Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2014.912156

54 (2015) 3269–3278
June

Taylor & Francis
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Anaerobic co-digestion of chemical- and ozone-pretreated sludge in hybrid upflow anaerobic sludge blanket reactor

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Received 3 October 2013; Accepted 19 March 2014

ABSTRACT

The present study is an attempt to anaerobically co-digest excess sludge from aerobic facility of dairy wastewater treatment plant in a hybrid upflow anaerobic sludge blanket reactor. The sludge was made amenable for anaerobic degradation using ozone and chemical pretreatment. The efficiency of the treatment at optimized condition (pH 11 and ozone dosage 0.06 gO_3/g suspended solids) showed 68 and 61% of chemical oxygen demand solubilization and suspended solids reduction, respectively. Further, anaerobic co-digestion of pretreated sludge was evaluated in two lab-scale hybrid upflow anaerobic sludge blanket reactors, namely experimental (ER) and control reactors (CR), with 5.6 L working volume for a period of 310 d. Treatment of dairy wastewater at the highest applied organic loading rate of 16.78 kg chemical oxygen demand/m^3 d, the biogas production increased in ER reactor (18.8 L/d) with the introduction of pretreated sludge than in CR reactor (17.9 L/d). The performance of ER reactor is not influenced by anaerobic co digestion of pretreated sludge, because no statistical difference between soluble chemical oxygen demand removal efficiencies of ER and CR reactors.

Keywords: Hybrid upflow anaerobic sludge blanket reactor; Anaerobic treatment; Dairy wastewater; Biogas; Sludge

1. Introduction

The biological (especially aerobic) treatment of high-strength wastewater from industries generates huge volume of sludge. The major problem that these industries facing is treatment and disposal of the sludge produced. One of such industry is dairy, which is facing the problem of sludge disposal that is generated during the treatment of wastewater. The high-strength dairy wastewater is characterized by high organic content, which is amenable to anaerobic treatment [1,2]. In order to solve this problem, anaerobic treatment is employed primarily to treat dairy wastewater which has several advantages such as fuel gas production and less sludge generation. In the present study, high rate reactor such as hybrid upflow anaerobic sludge blanket (HUASB) reactor is used primarily to treat dairy wastewater. The efficiency of

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high rate anaerobic reactors can be improved by restricting the supporting material between 25 to 30% of the reactor volume [3]. The supporting material plays dual role in the system such as minimizing the dead volume of the reactor and prevents washout of granular biomass from the reactor [4]. Further, the carrier material supports the growth of attached biomass and the population of attached biomass was found to be twice higher than the population of biomass in granular sludge [5]. Such a modification would further help to realize the advantage of both fixed film and upflow sludge blanket treatment. This kind of reactor, often called as hybrid anaerobic reactor, is more stable for the treatment of a series of soluble or partially soluble wastewater [6]. The substrate mixing inside the HUASB was good and can be comparable to a theoretical continuous stirred tank reactor [5], which facilitates potential substrate biomass contact. Over the years, hybrid reactors have been used to treat wastewater from sugar industry [7], distillery spent wash [8], palm oil mill [9], poultry slaughterhouse [10], pharma [11], phenolic [12], crude oil [13], tannery [14], and domestic sectors [15]. However, primary anaerobic treatment of high-strength wastewater requires subsequent secondary biological treatment to meet the effluent discharge limits. In dairy industries, aerobic treatment is employed widely to treat the primary anaerobic-treated wastewater. Among the aerobic treatment, activated sludge process is the most widely used biological wastewater treatment for industrial plants in the world [16]. Most of the industrial treatment systems use the activated sludge system, or a modified version, as core part of the treatment process. A considerable volume of sludge is generated during the operation of activated sludge process, part of which should be withdrawn and disposed of, in order to maintain the appropriate level of biomass concentration in the aeration basin [2]. About 40–60% cost of wastewater treatment is associated with handling, treatment, and disposal of excess sludge [17]. Recent regulatory pressure seems likely to increase the cost associated with sludge disposal. Considering the above-mentioned fact, the present study is focused on recycling the organic-rich Waste Activated Sludge (WAS) into HUASB. Poor biodegradability is the main parameter which hinders the recycling of WAS into HUASB. However, WAS can be made amenable to anaerobic degradation using various pretreatment techniques [18]. A number of pretreatment process such as thermal energy [19], ozonation [20], alkaline [21], mechanical disintegration [22], ultrasound [23], and microwave [24] have been investigated for decomposition and pretreating waste sludge. Among the above methods, combinative pretreatment treatment has several advantages such as simple manufacturing of device, easy operation, and high efficiency [25]. Considering the facts, present study has made an attempt to anaerobically co-digest the WAS in HUASB along with the mainstream treatment system. The present study evaluates the effects of sludge disintegration on sludge reduction and the performance of HUASB. Combined treatment of alkali and ozone was tested. The combination of the treatments was selected based on their synergistic effect. The performance of the chemical sludge disintegration in HUASB system including sludge reduction, inorganic accumulation, and effluent quality was investigated for more than nine months and quantitatively compared with the control HUASB at the same conditions.

