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A Short Review of Anaerobic Co-Digestion and Feasibility of Anaerobic Co-Digestion of Sewage and Food Waste for Sustainable Waste Management

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Abstract: Anaerobic co-digestion is the simultaneous digestion of two or more substrates and is an option to overcome the drawbacks of mono-digestion. This paper gives a short review of the research on anaerobic co-digestion of substrates reported and the feasibility of anaerobic co-digestion of sewage and food waste. The concept of this paper aims for integration of treatment of biodegradable solid and liquid waste in a single treatment plant with the possibility of resource recovery (energy, nutrients and water) in contrast to the present art of managing them separately. The successful implementation of the concept helps in sustainable waste management of small towns, university campuses, residential townships, and in upcoming smart cities. The anaerobic treatment of sewage and food waste by individual anaerobic digestion is a known technique. However, the biogas collection and its utilization are limited in case of anaerobic treatment of sewage as the organic loading rate is low. On the other hand, food waste is rich in organic carbon and successful operation of biogas plant is a challenge because of rapid acidification and low buffering capacity in the digester. In this context, it is appropriate to initiate research for the co-digestion of food waste and sewage to optimize the carbon to nitrogen ratio for better buffering and biogas production. The very initial challenges of the co-digestion are to know the optimum particle size to enhance the rate of hydrolysis of solid particle in anaerobic digestion, and to know how much proportion of food waste can be mixed with the sewage. The results of feasibility studies give the first-hand information to proceed further in this topic.

Keywords: *Anaerobic co-digestion, sewage, Food waste, biogas*

1. Introduction

Anaerobic digestion is an effective waste treatment method both for the pollution control and energy recovery, such as treating many agricultural and industrial wastes which contain high level of easily biodegradable substances [1]. Food waste (FW) is an important waste material largely produced from municipalities, college / university campuses and the business sector. The uncontrolled discharge of large amounts of FW causes severe environmental pollution in many countries [2]. Anaerobic digestion of food waste is a challenge because of rapid acidification and lowering of pH inside the reactor, which results in the inhibition of methanogenic bacteria which are responsible for methane production in the digester [3].

Application of up-flow anaerobic sludge blanket (UASB) technology to treat municipal sewage is increasingly being regarded as a viable sewage treatment option in developing countries such as India, Brazil, Colombia and Egypt. This is primarily due to the relatively low construction, operation and maintenance costs associated with these systems, as well as the relatively small physical footprint and low sludge production [4]. Because of the less organic carbon present in huge liquid volume, the yield of biogas from sewage treatment plant is not appreciable as there is a possibility of part of biogas will dissolve and escape with the effluent. This aspect and many other aspects of UASB operation of sewage treatment can be improved by adding biodegradable FW to sewage and having anaerobic co-digestion to recover the energy, nutrients and water. The technologies for nutrient recovery (as struvite) and water recovery (using membrane bioreactor) are already available.

Co-digestion dilutes the inhibitory effects of substrates, balance the micro and macronutrients, increase the organic loading with consequent higher methane yields per unit of digester volume; lastly diversify and synergize the microbial communities which play pivotal role in the methanogenesis [5]. Though, anaerobic co-digestion of FW and sewage appears to be a promising choice for sustainable waste management, there are no reports available in the literature. Therefore, this paper aims for a short review of the research on anaerobic co-digestion of substrates reported so far and the feasibility of anaerobic co-digestion of sewage and food waste.

