to 71.68 %, 52.73%, and 63.5 % respectively, also the biogas production increased and the pretreatment at 180 ^{0}C gives the high biogas production.

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