2. Materials and methods

2.1. Inoculation and characterization of dairy wastewater

The reactor was first seeded with filtered digested cow dung slurry. Synthetic dairy wastewater was fed along with the digested cow dung slurry at a ratio of 1:3 (v/v). The volatile suspended solid content of the inoculums was determined to be in a range between 10 and 20 g/L, as recommended for favorable reactor startup conditions for a UASB reactor. The synthetic dairy wastewater was prepared by following procedure mentioned by Rajesh Banu et al. [2]. The physico-chemical characteristics of synthetic wastewater used in the present study was detailed in Table 1.

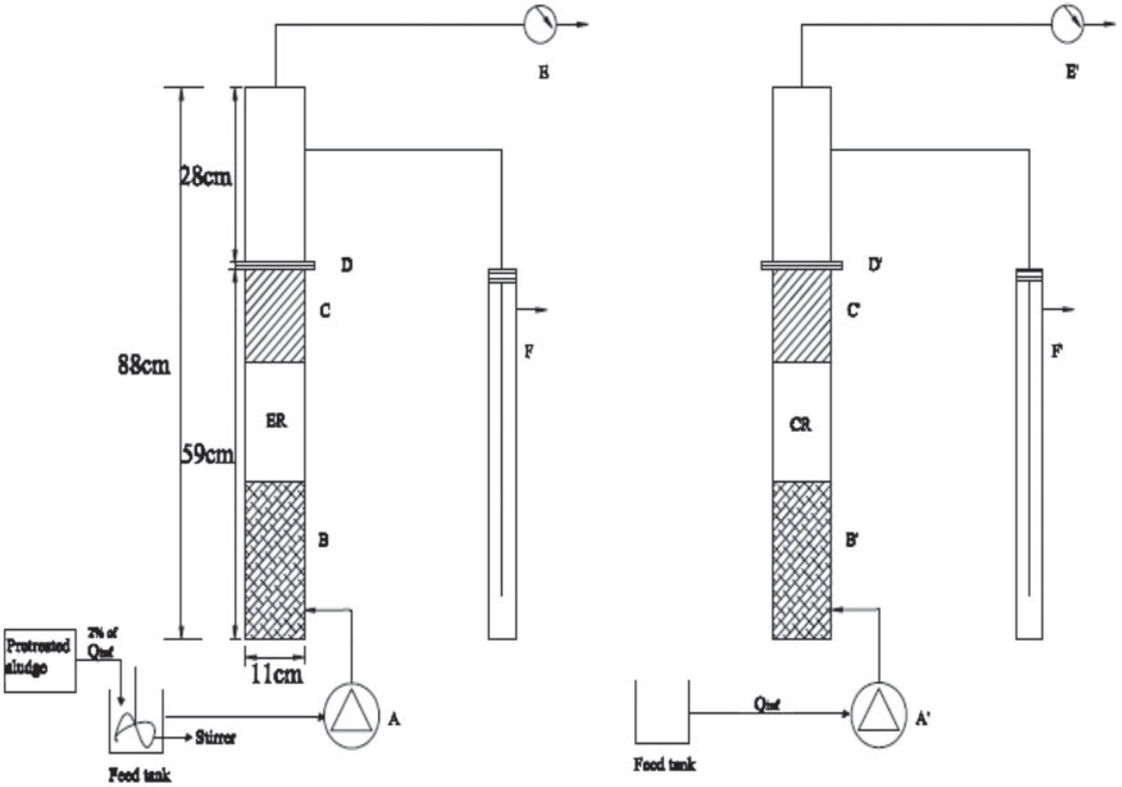
2.2. Reactor setup

The schematic diagram of the HUASB reactors used in this study is shown in Fig. 1. The working volume of empty reactor was 5.6 L. A screen was positioned at a height of 59 cm to arrest the floating packing material-polyurethane cubes.