2. A Review of Anaerobic Co-Digestion

Animal manures stand as the most reported substrate, agro-industrial waste and the organic fraction of the municipal solid waste (OFMSW) being the most reported co-substrates in anaerobic co-digestion. Most

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of the reported work use pig manure (PM) and cow manure (CM) compared to poultry manure. Regarding the co-substrates used agro-industrial waste stands as the most applied co-substrate (47%), followed by OFMSW (12%), crude glycerol (GLY) (9%), cheesewhey (5%), and olive mill waste (OMW) (4%). These co-substrates are characterized by high carbon to nitrogen (C/N) ratio, poor buffer capacity, and, depending on their biodegradability, the possibility of producing large amounts of volatile fatty acids (VFA) during the anaerobic digestion process. In contrast, manures have high buffer capacities and low C/N ratios, where ammonia concentrations usually surpass the requirements for microbial growth and may become inhibitory for methanogens. Therefore, anaerobic co-digestion between manures and C-rich wastes overcome these problems by maintaining a stable pH, within the methanogens range, due to their inherent high buffering capacity and reducing the ammonia concentration by dilution while enhancing methane production [6, 7].

Few studies have been carried out for optimizing the C/N ratio of anaerobic co-digestion of manure. For example, Wu et al. [8] reported the best co-digestion performance when a mixture between PM and cereal straws had a C/N of 20; Panichnumsin et al. [9], who co-digested cassava pulp and PM, reported the maximum methane yield when the feedstock contained a C/N ratio of 33; while, Zhang et al. [10] found an optimum C/N ratio of 16 when treating CM and OFMSW. These studies indicate that research is required to find out the optimal C/N when co-digestion is employed for maximizing the biogas production.

Though biodegradable industrial waste could be substituted in absence of agrowaste (due to seasonal availability), in dealing with industrial wastes the biggest concern is the little knowledge about the possible presence of compounds that can become inhibitory to anaerobic biomass, especially methanogens, if a certain dose is exceeded [11]. Therefore, before the addition of an unknown or insufficiently studied co-substrate, it is highly recommended to perform laboratory experiments to detect the presence of inhibitory compounds, which could lead to a process break down or decrease the methane production. Despite these concerns, the highest risk of process inhibition is because of adding C-rich waste as co-substrates in overloading rate resulting in digester acidification. In anaerobic co-digestion, the increase of the methane production is mostly linked to the increase of the organic loading rate (OLR). However, if a certain OLR value is exceeded the process can become unstable, which, if not solved, can lead to digester failure [7]. The optimal OLR depends on many factors such as characteristics of substrates, pH, temperature, active biomass concentration, presence of nutrients and micronutrients, absence of inhibitory substances, and degree of mixing during the anaerobic digestion.

Sewage sludge (SS) or wastewater treatment plant sludge ranks as the second most reported main substrate for anaerobic co-digestion. The low organic load of the SS together with the non-used capacity of the wastewater treatment plant digester is the main driving force behind SS co-digestion [12]. SS is characterized by relatively low C/N ratio and high buffer capacity [13]. Therefore, it is able to digest co-substrates with high amounts of easily biodegradable organic matter and with low alkalinity values. Moreover, in many cases, SS co-digestion can also lead to the dilution of some undesired compounds present in SS such as heavy metals, pharmaceuticals and/or pathogens [3]. The effect of the OLR, ranging from 1.2 to 8.0 kg VS/m^3/d, over process performance and stability was evaluated in a meso-philic pilot plant that co-digested SS and biowaste (mix of OFMSW and food and vegetable waste) by Liu et al. [14]. Although the process showed a maximum biogas production when the digester was operated at 8.0 kg VS/m^3/d, the high VFA level together with the reduction of the biogas yield (from 0.73 to 0.62 m^3/ kg VS) indicated a higher risk of acidification. On the other hand, these results indicate a possibility of co-diestion of sewage and a mix of OFMSW and food and vegetable waste in an appropriate reactor for enhanced biogas production.

Due to high methane potential of 0.7 to1.1 m^3/kg VS; Fat, Oil and Grease (FOG) is a very interesting co-substrate for anaerobic co-digestion of SS. It is very attractive when it is practiced on-site wastewater treatment plants. However, FOG dosing rate must be limited in order to avoid high concentration of long chain fatty acids (LCFA) resulting from lipid degradation in the digester. High concentrations of LCFA are a potential inhibitor of the methanogenic activity [15]. Moreover, FOG has been related with other operational problems like clogging in the liquid or gas systems, foaming and biomass flotation related to adsorption of lipids on to biomass [16]. In wastewater treatment plants, FOG represents 25–40% of the wastewater total chemical oxygen demand (COD) and it is usually removed (50–90%) prior to biological treatments [17]. Therefore, when FOG is utilized as a co-substrate in SS co-digestion, it saves the cost of treating the residue outside the plant.