The characteristics of floating packing material were shown in Table 2. The effluent line was positioned at a height of 71 cm. A gas headspace equivalent to 1.5 L was maintained above the effluent line.

Table 1
Physico-chemical characteristics of dairy wastewater

S. No.	Parameter	Values
1	pH	7.1
2	COD, mg/L	5,000 ± 200
3	TKN, mg/L	35 ± 1
4	NH_3-N, mg/L	0.25 ± .01
5	Chloride, mg/L	187 ± 4
6	Sulphate, mg/L	60.4 ± 2
7	Total phosphate, mg/L	15 ± 1



A, A′ - Peristaltic pump B, B′ - Sludge bed (granulated) C, C′ - Floating filter
D, D′ - Screen E, E′ - Wet gas meter F, F′ - Water seal
R – I – Control HUASB R-II – HUASB with pretreated sludge

Fig. 1. Schematic diagram of HUASB's used during the study.

A peristaltic pump (make: Watson and Marlow. Model No: PP20) was used to feed the wastewater into the reactor. The gas outlet was connected to a wet gas meter (Make: Ritter. Model No: TGI).

To evaluate the feasibility of HUASB for anaerobic co-digestion of pretreated sludge, two reactors were fabricated and were fed with synthetic dairy wastewater. Both the reactors were operated at same operational condition up to an OLR of 16.8 kg COD/m^3 d (180th day). Among the two HUASBs, one acted as Experimental reactor (ER), where pretreated sludge was introduced along with dairy wastewater as feed starts on day 181. The other reactor acted as control reactor (CR), where the reactor fed with dairy wastewater and there is no introduction of pretreated sludge happens. The efficiency of ER was evaluated by comparing its performance with CR.

2.3. Pretreatment

WAS was collected from an activated sludge process treating the dairy wastewater located at Tirunelveli, Tamil Nadu, India. The collected waste active sludge was subjected to pretreatment at an optimized pH

Table 2
Characteristics of the floating packing material

S. No.	Parameter	Values
1	Material	Polyurethane foam cubes
2	Number of cubes	110
3	Size of the cubes (cm)	2 × 2 cm
4	Weight of each cubes (g)	0.21 ± 0.04
5	Total Surface area (m^2)	5.81 ± 0.08

dosage of 11 [26]. The first step of alkaline pretreatment was to adjust the pH of sludge to 11 by adding sodium hydroxide. This was followed by keeping the sludge in the reactor in suspension by a slow-speed stirrer for 2 h (Digital Overhead IKA RW 20) to ensure homogeneity during alkaline treatment. After alkaline treatment, the mixed liquor was subjected to ozone pretreatment in 5 L fed batch reactor. The ozone was generated from pure oxygen by a generator (Faraday, L10G) and injected into the bottom of the reactor through a thin bubble diffuser. The SS (Suspended Solids) removal and COD solubilization for alkali and ozone were measured individually as well as combinatively. The pretreated sludge samples were prepared freshly, once in a week and stored in the refrigerator at 4°C and were used as feed for anaerobic co-digestion experiment.

2.4. Anaerobic codigestion

Feed for anaerobic co-digestion was prepared by mixing 24 L of influent (Q/d) and 0.48 L of pretreated sludge (2% of Q influent/day) in the storage tank. It is understandable that an increase in pretreatment Q of over 2% increases the percentage of sludge reduction. However, increase in the pretreatment of Q over 2% is not an economically viable option [27]. Consequently, a pretreatment of Q at 2% was maintained in the present study. In order to hinder the settling of SS in the storage tank, an overhead stirrer with 150 rpm was used.

2.5. Analytical parameters

Volatile fatty acids (VFA), COD, alkalinity, total solids, and volatile solids of the raw and treated wastewater were analyzed following APHA, 2005 [28]. VFA were analyzed by distillation–titration method in which 150 mL of distillate was collected and titrated against 0.1 N sodium hydroxide, using phenolphthalein as indicator and the result was expressed in acetic acid.

Methane content in the biogas was measured by Gas Chromatography (Chemito, Model: GC 1000) equipped with Flame Ionization Detector. The column used was Poropak Q. Soluble COD (SCOD) was measured by centrifugation at 20,000 × g, for 15 min, and subsequently filter the supernatant through 0.45 μm microfiber filter paper.

3. Results and discussion

3.1. Pretreatment of sludge

Excess sludge disposal is the main problem that treatment plants are facing today. The purpose of pretreatment study is to improve the anaerobic biodegradability of sludge particulate material and its subsequent co-digestion in anaerobic reactor. The expected effect of ozone-chemical treatment of sludge was to increase soluble materials, leads to SCOD solubilization. In this study, the ozone-chemical pretreatment was optimized by fixed pH at 11, reaction time for 2.5 h with varied ozone dosage. A pH of 11 is preferred because the usage of pH 12 and above increases the pH of the pretreated sludge which is unmanageable and renders subsequent anaerobic digestion [25]. The choice of alkaline agent was made from different studies indicated that sodium hydroxide (NaOH) was more efficient than other alkaline agents in solubilizing the sludge [29]. Optimization of ozone dosage was carried out by varying ozone concentration at a range of 0.08–1 gO_3/gss. Higher oxidation potential of ozone is responsible for disintegrating the sludge. As the sludge reacts with ozone, organic fraction of particle decreases, and solubilized fraction increases [30]. The solubilized fraction (SCOD solubilization %) of the sludge was considered as the main parameter for evaluation of sludge particulate material which evaluates the maximum level of sludge solubilization. This result indicates that increase in ozone concentration increases the SCOD release up to an ozone dosage of 0.064 gO_3/gss (Fig. 2). Further increase in ozone dosage decreases SCOD release. On lower doses of ozone cell, rupture occurs and resulted in increase of SCOD solubilization. Dosage in excess of 0.064 gO_3/gss causes mineralization of released soluble organics which resulted in decrease of SCOD solubilization.

However, SS reduction was found to increase with increase in ozone dosage. When the sludge was treated with ozone alone, 20% solubilization was observed at 0.064 gO_3/gss, whereas when it was combined with alkali, 20% solubilization was achieved in relatively a lower dosage level of 0.021 gO_3/gss. From the result, it is clear that combination of alkali with ozone not only increased the sludge disintegration efficiency but also saved considerable amount of energy, as ozone is considered to be costly by many authors. At optimized condition, 63% of solubilization observed was thrice higher than ozone alone and seven times higher than alkali alone. A TSS reduction of 60% was observed at optimum conditions. In addition to increase of solubilization efficiency, the added alkali also acted as a buffering agent to avoid pH drop due to ozone treatment. Therefore, the combination of alkali and ozone increased the solubilization efficiency and also reduced the treatment cost for sludge pretreatment. For subsequent anaerobic co-digestion studies in ER, the WAS at a fixed MLSS range of 6,000 ± 500 mg/L was pretreated at the optimized ozone dosage and pH, which is mixed with influent wastewater.

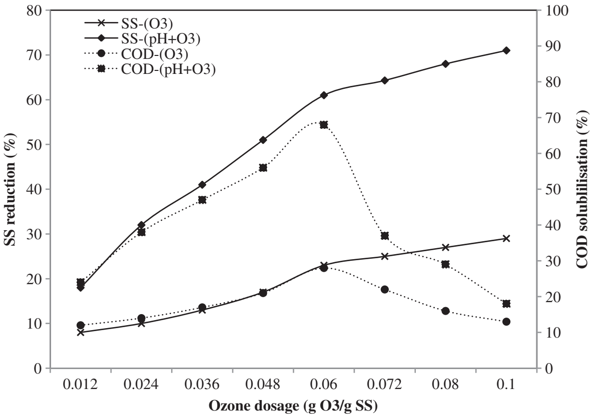


Fig. 2. Optimization of alkali-ozone pretreatment of dairy sludge.

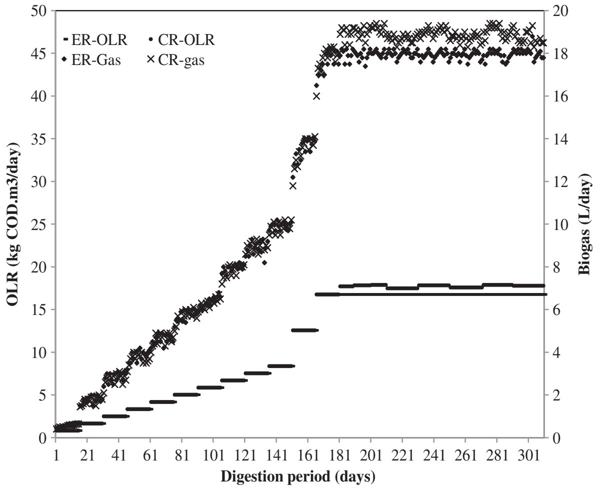


Fig. 3. Influence of OLR on biogas production during the study period.