3. Materials and Methods

3.1 Substrates, Innoculam and Batch Reactor

VIT Chennai campus sewage was used as main substrate and campus hostel and/or canteen food waste was used as co-substrate. Equalised sewage was collected from the campus sewage treatment plant and mixed foodwaste was collected from campus composting plant. Both grounded and non-grounded food waste was used in the study. The anaerobic innoculam used was collected from the anaerobic digestor of Nessambakkam Sewage treatment plant, Chennai. Conical flasks / reagent bottles (borosil make, India) of 250 mL / 500 mL capacity were used as batch reactors fitted with appropriate rubber cork for biogas outlet.

3.2 Moisture Content & Sieve Analysis of Food Waste

The percentage moisture content of the grounded and non-grounded food waste is determined by heating the duplicate samples (around 1 kg) in a hot air oven at 70 °C for 24 hours. After heating, the samples were desiccated and final weights were measured; and percentage moisture was determined. The percentage moisture content of the grounded and non-grounded food waste was 21.5% and 69.5%, respectively.

The sieve analysis of the dried, grounded and non-grounded food waste (known weight) was carried out using sieve sizes : 4.75 mm, 2.36 mm, 1.18 mm, 800 µm, 600 µm, 300 µm, 150 µm, and collecting pan as per the standard procedure by shaking 10 minutes. After shaking, the stack of sieves from the shaker was removed. The food particles retained on each sieve was weighed to plot the particle distribution curves and stored separately to use in the study.

3.3 Effect of Food Particle Size on Anaerobic Co-Digestion

Ten numbers of 250 mL conical flask fitted with rubber cork and biogas outlet arrangement were used to study the effect of food particle size on anaerobic co-diestion with sewage. One reactor was assigned for adding non-ground food waste and others for adding grounded food waste representing the each sieve size and less than 150 µm (from the collecting pan).

The reactors were started with 200 mL sewage, 2.5 g/L food particles and 20 mL of inoculum in each reactor with an approximate food to microorganism ratio of 0.2 g COD/g MLVSS/day. All the reactors were stoppered with rubber corks and the gas outlets were immersed in a water column (50 mm depth) to enable biogas to escape and to keep anaerobic condition inside the reactors. Studies were conducted in a temperature controlled shaker incubator (Scigenics Biotech, India) at a liquid temperature of 35 ± 0.2 °C and mixed at 135 RPM.The incubation was done for 3 weeks and pH and VFA were monitored at the end of 3 weeks.

3.4 Feasibility of Anaerobic Co-Digestion of Sewage and Food Waste

Ten numbers of 500 mL capacity reagent bottles with biogas collection arrangement were used. The photograph of the experiment set up is shown in Fig. 1. The reactors were started by filling 400 mL of sewage and 150 mL of inoculum (17.7 g/L as MLSS) and were stoppered with rubber corks with biogas collection arrangement.

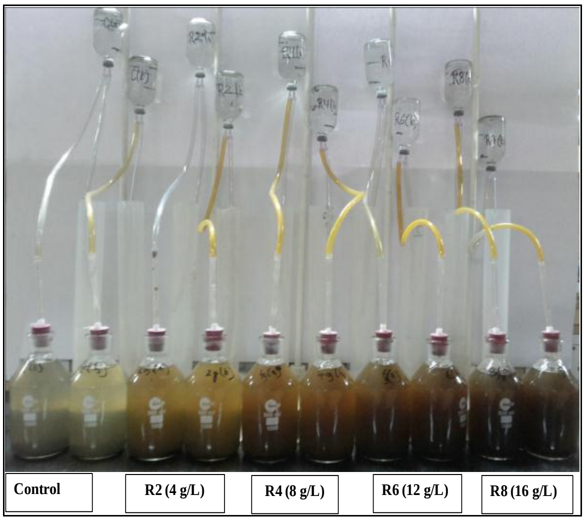

Fig. 1 *Batch reactor experimental set up for feasibility of anaerobic co-digestion of sewage and food waste*