3.2. Biogas production

The proper startup of the reactor was responsible for the success of anaerobic treatment and can be evident by increasing biogas production. In the present study, ratio of 30% (v/v) of anaerobically digested cow manure from active biogas plant was used to startup HUASBs. Similar study by Brambilla et al. [31] used cow manure as an inoculum for the startup of reactors and also for granular sludge cultivation. The loading pattern and the biogas production of HUASBs during the startup phase are presented in Fig. 3.

The initial OLR applied during startup phase was 0.84 kg COD/m^3 d and the corresponding hydraulic retention time (HRT) was 56 h. This HRT was preferred initially to prevent the washout of inoculated biomass [1]. The OLR was increased to 8.5 kg COD/m^3 d in a stepwise manner by decreasing the HRT from 56 to 5.6 h, over a period of 150 d. The average biogas production for the initial OLR (0.84 kg COD/m^3 d) was found to be 0.55 L/d for both the HUASBs. When the OLR was increased, corresponding biogas productions for both HUASBs increased. The average biogas production for the highest applied OLR (8.5 kg COD/m^3 d) during startup phase was found to be 9.6 and 9.9 L, respectively, for ER and CR HUASB. After the successful startup of both reactors, there is a stepwise increase of influent COD was carried out at fixed HRT of 5.6 h. At this stage, OLR was increased from 8.4 to 16.8 by increasing COD of the influent from 2,000 to 4,000 mg/L and corresponding period is called treatment phase (TP-I) and it lasts for 30 d. A *t*-test analysis showed the difference in biogas production between ER and CR which are not statistically significant up to day 180. However, after the introduction of pretreated sludge in ER (181–300 d) showed a significant difference between biogas production of ER and CR. This could be due to the fact of introducing pretreated sludge in ER reactor. It is evident from the literature that the pretreated sludge is having readily degradable soluble compounds for efficient anaerobic degradation [25,32]. Thus, the increase in biogas production in ER was due to the introduction of soluble organic-rich pretreated sludge, which in turn increases the organic loading (16.8–17.7 kg COD/m^3 d) of the reactor and increases the biogas production. From the above results, it is clearly evident that the anaerobic co-digestion of pretreated sludge in ER has the advantage of generating additional fuel gas.

During the initial stages of startup period, the effluent pH of both the HUASBs was found to be in the range of 6.8–7. This may be due to acid fermentation phase which was always rapid than methanogenic phase. Drop in pH during the first few week of startup period is a common phenomenon in a4naerobic digestion [33]. During the remaining stages of startup period, pH of the treated wastewater was found to be in the range of 7.3–7.4 for both the reactors. The variation of pH with digestion period is shown in Fig. 3. During the treatment phase, the pH of the treated wastewater was found to be similar for both the reactors and was fluctuating in the range of 7.5–7.6. After the introduction of pretreated sludge in ER, the pH of treated wastewater was found to be slightly higher than CR and was found to be fluctuating in the range of 7.7–7.9. This slight increase in effluent pH of ER attributes to the alkaline nature of pretreated sludge. It is known that, pH less than 6.8 and greater than 8.3 would cause souring of the reactor during anaerobic digestion. The pH of the ozone-chemical pretreated sludge was found to be in the range of 9–9.2 and is detrimental to anaerobic digestion if it was fed as such. However, on dilution with influent wastewater, it does not cause any harm to anaerobic methanogens. One of the disadvantages of using carrier material is the clogging problem, however, in the present study, the clogging is not a problem and the reactor (ER) got clogged only once (Day 210) and this may be due to the usage of synthetic wastewater, which devoid of solids and high applied velocity (0.110 m/h). From previous study, it was understood that solids in the feed and high applied velocity are the main governing parameters responsible for clogging of carriers in hybrid reactor [4].

Fig. 4 illustrates alkalinity of the medium during the study period. Alkalinity in the treated wastewater was 1.7 g/L at the initial stage of the startup but increased gradually with increase in OLR and reached 1.9 g/L at an OLR of 8.5 kg COD/m^3 d. During treatment phase, alkalinity of the treated wastewater was found to be in the range of 1.9 and 2.2 g/L for both the HUASBs. A sharp decrease in alkalinity during normal operation level has been used as an indicator for reactor failure. This can also be caused by an accumulation of VFA due to the failure of methane-forming bacteria to convert the organic acids to methane. Gerardi [34] on his review about the microbiology of anaerobic digester has reported that the decrease in alkalinity usually precedes rapid changes in pH. This type of change was not observed in the present study, which indicates the healthiness of anaerobic reactor during the study period. The alkalinity of the treated wastewater of ER HUASB was found to be higher than CR after the introduction of pretreated sludge. This could be due to the alkaline nature of pretreated sludge, which causes a marginal increase in alkalinity.

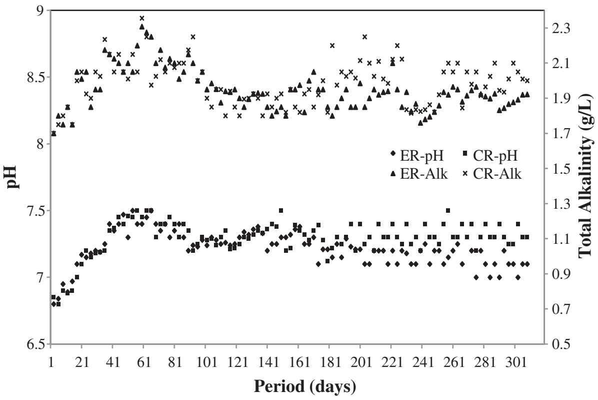


Fig. 4. Influence of thermochemical pretreatment on pH and alkalinity during the study period.

3.3. COD removal and VFA profile of the reactor

Fig. 5 shows data on SCOD removal and VFA in the medium during the study period. As expected, COD removal increased with digestion period during the startup phase. The SCOD removal was 59 and 60% at day 1 for both HUASBs, but it increased gradually with increase in digestion period during startup phase. At the end of the startup period (8.5 kg COD/m^3 d), COD removal of both HUASBs were found to be 91%. The overall performance of the reactor during the startup was more satisfactory. It is known that selection of seed material plays a crucial role in minimizing the time required for initial biofilm establishment [35]. Also the biogas slurry possesses sufficient numbers of physiologically active micro-organisms. At the highest applied OLR (16.8 kg COD/m^3 d), the SCOD concentration in the wastewater was varied in the range of 15–105 mg/L for ER and 20–95 mg/L for CR, respectively, and the corresponding average COD removal efficiency for ER and CR was found to be 92 and 91%.

The initiation of anaerobic co-digestion of pretreated sludge was effected on day 180 in ER reactor and lasted for 300 d. The major portion of the pretreated sludge consists of intra-cellular organic matter, released together as SCOD, proportioned with organic debris, extracellular polymeric substance (EPS) soluble and microbial products [36]. It has been reported that in aerobic wastewater treatment processes including disintegration-induced sludge degradation, the effluent water soluble organics increased slightly due to the release of degradable substance such as soluble microbial products [37]. In contrast to aerobic treatment, anaerobic co-digestion of pretreated sludge resulted in complete removal of SCOD, which can be

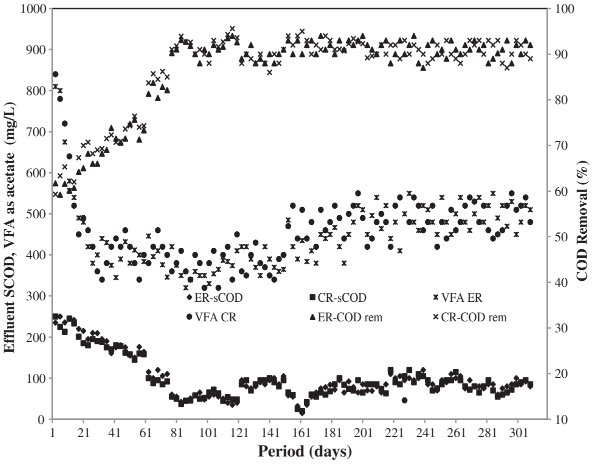


Fig. 5. Influence of thermochemical pretreatment on sCOD removal efficiency of HUASB's.

evident from the results of ER, where SCOD removal efficiency remains unaffected before and after the introduction of sludge pretreatment. Table 3 shows *t*-test analysis result, since the calculated t is less than expected t value from the table, the mean is not statistically significant.