The reactors (in duplicates) were operated in a non-mixing condition at a room temperature varying between 26 and 36 °C. All the reactors were covered with black polythene sheet to avoid photosynthetic activity inside the reactors during the digestion. The start-up conditions of the reactors are shown in Table 1. The batch reactors were operated for 18 days and biogas produced or generated was monitored on every working day using the liquid displacement method. The parameters pH, ORP, VFA, bicarbonate alkalinity and soluble COD were monitored for every sample during the start and the end of the batch study.

Table 1 *Startup conditions of the feasibility study*

BR	Food (g/L)	pH	ORP (mV)	VFA	Alkalinity	SCOD (mg/L)
C	0	8.34	-373	Nil	26.75	144
R2	4	8.25	-356	Nil	26.75	144
R4	8	7.98	-365	Nil	26.78	144
R6	12	7.88	-373	Nil	26.79	144
R8	16	7.54	-368	Nil	26.86	144

BR- Batch reactor, C-control reactor, VFA- meq/L as acetic acid, Alkalinity- meq/L as bicarbonate

3.5 Analytical Techniques

All physico-chemical analysis was carried out as per Standards Methods [18]. Volatile fatty acids (VFA) and bicarbonate alkalinity of anaerobically treated effluent was determined as per procedure developed by Anderson and Yang [19]. The instrument used to measure pH and ORP was pH meter (WTW inoLab pH 720, Germany). A double junction platinum ORP electrode connected to a calibrated pH meter in mV mode was used for measuring ORP. ORP electrode (Pt-Ag/AgCl), was calibrated using RH 28 supplied by WTW, Germany. Closed reflux method was used for COD analysis by using the COD digester (WTW-CR 3200, Germany).

4. Results and Discussion

4.1 Sieve Analysis & Effect of Food Particle Size on Anaerobic Co-Digestion

Figs. 2&3 show the sieve analyses of dried, non-ground and ground waste food samples, respectively. The results showed that grinding helps in getting smaller sized food particles, which may aid the hydrolysis rate in anaerobic digestion. The Table 2 shows the pH and VFA after 3 weeks of incubation of the batch study as described in section 3.3.

The results clearly show that the particles sizes from 425 µm to 600 µm showed an enhanced VFA production. So this limited study indicates that sizes of food particles are important when it is used for anaerobic co-digestion with sewage. However, a detailed further study is warranted to optimize the food particle sizes and to understand the mechanism of enhanced acidification.

Table 2 *Effect of food particle size on anaerobic co-digestion*

Size of particle	pH	VFA, meq/L
Lump (≥ 5 mm)	6.05	104.2
4.75 mm	7.12	84.1
2.36 mm	7.05	98.3
1.18 mm	7.11	62.4
800 µm	7.03	104.3
600 µm	6.86	120.9
425 µm	6.98	134.0
300 µm	7.06	83.7
150 µm	7.10	62.4
≤ 150 µm	6.96	90.8