VFA, a recognized intermediate, formed during anaerobic treatment [38] and is considered to be a critical parameter for anaerobic treatment [39]. The VFA in the effluent on day 1 was 820 and 780 mg/L for ER and CR, and reduced to 520 and 480 mg/L on day 16 for ER and CR, respectively. Higher levels of VFA in the wastewater during the initial period of HUASBs operation (701 mg/L as acetate) indicate the prevalence of acid fermentation [40]. Subsequently, VFA in the wastewater decreased and was in the range of 640–420 mg/L up to day 180 indicating healthy anaerobic environment and satisfactory methanogenic activity. Previous reports on treatment of wastewater in HUASB found that increase in OLR often increase the chances of VFA accumulation and subsequent souring of reactor. The introduction of pretreated sludge in ER (180–300 d) increases OLR from 16.8 to 17.7 (kg COD/m^3 d), but VFA accumulation was absent. During this period, VFA concentration of ER and CR was found to be in the range of 540–410, respectively. The commonly encountered problem of VFA induced "souring" of the reactor was not observed during the present study as the VFA levels were within the recommended range for normal operation of reactors. This could be due to the fact that in the present study, both the HUASBs were operated in a relatively less OLR (below its threshold level) than others [1,33].

Soluble and particulate matters are the two major organic portions associated with pretreated sludge. Among the two organic portions, soluble matter was easily degradable and demonstrated in the present study. However, the degradation of particulate matter was difficult and was assessed in the present study by the following SS profile in both the HUASBs. Finally, a mass balance equation was arrived under stable operational condition by considering the following parameters.

Table 3
Results of *t*-test analysis

Values	ER-SCOD	CR-SCOD
Mean	76.08831	75.4
Variance	455.0307	445.5817
Observations	77	77
Hypothesized mean difference	0	NA
t stat	0.201262	NA
P (*T* <= *t*) one-tail	0.420381	NA
t critical one-tail	1.65494	NA
P (*T* <= *t*) two-tail	0.840763	NA
t critical two-tail	1.975694	NA

NA—not applicable.

$$\text{SS Influent} = [\text{SS accumulated} + \text{SS degraded} + \text{SS effluent}] \tag{1}$$

$$\text{SS Influent} = [\text{SS influent ER} - \text{SS effluent CR}]$$

Since the influent wastewater was a simulated one and devoid of SS, the SS associated with ER influent was assumed to be off from pretreated sludge. Therefore, equation can be written as follows.

$$\text{SS influent of ER} = [\text{SS accumulated} + \text{SS degraded} + \text{SS effluent}] \tag{2}$$

where

$$\text{SS accumulated} = [(\text{SS in sludge blanket of ER} + \text{carrier of ER}) - (\text{SS in sludge blanket of CR} + \text{SS in carrier of CR})] \tag{2a}$$

$$\text{SS effluent} = [\text{SS in effluent of ER} - \text{SS in effluent of CR}] \tag{2b}$$

The SS concentration of CR accounts for biomass washout and ER accounts for both pretreated and biomass washout. By rearranging the mass balance Eq. (2), it was possible to calculate the amount of SS degraded.

$$\text{SS degraded} = \text{SS influent of ER} - [\text{SS accumulated} + \text{SS effluent}] \tag{3}$$

The total SS in sludge blanket region of ER accounts for the sum of biomass and a portion of accumulated pretreated sludge whereas, CR represents biomass only. Hence, the accumulated pretreated sludge in ER can be calculated by taking difference in sum of SS between ER and CR (Eq. (2a)). Estimation of solid concentration along the blanket height was difficult and varies greatly. While studying solids concentration along the profile of sludge blanket in UASB (1.2 m) Kripa shankar et al. [41] have noticed that the