4.2 Feasibility of Anaerobic Co-Digestion of Sewage and Food Waste

Table 3 shows the results of the feasibility of anaerobic co-digestion carried out for 18 days. The ORP values clearly indicate conducive environment for anaerobic digestion, especially when food waste is added (ORP reduced as the organic load increases). The parameters pH, VFA, alkalinity, and the ratio of VFA/alkalinity are within safe limits of anaerobic digestion. The low ratio of VFA/Alkalinity (<0.4) indicates that anaerobic digestion is effective in the batch reactors [20]. The SCOD value increases as the food waste amount increased in the batch reactor, whereas there was no corresponding increase of VFA. This also clearly showed the anaerobic digestion was effective, but the increase of soluble COD could be due to the presence of non-biodegradable and/ or difficult to degrade organic fraction contained in the mixed food waste. Another indirect evidence of effective anaerobic digestion is the increase of biogas production as the loading rate in the batch reactors increased. As anticipated, the highest biogas production was recorded in the reactor where 16 g/L food waste dosed. The averages of daily biogas production in the various reactos are shown in Fig. 4 and such trends in biogas production are usual in any uncontrolled reactor (there was no control of temperature and pH). The results showed that a further increase of loading is possible and there is a need to optimize the C/N ratio for effective co-digestion.

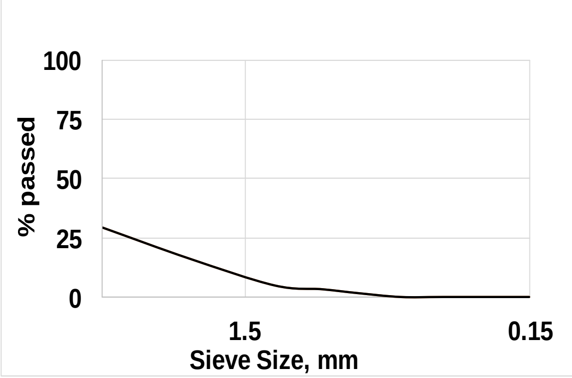

Fig. 2 *Sieve analysis of non-ground samples*

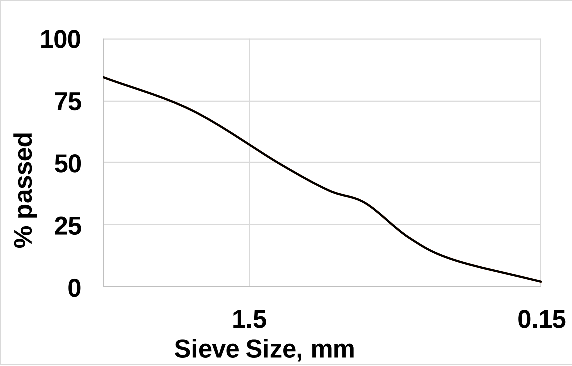

Fig. 3 *Sieve analysis of ground sample*

Table 3 *Results of the feasibility study*

BBR	pH	ORP (mV)	VFA	Alkalinity	SCOD (mg/L)	Cumalative Biogas, (mL)
C	7.5	-295	2.1	16.29	115.2	41.5
R2	7.9	-388	2.2	16.22	345.6	91
R4	7.5	-362	2.1	16.29	460.8	163
R6	7.7	-333	2.2	16.24	633.6	232
R8	7.7	-377	2.2	16.24	936	314

VFA/Alkalinity ratio in all reactors = 0.13

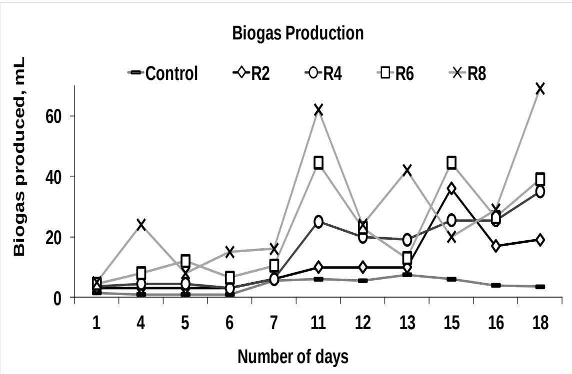

Fig. 4 *Biogas produced during the feasibility study*

5. Conclusions

The review on anaerobic co-digestion show that the co-digestion of sewage and food waste is not studied. The limited feasibility study shows that during co-digestion, the VFA production depends on the size of food particles and 0.4 to 0.6 mm size particles appear to be be easily hydrolyzable. Also, the study indicates that co-digestion of food waste and sewage is highly feasible and could be employed in sustainable waste management of a community. However, further investigation is required before field application.

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