Table 4
Mass balancing of solids during sludge pretreatment phase

S. No.	Values	ER-solids	CR-solids
1	*SS Influent (g) (Eq. (1))*	145.8 g ± 5	
2	Solids in sludge blanket (g)	68 g ± 3	51 g ± 2
2a	Solids accumulated in sludge blanket	(68 − 51 g) = 17 g	
3	Weight of solids in carrier material (g)	6.7 g ± 0.5	5.2 g ± 0.2
3a	Solids accumulated in carrier material of ER	(6.7 − 5.2 g) = 1.5 g	
4	*SS accumulated (Eq. (2a))*	*18.5 g*	
5	Solids in the effluent (g)	267 g ± 8	168 g ± 6
6	*SS effluent (g) (Eq. (2b))*	(267 − 168 g) = *99 g*	
7	*SS degraded (g) (Eq. (3))*	*28.3 g*	

concentration of solids was significant up to 50% of its total height (0.6 m). Similar kind of trend in solid distribution was observed in the present study. Based on the fact, SS above 0.6 m height of both the HUASBs was not taken into account for calculation. Total SS in sludge blanket region of the both HUASBs was calculated by withdrawing samples at four different points (10 cm intervals) from the bottom of the reactor and taking its average. Mass balancing of solids during the pretreatment phase of the study period was calculated using the equation arrived and was tabulated in Table 4.

From Fig. 6, it was evident that the average effluent SS concentration of both the reactors was found to be similar before the initiation of anaerobic co-digestion (0–180 d). The average SS concentration CR was found to be (120 mg/L) and it corresponds to biomass washout.

The average effluent SS concentration of ER after the initiation of anaerobic co-digestion was higher than CR (180 mg/L). An increase of SS concentration in ER of about 60 mg/L (calculated using Eq. (2b)) was accounted to the undergraded portion of pretreated sludge. As a result of higher SS washout in ER, the total COD (tCOD) concentration in effluent increases. The average tCOD of ER and CR was found to be 280 and 203 mg/L, respectively. Using the mass balance Eq. (3) and corresponding values in Table 2, SS degraded in ER was calculated and was found to be 15%. The currently observed SS reduction was comparatively lower than the value reported for anaerobic degradation of WAS. However, aerobic digestion demands more energy for the oxidation of additional organic load to the reactor, whereas in anaerobic digestion, degradation was done in cost-effective manner. In addition to that, anaerobic co-digestion yields more energy in the form of methane. From the above results, it was demonstrated that high-rate anaerobic treatment can be used to co-digest excess sludge without affecting its treatment efficiency. For example, the SCOD concentration of both the reactors remains unaffected and was found to be 90 mg/L for ER and 88 mg/L for CR, respectively. Future investigations will be focused on reactor operation at high HRTs to find the possibilities of improving the amount of SS degraded.

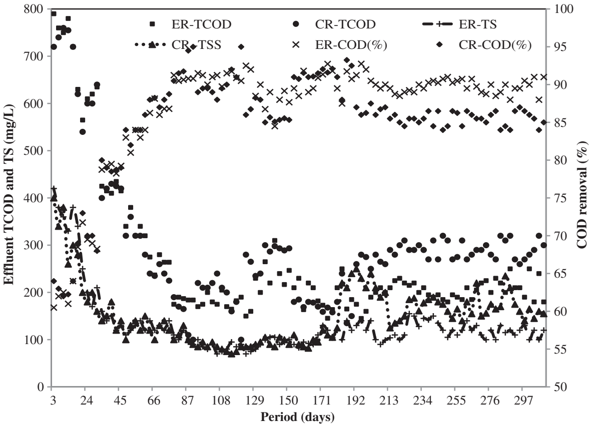


Fig. 6. Influence of thermochemical pretreatment on TCOD removal efficiency of HUASB's.

4. Conclusions

The present study showed that introduction of pretreated sludge did not affect the performance of HUASB. As a result of extra carbon source from pretreated sludge, increase in biogas production from HUASB was observed. A marginal sludge reduction (15%) was obtained when a part of the sludge pretreated at an Ozone dosage 0.064 gO_3/gSS with pH 11 was introduced in HUASB. The study also details that the solubilized fraction of the mixed liquor obtained by pretreatment might be easily biodegraded by anaerobic digestion. There was a slight increase in effluent tCOD concentration and was associated with undegraded particulate portion of pretreated sludge. Thus the study concludes thermal-ozone pretreated sludge in HUASB reactor-enhanced anaerobic co-digestion.

Acknowledgment

The authors are thankful to the Department of Science and Technology (DST), Government of India for providing financial assistance for this Project (SR/FTP/ETA-0021/2010) under their Young Scientist program.

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